NEW ENERGIES FOR THE CITIES

edited by

Alessandro Rogora and Paolo Carli

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PART II - Evaluation and Modelling Systems, and Tools

Editors and Authors

Alessandro Rogora, architect, Ph.D. in Architecture and Environmental Technology, is a full professor of Architecture Technology at the Department of Architecture and Urban Studies (DAStU) of the Politecnico di Milano. He has taught at the universities of Ferrara, Venice, Lugano, and numerous international institutions, including ETSAB-UPC in Barcelona. A specialist in sustainable design, he has participated in numerous national and international research projects and has published over 200 scientific contributions and numerous books on the relationship between architecture, construction, energy, and sustainability. He has also worked as a designer and energy consultant, contributing to the realization of lighting projects in Italy, a great passion of his research and work, and sustainable building projects, receiving various awards and recognitions in design competitions.
E-mail: alessandro.rogora@polimi.it

Paolo Carli is an architect and Ph.D. in Architecture Technology. He was/is a researcher at the Dipartimento di Architettura e Studi Urbani (DAStU) of the Politecnico di Milano. He focuses on urban and micro-urban environmental design, an area in which he has coordinated and participated in national and international research projects. His methodologies and strategies involve inclusion of people, co-design, and citizen participation in both design choices and actions for the construction and maintenance of shared spaces.
E-mail: paolo.carli@polimi.it

Benoit Beckers is an engineer, Ph.D. in Architecture, and full professor at the University of Pau (France). His most important publications concern computational geometry, and more particularly the partitions and projections of the sphere, which are the bases of geometric methods for radiative transfer simulation. Currently, he is working on their connection with the Finite Element Method in problems related to urban physics. At the same time, he is developing more personal research on the perception of waves, considering its influence on the history of architecture and the city. He is the author of monographs on the evolution of concert halls, perspective representation, color systems, and, in progress, the shape of cities, presented in the form of conferences and reports on his personal site, www.heliodon.net.
E-mail: benoit.beckers@univ-pau.fr

Stefano Bellintani, associate professor of Architectural Technology at the Dipartimento ABC - Real Estate Center of the Politecnico di Milano, is co-founder of the Italian Proptech Network (DABC, Politecnico di Milano) and a member of the board of Assofintech. He is also a Founding Partner of BRaVe m&t - Management and Technology, a spin-off of the Politecnico di MIlano, as well as the author of several national and international books and scientific publications.

Matteo Clementi, is associate professor of Building Technology and Environmental Design at Department DAStU of the Politecnico di Milano, he carries out research activities dealing with tools to support sustainable design on neighbourhood and urban scale and to support the development of local self-sufficiency scenarios at the territorial scale. He is particularly interested in the application of open source tools in order to support processes consistent with the bioregional development and the circular economy.
E-mail: matteo.clementi@polimi.it

Valentina Dessì is an architect, Ph.D., and associate professor. She belongs to the Dipartimento DAStU of the Politecnico di Milano. She teaches Environmental Design and Architecture Technology and carries out research activities mainly oriented to the bioclimatic design of urban spaces and to the evaluation of the outdoor and indoor environmental comfort conditions. She is currently involved in international researches: (H2020-MSCA-ITN) on adaptation strategies to climate change, and in particular on the role of water as a strategy to reduce the urban heat island, and Bize_UrFarm on the potential of urban farm integration in the architecture. She publishes on books and scientific journals, and participates as a speaker at international conferences.
E-mail: valentina.dessì@polimi.it

Ilaria Fiocchi, architectural engineer, graduated cum laude with a thesis in Sustainable Building Design at Sapienza University of Rome with Honours Programme in 2023. Her interests are based on urban regeneration, hydraulic risk in urban spaces and building renovation. In 2022 she attended two international workshops on climate change. She worked as a Project Manager Assistant in an engineering company focused on infrastructures design. She is currently a Facility and Project Manager Specialist in an engineering consultancy company.

Roberto Giordano is a full professor in Environmental and Building Design at the Politecnico di Torino. His Ph.D. thesis at the Politecnico di Milano focused on methods for assessing the environmental sustainability of building products.

He participated in and directed research on designing and implementing Living Wall Systems. He co-founded a start-up enterprise at the Politecnico di Torino. Its objective was to implement a modular vegetated façade, for which a patent was filed. He lectures on Transition Energy - Low Carbon and Design for Climate Resilience courses at the Master of Science in Architecture for Sustainability at the Politecnico di Torino. He is the author of more than 100 publications.
E-mail: roberto.giordano@polito.it

Mariana Pereira Guimaraes, graduated from the University of São Paulo in Civil Engineering, obtained a degree in Public Health from the Harvard T.H. Chan School of Public Health, and a degree in Urban Planning from the Harvard Graduate School of Design. She is currently pursuing a Ph.D. at the Politecnico di Milano as part of the H2020-MSCA-ITN-EID SOLOCLIM research program, focusing on Solutions for Outdoor Climate Adaptation. The topic of her thesis is: 'The evaporative city: Guidelines on urban adaptation and regeneration using water.'

Taehan Kim has been working at Sangmyung University since 2009 and is currently a full professor. He conducts research on the development of climate change response technology and performance evaluation using green infrastructure. Additionally, he is involved in projects ordered by government agencies such as the Ministry of Environment, Ministry of Agriculture, Food and Rural Affairs, Korea Forest Service, and Small and Medium Business Administration. As a member of the government committee, he served on the Central Urban Planning Committee under the Ministry of Land, Infrastructure, and Transport. In terms of academic activities, he holds positions as the vice president of the Korean Institute of Landscape Architecture, the Korean Institute of Traditional Landscape Architecture, and the Society of People, Plant, and Environment.
E-Mail: taehankim@smu.ac.kr

Simona Mannucci Ph.D. in Architecture and Urban Planning at Sapienza University. She is a researcher at the Department of Civil, Building, and Environmental Engineering DICEA, at Sapienza. Her research interests include adaptive approaches to increase resilience in urban planning in case of climate-related uncertainties, specifically urban floods. She is also involved in a project to produce a database of building archetypes and investigate the role of Bio-based insulations for energy savings.

Michele Morganti, architectural engineer by education, PhD in Architecture, Energy and Environment, he is associate professor of Sustainable Building Design at Sapienza University of Rome. His research addresses the environmental performance of buildings, urban spaces, and cities, ranging from energy use to human well-being. Current studies focus on the relationship between urban climate change, microclimate, and building energy performance, with a particular interest in housing. He was the winner of *UPC Barcelona Tech's Special Doctoral Award* for his PhD thesis *Sustainable Density*, and of Politecnico di Milano's 2018 *Best Young Researcher Publication* for the book *Ambiente costruito mediterraneo: forma, densità, energia*.
E-Mail: michele.morganti@uniroma1.it

Marco Migliore is an architect, Ph.D in Technology and Design for the Built Environment, and research fellow at Departement of Architecture and Urban

Studies of the Politecnico di Milano. Author of national and international publications, he deals with issues relating to the circular economy in the construction sector, as well as the study of experimental structure for the cultivation in urban areas on impervious surfaces

Lorenzo Savio is an architect, Ph.D. in Innovation Technology for the Built Environment, and associate professor at the Dipartimento DAD of the Politecnico di Torino. He has been collaborating continuously since 2008 on numerous research activities related to the recovery of rural and twentieth-century architectural heritage, energy retrofitting and the use of renewable energy sources in buildings, low-impact materials for sustainable architecture, and physical and perceptual accessibility to the built environment.

Gianni Scudo, architect and former full professor of Architectural Technology at the Politecnico di Milano, he has been conducting research in the field of environmental design and the integration of renewable energy technologies at the building and micro-urban scale since the 1970s. He has served as President of the Degree Program in *Environmental Architecture* and Vice Dean of the *Faculty of Architettura e Società*, as well as a Visiting Professor at several European universities, including Barcelona, Lausanne, and Mendrisio. He was also the scientific director of the journal I*l Progetto Sostenibile*. He has published dozens of books, scientific articles, and popular articles in the field of bioclimatic and environmental design.

Adrian Moredia Valek, graduated in architecture from the Autonomous University of Guadalajara, obtained a Master's degree in Urban Management & Development from the Institute for Housing & Urban Development Studies at Erasmus University Rotterdam. He completed his Ph.D. at the Politecnico di Milano as part of the H2020-MSCA-ITN-EID SOLOCLIM research program, focusing on Solutions for Outdoor Climate Adaptation. The topic of his thesis is: 'Cooling Cities: Innovative Water-Based Cooling Systems in the Era of Urban Heat.'

Mónica Alexandra Muñoz Veloza is a Colombian research fellow at the Department of Architecture and Design (DAD) of the Politecnico di Torino, where she obtained her cum laude Ph.D. in "Architecture. History and Project" in 2022 and her Master's degree in "Architecture for Sustainable Design" in 2017. She is currently employed in the field of architectural technology and environmental design, conducting her research within the project "S[m2]art (Smart Metro Quadro) Guardando la città metro per metro."
E-mail: monica.munozveloza@polito.it

Qian Zhang is an architect and researcher specializing in microclimate-oriented architectural design. Currently pursuing a Ph.D. in Architectural, Urban, and Interior Design at the Polytechnic University of Milan, Qian has over 10 years of experience in architectural design schools and renowned companies. Qian's focus on pushing boundaries and exploring new approaches is reflected in his rich research achievements.
E-mail: qian.zhang@polimi.it

Foreword. New Energy for the City

Gianni Scudo

We have definitively entered, too silently, the era of the **Anthropocene**.
The Anthropocene is defined as the most recent human-influenced or anthropogenic period of the Earth's geologic time, based on the globally accepted evidence that the Earth's atmospheric, geological, hydrological, biospheric weathering processes are caused by more than 50% from human activities.
As a result, most of the exceptional climatic, atmospheric, hydrogeological and bioecological events that have occurred in recent decades (increase in temperatures of air, land surface, seas and oceans, the melting of ice caps and mountain glaciers, the disastrous and largely unpredictable of weather events, floods due to changes in water regimes, alteration and destruction of terrestrial and marine ecosystems, etc.) are caused by human activities linked to the radical change in territorial and urban metabolism which, starting from the industrial revolution, has introduced into the environment increasing amounts of climate-altering gases and waste materials, coming from the deformed productive and urban metabolism.
How did we get to this point, that some consider to be **no return**? *The culture of modern society had forms of reflexivity and environmental criticism; therefore, it knew at least since the second half of the nineteenth century (or even earlier) the processes of environmentally destructive use of resources. Many authors had proposed a radical reform of the economy based on the study of the damage caused by the use of fossil energy sources and the potential of the use of renewable energy sources (Clausius, Geddes, Sacher, the Italian Ciamician, only for name a few), and on the emergence of awareness of the metabolic fracture between human society and nature (Darwin,*

*Haekel, to name just the '*leaders*'). Later studies and reflections on the destructive use of resources based on knowledge of the planet's limits (*The Limits to Growth, Club of Rome, Silent Spring, etc.*) gave impetus to a long chain of studies and conferences (Stockholm '72, Rio '92, Bruntland report, recent COPs, IPCC summaries, etc.). So, it cannot be said that we did not know in which catastrophic direction the 'industrial machine' was taking the planet. The conclusion is that our predecessors destroyed the environment with full knowledge of the facts. «*What is called the 'schizophrenia' of a modern age which has always thought of man as a product of surrounding things, of the environment precisely, but at the same time has allowed him to alter and destroy them*.» (*Bonneuil, Fressoz, 2019: 245*)*

Urban metabolism - which can be defined as the set of all materials, energy, services and waste used to decently support the lives of the inhabitants (at home, at work, in leisure spaces!) has been the subject of a radical change between the 19th and 20th centuries, in particular with the introduction of technologies (for the built environment, for mobility, for production processes, etc.) based on fossil fuels, highly polluting and non-renewable , which rapidly brought settlement systems into metabolic conditions very far from environmental (and thermodynamic) balance.

With the bulimic spread of consumption for the 'rich' part of the population, the imbalance led to the alteration of the city/territory relationship which guaranteed a solid metabolism (partial supply of food and materials, absorption of CO_2, organic waste materials, practices of reuse of building and furnishing materials), as well as offering climate-mitigating green structures for parking and slow mobility (canals, woods and parks, roads and tree-lined paths).

*The IPPC forecasts are very worrying; if emissions of climate-altering gases are not rapidly eliminated by 2050, half of European territories will be at high risk of overheating, leading, in addition to the health risk for half of the European population, drought and a clear decrease in agricultural production (*IPPC, 2023*), probable large migrations, rising sea levels, so much so as to determine a new geography of the Anthropocene.*

To strategically address this situation, the EU Council has promoted a series of rules aimed at incentivizing and promoting climate change mitigation processes and programs, with the aim of eliminating greenhouse gas emissions by 2050 in all production sectors (built environment, agriculture, industry, mobility, etc.).

The objective is to guarantee a transition to zero emissions to reduce the vulnerability of the environment, society and all sectors of the economy to climate change; a fair transition that leaves no one behind.

*EU Environment Ministers in June 2021 approved the new EU climate change adaptation strategy. The strategy outlines a long-term vision for the EU to become, by 2050, a "*society resilient to climate change and fully adapted to its inevitable impacts*".*

The measures foreseen in the strategy are based on data's better collection, sharing and processing, for a better access to knowledge on climate impacts and their change, on the use of Nature-Based Solutions to help build resilience to climate change and protect ecosystems, on the integration of adaptation actions with fiscal policies.

The essays of this book are divided into two parts, within the context of this regulatory framework and actions promoted and financed by the EU (in particular, those based on Nature-Based Solutions). The first part is more oriented towards the analysis of urban climate and microclimates, and it ranges from an approach to transcalar tools for their reading, to the dynamic of adaptation devices on an urban scale and of architectural typologies to the micro-urban one, up to specific indications for some Nature-Based Solutions; the second part is instead more 'instrumental' and aims to provide, on one hand, tools for evaluating energy and CO_2 flows to be integrated into the plan tools, and on the other, illustrates repertoires of Nature-Based Solutions, also in the context of 'smart communities', and other tools to stimulate the social acceptability of technical solutions.

The essay by Benoit Beckers, **Urban Physics lecture program for architects**, *constitutes a very important contribution for the training of environmentally and climate-conscious architects. Introducing urban physics, a recently developed discipline that is aimed at providing tools for the design of transcalary environmental architectures. 'From the room to the city' to address the effects of climate changes that characterize the initial phase of the Anthropocene, while remaining within the specific context of the Vitruvian tradition of European architecture and, therefore, with great attention to urban morphologies.*
The contribution describes in detail the structure of the course in twelve lessons that take students from the first CAD practices to simulation models and experiences of on field measurements (solar radiation, infrared, light, shadow, sounds, ventilation) which will gradually transform the computer in an urban physics laboratory, capable of quantitatively treating the aspects of multisensory perception of built environments at different scales. In addition to the ability to install and manage various drawing and post processing computation programs, particular attention is given to the graphic quality of the results.

The essay by Michele Morganti, Simona Mannucci and Ilaria Fiocchi, **Pluvial Flooding in Compact Neighborhoods: Dynamic Analysis for Climate-Adaptive Buildings and Urban Spaces**, *addresses the problem of pluvial flooding in compact city neighborhoods. The plug-in developed by the working group allows to identify and process through maps and visual scenarios the urban spaces and buildings most exposed to hydraulic risk. The scenarios can assist decision makers and planners to develop priority strategies and define solutions to facilitate adaptation to climate change, introducing sustainable urban drainage systems already implemented in many European cities, cited as examples of good practice. The proposed workflow is based on the Grasshopper software which has the potential to include and analyze various environmental phenomena. And, therefore, to include different aspects of mitigation and adaptation that characterize urban sustainability (energy, well-being, supply of goods - for example, food, etc.).*

Qian Zhang's essay, **Association Between Spatial Characteristics of Courtyards in Different Historical Periods and Microclimate. A Case Study from China**, *explores the interaction between historical urban morphologies and environmental microclimate conditions by simulating the summer microclimate of some courtyard typologies in their transformations over the last 400 years. This is a study that we could define as 'typological-anthropological' aimed at re-evaluating the characteristics of the traditional Hui typology (of Islamic origin) which have been largely thinned out by contemporary 'high rise' settlements. The results suggest that the average daily temperature of the courtyard in the East - West direction is lower than that the one of the courtyards in the North - South axis. The increase in height of the surrounding buildings leads to an increase in the average daily temperature. Furthermore, the influence of the openings of the courtyard is evaluated which, if placed in the direction of the prevailing winds, tend to have a lower temperature than that of the courtyards without openings. Therefore, the contribution is also a complaint of the inappropriateness of modern urban development, which results in the blocking of natural ventilation, the accumulation of pollutants, the imbalance of road sections which reduce the turbulence of heat transfer and the greenhouse effect; all factors that have contributed to the worsening of urban microclimate problems.*

The essay by Valentina Dessì, Adrian Moredia Valek and Mariana Pereira Guimaraes, **Water Based Solutions for Cooling the Cities: from City to Building**, *presents interesting research results developed in two doctoral theses in the Dipartimento di Architettura e Studi Urbani of the Politecnico di Milano, within the EU-funded research project Soloclim (Solutions for Outdoor Climate Adaptation). The first thesis, focused on the urban context, developed guidelines for designers and public administrations interested in the integration of Water Based Systems in urban spaces, in the wake of the European Council's promotion of Nature-Based Solutions to help create urban resilience to climate change. The second thesis, on a building scale, proposes an envelope system based on the implementation of traditional cooling systems, reinterpreted to be integrated* *into existing buildings. The air cooled by evaporation (the downwash effect, adiabatic cooling, and the downdraft effect) serves the external space and creates the conditions for reducing thermal stress in urban spaces, together with the other 'elements' that collaborate in the microclimate mitigation (vegetation, materials, etc.).*

The essay by Matteo Clementi and Marco Migliore, **Open-Source GIS to Support Energy and Carbon Flows Accounting in Urban Areas***, proposes a methodology (and related tools) to support regenerative design activities in an urban context. The contribution focuses on the potential use of free and open-source software (FOS) GIS (Geographical Information Systems) and open data, to develop maps to support regenerative environmental design. Environmental design is oriented towards the integrated management of the main dynamics that characterize a territorial area with two objectives:*
- maximize the use of solar energy useful for supporting the main activities that characterize the local territorial metabolism (living and working, feeding, cleaning, moving and communicating, etc.);
- ensure and maximize the circularity of the material, maintaining the balance between production and consumption flows.
The aspect of circularity means the possibility of knowing and increasing the potential to locally close the production and consumption cycle through regeneration cycles associated with the environmentally conscious use of materials.
The use of local solar energy and the diffusion of circular economy practices affect all living activities, and can easily be accounted for, intercepting the spending flows that characterize the specific lifestyle of a community, with the possibility of acting – at least - on local consumption and production for energy, mobility, nutrition, etc. Remembering that the 'lifestyle' is the basic driver of changes 'bottom up', as demonstrated by the experiences of the 70s such as that of the **Beati Costruttori di Pace** *(Blessed Peace Builders), and as we are trying to do with the problems of energy poverty (see* **Italian Observatory on Energy Poverty – OIPE***).*

Alessandro Rogora's essay, **Social Acceptability of Technical Solutions and Role of**

Human's Behaviour*, starts from the observation that it is unthinkable to respond to the completely unsustainable impact of our society on the planet by increasing the efficiency of products and processes. A profound change in human behaviour is needed and the key words that should guide the change are sufficiency, parsimony and limit. We must, together and as individuals, move towards a less unsustainable future. The contribution presents the* **TRACES** *research project which developed a simulation game of the effect of behavioural changes in the processes of use of environmental resources towards a sustainable environment in terms of resource flows (energy, materials, knowledge, water, etc.). In the early stages of the research, an important job was to outline the general structure of the game, trying to simplify it as the level of complexity increased. In the work, the author noted that by moving solutions to a problem from a remote level (for example, power, energy) to the level of local solutions, the degree of resilience of the system is increased. The research is looking for ways to incorporate this trend into the model, and define the impact of goods and services, produced locally, valued in terms of flows (and local money) in the perspective of a transition to a not only circular economy , but above all inclusive, and capable of building future communities, starting from the sharing of mandatory needs for the parsimonious use of resources within the limits of planet earth.*

Tae Han Kim's contribution, **Green Infrastructure Based on Smart Technology***, is aimed at developing evaluation methods and experimental technologies to deal with climate change and environmental sustainability problems, through proposals for interventions on the water cycle, air quality, renewable energy, using Nature-Based Solutions (NBS). The NBS have as their basic objectives the restoration of urban ecosystems throughout the national territory and in urban centers, the creation of 's***mart'***, green and safe cities, to improve the quality of life of citizens.*
The research group represented by Kim has three areas of interest: the local urban water cycle, urban air quality, and PV energy production. The water cycle is controlled through experimental equipment that allows testing different technologies for containing the effects of precipitation on the ground. As regards air quality, a **'vegetable'** *biofilter*

*system has been developed which allows the '***capture***' of part of the dust pollution, in particular heavy PM 2.5, such as iron oxide, whose accumulation presents serious risks of neurological diseases. Finally, for energy, the integration of PV systems with green roofs was tested and gave good results (increase in the efficiency of PV collectors by 7%, reduction in the surface temperature of the panels and the environmental temperature).*

The essay **S[m2]art Project: From Digital Island to Vertical Ring. Integration of Environmental Monitoring Technology into Street Forniture***, written by Mónica Alexandra Muñoz Veloza, Lorenzo Savio and Stefano Bellintani, documents part of the research of the* **S[m2]art** *(***Smart Metro Quadro/Smart Square Meter***) project which aims to develop furnishings for urban spaces that can provide general services and personalized to the Public Administration and citizens. The main result of the research is a prototype of urban furniture architecture called '***vertical ring***'. The research starts from the suggestions of the landscapes originating from the network of telephone booths for more than a century. Recent technological innovation (smart phones and wireless services) has decreed the disappearance of traditional telephone communication and cabin networks which constituted a significant system of '***visible***' communication in urban landscapes. The research, revisiting the urban meaning of the telephone booth, launches the diffusion of '***vertical ring***', a totem that integrates information technology into urban furniture projects that adapt to current and future city life. It provides tangible and intangible tools capable of collecting, monitoring and analysing in real time the different variables that characterize the quality of the urban environment (microclimate, energy, comfort, air quality, precipitation, etc.). Two '***vertical ring***' prototypes were created by a consortium made up of universities and industries, then installed in the two research partner campuses (***Politecnico di Torino*** *and* ***Politecnico di Milano***), starting a data collection campaign, starting from those classics of microclimates and air quality (air temperature, radiant, RH, wind speed, etc.). The 'vertical ring' network, in addition to monitoring, can provide physical and digital services to citizens (Wi-Fi, charging of equipment, info on bike parking, info on defibrillators available in the area, electric car charging stations, etc.). The contribution presents the meta-project, the executive project, and the assembly phases of the two '***vertical rings***'. The experimental phase was underway while the article was being written.*

Roberto Giordano's essay, **Nature-Based Solutions as a Strategy for Adaptation to Climate Change***, for the* **Technology and Environment research group***, begins with the definition of Nature-Based Solutions as urban infrastructures based on greenery to address the full potential of sustainability by maximizing the benefits of nature. The NBS they propose completely use plant elements, unlike other NBS which require integration with building materials (for example, green roofs). The research group of the* **Politecnico di Torino** *has carried out some research projects on NBS over the years. One of these is focused on the design, construction and monitoring of living wall systems.*
Living wall systems generally include a module that contains the plants and the nutrient system. Living wall systems are fixed on the wall directly or through a support structure, incorporating the irrigation and nutrient system, and have a higher green density than traditional green walls.
The experimentation was conducted on a building divided into two parts: one with the living wall system, the other with an isolated wooden structure. The two sides have the same conductance. The results of the experiment show how the living wall system, with a thickness of only 6 cm, reduces the surface temperature and therefore mitigates the effects of the Urban Heat Island (UHI).
Other studies on living wall systems show further environmental performances regarding the ability to absorb substances from the air, in particular nitrogen, present in rainwater.

As I wrote at the beginning of this preface, we have entered the Anthropocene too silently, with a schizophrenic attitude of construction and destruction of the environment *in which we live. Let's consider climate change; the* Intergovernmental Panel on Climatic Change (IPCC, 2023*) has reached, through more than 20 years of studies and monitoring, very clear conclusions: it is necessary to eliminate climate-changing emissions by 2060, just to maintain the increase in temperature average below 1.5 °C. But the world is still failing to provide answers capable of reducing the global footprint of climate-changing gas emissions. For this reason, alongside major mitigation policies, it is important to promote adaptation actions that include innovations in clean energy in the various sustainability objectives promoted by international agencies and governments of geopolitical areas - such as the EU - and by local governments, but also by sustainable communities at a territorial, urban and neighborhood scale. All actors must mobilize by recognizing that each of us will be engaged, in some way, in these radical transformations, and to do this efficiently, everyone will need strategies, tools, good practices such as those covered in the different essays of this book.*

Gianni Scudo

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An Informal Glossary

Paolo Carli

Urban settlements are constantly increasing, and we are approaching a point where over half the human population will live in cities. This human concentration gives rise to complex problems, ranging from pollution to difficulties providing resources to sustain the inhabitants' lives.
This situation results in low resilience of urban settlements to events that may affect the territory and the settled society. The complexity of consumption patterns and the flows of energy and matter in transit (inflows and outflows) require a profound rethinking compared to the past, as these flows differ in magnitude and complexity.
This book, *New Energies for Cities*, represents an initial attempt to reflect on the complexity and specificity of urban metabolism, as well as on potential solutions to address and transform the identified critical issues into possible elements for mitigating problems.

Since this book consists of a series of very specific thematic essays on topics and themes related to energy, even though more from a quantitative than a qualitative point of view, it seems appropriate to introduce a kind of glossary, very informal, of some terms that recur in the following pages. Contributions that, however, for reasons of brevity, sometimes imply certain concepts, meanings, and important information that – as editors of the volume – we feel obligated to specify and define to support readers in a comprehensible and useful reading.

The glossary, although informal, is alphabetically ordered, thus providing the reader – from the very beginning of the book – with the complexity of the topic addressed, but also offering a useful tool for using the information contained in the text. “Informal” is indeed meant here as – and here is the first definition of the glossary – a frank, direct, and free way to highlight some key issues that deserve necessary and continuous further exploration, as well as to refresh information and concepts underlying the energy-city dualism that, perhaps, younger readers do not know.

Anthropocene: Term used to describe the current geological era, characterized by the dominant influence of human activities on the Earth’s climate and ecosystems. Some scientists propose that the Anthropocene began with the Industrial Revolution in the 18th century, while others suggest more recent dates, such as the mid-20th century, when human activity had a more evident and widespread global impact. Recognizing the Anthropocene, despite ongoing debates among scientists, implies greater awareness of human responsibility in shaping the planet’s future, pushing society to reflect on necessary actions to mitigate negative impacts and promote environmental sustainability.

Circular economy: (see also Life Cycle) An economic model emphasizing the reuse, repair, recycling, and regeneration of materials and products, minimizing waste, and the use of natural resources. The circular economy represents a revolutionary paradigm compared to the traditional linear economic model based on “*take, make, use, and dispose*”, leading to inevitable resource depletion and exponential waste increase. In contrast, the circular economy aims to create a sustainable and resilient system that mimics natural cycles. The circular economy aims for an ambitious but necessary goal: decoupling economic growth from the exploitation of natural resources and waste production.

CO_2 (Carbon dioxide): A greenhouse gas produced by the combustion of fossil fuels, the respiration of living beings, and other natural and anthropogenic activities, contributing to global warming. Carbon dioxide is essential for life on Earth: it plays a crucial role in photosynthesis, climate regulation, and the carbon cycle, and is widely used in various industrial and medical sectors. However, managing and reducing CO_2 emissions is vital to mitigate climate change and protect global ecosystems. According to Barry Commoner’s Four Laws of Ecology outlined in “The Closing Circle” (1971), CO_2 perfectly represents the delicate balance expressed by the first Law, “*Everything is connected to everything else*,” as controlling/reducing its emissions means reducing the rise in average global temperature, thus preventing sea-level rise (caused by thermal expansion of water and melting glaciers and polar ice caps) and ocean acidification, which has devastating effects on marine life, crucial for maintaining ecosystems and human communities. The decrease in biodiversity, measured through habitat loss, threatened species, and extinctions, is a critical indicator of ecosystem health, as is the loss of forests, which negatively impacts biodiversity, the carbon cycle, air quality, and land use/consumption, such as urbanization, intensive agriculture, and desertification, affecting the planet’s ability to sustain life.

Compatibility ecology: The ability of a project or practice to coexist and function harmoniously with local ecosystems without causing significant harm. Many years ago, about thirty, the term “*sustainable architecture*” was often used, a phrase bordering on an oxymoron, at least according to the famous aphorism of the Ticinese architect Luigi Snozzi, who said, “*Ogni intervento presuppone una distruzione…distruggi con senno!* (Every intervention presupposes destruction… destroy wisely!)”. It took us a few years, but the concept underlying the principle, not to mention the mandatory design requirement in the field of building activities, of *Do Not Significant Harm* is now taken for granted: any production process, even those related to the digital dimension, creates environmental harm as they invariably and certainly withdraw some common resource from the environment, be it air, water, or soil. This awareness, albeit late and still not fully sedimented in society, is nonetheless a step forward from the vain hope that a technology to save our planet's fate will soon emerge.

Decarbonization: The process of reducing carbon emissions, typically through the adoption of renewable energy, energy efficiency, and other low-carbon technologies. In recent years, this term has replaced the concepts of sustainability and ecology in everyday speech. Decarbonizing means reducing the carbon (CO_2) of all activities, progressively converting the entire economic system sustainably by reducing the use of fossil fuels in favor of renewable energy sources, efficient use of energy resources, and the new technologies available. It is unclear whether the term has gained traction for simplicity of communication, a form of greenwashing, and an update of the vocabulary of non-specialists, or whether it responds more to a logic of decomposing the problem, focusing action on the most delicate balance element for the planet, namely carbon dioxide.

Energy saving: Energy saving refers to the reduction of energy consumption through various strategies and technologies aimed at increasing efficiency and promoting conscious behavior. This can be achieved through the adoption of advanced technologies such as LED lighting, energy-efficient appliances, and smart thermostats, which reduce energy use without compromising comfort or productivity. Additionally, energy saving involves improving building insulation, using energy management systems, and implementing renewable energy sources like solar panels to reduce reliance on non-renewable resources. Effective energy saving contributes significantly to the reduction of greenhouse gas emissions, lowers energy bills, and lessens the overall environmental impact, supporting global efforts to combat climate change and promote sustainability.

Green infrastructure: Green infrastructure is a strategically planned network of natural and semi-natural spaces designed to deliver a wide range of ecosystem services, such as water purification, air quality improvement, and temperature regulation. This network includes parks, gardens, urban forests, green roofs, and walls, as well as blue spaces like rivers, lakes, and ponds. Green infrastructure not only enhances urban biodiversity by providing habitats for wildlife but also improves the quality of life for city residents by offering recreational spaces and mitigating the urban heat island effect. Moreover, it enhances urban resilience by managing stormwater, reducing flood risks, and buffering against extreme weather events. The integration of green infrastructure into urban planning is essential for creating sustainable and livable cities that can adapt to climate change and environmental challenges.

Hydrological cycle: The continuous movement of water on, above, and below the Earth's surface, including processes such as evaporation, condensation, precipitation, and infiltration. The hydrological cycle contributes to regulating the Earth's climate, influencing temperatures and precipitation distribution. In this context, the city is often seen only as a "withdrawal point" from the hydrological cycle, while this book advocates for urban space regeneration that places water projects at the center, as a fundamental element of the landscape and—especially—of the urban environment, as well as an element of hygrothermal regulation and contrast to the urban heat island phenomenon through its use in NBS.

Life cycle: (see also Circular economy) The set of stages a product goes through from production to final disposal, including raw material extraction, manufacturing, distribution, use, and waste management. The concept of the Life cycle, understood as a methodology for assessing a product's environmental impact, originated in the 1960s/70s, was codified in the 1990s (LCA – Life Cycle Assessment), and has become a common practice used by companies and governments to evaluate and improve the sustainability of products and processes as environmental concerns and the push towards sustainability increase. LCA has become a fundamental tool for analyzing environmental impacts and promoting the circular economy. The paradox of Life Cycle analysis of production in an open and linear production paradigm, declared since the 1970s by North American counter-culture movements and eminent scientists (Carson, Commoner, Lovelock, etc.), has emerged powerfully in recent years, giving a new centrality to LCA, thanks to the concept of a circular economy—also dated, see the Astronaut Economy in "The Economics of the Coming Spaceship Earth" by Kenneth Boulding, 1966.

Mobility sustainability: Mobility sustainability focuses on creating transportation systems that minimize environmental impact and promote the health and well-being of urban populations. This includes encouraging the use of public transportation, cycling, walking, and electric vehicles while reducing dependence on fossil-fuel-powered private cars. Sustainable mobility strategies involve the development of efficient public transit networks, safe cycling infrastructure, pedestrian-friendly urban design, and the promotion of car-sharing and ride-sharing services. Additionally, integrating renewable energy sources into transportation, such as solar-powered buses or electric vehicle charging stations, further enhances sustainability. The goal of mobility sustainability is to reduce greenhouse gas emissions, decrease traffic congestion, and improve air quality, ultimately leading to healthier, more accessible, and environmentally friendly cities.

Paris Agreement: An international treaty adopted in 2015 during the Conference of the Parties (COP 21) in Paris, aiming to limit global warming to well below 2°C above pre-industrial levels, preferably to 1.5°C. The Paris Agreement remains the global framework for climate action, and member states continue to present their Nationally Determined Contributions (NDCs) to strengthen their greenhouse gas emission reduction policies. However, recent climate conferences, such as COP 26 held in Glasgow in 2021, have reiterated the urgency of strengthening global efforts to limit global warming. Despite progress, many experts warn that current policies and commitments are still insufficient to reach the 1.5°C target, necessitating greater commitment and more ambitious actions from all countries (IPCC, 2023).

Renewable Energy: Renewable energy is energy generated from natural resources that are replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. Unlike fossil fuels, which take millions of years to form and release harmful emissions when burned, renewable energy sources produce little to no greenhouse gases during operation, making them essential in the fight against climate change. Technologies harnessing renewable

energy include solar panels, wind turbines, hydroelectric dams, and geothermal plants. The transition to renewable energy is crucial for reducing carbon emissions, enhancing energy security, and fostering sustainable economic growth. Additionally, advancements in energy storage and smart grid technologies are making it increasingly feasible to integrate renewable energy into existing power systems, paving the way for a cleaner and more resilient energy future.

Resilience: Resilience refers to the ability of urban settlements to withstand, adapt to, and recover from adverse events such as natural disasters, economic shocks, and social disruptions. Building resilience involves enhancing the capacity of cities to absorb and bounce back from these impacts through robust infrastructure, effective governance, and community preparedness. Key strategies include disaster risk reduction, climate adaptation planning, and the development of resilient infrastructure systems that can continue to function during and after crises. Social resilience, which focuses on strengthening community networks and ensuring equitable access to resources, is equally important. By fostering resilience, cities can protect the well-being of their inhabitants, maintain economic stability, and preserve environmental health in the face of challenges.

Resource Consumption Complexity: Resource consumption complexity refers to the intricate patterns and dynamics of how resources such as water, energy, and materials are used within urban environments. Modern urban settlements exhibit complex inflows and outflows of resources due to diverse consumption patterns driven by population growth, economic activities, and technological advancements. Understanding and managing this complexity requires a multidisciplinary approach that considers the entire lifecycle of resources, from extraction and production to distribution, consumption, and waste management. Addressing resource consumption complexity involves promoting circular economy principles, improving resource efficiency, and implementing sustainable practices that minimize environmental impact while meeting the needs of urban populations. By doing so, cities can achieve a balance between development and sustainability, ensuring the well-being of current and future generations.

Urban Metabolism: Urban metabolism is a conceptual framework that likens the flow of energy and materials within a city to the metabolic processes of a living organism. It involves the analysis of inputs (such as food, water, and energy), their transformation within the urban system, and the generation of outputs (such as waste and emissions). Understanding urban metabolism helps identify the environmental impact of cities, uncover inefficiencies, and develop strategies for sustainable resource management. By mapping and analyzing these flows, urban planners and policymakers can design interventions to reduce resource consumption, minimize waste, and enhance the overall sustainability of urban areas. Effective urban metabolism management promotes the creation of more resilient and self-sufficient cities that can thrive within the limits of natural ecosystems.

Urban Settlements: Urban settlements are areas where human populations live in concentrated and structured communities, typically characterized by higher population density and infrastructure development compared to rural areas. The continuous increase in urban settlements is driven by factors such as economic opportunities, access to services, and social amenities, leading to a global trend where over half of the human population now resides in cities. This concentration of people gives rise to complex problems, including pollution, resource scarcity, and challenges in providing adequate housing, transportation, and public services. Urban settlements also face heightened vulnerability to environmental hazards and climate change impacts, necessitating comprehensive planning and management to enhance their resilience and sustainability. Effective urban planning must address these issues by integrating green infrastructure, promoting sustainable mobility, and ensuring equitable access to resources, thereby creating liveable, inclusive, and sustainable urban environments.

As cities continue to expand, now encompassing over half of the global population, the complexity and challenges they face grow exponentially. From pollution to resource scarcity, the intricate dynamics of urban living demand innovative and sustainable solutions. "*New Energies for Cities*" delves into these complexities, offering a detailed exploration of urban metabolism and the transformative potential of new energy strategies. The accompanying glossary serves as a tool, guiding readers through the nuanced terminology and concepts essential for understanding and addressing the energy-city dualism. In an era marked by rapid urbanization and environmental challenges, the essays in this book are a crucial step towards envisioning and realizing a sustainable future for our cities, where human activities harmonize with the planet's ecological balance.

Paolo Carli

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PART I

URBAN CLIMATE AND MICRO CLIMATE

Urban Physics Lecture Program for Architects

Benoit Beckers

Urban Physics is an emerging discipline that is not yet taught fully and consistently anywhere. We place ourselves here within the framework of the Bologna process, by offering a master program open to graduates in architecture, science or engineering who wish to participate in the necessary renovation of the cities of the 21st century, everywhere in the world, and based on principles developed in Europe. On our continent, the urban project has long been at the crossroads of an art of building and a science of construction. A Vitruvian architecture - at once beautiful, useful and durable – is expected now to produce smart, safe and sustainable cities.

Introduction

This program is designed for students with a degree in architecture who feel capable of upgrading their skills in mathematics and physics, as well as those who, with a science or engineering degree in hand, are attracted by the applications of urban physics, aware that they will have to learn how to see and work in the space of architecture, and acquire a culture about the history of cities and the buildings that make them up.

You were born when most of humanity had already become urban, when cities were spreading faster than ever all over the surface of the globe, when they were beginning to suffer the effects of climate change, from which they were also one of the causes, when the development of the Internet network was giving everyone the impression of living in freedom in a global village full of promises, whereas, for the vast majority, the real framework had become that of monotonous residential districts, gray suburbs, soulless urbanizations, or hopeless slums.

Growing up, you have had the opportunity to travel, to discover the historic cities of Italy and around the Mediterranean, and those found going up to the north of Europe or near the ocean. Many of you have family or friends in Africa, Asia, or America. You have dreamed about the ruins of past civilizations. You have made some memories of busy streets, splendid perspectives, exotic products, smells and colors spread out under arcades... Back home, you no longer wanted to believe that it would be enough to beautify the cities with lined-up trees, cycle paths, or electric cars, and you became aware that the ideal of the single-family house with its screened garden and its two-car garage could never become that of humanity as a whole, and that this dream itself, if you followed it, would lazily draw you away from the impetuous course of real life and progress in the sciences and the arts.

Every morning, we wake up in the middle of a sound field that brings to our ears the rumors of the city and the nature. We open our eyes to a field of light made up of strange or familiar shapes and colors. When we get out of bed, we shiver because a combination of heat diffused inside the walls, moving air rubbing against the walls, infrared radiation exchanged with the sky and other buildings has balanced during the night to create a thermal field, which seems a little too weak to us in winter, and which will seem a little too strong when summer comes.

Therefore, like generations of architects before you, perhaps do you dream of understanding how these fields of acoustic, thermal and luminous energy, transport of matter and momentum are formed and transformed by the urban scene where they happen. Indeed, if you understood all this, wouldn't it become possible to design urban forms capable of better controlling all these flows: ventilation, light and shade, noise, heat? Wouldn't it be possible to design sober, pleasant, beautiful, and functional cities all at the same time? Well, what still seemed utopian ten years ago is made possible today by advances in measurement and computing.

The program described below is that of an ideal master cursus which, in two years, would give you all the knowledge necessary to start working in a team on urban renewal projects, or even on the design of new towns or new districts. It consists of twelve courses, each accompanied by computer practices and measurement work. On the other hand, there are no activities in the laboratory, because the physical phenomena that take place on an urban scale offer very few similarities with scale models placed in a wind tunnel or in climatic chambers. Therefore, your laboratory will be the city itself and, for projects in the future city, your own computer.

From the first computer training practices, you will be led to develop your functions, from models given during the course, which will gradually transform your computer into an urban physics laboratory. You will gradually install programs for data processing, drawing, design aid, computation, and post-processing, which you will make compatible with each other, thanks to your expertise in exchange formats. You will pay particular attention to the graphic quality of the results, in order to illustrate short, precise reports that are useful to the other students.

By measuring, you will look at the city with other eyes: in the infrared and the ultraviolet, and you will reveal, thanks to the new acoustic and aeraulic cameras, the sound field and the movements of the air. You will also have to learn how to measure the optical, thermal, and acoustic properties of the studied scene, in order to feed your future numerical simulations. Finally, you will compare your measured and simulated results, to interpret convergences and differences, and thus approach the Urban Digital Twin, which is the final promise of this course program.

Urban physics in twelve lessons

Each of the twelve lessons is described by a title, followed by a line of keywords, then three sections that briefly describe the content of the course, computer practices, and measurement work. Some bibliographical elements are given at the end of the text.

1. Computer aided geometry

Coons' patches, Delaunay's triangulation, solid angles, ray tracing, partition of the sphere, projections, solar paths

You will first learn to see and work in space. In three dimensions, angles become solid, they are measured in steradians on the unit sphere, where trigonometry has become spherical. The projections of the sphere on the plane, called cartographic, have different properties that must be explored in detail. They allow partitions of the sphere to be made in the best possible way, which in turn serve as guides for spatially uniform ray tracing from a point source. Another application is the solar diagram, which makes it possible to describe the apparent paths of the sun in the sky according to date and latitude. Finally, you will be interested in the mesh of a scene, which can be structured (Coons' patches) or unstructured (Delaunay's triangulation).

Figure 1. Survey of Petit Bayonne geometry by remote sensing

All the notions presented so far have the particularity of being purely geometric. Course notes are already available, written in French. They are accompanied by short Matlab© routines that you can use directly in the text, in order to guide you in your first programming exercises (Beckers, 2017).

The first devices you will handle belong to photometry, the measurement of light. The luminancemeter, which is used to measure glare, looks like a telescope. It gives a directional measurement, directly related to the notion of solid angle (the quantity measured is the luminance, which is expressed in lux per steradian). The luxmeter, on the other hand, measures the illuminance of a surface (in lux). It therefore gives a hemispherical measurement, integrating all the rays that fall on the surface, penalized by their angle of incidence. The associated geometric quantity is now the view factor, whose definition is purely geometric, but whose meaning is physical, since it describes the quantity of energy that two surfaces can exchange. This concept therefore serves as a transition with the following course, which deals with light.

2. Rendering
View factors, Fredholm integral equation, radiosity method, Monte-Carlo method, illumination

Computer-generated images have become so familiar to us, through video games and cartoons, that they directly inspire architects, to the point that many contemporary buildings, with their capricious curves and bright colors, seem images of computer screens. In this course, you will learn how to produce beautiful images, and how, with the same algorithms, it is possible to calculate the distribution of light in a complex urban scene. We will start from the integral equation studied simultaneously by the mathematicians Vito Volterra and Ivar Fredholm at the beginning of the 20th century, and you will learn how to combine two solution methods: that of radiosity (from extended view factors) and that of Monte-Carlo (from the ray tracing seen previously) (Bugeat, 2020).

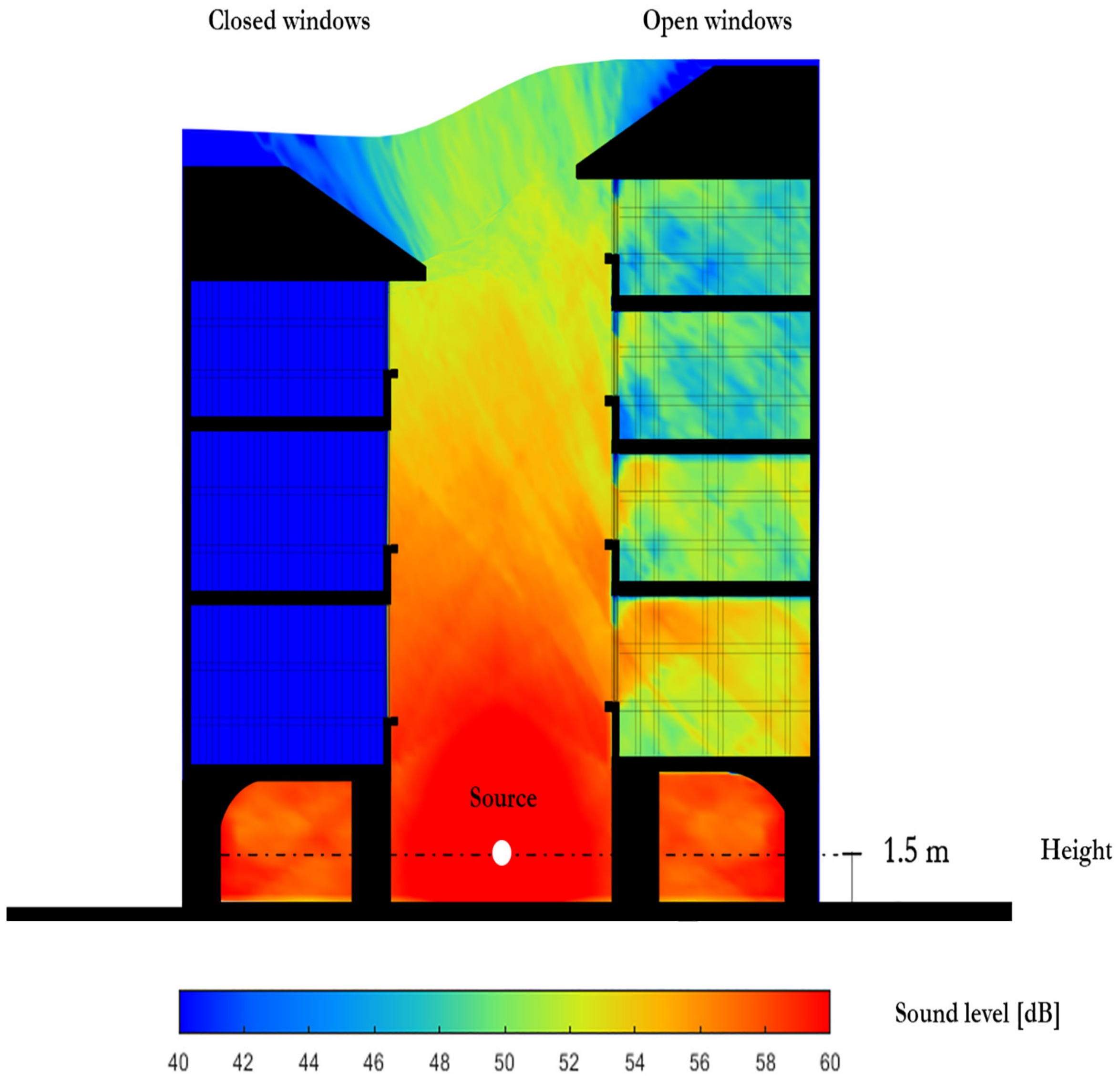
The Radiance software package remains the standard for lighting simulations (Ward, 1998). You will learn how to use it, and how to post-process its results, to obtain, for example, panoramic images from the projections studied in the previous course. Some of you will choose to explore other software or, on the contrary, to return to much older working methods to overcome the limitations intrinsic to computer hardware, concerning the reproduction of color, and to acquire by the practice of painting a better sensitivity to the chromatic compositions of the urban project.

You will learn how to handle the camera, and its optical parameters (which are the same in the real world and the virtual world of realistic rendering). Through filters, you will photograph the near-infrared and the ultraviolet, two unappreciated components of the solar spectrum, which are distributed in the sky, on vegetation, and in urban scenes quite differently from visible light (Acuña Paz y Miño, 2020).

3. Geometric methods for optics and acoustics
Impulse response, room acoustics, specular reflection, optical devices
Curved mirrors – spherical, elliptical, parabolic, portion of a logarithmic spiral – have remarkable properties, some of which were already used in Antiquity. Geometric optics, which describes them, has its counterpart in acoustics, and the same methods of designing a luminaire to reflect harmoniously the light from a lamp can be applied to the design of the ceiling of a large concert hall in order to direct the sound from the stage to the last rows of spectators. As long as we know the limits of their field of validity, geometric methods have the advantage of leading directly to work on shape. Controlling the propagation of sounds and noises in the city becomes possible (Beckers, 2014).

In acoustics, the image method presents itself as an interesting alternative to ray tracing. The Radit2D software, designed for room acoustics, is a first successful example of design assistance, which will effectively support your first acoustic projects, and which you can even try to bring to an urban scale, if you got a taste for programming (Beckers, 2002).

Figure 2. Sound exposition in an urban environment, rue des Tonneliers, Petit Bayonne.



The first acoustic cameras – the old dream of acousticians finally made possible to be able to visualize the sound field at the scales of architecture and, no doubt, of the city – confirm first, and in a striking way, the preponderance of specular reflection in built spaces and, therefore, the validity of geometric methods (Izumi, 2021). This is just the beginning, and you will have the opportunity to make all kinds of discoveries as you walk through the urban scenes, even bringing the less intuitive aspects of the sound field into our common visual experience. Unlike that of light, the propagation of sound cannot be considered instantaneous: you will learn to measure delays, perceive echoes and reverberation, build and interpret the impulse response, deduce from it the main parameters of sound perception (de Bort, 2023).

4. Electromagnetic radiation

Infrared radiation, black body, emissivity, thermography, ultraviolet radiation

William Herschel discovered infrared radiation in 1800, and it took exactly one century for Max Planck to give its origin, in a famous article published in December 1900. A few years later, Niels Bohr proposed a simplified model of the atom that makes it possible to clearly explain the properties of the ideal black body, whose radiated spectrum depends on only one parameter: the temperature of its surface. That of the Sun is 5770 Kelvins, and it emits only short waves – the ultraviolet, the visible, and the near-infrared – which are now familiar to you. The Earth's surface, whose average temperature is 15 degrees centigrade, emits long waves, those detected by the thermal camera. The different components of the electromagnetic spectrum are perceived with different sensitivity curves by our eyes (day and night vision), by our skin (average radiant temperature, but also health risk in the ultraviolet), by plants (photosynthesis), by solar panels (photovoltaic effect) and, more generally, by the surfaces encountered (solar gain).

The Dart software will allow you to familiarize yourself with these different components of radiation, their passage through the atmosphere, and their contact with the objects, plants and animals that inhabit the Earth (Gastellu-Etchegorry, 2008).

Photography gives us instant images; it is the world of short waves. In acoustics, reflections no longer occur together, but are scattered over time: the sound space is made up of delays, reverberation and echoes, which are measured in milliseconds. The world of the thermal camera is inertial: what appears in thermography depends on phenomena that occurred hours, days, or even weeks earlier. In town, thermographic measurement campaigns are difficult, because you have to shoot sequences over several hours in a rather hostile environment, which will require a lot of organization. The reward is to discover, in a non-intrusive way, the daily history of a street or a district, punctuated by the passage of the sun, the clouds and the wind, the shutters which open on differently heated or refreshed apartments, heat rising from thermal bridges or manhole covers, construction secrets hidden in the walls (Vollmer, 2017).

5. Atmospheric physics

Global radiation balance, Coriolis force, circulation of oceanic and atmospheric currents, Earth's climates, traditional habitat

Three major actors share the theater of the world: the Sun, which speaks in short waves, the Earth, which responds in long waves, and the atmosphere, fine and light, but whose role is principal: it is the one filtering the unequal dialogue of the two stars and which balances it, by means of a window that it veils or reveals, according to its clouds, their greenhouse effect, latent heat, and the great air currents stirring up particles and temperatures. From a few elementary notions of astronomy and a brief description of the layers that form the atmosphere, you will understand why it often rains on the Equator and in temperate latitudes, and why the great deserts are found around the Tropics, from where the trade winds come from, in which direction hurricanes and typhoons turn, how Eratosthenes was able to precisely measure the radius of the Earth almost twenty-three centuries ago, what paths the Spanish navigators had to take to go up the coasts of Chile or join those of Mexico from the Philippines, and, finally, how traditional architecture found everywhere the same formal solutions to ensure the comfort of the inhabitants according, mainly, to solar paths and, therefore, to latitude (Beckers, 2013).

The Heliodon2 software is a very effective tool for design assistance with solar paths. It will assist you first in the study of the best architectural solutions on the Equator, in the Tropics, then, until crossing the Arctic Circle, in temperate and cold climates. Its graphics will make you think about the orientation of a street, its aspect ratio, the glazing rate of its façades, solar protection, skylights, and interior space layout (Beckers, 2003).

You will also work on the achievement of a robust and inexpensive weather station, easy to install, to maintain, adapted to the cities of Africa, Latin America and South-East Asia, where the urban growth is the strongest. and where, paradoxically, universities are the least equipped to work on the city.

6. The city in the 21st century

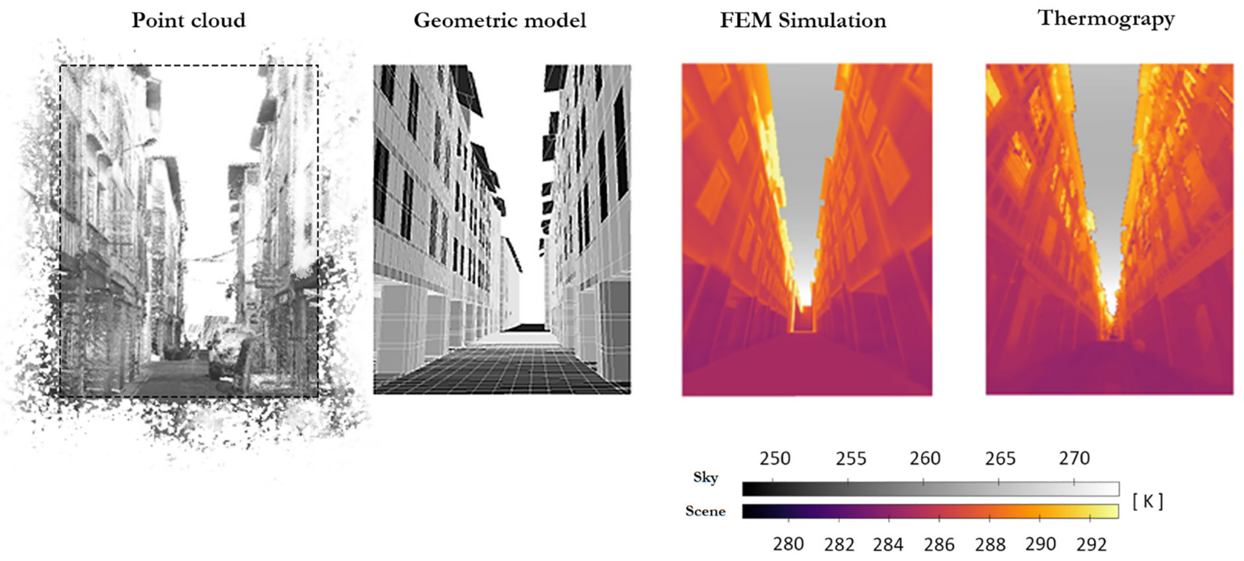
Neolithic revolution, industrial revolution, 21st century, Art and science of the city, drones, point clouds

The course begins by showing the effects of the industrial revolution on cities from the beginning of the 19th century, and the responses provided by emerging town planning, with a detailed analysis of Haussmann's Paris and the Eixample of Barcelona. The increasing difficulties presented by the urbanization of the 20th century, in particular in the 'new towns' in France, India (Chandigarh) and Brazil (Brasilia), are largely explained by the impossibility of modeling increasingly complex situations. We then go back to the highest antiquity to explain what a city is and how it is perceived, from Sumer and Egypt, passing through the key cities of the Greco-Roman Mediterranean (Athens, Alexandria, Rome, Constantinople) and the Middle Ages (Cordoba), and we emphasize the decisive contribution of the new tools of representation (perspective projection) in Renaissance and Baroque urban compositions. Finally,

Figure 3. Thermal study on the scale of rue des Tonneliers, Petit Bayonne. Finite element simulations performed on Cast3m (Acuña Paz y Miño, 2021)

present and future issues are discussed, in particular those related to demographic change, urban sprawl, interactions of cities and climate, availability and integration of renewable energies.

Two competing techniques – photogrammetry and LIDAR (Light Detection And Ranging) – now make it possible to automatically record the geometry of a terrain, a forest, or a city. The main difficulty lies in the post-processing of images (identifying windows, simplifying trees) and point clouds (identifying planes, edges, and corners). You will be interested in pattern recognition techniques that are still insufficiently efficient, but are progressing rapidly.



The LIDAR device can be carried in a backpack, on a car or a train, under a drone, a helicopter or an airplane, or even on a satellite. This gives different points of view on the city and its environment. You will be particularly interested in drones, which, once authorizations have been obtained, can move perpendicular to façades and skim over roofs, offering the best views of urban surfaces and cavities.

7. Heat Diffusion

Fourier equation, *functional*, *Rayleigh-Ritz*, *isoparametric finite elements*, *conduction*, *convection*, *transient*, *radiation*

The course deals with heat transfer by conduction, convection, and radiation in steady and transient regimes on a geometry meshed with Coons' patches. These are the precursors of CAD (Computer Aided Design) techniques developed intensively in the 1970s and which led to Bézier techniques, B-splines, and NURBS (Non-Uniform Rational B Splines). The transition from the Coons' patches to the finite elements results is the use of isoparametric finite elements, in which the considered field is discretized with the same approximation as the geometry (Irons, 1966).

The examples and exercises are chosen after referring to the students of previous years to highlight the behavior of the finite element method and its numerical implementation: property of conductivity and capacitance matrices, verification of balances and flow equilibrium. Detailed course notes present Matlab© functions as short as possible in order to illustrate, in particular, the radiative contributions (black bodies and gray bodies) as well as the structured meshes built from Coons' patches. All of these functions form the 'Fiammetta' software, which will allow you to follow the finite element method step by step on simple cases, but is very interesting for urban heat transfer analysis: cavities, street profiles, and thermal bridges (Beckers, 2023).

You will also be interested in satellites located on low orbit, sun-synchronous polar or geostationary, for the observation of the Earth and its cities, as well as for telecommunications and geolocation, and even those located much further away, on the Lagrange point L2, in the shadow of the Earth, for observing the universe and its history. This will allow you to further increase your culture on electromagnetic radiation.

8. Computer Aided Design

Procedural methods, mesh, urban mockup, exchange formats

You will start by developing an urban CAD model, which can support the different required meshes (radiosity, finite elements, fluid dynamics, etc.). It is a semi-automatic model, based on building typologies, with the desired level of detail (windows, real interiors) and with all the information necessary for the different simulations (optical and acoustic properties of surfaces, thermal properties of materials...). The geometry is described starting from buildings of simple shape, like parallelepipeds with flat, double slope, or quadruple slope roofs. The city is introduced in procedural form, so that it is easy to generate models composed of a large number of buildings.

For the thermal problem of the building/block/neighborhood, you can proceed in different ways:

1. You use a finite element method on a mesh of the scene (therefore on the geometry as precise as you wish). If three of you solve the same problem, they will find the same solution.
2. If you use a nodal method, everyone will pose the problem in his own way (for example: how to define a veranda, a buffer space like a garage, etc.). The solutions will be very different from each other, and it will be impossible to decide which solution is closest to reality.
3. On this observation, the developers of the nodal methods first added all kinds of modules allowing the taking into account of buffer spaces, verandas, but also heat pumps, radiators, controlled mechanical ventilation, ... They have also used specialized codes for a more precise calculation of certain aspects (typically: solar gain, lighting consumption, etc.). This time, if we entrust the same calculation to just one of you, asking him to perform it on three different Dynamic Thermal Simulation programs, he will find very dissimilar results (typically, differences of more than 20% on simple problems, and far superior on complex configurations). Himself will be absolutely unable to say which is the best solution (the best program), because all these codes have become black boxes.
4. Faced with these well-known problems, the authors of these software seek to degrade their tools, but at the same time to add modules. It is endless and without a solution: it remains a black box, and only specialists (that is

to say people who know the solution in advance) manage to succeed. Even then, the codes only serve to comply with a regulation (because it requires dynamic thermal simulation) or to convince a customer (because it gives the appearance of a complex calculation). These codes are not intended to find original solutions, nor to make people understand non-intuitive aspects of physics. In fact, the only argument in favor of nodal methods, still valid fifteen years ago, was that the finite element calculation was too long (which is no longer true) and too complicated to set up (which will no longer be true after this course, since you will have learned to automate CAD and meshing).

For your simulations, you will need to obtain the boundary conditions and the initial conditions through a specific measurement campaign: measurement of the reflection coefficients in the different wavelength bands studied, identification of the type of reflection (diffuse, specular, a mixture), measurement of emissivities, etc. A series of thermographs giving the surface temperatures at the initial instant can be used for a first simulation by finite elements in steady state, which gives the initial conditions for the thermal problem in transient condition.

9. Urban Physics

Ground, celestial vault, air, water cycle, materials, devices, vegetation

The celestial vault is a virtual surface on which the Sun, the sky and the clouds are projected, for the sole purpose of serving as a radiative boundary condition. It ignores the wind, which moves the clouds and blows in the streets, the rain that trickles from the roofs, then washes the sidewalks and the snow, which piles up and then melts, the water that evaporates, the plants that sweat, the basement with the metro trains, the dirty water from the sewers, the electric cables, the gas and water pipes, … However, you do not want to understand only the city where you live, but all the cities of the world. Whether you move in latitude or altitude, approach an ocean, or move away from a river, everything changes: the species of plants, their rate of growth, the prevailing winds, the building materials available, the traditional or modern devices put in place, and their performance. As soon as we move away from the solar paths and their astronomical regularity, the characteristics of the climate, the relief, the geology, the history become abundant, and we can hardly hope to bring order to them. We will propose, for each city, to draw up a sheet that takes up the main physical and historical characteristics, in order to guide the architectural or urban renovation project. Just one example: two towns are separated by only a few tens of kilometers, the summer there is very hot, but in the first, which may be located in the middle of mountains, the sky is generally clear, whereas in the second, a harbor by the ocean, the sky is almost always overcast. The first will therefore give the possibility of exploiting radiative cooling, while, in the other, there will be little other resource than to let the sea breezes circulate as well as possible.

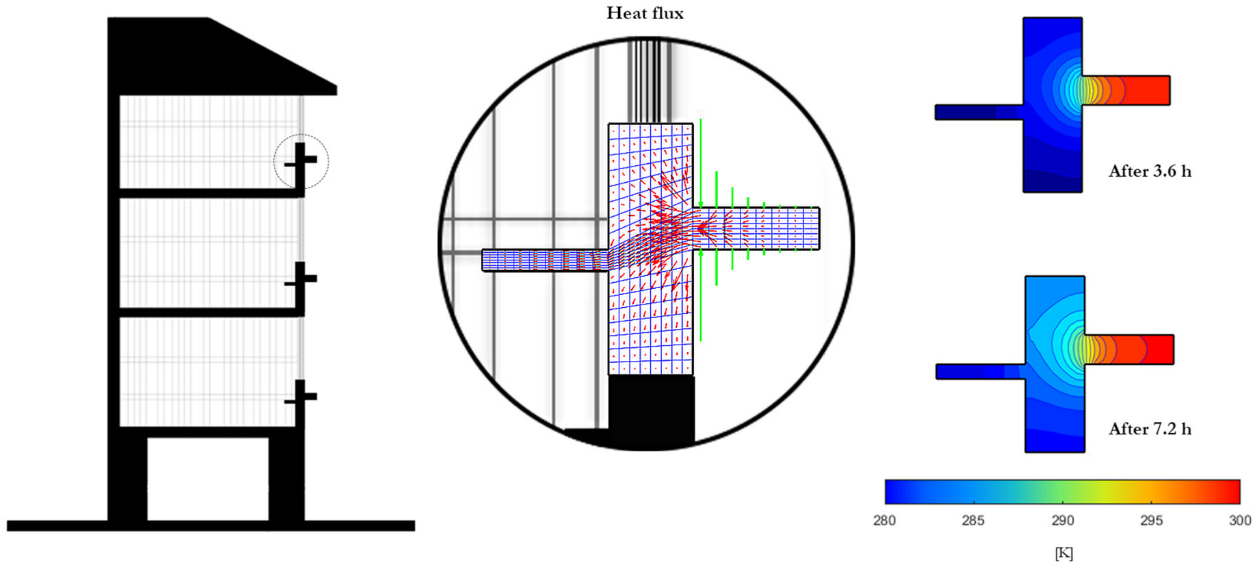
To dominate urban physics by calculation, you still have to master fluid dynamics. However, if there are universal software for simulation known as CFD (for Computer Fluid Dynamics), they are extremely slow and unsuitable for urban scales. You will not be interested in it, because there is another way, much more fruitful and closer to the general spirit of this master, which involves measurement.

For the measurement, so far, we have preferred the use of photographic, thermographic and acoustic cameras, in order to obtain spatial descriptions of the energy fields in urban environments, better able to help in the analysis and architectural design than the usual point measurements (luxmeters, pyranometers, thermometers, sound level meters), which are particularly difficult to use in urban areas. You are now going to extend this practice to the aeraulic field, by means of the techniques of strioscopy (or Schlieren, according to the established German term) which today seem sufficiently developed to be applied on the scale of a building room, even more. In an interior, the quantities of interest are:

- the average airspeed (which can be linked to the concept of comfort);
- the air renewal rate (which is involved in air quality, and also in the calculation of the building consumption);
- the convection coefficients of the different surfaces (which enter as boundary conditions for the thermal simulation of the building).

'Schlieren' images, to which one can add specific measurements and thermographic images, should make it possible to quantify these three quantities of interest and, in the most complex situations, where the architect lacks a sufficient understanding of the phenomena involved, to make it possible at least to visualize the movement of the air by means of careful post-processing (Settles, 1997).

Figure 4. Study of the diffusion of heat through the walls of buildings, and highlighting of a thermal bridge ('Fiammetta') (Beckers, 2019)



10. Signal Theory

Transfer function, convolution, sensors, filters, sensor network, smart city

Opposed to our vision of measurement for urban physics, which consists of carrying out very short and non-intrusive campaigns ('one person, one camera, one day'), using more or less sophisticated cameras that allow to visualize the physical fields and to obtain, by post-processing, clear and synthetic information that is easy to interpret, there is another vision, very fashionable, which starts from the observation that today we have all kinds of miniaturized sensors which are also very cheap, and can be directly integrated into 'intelligent buildings' (some have tens of thousands of such sensors), with the hope that artificial intelligence techniques will make speaking the enormous mass of information gathered in real-time. So far, the results are not conclusive, and the data often accumulate without anyone to process them. However, for certain particular applications, it seems legitimate to be interested in these techniques: detection of repeated patterns in point clouds (for example: automatic identification of windows on façades), maintenance of complex systems (electrical network, water, road signs) ...

In programming, you will learn how to go from the time domain to the frequency domain using the Fourier transform, to detect periodic phenomena (for example: peaks in electricity consumption). You will be interested in the simulation of human activities in the city, even if, here too, a cultural approach seems more interesting to understand the differences in the rhythms, schedules, and activities of the inhabitants according to the climate, the cultural habits and the history.

For the measurement, even if you favor short measurement campaigns, over a single day, it is very important to anticipate them by placing a few sensors (thermometers, anemometers, hygrometers) over a longer period, in order to specify the initial conditions of the simulations.

11. Solar energy

Solar potential, energy mix, solar power plants, photovoltaics

Solar energy is available everywhere and close to users. In the most favorable situation, it can be enough to provide all the electricity that the buildings of the city need. There is no universal model, which would apply to all urban configurations regardless of climate, history and economy. To take the right decision, it is necessary to precisely evaluate the solar potential of each available surface - which implies a detailed model of the city -, the type of installation - panels integrated into the framework, or located on frames that will modify the shape and the use of roofs – the connection to an electrical network, trying to avoid the use of expensive and polluting batteries as much as possible. In the long history of cities, the transition from one main source of energy to another - from water and windmills to coal, then to oil, gas, and nuclear - has always led to deep changes in the construction of buildings, in the lives of the inhabitants and even in international relations. If you imagine an energy transition policy over fifty years, which seems reasonable, you still need to know what the studied city will look like in fifty years. You therefore need a digital model of the city, with evolution scenarios, which has never been done carefully so far, but you are now able of it. Will you be the first?

You will need to learn how to simulate the photovoltaic system, taking into account the characteristics of the panels, their eventual, partial and temporary shading, the possibility of motorizing them to follow the movement of the sun, their efficiency, the characteristics of the electrical network that receives their contribution, the short-term forecast of a cloud that would hide the sun. To estimate the needs, you will need to simulate other systems that are offered as complements – heat pump, wind, hydraulic – or as alternatives – photovoltaic or thermodynamic solar power plants [Beckers 2023b].

You will finally learn how to measure the surface temperatures of large photovoltaic installations by means of the thermal camera, correcting for the specular reflection of the sky.

12. Urban Digital Twin
The successful wedding of measurement and simulation at urban scales, measurement and simulation of comfort and consumption
A digital mockup is an idealization of reality, simplified in a specific direction chosen according to the expected results. One simplifies either the physical model (by treating certain aspects of the problem in a schematic way), or the mathematical model (by resorting to the discretization of the fields, their linearization, their lumping, etc.), or the studied application (for example, limiting the study to a piece of the object), or a bit of all three, hoping to be clever enough to capture a substantial part of reality.

The digital twin represents the hope of obtaining, thanks to recent advances in measurement and simulation techniques, a model of the real object so complete that it reacts to the constraints virtually imposed on it (initial conditions, boundary conditions, modification of geometry or materials) in the same way as the real object subjected to these same constraints in the real world.

In the previous course, you participated in the development of a specific digital model for solar potential. It cost you a lot of time, and of course you would like this model to be used for a whole other study as well, for example for the control of the sound field. If your sponsors - probably: the technical services of the city, or the agglomeration - follow you, they will soon want to test other ideas, relating to the consumption, to the comfort of walkers... When you have gone through the complete physics, it will no longer be a mockup of the city, but its digital twin.

In April 2023, the urban digital twin remains a dream, but its realization is now affordable. Many aspects remain to be studied, and many problems remain to be solved, but we have already made a lot of progress. At the end of this master, do not doubt that you will find the job of your dreams, because your new knowledge has no equivalent elsewhere and, for the cities of the world, no price.

Whether you soon work for the technical services of a city, in Europe or anywhere in the world, or in one of those companies, still too rare, which have given up following the sirens of greenwashing or fashionable technologies, and who believe that scientific progress is still necessary and possible, you can continue to participate in research, bringing new questions and ingenious applications, to save all our cities from a mediocre destiny, which is anything but inevitable.

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Pluvial Flooding in Compact Neighborhoods: Dynamic Analysis for Climate-Adaptive Buildings and Urban Spaces

Michele Morganti, Simona Mannucci and Ilaria Fiocchi

Mediterranean compact cities are increasingly at risk because of climate change and, in particular, extreme rainfall events. The increased intensity of these phenomena poses a significant threat in terms of infrastructure damage and human loss. The proposed work aims to create an unambiguous methodological process that can be repeated in any context and at any geographic scale to create adaptive urban planning and reduce pluvial flooding risk, within compact urban fabric. The realized process creates a dynamic simulation of rainfall flows within the urban fabric, depending on topography, housing density and the presence of permeable surfaces. This parametric simulation allows to highlight buildings and areas exposed to risk from extreme rainfall events, through iterative analytical processes. The research highlights suitable urban spaces for introducing sustainable drainage systems and nature-based solutions useful to reduce environmental, social and economic damage from heavy rainfall and subsequent flooding.

Urban climate change

Since the advent of the Anthropocene, cities have been particularly susceptible to climate risks, but nowadays is getting increasingly evident due to frequent extreme climate events: flash floods and hailstorms, floods, intense heatwaves, droughts, etc. (Folland et al. 2001). Counteracting the urban climate risk is of paramount importance due to implications for the safety and health of individuals, as well as the significant economic costs associated with damages to infrastructure and urban areas. Floods, in particular, are closely linked to hydrogeological disasters and the expansion of urban land use, contributing to increasing hydraulic risk in urban areas (Bonanni, 2020; Bonanni 2020). Currently, research debate in the urban planning and design fields seeks to explore cutting-edge approaches to conceive new methods and tools to better grasp and analyze the inherent complexity of floods dynamic in urban areas (Naboni et al. 2019; Mannucci, Morganti, 2022).

In Europe, The European Climate Action forms a comprehensive framework for promoting the above-mentioned debate and reaching objectives on sustainable development, resilience, and climate action, following the United Nations Framework Convention on Climate Change and The Sustainable Development Goals (SDGs) 11 and 13 (UN, 2015; Guterres, 2020). The European Climate Action further reinforces these goals by offering specific policies, strategies, and funding mechanisms to support climate change mitigation and adaptation efforts across the region. European nations strive to achieve sustainable urban development, foster environmental-friendly communities, and enhance climate resilience. The SDGs and the European Climate Action are guiding principles, providing a roadmap for policy formulation and implementation and encouraging research and innovation in sustainable design solutions and practices.

This study focuses specifically on urban flooding – a phenomenon closely linked to average temperatures rise – which recently occurs at an increased rate and extreme intensity, exposing urban areas to high risks.

The escalating process of urbanization contributes to flood vulnerability due to the extensive concentration of impermeable areas, impeding the natural cycle of accumulation and discharge of water into the aquifers, and disrupting the natural processes of water runoff (Rosso et al., 2019).

The scientific literature on urban climate change highlights the importance of adapting cities to cope with extreme events. Namely, the urban system should accommodate rapid changes facilitating a swift recovery of usual activities. This concept is closely associated with resilience, often translated into architectural and urban design measures to enhance public spaces' spatial and thermal quality (Folland et al., 2001; Folland et al., 2001). Since the 20th century, developed countries have formulated policies and strategies to address water-related issues, progressively shifting their approach from excluding to making room for water in urban areas.

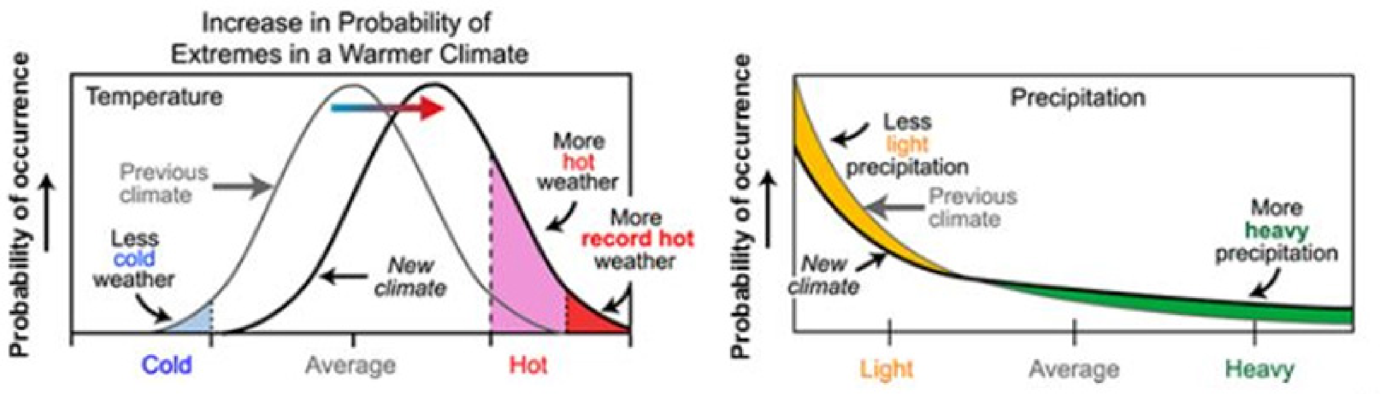


Figure 1- Folland C. K., Karl T.R., Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of Intergovernmental Panel on Climate Change - Curves illustrating the causes of increased hydraulic risk.

These strategies aim to achieve an integrated system of urban water management (IUWM) (Schuetze, Chelleri 2013) encompass practices of best management (BMPs), low-impact development (LID), water-sensitive urban design (WUSD) (Lloyd, Wong, and Porter, 2002), sustainable urban drainage systems (SuDS) (Griffiths, 2016) and Sponge City (Chan et al., 2018).

Notably, the Sponge City project was introduced following the Beijing flood in July 2012 by Professor Kongjian Yu, Turenscape's founder, and a Peking University professor. This new concept for cities is based on the idea of allowing pluvial water to infiltrate the ground, be retained locally, and be used for the city's water supply. By reducing the flow rates and increasing the collection times of the sewer system, the water reaches the final receiving bodies with a delay, thereby reducing peak flows and the risk of flooding (Nguyen et al., 2020). This concept has spread globally, including in Europe; Berlin became the first European city to embark on this path in 2016. The core idea is to enable the city to balance the effects of urbanization, such as reduced soil permeability, implementing sustainable urban drainage systems (SuDS), managing stormwater effectively, and restoring the hydrological balance. The main solutions involve natural-based approaches (NBS) (Zandersen et al., 2021) that have a low impact but are widely integrated into the urban fabric. Broadly speaking, we can summarize the three-fold objectives of Sponge City as follows: Firstly, it aims to control urban flood disasters. Secondly, it seeks to improve water quality through self-purification systems, which have additional co-benefits for public health and microclimate. Lastly, the concept aims to recycle rainwater and transform it into a valuable resource for use during periods of drought.

In this perspective, in Europe, several cities have taken measures to address the issue of hydraulic risk by transforming urban plans into climate adaptation plans (Reckien et al., 2014). For example, cities such as Amsterdam, Rotterdam, and Copenhagen have developed master plans using analytical models to identify areas within the cities where excess rainfall accumulates during heavy rain events. These areas have been classified according to different risk levels, which have led to the identification of interventions to be implemented in terms of infrastructure and environmental modifications. These strategies have resulted in a shift in approach by local administrations, moving from a purely hydraulic focus to a functional one, investing in urban spaces and buildings to improve the quality of urban environments and the lives of citizens holistically. In Barcelona, conversely, due to its rigid urban fabric, a system for collecting rainwater has been developed using underground storage tanks, supporting the process of greening neighborhoods by acting on urban spaces and road networks to increase security and health for citizens and urban quality. A similar system has been planned for the city of Paris, which, in addition to utilizing sustainable urban drainage systems, has also focused on citizen awareness projects (Bassolino, 2019).

Despite frequent extreme weather events followed by catastrophic consequences in Italy, the adaptation process is still in its early stages. The cities of Milan and Rome have joined organizations, such as 100 Resilient Cities and C40 Cities Climate Leadership Group, which seek to define strategies for adapting cities to climate change. The only regulatory instrument in Italy is the 'Flood Risk Management Plan' established by Directive 2007/60, approved by the European Parliament and Council, and implemented into Italian law by Legislative Decree 49/2010The directive sets common guidelines for all member states to develop maps representing flood hazards and risks and to prepare a specific Flood Risk Management Plan. The directive also requires that the plan be prepared at the level of River Basin Districts: Eastern Alps, Po River, Northern Apennines, Central Apennines, Southern Apennines, Sardinia, and Sicily. Flood risk management is expected to be prioritized in areas with a significant potential risk of flooding or where such risk is likely to occur. The plan establishes four measures to reduce the negative consequences arising from the significant

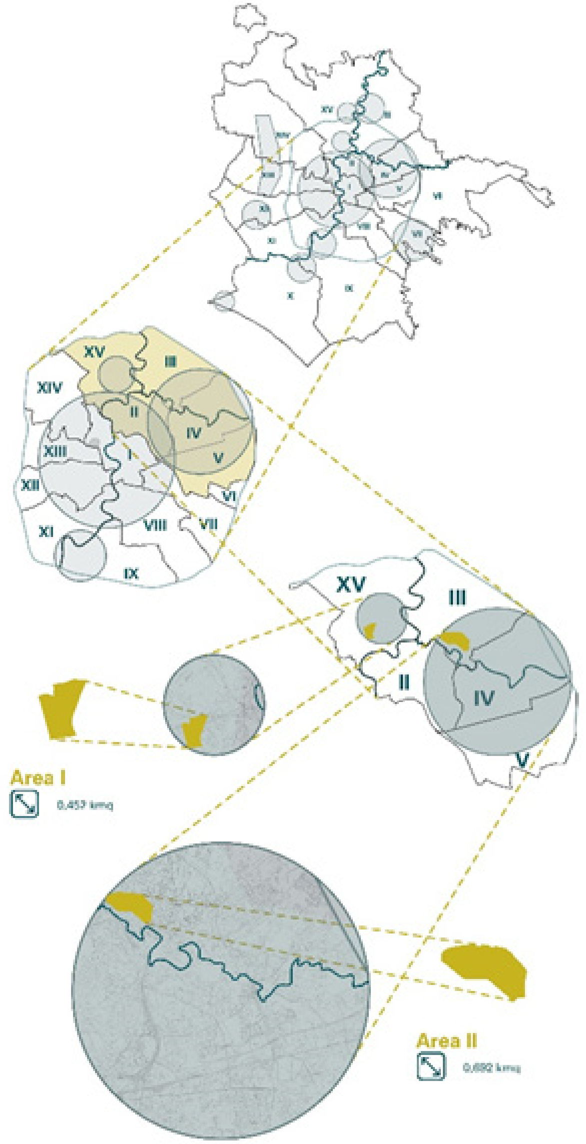
potential risk of floods: prevention, protection, preparedness, and return to normal conditions. Furthermore, it divides the territory into River Basin Districts, which identify hydrographic basins characterized by homogeneous areas.

Nevertheless, despite the growing attention to urban climate change is promoting new methods and paradigm shifts from the usual design planning conceptions, there is currently a lack of a multiscale approach, that allows for a unified treatment of the issue, regardless of the specific area or desired scale. To address these limitations, we propose a novel workflow based on a constellation of digital tools. The workflow enables the dynamic simulation and interactive representation of extreme rainfall events in urban areas, highlighting the most vulnerable buildings and areas using parametric software and color gradients. For this study, we selected a relevant case study to explore the potential of the proposed workflow, analyzing and addressing the issue of hydraulic risk in compact Mediterranean cities. Specifically, we focused on the River Basin District of Central Apennines, the Tiber River basin, and the city of Rome. In the following sections, we introduce and discuss the case study characteristics and the workflow application, highlighting current limitations and potential for further research and planning outlooks.

Pluvial flooding in the compact city

For the application of the workflow presented in this study, we selected relevant case studies in the Metropolitan City of Rome. The most vulnerable areas within the Grande Raccordo Anulare (the ring road motorway that surrounds the city), have

Figure 2 – Keyplan of selected areas in Rome (IT).



been identified by overlapping territorial maps, containing classes of hazard and the Areas at Significant Risk.

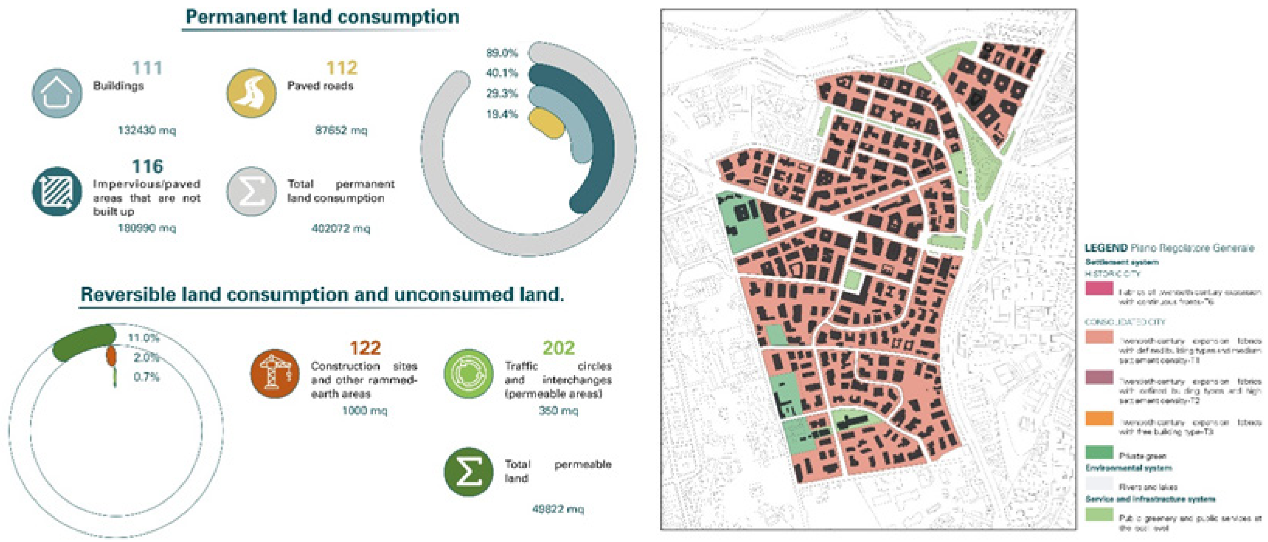


Figure 3 - Example of urban analysis and associated metrics of the Conca D'Oro area

Estimating the number of inhabitants and assets exposed to risk, along with the classification of water bodies, the set of measures adopted for the area, and the cartography of the Master Plan for Hydrogeological Planning, enable the identification of specific Areas at Significant Risk where a priority risk management must be implemented. The outcome highlighted two distinct areas with high vulnerability to flash floods: Significant Risk Areas INT-TEV-7 and INT_ANI-PRA-TOS-1 in the III and XV Municipalities, corresponding to the Conca D'oro and Tor di Quinto neighborhoods. Both the urban texture are characterized by a compact pattern, consistent with the definition provided in the General Master Plan of the City of Rome in 2008.

An analysis of the territory was conducted on these areas using open data provided by the Institute for Environmental Protection and Research (ISPRA). The analysis shows that the surfaces with a permanent land consumption level (89%) are higher than permeable areas.

In these areas, an urban form analysis based on the Spacemate method was developed (Berghauser Pont, Haupt. 2010). This method relates density metrics and urban form through four main variables: base land area, network length, gross floor area, and footprint. These variables generate density indicators such as floor space index and gross space index, allowing for a parameterized description of the city. Based on numerical analysis – despite having different footprints and heights – the analyzed areas fall into the class medium-height row buildings (E). This analysis also enables the correlation of these parameters with others, establishing relationships between the qualitative characteristics of urban form, energy performance, environmental aspects, heat island effect, and comfort.

High-resolution dynamic modeling

The focus of the work has been on the development of a high-resolution methodological process for identifying buildings and areas at higher hydraulic risk in an urban context through dynamic simulation of rainfall phenomena.

This simulation was developed through six main steps:

1. Data gathering was carried out on the National Geoportal and the ISPRA website for spatial data suitable for Geographic Information System tools (QGIS). These data

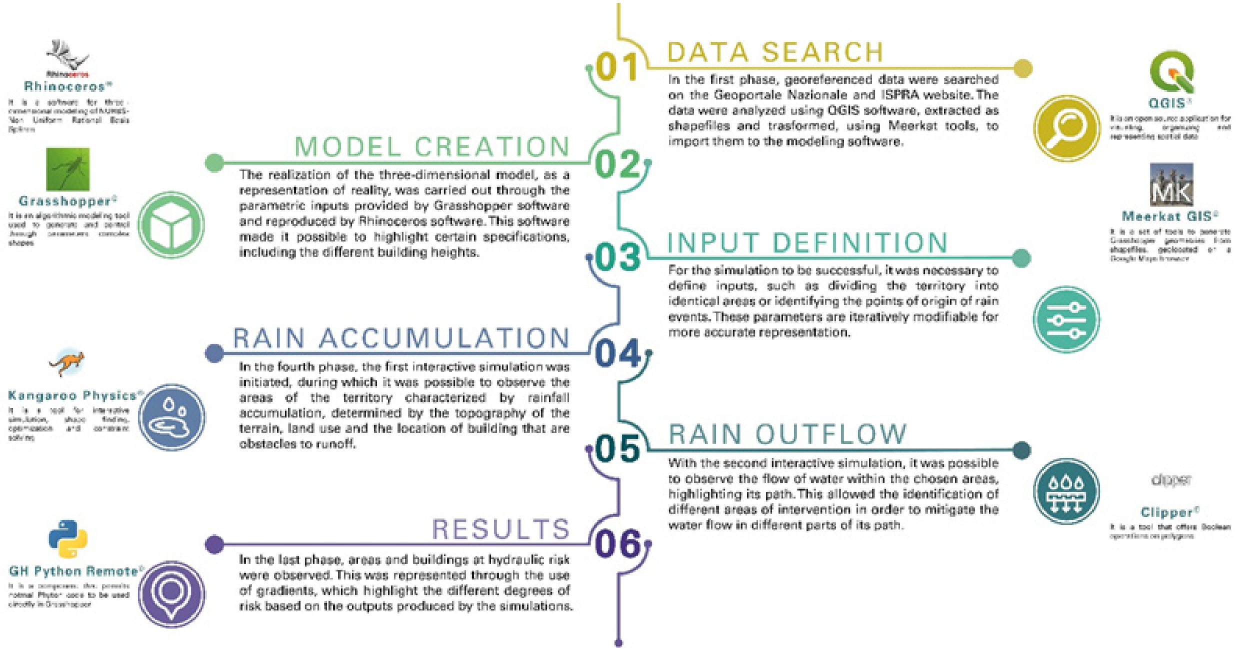


Figure 4 - Workflow for the dynamic simulation of hydraulic risk in urban areas following extreme rainfall events.

were transformed into shapefiles and used for the model through Meerkat (a plugin that generates geometries for the Grasshopper software from geolocated shapefiles on a Google Maps browser).
2. The obtained data were used for creating the model on the Rhinoceros interface through processing performed using Grasshopper.
3. To obtain a reliable simulation, prespecified input parameters, e.g. the parts dividing the area, were considered that can be iteratively modified for a more accurate representation.
4. Following these steps, the first interactive simulation was conducted to identify rainfall accumulation areas. These areas are determined by the terrain topography, land use, and the position of buildings, which obstacles the runoff.
5. The path of stormwater runoff is highlighted in the second dynamic simulation.
6. Finally, the simulation makes it possible to visualize buildings at higher hydraulic risk through color gradient maps.

The data gathering focused on three different types of information and associated sources:

- A Digital Elevation Model (DEM) provides the necessary data to generate georeferenced terrain topography through the open-source software QGIS.
- Land use data provided by ISPRA
- Building datasets provided by the National Geoportal to create georeferenced maps

Based on these data, after further file format modifications, into shapefiles, it was possible to create a georeferenced and interactive three-dimensional model of the areas of interest using Grasshopper software and displayed it on the Rhinoceros interface.
Once the model was created, the initial parameters were defined to divide the topography into equal areas and determine the number of elements composing the simulation. This determines the simulation's accuracy level, which can be modified later for a representation closer to reality.

Pluvial flooding in compact neighborhoods
In case studies, the topography was divided into a grid of 90x90 sectors, resulting in 8,100 elements constituting the meteoric water, each located at the center of each zone, symbolizing the rainfall event represented by the simulation. By initiating the dynamic simulation, the elements, represented by spheres associated with a rainfall intensity derived from pluvial data, accumulate in certain zones based on the topography and the presence of buildings or permeable areas, symbolizing the rainfall event in a specific zone.
As mentioned, a more detailed simulation was then carried out, taking into account the final accumulations of meteoric water and the actual pathway within the urban fabric. This process highlights areas most affected by the runoff of pluvial water, which allows the identification of effective urban design strategies not only in the accumulation areas but also along the entire runoff pathway.

Figure 5 - Step 4. Rainwater accumulation at the end of the first dynamic simulation in the reference area – 'Significant risk area I-INT-TEV-7'.

Figure 6 - Step 6. Results of the buildings subject to greater hydraulic risk within reference area I represented with color gradients - 'Significant risk area I-INT-TEV-7'.

The process allows the accurate visualization of buildings at higher hydraulic risk. The representation is achieved through color gradients based on the results of the dynamic analysis. Grasshopper software can track the elements that reach different buildings during a pluvial event's timelapse and represent them with a color scale. Once the simulation is completed, this results in a comprehensive representation of buildings at higher hydraulic risk. In addition, based on the simulation results, the areas subjected to a higher water concentration were identified. This was achieved through Surfer software, which allowed for representation using contour lines, also characterized by color gradients. These contour lines were obtained using values derived from the spatial distribution of water elements at the end of the simulation, representing the amount of water affecting individual buildings and urban spaces after a rainfall event.
To establish soil permeability and the presence of aquifers, the method is based on a hydrogeological analysis using maps of the considered areas.

For the definition of sustainable urban drainage systems, we considered the different types of spaces commonly found within the European compact city: main and secondary urban streets, squares and gardens, parking lots, and private courtyards. After the identification of the different spaces within the selected neighborhoods, we assessed how the implementation of SuDS (Sustainable Drainage Systems) can be achieved based on the specific needs of different urban spaces(Mannucci et al., 2022).

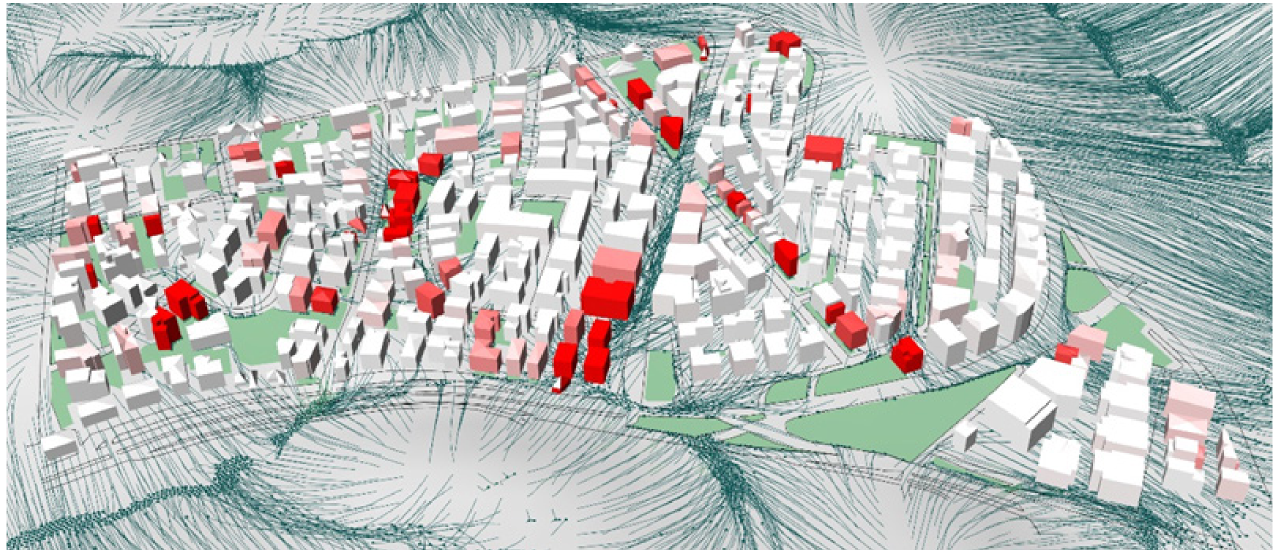


Figure 7 - Significant pluvial flood risk gradients in case studies.

Among the applications of SuDS at the urban scale, we selected detention basins. These basins are designed to collect and temporarily store excess water, thus reducing the volume of water that flows into the sewer system. Specifically, to proceed with the basin sizing, we considered the rainfall intensity through a statistical analysis that defines the probability rainfall curves, which vary based on the return period. The intensity was considered constant during the rainfall event to define a rectangular design hyetograph. Furthermore, we calculated the flow rate at the closing section using the inflow factor. In line with the scope of the project, this coefficient has been considered as 0.3 in permeable areas and 0.8 in impermeable areas to make the calculation more realistic compared to the values provided by the simulation (taking into account the inflow coefficient

as 0 in permeable areas and 1 in impermeable areas). An additional step to evaluate the correct sizing of the basin is the assessment of the kinematic method, and calculation of the critical event, defined as the duration required for water to travel from the furthest point within a watershed to the outlet of the watershed.
To quantify the volume of the detention basin, we relied on the Rational Method (Metodo delle sole piogge o formula razionale)(Guo, 2001), considering the principle of hydraulic invariance as requested by the Italian Flood Risk Management Plan. From a quantitative perspective, the inflow basin of a detention basin consists of various elements that reach the area of interest at the end of the process, some of which are located in the impermeable zone and others in the permeable zone. Therefore, in addition to graphically and numerically identifying buildings and areas subject to higher hydraulic risk, the developed process can also be used for sizing the storage volumes of various sustainable urban drainage systems.

Climate-adaptive neighborhoods

The proposed workflow has been tested through the dynamic analysis of two typical compact neighborhoods in the city of Rome, as it has been tailored to studying the compact city model and its response to extreme pluvial flooding. The approach at the base of the workflow and the associated method explores the potential innovative digital tools for supporting dynamic studies on pluvial flooding and hydraulic risk analysis in urban areas. The main characteristics and associated advantages of this approach are:

High-resolution analysis: we obtain to investigate the spatial distribution and read associated gradients of hydraulic risk at the neighborhood scale according to the characteristics of the urban fabric.
Digital tools integration: we combine existing digital tools for architects and engineers intending to collect necessary data and properly develop the modeling and visualizing results (QGIS, Rhino, and Grasshopper plugins)
Design-oriented: we offer non-specialized designers the possibility to include pluvial flooding analysis in their professional practice by providing an approach based on widely-spread digital tools and using visualization as a powerful tool for clearly communicating the result of complex analysis; moreover, the Grasshopper parametric design platform has been selected as it is becoming increasingly the more diffused design environment that provides open-source plugins for building and urban environmental analyses.

Grasshopper has the potential to include and analyze different environmental phenomena; therefore, the same workflow could be applied for further assessments relying on several plugins requiring a specific dataset. By producing evidence-based maps and visual scenarios, urban spaces and buildings that are more exposed to hydraulic risk during extreme rainfall events can be identified. This can assist designers and decision-makers in formulating strategies to prioritize and spatial-defining solutions to facilitate climate change adaptation by introducing sustainable urban drainage systems. The implementation of these systems helps reduce hydraulic risk while simultaneously improving the quality of urban spaces, safety, and residents' well-being throughout the year (Masseroni et al., 2018; Masseroni et al., 2018).

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Association Between Spatial Characteristics of Courtyards in Different Historical Periods and Microclimate. A Case Study from China

Qian Zhang

The extreme heat events in cities appear with an increasing frequency, which is more intense in the old urban areas with chaotic construction conditions. Scholars have proved that microclimate can be optimized by changing the spatial characteristics of buildings. However, most of these conclusions were drawn from the analysis of the current urban space. To explore the influence of spatial changes that can reflect the real living needs of residents on microclimate, we simulate the summer microclimate of a courtyard in different historical periods, which is the first time that one residential courtyard with a time span of more than 400 years has been used for simulation research. Then the correlation between courtyards with different spatial characteristics and their microclimate is analyzed. The results suggest that the average daytime temperature of the courtyard in the east-west direction is lower than that in the north-south direction. In addition, the increase in the height of surrounding buildings will lead to a rise in the average daytime temperature in the courtyard. For courtyards with openings in different positions, the average daytime temperature in the courtyard with only one opening in the direction of prevailing wind is the lowest, while that of the enclosed courtyard without opening is the highest. This research gives fully consideration to the reflection of the changes in the living needs of residents in different periods on the spatial characteristics.

Contradictions caused by urban renewal in Ethnic Minority Areas

Urban renewal is an inevitable process that occurs in any city worldwide during the urbanization process, particularly in the accelerated development phase. This process involves the information feedback of various urban political, economic, and social factors, and reflects the rights and interests disputes among the government, developers, and residents. The urban renewal conflict of Sa Jinqiao in Xi'an, which took place in 2005, caused a significant stir in the local society, and its impact on the urban planning and construction of Xi'an continues to persist. A renewal project, aimed at enhancing the urban environment and improving the quality of life for residents, led to the strong protests of tens of thousands of people, which necessitates a reevaluation of the issue of urban renewal.

Sajinqiao, located in the western end of the Hui inhabited area in Xi'an, spans a total length of 1140 m and is home to approximately 2000 families, with around 90% of the population identifying as Muslims who practice Islam. Owing to the distinct settlement structure of the Hui inhabited area, which is relatively enclosed, urban planning has historically been unable to penetrate the area. Consequently, the streets in Sajinqiao are narrow, leading to traffic congestion, and the public service facilities are also inadequate. This not only hampers the daily lives of the Hui people, but also impedes the economic development of the region. While the government and residents share a common aspiration of improving the living environment, the challenge lies in determining the uncertain form of the Hui community after urban renewal, which has the potential to create conflicts.

The Hui community in Xi'an is a longstanding community that dates back over a thousand years. The Hui ancestors built a mosque in this area and established their homes around it, and over time, it has grown to become the largest urban minority community in China. This residential area is not just a place where Hui people have lived for generations, but also a spiritual center that holds deep significance for their religious beliefs and cultural identity. With the rapid pace of urbanization, the local government has devised an efficient urban renewal model: demolishing all low-rise residential buildings in the renewal area and replacing them with modern high-rise buildings and commercial properties. However, this model is ill-suited to preserving the traditional lifestyle of Hui Muslims and fails to meet their religious and cultural needs. The transformation of the Hui community raises questions about whether urban Hui residents will see an improvement or decline in their quality of life. The Hui inhabited areas are not just a repository of shared urban memory but also fulfill an indispensable urban function. In the face of the intense construction and urbanization taking place, these areas are facing severe challenges.

The aggravation of urban microclimate problem

Between 1950 and 2015, the proportion of the world's urban population in the total population increased from 30% to 55%. From 1980 to 2015, China's urbanization rate increased from 20% to 56%. The continuous expansion of urban regions around the world has resulted in the exacerbation of microclimate issues in urban areas. Factors such as reduction in evaporation surfaces, anthropogenic heat source emissions from human activities like transportation and industrial processes, canyon-like streets that reduce long waves reflected to the sky, improper design of urban spatial form resulting in the blocking of natural wind and the accumulation of air pollutants in urban areas, the imbalance of urban street ratio reducing turbulent heat transfer, and the greenhouse effect have all contributed to the exacerbation of urban microclimate problems. Over the past three decades, the temperature growth rate in urban areas with intensive urbanization has been significantly higher than that of other regions. For example, the temperature growth value in metropolitan areas along the Great Lakes in the United States and Canada is approximately 50% higher than the global average temperature growth rate. The temperature growth rate is also higher than the average in Eurasia, with a value of 20% to 30%. According to the latest 'China Climate Change Monitoring Bulletin', the scope of the haze area in China has expanded nearly tenfold over the past 50 years due to slow diffusion of pollutants caused by decreased wind speed in urbanization regions. In these regions, the average annual haze days exceed 60 days. Toshickt Ichinose analyzed the historical climate data of metropolitan areas along the Pacific coast of Japan, such as Jingbin, Hanshin, Setonoi, and Kitakyushu. During the 1960s-1980s, with the rapid development of the economy and urbanization in Japan, the heat island effect in the central areas of Tokyo and Osaka was very prominent, and the wind and environmental quality in urban areas decreased significantly.

Introduction of Xi'an

Xi'an is located in the southern part of the Guanzhong Plain in Shaanxi province, with the Qinling Mountains to the north and the Wei River to the south. It is situated between 107˚40'—109˚49' East Longitude and 33˚ 42'—34˚ 45' North Latitude. The city's jurisdiction measures 204 km from east to west and 116 km from north to south, with a total area of 10,108 km^2. The urban area covers 3,582 km^2. Xi'an is the capital of Shaanxi province and the largest industrial base and educational center in Northwest China.

Xi'an, formerly known as Chang'an, is the cradle of the Chinese nation and one of the sources of Oriental civilization. It is also one of the world's most ancient capitals. Throughout its 3,100-year history of development, 13 dynasties have held it as their capital. Starting from the Western Han Dynasty (202 B.C. - 8 A.D.), Xi'an became a major hub for economic and cultural exchange, as well as international cooperation. The famous Silk Road originated from Chang'an, now known as Xi'an, and extended all the way to Rome in the West. Chang'an culture has evolved into the mainstream of Chinese civilization. Today,

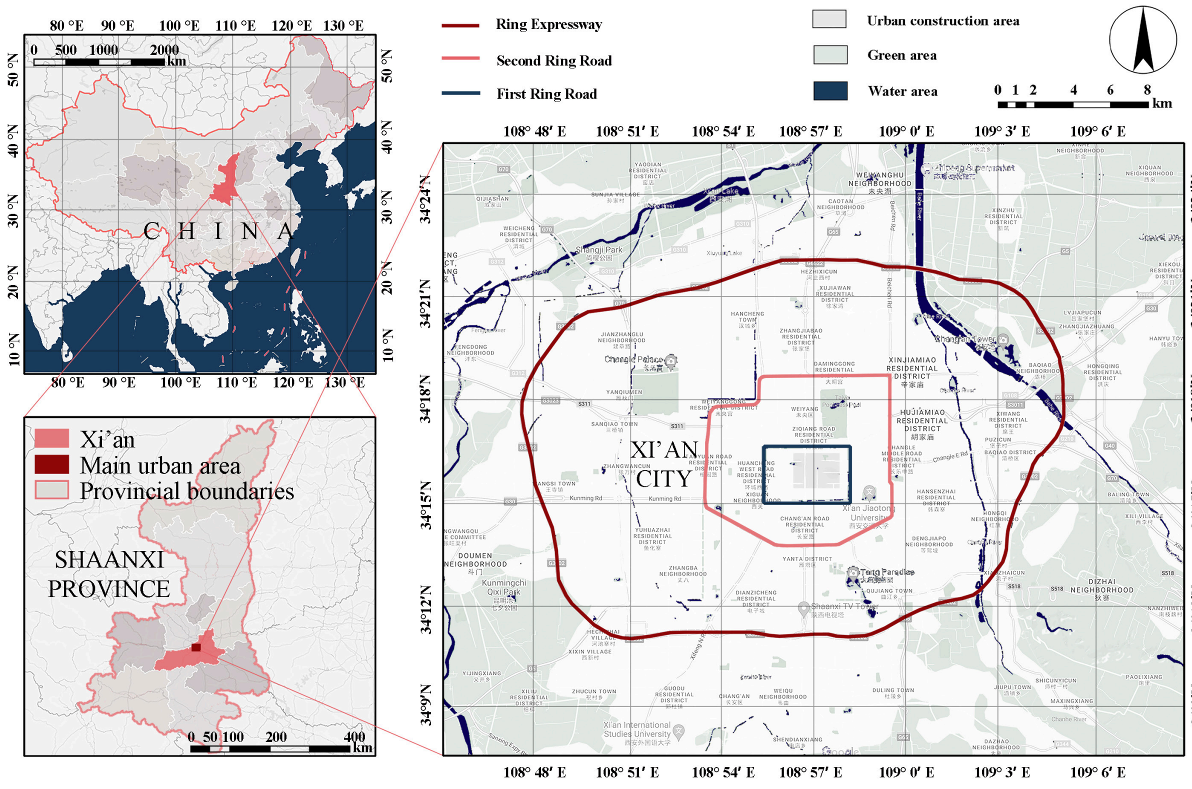

Figure 1. Location of Xi'an City

the city still has the Ming Dynasty city wall and many historical heritage sites. It is listed as one of the seven Famous Historical and Cultural Cities of China. The city's master plan has incorporated many lessons from the ancient city development modes in Chinese history. Xi'an has a warm temperate semi-humid continental monsoon climate, characterized by four distinct seasons. Summer is hot and rainy, winter is cold and snowy, and spring and autumn are characterized by continuous cloudy and rainy weather. The annual average temperature in Xi'an and its suburban counties ranges from 13.1 to 13.4 ˚C. The annual extreme maximum temperature is between 35 and 41.8 ˚C, while the extreme minimum ranges from -16 to -20 ˚C. The hottest month in Xi'an is July, with a monthly average temperature of 26.1 to 26.3 ˚C and a monthly average maximum temperature of approximately 32 ˚C. January is the coldest month, with a monthly average temperature of -0.3 to -1.3 ˚C and a monthly average minimum temperature of about -4 ˚C. The annual temperature range is 26 to 27 ˚C. Precipitation in Xi'an varies greatly from year to year, with a maximum difference of 590 mm between rainy and less rainy years. The seasonal distribution of rainfall is also highly uneven, with 78% of rainfall concentrated from May to October, and July to September accounting for 47% of the annual rainfall. Rainstorms occur from time to time. The annual average relative humidity is about 70%, while the average wind speed is 1.8 m/s, with the prevailing wind direction being northeast throughout the year.

The historical changes of Xi’an City

As early as ancient times, Xi'an was home to the ‘Lantian ape man’, while the Neolithic ‘Banpo ancestors’ established tribes in the region. Agricultural production played a critical role in the economic life of the Banpo people, who engaged in activities such as burning trees, reclaiming farmland, and cultivating dry-land crops like millet. During this period, people primarily used tools made of stones, animal bones, antlers, and pottery. The Banpo people also began to grow vegetables and establish a livestock breeding industry, with pigs being the primary source of livestock. Hunting and fishing were also significant production activities during this era.

Xi'an has been an ancient Chinese capital for over 1000 years, the longest period in Chinese history. These ancient capitals not only give Xi'an a rich historical background but also serve as useful examples for modern urban planners. The Zhou Dynasty's Feng Jing and Hao Jing were the first capitals to take Xi'an as their capital from 1066-771 BC. The Western Zhou Dynasty (1046-771 BC) was the first Chinese dynasty to do so, with ‘Kaogongji craftsman’ documenting the rules and systems of the King City at that time. This system was created at the beginning of the Western Zhou Dynasty and marked the first peak of capital construction, represented by Yingluo, the Duke of Zhou.

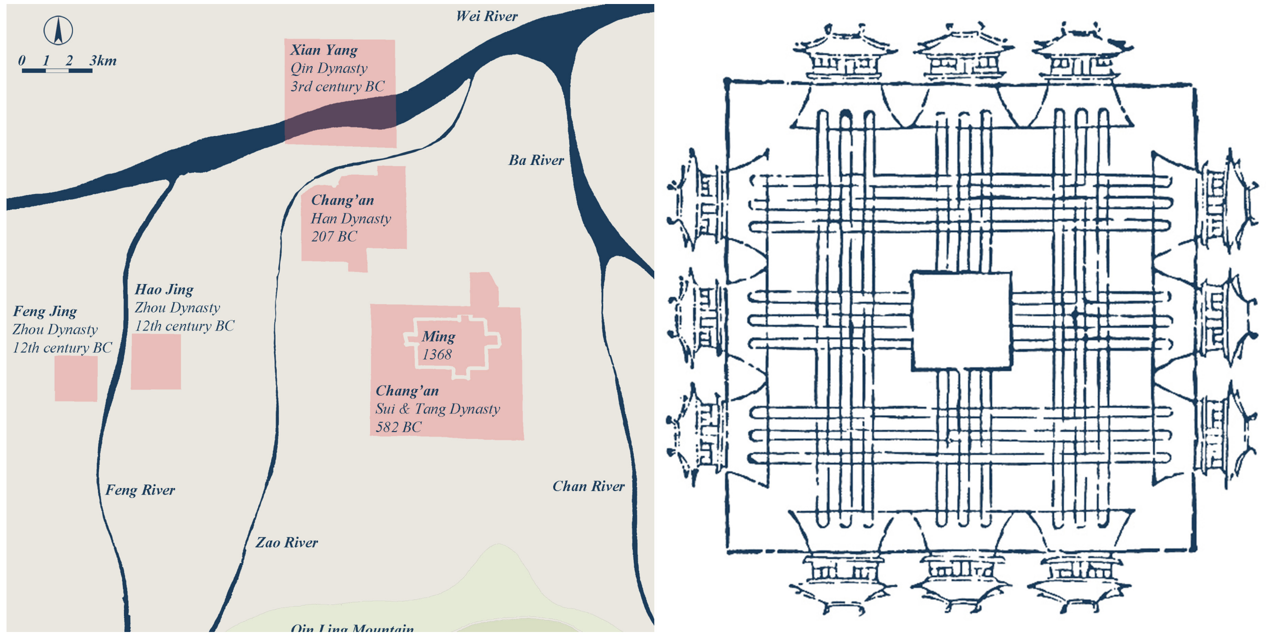

Figure 2. The geographical location and urban form changes of Xi'an in different dynasties

In the Zhou Dynasty, there were basic principles for constructing cities, which represent the beginning of urban planning in China. This layout principle has been repeated in numerous Chinese references and can be generalized and translated as follows: a city should be constructed as a square with 9 Li on each side, with one Li equaling 4500 m. Each side should have three gates, and there should be nine streets in the east-west and north-south directions. The width of each street should be nine times the width of a carriage, and a temple for ancestors should be located on the left side of the city, while the Altar of the state should be located on the right side. Governmental agencies should be located in front of the

Royal Palace, while markets should be located at the back, with both being within 100 steps.

After the decline of the Zhou Dynasty, the Qin Dynasty built its capital in the northeast of the former capital. However, since ancient Chinese buildings were constructed with wood, the new leaders burned down all the buildings in the Xianyang palace after the fall of the Qin Dynasty, leaving no graphic record of the palace. Nevertheless, as the first dynasty in China, the Qin Dynasty's first emperor, Qin Shihuang, wielded supreme power. His mausoleum is the largest in China, and to date, the main body of his mausoleum has not been excavated for protection. In addition, his terracotta army was discovered 1.5 km to the east of the mausoleum due to villagers digging a well. More than 8000 terracotta warriors and horses, all similar in size to human beings, have been found. This gives us an idea of how magnificent Qin Shihuang's Xianyang palace might have been.

The most famous Chinese capitals in history were during the Han and Tang Dynasties. Xi'an was renamed Chang'an during the Han Dynasty, and the Han Chang'an was located approximately 10 km away from the current old town of Xi'an. The Han Chang'an had a perimeter of about 22 km. Chang'an of the Tang Dynasty was even more impressive and became the largest city in the world at that time, serving as China's capital. The construction of Tang Chang'an was well planned and executed step by step, starting from the city wall to the inner-city streets. According to a survey conducted after

1949, the city wall of Tang Chang'an was 9721 m in the east-west direction and 8651 m in the south-north direction. The total urban population was about 1 million, and the city was divided into 108 Fangs with a rigid grid street system. Fangs were a traditional neighborhood unit in China, with the largest one measuring 838 m in the south-north direction and 1125 m in the east-west direction, while the smallest one was 500 m to 590 m in the south-north direction and 120 m to 1125 m in the east-west direction. To improve the microclimate of Tang Chang'an, many low sites were dug into lakes, resulting in numerous lakes in the city. The prosperity of Tang Chang'an facilitated trade and friendships with foreign countries, and the city's urban construction had a significant influence on other cities, such as Ping'an Jing, now present-day Kyoto in Japan.

The Muslim district in Xi'an was established in the late Tang Dynasty, but there is no specific record of its architectural design and style. However, based on records of other buildings during the Tang Dynasty, we can infer the architectural style of the Muslim district. According to official historical records, each of the 108 blocks in Chang'an City had its own walls, and the gates were closed every night and opened in the morning, which meant that there were no commercial facilities along the streets. This information is also reflected in Dunhuang frescoes. To strengthen management, commercial and trade buildings of the Tang Dynasty were concentrated in two places: the west market specialized in import and export trade, while the east market was for local trading. The gates of the markets were also closed at night and reopened in the morning. In the restoration pictures of Tang Dynasty buildings, the gate of the west market was in the form of a two-story attic. Although this kind of gate did not exist in China, it was prevalent in Japanese temples and Dunhuang frescoes. The figure below shows the west gate of Osaka shrine in Kyoto, Japan, which is similar in architectural form to Dunhuang frescoes.

The present Old Town of Xi'an was the site of Xi'an in the Ming and Qing Dynasties. During the Qing Dynasty, Xi'an was no longer the capital but a military base in Northwest China, resulting in the city's significant reduction in size compared to Chang'an in the Tang Dynasty. In the early years of the Ming Dynasty, Emperor Zhu Yuanzhang appointed his second son Zhu Xiu as the king of Qin and began to expand and build Xi'an City towards the east and north, eventually forming the scale of the Xi'an City Wall we see today. Due to the expansion of the city wall to the east and north, the north and east walls of the original Fengyuan Road City were demolished. However, the relics of the Tang, Song, and Yuan Dynasties were preserved to some extent in the west and south of the wall of the Xi'an Mansion in the Ming Dynasty. For instance, the southwest round corner platform (remains of the Yuan Dynasty), the Hanguangmen site (remains of the Tang Dynasty) in the Nancheng wall, and other historical relics, along with the utilization of the positions of the West Shunyi Gate and the Nan'an Gate, serve as historical evidence of the long-term use of this city wall. Compared to the Ming Dynasty, the overall scale of Xi'an City remained relatively

stable during the Qing Dynasty. The northeast of the city was designated as a closed military zone, while the southeast corner was a defense area for the Han army. This left only the western half of the city available for residents. By the end of the Qing Dynasty, the urban population of Xi'an was estimated to be around 110,000.

Xi'an Hui inhabited area

Xi'an Hui inhabited area, also known as the Xi'an Muslim community, is located in the central part of the ancient city of Xi'an. Its origins are deeply intertwined with the ancient Silk Road, and it is one of the Hui inhabited areas in urban China with the longest history. Despite experiencing several ups and downs in development, there has never been a historical fault in the area. It not only records the history and culture of the Hui ancestors but also bears deep traces of significant cultural transformations in Hui development throughout history. The research object of this project mainly encompasses the northwest area within the Ming city wall of Xi'an, covering approximately 1.3 km^2 and a population of approximately 60,000, of which approximately 35,000 are Hui residents. In terms of the time dimension, the investigation of the research object extends from the period of Tang Dynasty settlement in Chang'an by the Hui ancestors to the present day.

Today, the residents of the Hui inhabited area in Xi'an continue to preserve their Islamic culture and customs. Their houses are densely clustered around the mosque, creating a unique spatial character with high building density and low building height, setting it apart from other areas of the city. Although there has never been a large-scale, unified planning and transformation, small-scale construction activities have never ceased in this area. Over the past several centuries, the residents here have continuously transformed, demolished, and rebuilt their courtyards to suit their individual needs. The changes in building height, form, and material over time have occurred primarily within the courtyard. Hence, we consider the courtyard as the smallest unit to analyze the impact of urban spatial form on microclimate in different historical periods.

Classification of residences in Xi'an Hui inhabited areas
We conducted a comprehensive survey in the Hui inhabited area and identified 232 courtyards in the study area. We classified them into five categories based on parcel orientation and courtyard orientation. The specific classification of courtyards in the Hui inhabited area of Xi'an is depicted in the figure below. The majority of these courtyards possess a long and narrow spatial structure, with their parcel orientation predominantly influenced by the location of the entrance, thereby being perpendicular to the street facing the entrance. While the orientation of most courtyards coincides with that of their parcels, a few courtyards have an entirely different orientation due to various reasons. Courtyards within the same category share high similarities and can be uniformly analyzed through typology. However, even within the same category, courtyards have varied layout methods, warranting further discussion in subsequent research. Notably, the

courtyards with irregular parcels often occupy a significant area and have diverse courtyard orientations among the five types of courtyards.

This type of residential layout is commonly found in Hui inhabited areas, situated on one side of an east-west street, with the house entrance located at the north or south end of the parcel. These residences often have a narrow space with an aspect ratio of over 2. Residents typically reserve a slender courtyard space in the middle of the parcel and construct buildings around it, resulting in symmetrical spatial characteristics. However, due to some parcels being too narrow for this spatial arrangement, homeowners may opt to arrange the courtyard on one side of the east or west sides of the parcel and undertake construction activities on the other side. While this asymmetric courtyard layout possesses unique spatial characteristics, when compared to symmetrical residences, the courtyard space becomes enclosed by buildings. Influenced by the orientation of the courtyard, except for the main houses at the north and south ends, all other buildings face west or east. Similar to the residences mentioned before, these dwellings are situated along one side of an east-west street. However, their parcel shape is irregular with varying widths, resulting in a winding courtyard wall. The east-west buildings divide the long and narrow parcels into two or three smaller areas. Each area features a small central courtyard surrounded by surrounding buildings. Some courtyards have an east-west orientation, while others are north-south. As a result, the internal space is more complex than that of the aforementioned residences.

This is the largest spatial pattern found in the study area, characterized by being located on one side of the North-South Street. These buildings and courtyards have a striking resemblance to the residences described before, which can be obtained by rotating them 90 degrees. Similarly, these residences have both symmetrical and asymmetric layouts. As for the asymmetric mode, the buildings are usually arranged on the north side of the courtyard facing south to maximize sunshine and natural lighting. However, due to the orientation of the courtyard, a row of buildings will be facing north, which usually contains non-important spaces such as kitchens, toilets, and warehouses due to insufficient natural lighting. The layout pattern of these east-west parcels with mixed orientations courtyards is essentially similar to the residence described before, except for their different orientation. These long and narrow parcels are divided into several smaller plots by buildings in the north-south direction. In the middle of each plot is a courtyard surrounded by buildings. The orientation of the courtyard is determined by the size of the parcel and the surrounding buildings. The houses in this classification also have two modes: symmetrical and asymmetric layout. Among them, the courtyards of the houses with a symmetrical layout are narrower, while the courtyards with an asymmetric layout are often located in the south of the parcel of land and are connected by an east-west narrow corridor. Typically, more than one family lives in such a house, either sharing a house with their brothers of the same surname or the house owner renting part of the house to nearby workers. Therefore, there exist complex spatial patterns and diverse personnel compositions.

Among the five types of residential layouts, the irregular parcels are characterized by their large size and varied courtyard orientations, which can be seen as a combination of several of the four types of residences described above. Crisscross open spaces are interspersed among the buildings, forming a maze-like courtyard layout. Prior to conducting microclimate simulations, it can be predicted that this layout has a complex distribution of thermal and wind environments. The majority of buildings with more than four floors in the study area are located in irregular parcels, and the number of residents in these areas is typically higher due to their higher floor area ratio. This type of residence encompasses all other types of courtyards and therefore analyzing an irregular residence can provide insights into the thermal environment characteristics of courtyard spaces with various orientations.

Comparison of Spatial renewal modes

In Hui inhabited areas, self-organizing renewal modes for individual buildings can take four forms: new constructions, building renovations, reconstruction after demolition, and expanded buildings. These modes occur when the original courtyard is disintegrated, and changes to the space in the residential area occur as a result of modifications to individual buildings. New constructions in Hui inhabited areas can take on various forms. From field research, we have identified four categories of new constructions: additional building on top of an existing building, temporary structure added to the roof of a building, temporary structure added to the ground, and new building constructed on the ground. These four categories may exist in the same building or in different buildings, and the materials and functions of these new constructions can also vary greatly. When the roof surface is relatively flat, homeowners in Hui inhabited areas tend to utilize a ‘covering’ construction method whereby the roof is treated as a ground floor for secondary construction. This upward development construction method results in a more spacious and relaxed environment compared to a two-dimensional expansion of space. The additional space is typically utilized as a bedroom, storage room, or sunroom, and various materials are used for construction, including masonry, concrete, color steel plate, and light partition. ‘Facade external hanging’ refers to the local addition of an extension attached to the facade of the original building, which extends the indoor space through overhanging. The added part is integrated with the original building, becoming a seamless part of it. This method is commonly utilized to supplement indoor space for new functions, without disrupting the relationship between the indoor and outdoor spaces of the original building. The additional space is often located in the balcony area of the bedroom or kitchen, with masonry and concrete materials commonly used in construction.

In addition to the overflow of residential living space, some homeowners in Hui inhabited areas also utilize added space for dovecotes during building renewal. These small buildings are typically constructed using masonry, color steel plate, and barbed wire mesh, and are attached to the roof or high facade of the building. A channel for feeding pigeons is reserved,

resulting in a layout that closely resembles the function of the original space. In addition to the added buildings on the roof, there are also temporary buildings added on the roof, which are also considered as secondary construction with the roof as the ground floor. During the construction process, the original building is preserved, and simple materials are used to build sheds with various functions on the roof, such as a canopy to enclose the courtyard space into indoor space to increase the living area, or a drying platform to dry clothes and food. The materials used for these additions are diverse, including plastic plates, color steel plates, asbestos nets, and others. Building a new structure on the roof does not require large-scale construction, and has the advantages of a short completion cycle, detachable reorganization, and so on.

In the Hui inhabited areas, there is no designated construction site or professional design for the construction of added buildings on the ground. Rather, construction activities take place in public spaces such as open areas within the courtyard or the roadway outside the courtyard. These newly added buildings serve a variety of functions, including bedrooms, kitchens, bathrooms, storage rooms, and more. The added buildings on the ground in the Hui inhabited area are typically small in scale due to the limitation of land area. They are usually constructed in the courtyard traffic spaces, such as the gaps between multiple buildings, corners of the courtyard, and one side of public passages. Unfortunately, the reduction of traffic space and public space has serious negative consequences on residents' daily lives, such as the deterioration of lighting and ventilation within the house and the reduction of spontaneous public activities. The added buildings on the ground are commonly constructed using brick and concrete structures. However, due to cost constraints, residents often do not prioritize the architectural style and quality of these buildings.

Another renewal mode on the ground in Hui inhabited areas involves the addition of temporary structures, which come in a wide variety of forms, including stairs, platforms, partitions, pools, and more. These structures are intended to address the issues associated with early rise construction of houses in Hui inhabited areas, and serve to improve the quality of life for residents. This self-organizing renewal mode can be observed throughout Hui inhabited areas, where a wall, shed, or even a simple step is often added to meet the specific living needs of residents. As such, the functionality of these structures far outweighs any other characteristic they may possess.

Typical renewal case analysis
Mr. Ma's courtyard was selected for analysis due to its historical significance and traceable history. Built around 1600, it has a rich history of more than 400 years. Through research from local chronicles and on-site inquiries to residents, we sorted out the spatial layout of the Ma' courtyard in different years and compared them with 3D models.
As shown in the Figure 3, the courtyard was originally composed of one-storey sloping roof buildings. Due to the limited availability of building materials, there were

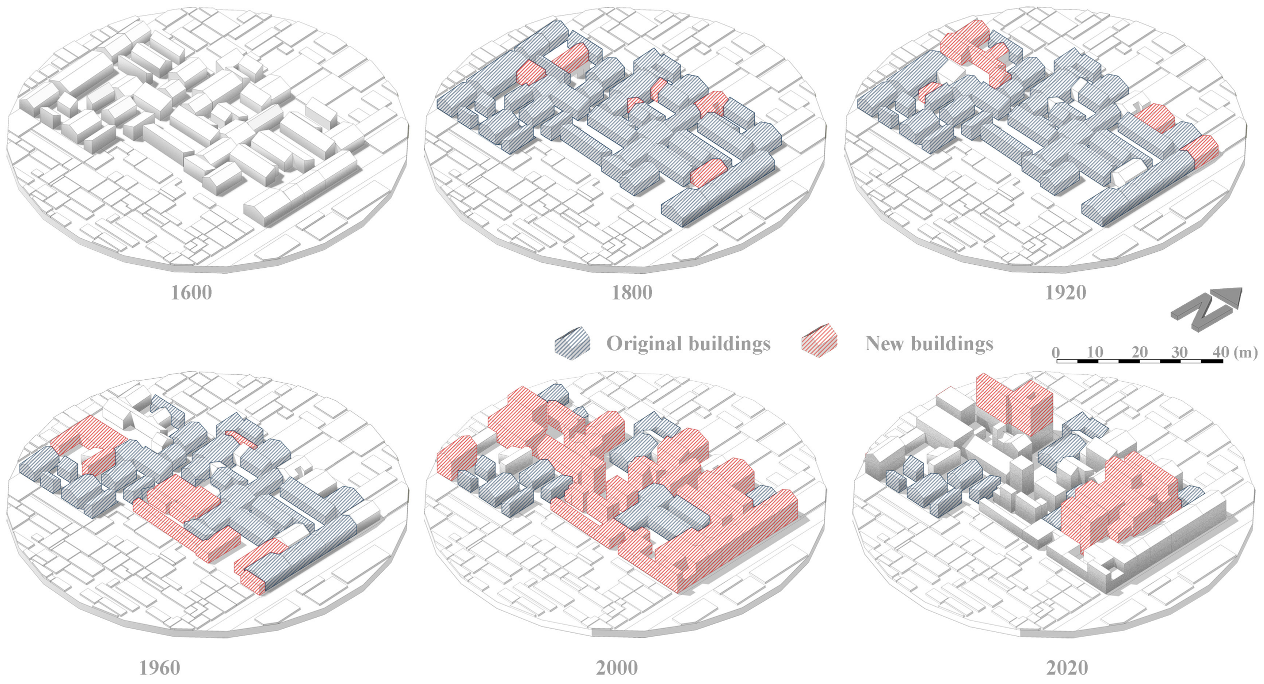

Figure 3. Spatial comparison models of Ma' courtyard in different historical periods

no significant changes to the number of building floors or overall layout for the following 300 years. By 1960, as part of the property right of the courtyard was nationalized and used for governmental offices, there was large-scale demolition and reconstruction on the south side of the courtyard, leading to damage to some of the historic buildings. By approximately 2000, due to the improvement of people's living standards, the traditional architectural space could no longer meet the residents' needs. Moreover, the awareness of the protection of historical buildings was weak, leading to the demolition and reconstruction of almost all original buildings. All buildings along the street have been rebuilt into two-story shops for commercial activities.

Today, the courtyard contains many four- or even five-story buildings for rent to people working in Hui inhabited areas. In general, the courtyard that has been preserved for hundreds of years has experienced significant spatial transformations in a matter of decades.

From August 23 to 25, 2021, air temperature data for three consecutive days in the research area were collected, and then the validity of the model and boundary conditions used in the simulation was verified by comparing the measured data with the simulated data. As shown in the Figure 3, the five lines show similar fluctuating trends. Further statistical analysis presented the strong correlation between simulated data and measured temperature, indicating that the model and boundary conditions are effective and reliable.

Influence of courtyard orientation on its microclimate

The microclimate of the Ma family courtyard in six historical periods were simulated by the ENVI-met software. Although the space in the Ma family courtyard has changed several times in the past hundreds of years, the air temperature fluctuations of all models in a day show similar trends: They maintained a continuous upward trend from 7: 00 a.m. (after sunrise) and began to decline slowly after peaking at about 5 p.m. This result is consistent with the field measured temperature trend in this study and some other previous researches in Xi'an which further confirms the validity and reliability of the simulation results. Influenced by the square and orderly planning of Xi'an city since ancient times, the

layouts of most buildings here are parallel or perpendicular to the longitude, which is the reason why the layouts of most courtyards in Xi'an are in North-South or East-West directions. By comparing the air temperatures at different locations in one same simulation result, a significantly correlation can be found between the courtyard orientation and its thermal environment.

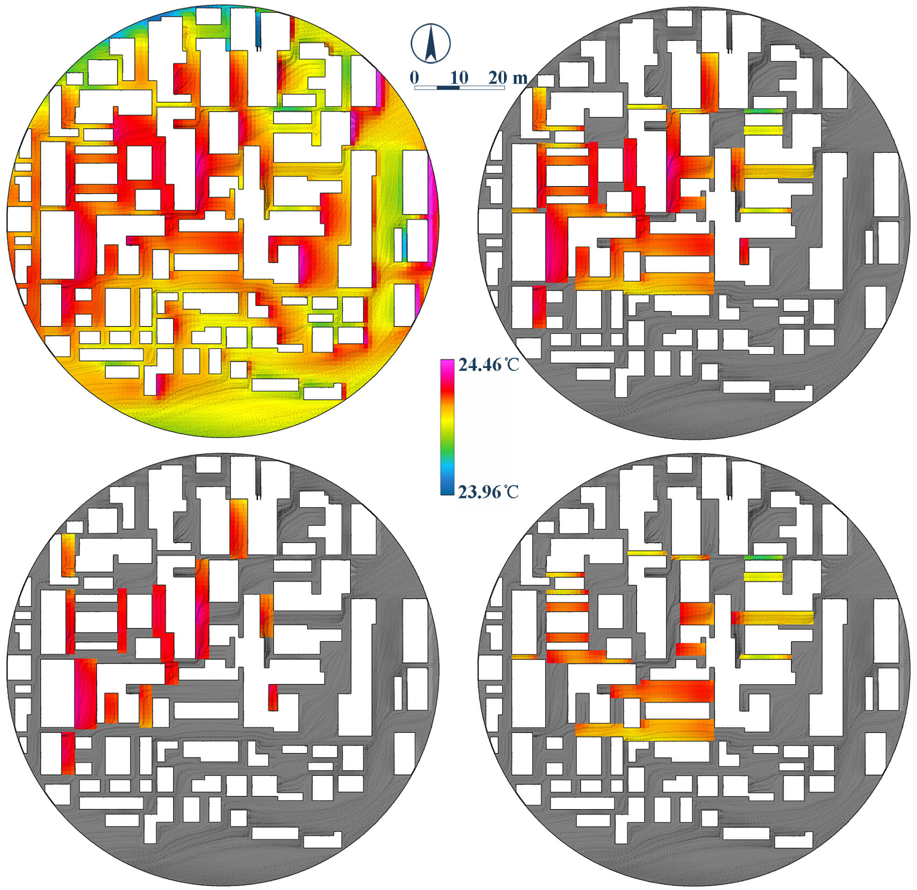

Figure 4. Simulated thermal environment at 1.5m height of the Ma family courtyard in 1600

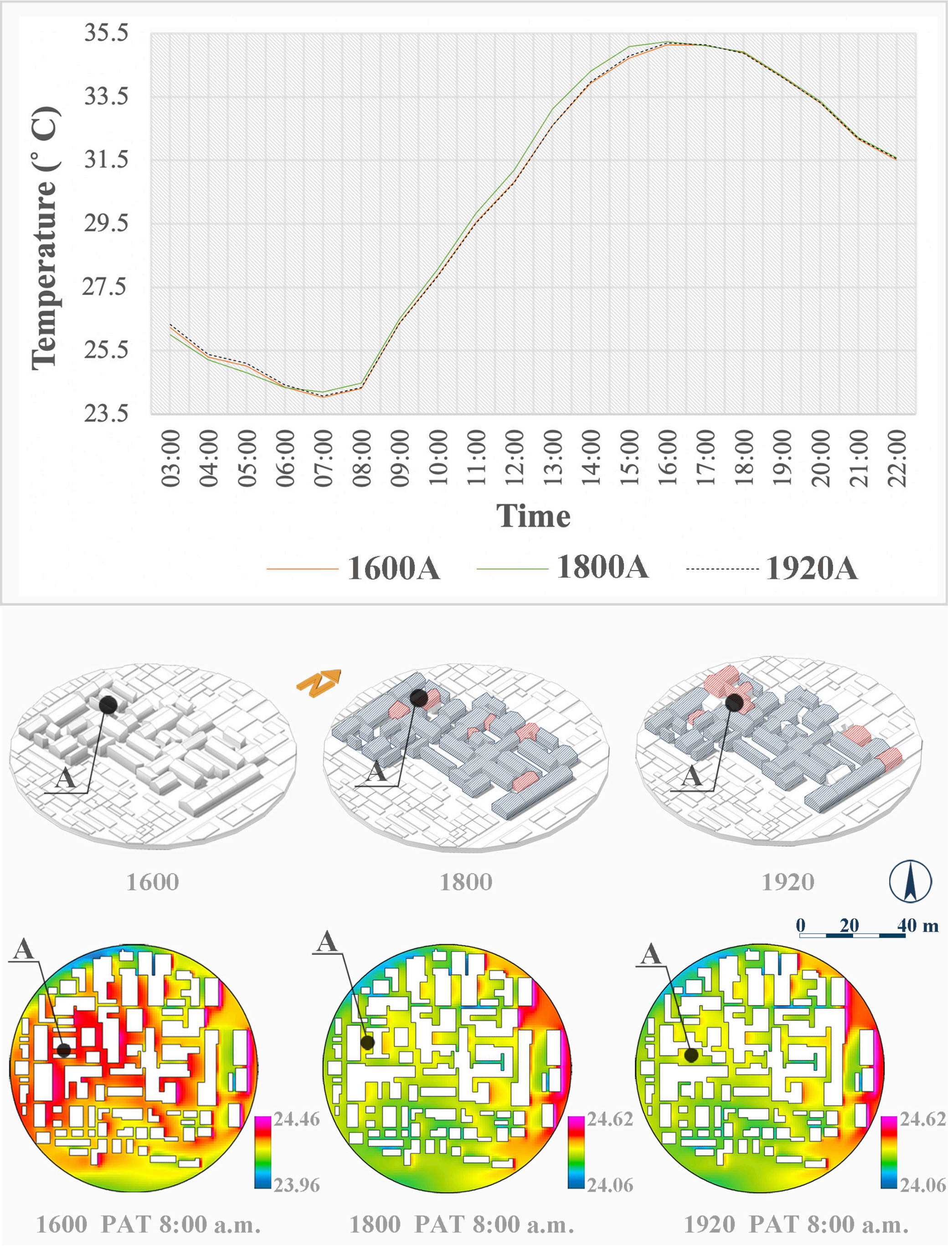

Figure 5. Comparison diagram of thermal environment of courtyards with different orientations

Taking the simulation results of 1600 as examples. As shown in the Figure 4, the simulation areas in North-South and East-West directions were marked respectively, it can be clearly seen that the air temperature of the courtyards in the North-South direction is higher than that in the East-West direction.

Same conclusion can be drawn from the simulated thermal environment in different historical periods. In 1600, the plane of the courtyard marked in Figure below was in East-West direction, and it changed to North-South direction in 1800. The simulation results show that this variation has brought an increase of more than 0.2 ˚C to the daily average temperature in the courtyard, and the maximum temperature difference is nearly 0.4 ˚C. At the end of 1920, the courtyard at this location was rebuilt into East-West direction, and the internal air temperature returned to the same trend as in 1600.

To arrange more houses in the limited urban area, almost all the traditional dwellings in Xi'an adopt the layout with narrow and long characteristics. When the long side of the courtyard is parallel to the North-South direction, the east and west elevations inside the courtyard will be affected by the direct solar radiation at different times of the day, resulting in the continuous rise of the temperature in the courtyard. However, when the long side of the courtyard is parallel to the East-West direction, a courtyard height width ratio of more than 1.5 can ensure that the buildings on the south side of the courtyard form a shadow area in the courtyard, reducing the impact of solar radiation on the microclimate in the courtyard, which explains the phenomenon that its internal air temperature is lower than that of the North-South courtyard. The previous analysis leads to the first conclusion: As for the traditional narrow residences in Xi'an, the summer daytime temperature of the East-West courtyard is lower than that of the North-South courtyard.

Influence of the height of surrounding buildings on the microclimate in the courtyard

Scholars have proved that the building height is related to its surrounding microclimate (Nugroho et alt., 2022; Shareef et alt., 2020). The increase in the building height of the Ma family courtyard mainly occurred between 1960 and 2000, in which the heights of buildings around two East-West courtyards increased at the same time. The simulation results of these two courtyards in different years are shown in the Figure 6. After the increase of building heights, the average daytime temperature in the courtyard has increased around 0.3 °C. This is far from the original expected result: The increase in building height brought more shadow areas, which leads to a decline in the temperature in the courtyard.

By analyzing the wind speed simulation results under the same boundary conditions, we found the reason for the temperature rise caused by the increase in the building height. Like most traditional residences in Xi'an, the Ma family courtyard adopts a sloping roof with an inclination of about 30 degrees. The roof edge adjacent to the courtyard is about 3 m away from the ground, and the height of the highest part

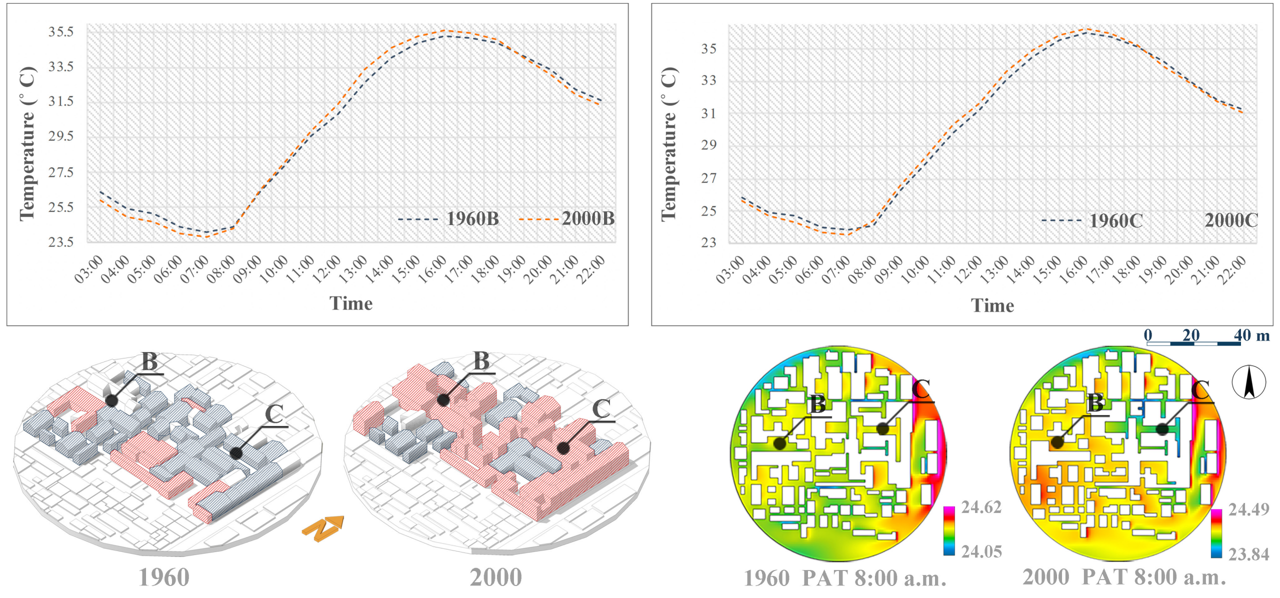

Figure 6. Comparison diagram of thermal environment of courtyards with different surrounding building heights

of the building is no more than 4 m, which ensures the flow of air in the vertical direction. When the height of the surrounding buildings increases, it becomes difficult for the external air to form vertical convection with the air in the deep well shaped courtyard space. The simulation results show that the average wind speed at both locations B and C decreases significantly while the increase of the height of the surrounding buildings, which is mainly responsible for the temperature rise in the courtyard.

Influence of opening position of courtyard on its microclimate

There are a variety of building combination modes in the Hui inhabited area of Xi'an, resulting in courtyards with openings in different positions. These courtyards are divided into four groups according to the relative position between their openings and the prevailing wind direction in Xi'an (Northeast by North): Courtyard with a total of two openings, which are located in the direction of prevailing wind and the opposite direction; Courtyard with only one opening, which is located in the direction of prevailing wind; Courtyard with only one opening, which is located in the opposite direction of the prevailing wind; Enclosed courtyard. Different opening positions affect the temperature fluctuation by changing the shadow area and air flow in the courtyard.

By comparing the spatial variation of different locations in different historical period, the area marked with D in Figure 7 is screened out for further analysis. The reason for choosing this area is that its spatial characteristics in different historical periods include the above four kinds of enclosure modes of courtyard. Among them, the courtyard where point D is located had two openings in the direction of prevailing wind and the opposite direction in 1600. In 1960, there was only one opening in the opposite direction of the prevailing wind. In 2000, it was turned into an enclosed courtyard, that is, there was no opening. In 2020, an opening appeared again in its prevailing wind direction.

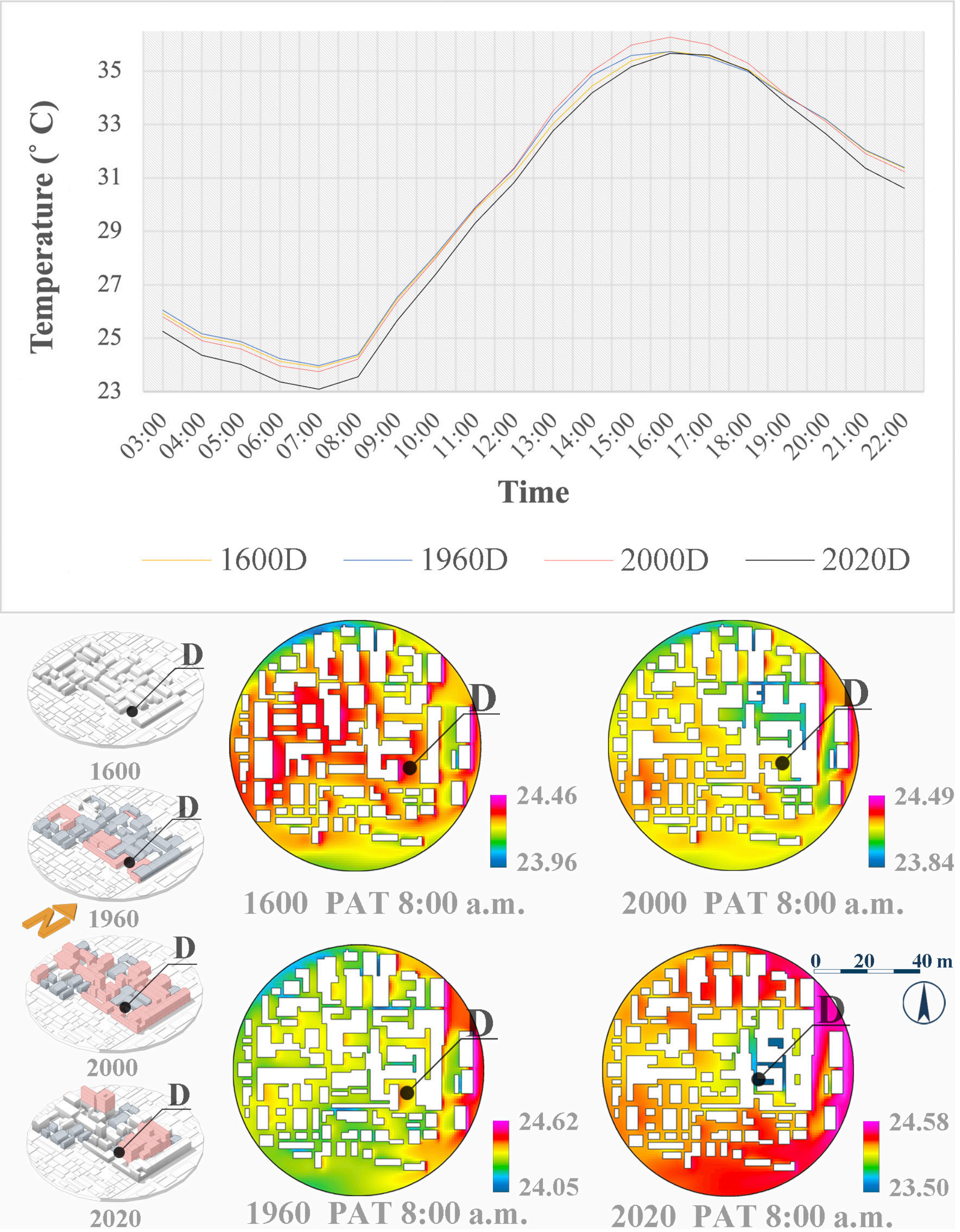

Figure 7. Comparison diagram of thermal environment of courtyards with different opening positions

The air temperature fluctuation curves at point D are shown in the Figure 7. It can be seen that the four lines fluctuate with almost the same trend, but there are differences between air temperature in different historical periods. The most obvious difference illustrated in the line chart is that the temperature at point D is the highest in 2000 and is the lowest in 2020. That is, the daytime thermal comfort in summer of the courtyard with only one opening in the direction of prevailing wind is better, and the enclosed courtyard is the worst. Look at the line chart in more detail, the temperature curves of 1600 and 1960 increased synchronously with that of 2000 in the morning. From around 1:00 p.m., the temperature rises rate of 2000 increased, and then intertwined with the curves of 1600 and 1960 again after 7:00 p.m. On the contrary, these two curves overlapped with the temperature curve of 2020 between 4 and 6 p.m. Ordinarily, it is believed that a space with two openings in the direction of the prevailing wind and its opposite direction is easier to form a ventilation corridor, through which the air flow can effectively take away the heat inside the space, thereby reducing its temperature. Nevertheless, the reality is that in addition to the influence from air flow, the fluctuation of temperature caused by shadow area of buildings should also be considered. The synergistic effect of these factors explains the conclusion that the courtyard with only one opening located in the direction of the prevailing wind has the lowest temperature.

We present a scientific investigation that explores the impact of spatial variations within a residential courtyard on its thermal environment. Our research employs microclimate simulation to analyze the Ma family courtyard in Xi'an, China, over a period spanning more than 400 years. To our knowledge, this is the first study of its kind to examine a single residential courtyard with such an extensive time frame. Our findings reveal several important conclusions. First, the daytime temperature during summer is lower in the East-West direction of the open space within the courtyard than in the North-South direction. Second, the average daytime temperature in the courtyard increases with the height of the surrounding buildings. Third, courtyards with openings in different positions exhibit varying temperatures. For instance, the courtyard with only one opening located in the direction of the prevailing wind experiences the lowest average daytime temperature, while the enclosed courtyard without any opening records the highest. Our research considers changes in the residents' living needs across different historical periods, as well as the architectural and environmental characteristics of the courtyard. Consequently, the results of our study offer insights that can inform the design of courtyards with similar natural conditions to our study area, thereby enhancing their thermal comfort.

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Water Based Solutions for Cooling the Cities: from City to Building

Valentina Dessì, Adrian Moredia Valek and Mariana Pereira Guimaraes

For many years, it has been widely acknowledged that cities are among the largest consumers of energy derived from fossil fuels. Consequently, they are major contributors to climate change. The observed effects of these changes impact the entire planet, albeit in different ways depending on the geographical, physical, and climatic context. There is no straightforward cause-and-effect relationship between those who generate the impacts and those who suffer from them. The most severe effects are often concentrated in environmentally fragile areas with significantly lower CO_2 *emissions. Conversely, a stronger correlation likely exists between cities contributing to climate change and those implementing environmental adaptation measures to enhance their resilience.*

Cities serve as proper laboratories where strategies are implemented to make them more resistant and resilient, often leading to modifications in urban configurations, urban spaces, functions, and environmental conditions. While it remains crucial to take decisive and effective action both to mitigate the causes of climate change and to adapt cities accordingly, this contribution aims to delve into the topic of adaptation to climate change associated with global warming, specifically focusing on the challenges posed by urban heat islands and the intensification of summer heatwaves.

Introduction

The overheating of cities, the most harmful effect we have been aware of for about twenty years, has traditionally affected the southern European Mediterranean region. The worsening conditions, also linked to the delay in implementing measures to mitigate the phenomenon, increasingly involve areas of northern Europe, with more noticeable effects in urban areas. Heatwaves in cities such as London, Amsterdam, and Paris are now part of summer news reports and call for adjusting their Adaptation Plans. In addition to the well-known issues of excessive water due to heavy rainfall, river flooding, and rising sea levels, these plans will also need to address prolonged periods of rainwater scarcity and, above all, the rising temperatures, particularly during summer heat waves.

Soloclim (Solutions for Outdoor Climate Adaptation) is an EU-funded research project involving three universities in Europe (Wageningen, Kent, and Politecnico di Milano) and four firms (ZinCo, Foster Associates, Carlo Ratti Associati, and Arcadis NL). The project engaged six young researchers who developed innovative systems to mitigate the impacts of overheating in urban areas, providing solutions at both the neighborhood and building scales. The strategies considered included using vegetation, water, and innovative shading systems. This research endeavor was particularly significant as it was conducted in synergy between academia and industry, often involving stakeholders and domain experts.

The Milan group, coordinated by Valentina Dessì and developed by the young researchers and co-authors of the paper, has delved into the topic of water for cooling urban spaces. Water is the most recurrent element when discussing adaptation to climate change: water that is scarce and restricted for uses considered unnecessary, which unfortunately includes the irrigation of urban greenery, resulting in the decline of young trees; water that needs to be managed during frequent instances of excessive rainfall, transforming our increasingly paved streets and squares into veritable riverbeds, with established urban sewer systems that are no longer adequate and thus insufficient; and finally, water as a resource for cooling, leading to reductions in air and surface temperatures and consequently improving thermal comfort conditions.

The two research projects, which are being carried out in two ongoing doctoral theses at the Department of Architecture and Urban Studies (DAStU) of the Politecnico di Milano, have addressed the theme at two different scales. The first research, focused on the urban context, aims to develop guidelines for designers and public administrations interested in integrating WBS (Water-Based Systems) in urban spaces. The second research project, conducted at the building scale, proposes a (partial) building envelope system that, through the implementation of traditional residential cooling systems, seeks to reinterpret the system and integrate it into existing buildings to cool urban spaces, such as pedestrian areas or rest areas, thereby contributing to the creation of cool niches and improved thermal comfort conditions.

It is important to note that the multi-scalarity has not been considered a linear pathway from the city to the building. Instead, the two scales intersect and allow, once the performance of different systems is identified, also considering the morphology of the context and its climatic conditions, to determine the most effective WBS system typology and return to a larger scale where integration within the broader context of the neighborhood and the city is possible. This approach follows a logic of an urban system and, therefore, can contribute to reducing the urban heat island effect in terms of temperatures within individual urban spaces and urban thermal comfort.

Another aspect to highlight is that when discussing urban spaces with integrated passive cooling systems, we consider places that are multi-functional. They often adapt to critical situations, such as contributing to cooling, but in general, we are referring to spaces where their livability and attractiveness are also improved.

Water for cooling the environment

When we hear the sound of water from a fountain or glimpse it in the distance after walking under the sun during summer, we anticipate the refreshing sensation. The psychological aspect is highly effective and should not be underestimated in our projects. Similarly, there are water features, such as narrow channels along pathways or small fountains, where the water mass is limited and insufficient to absorb and accumulate an adequate amount of solar radiation. In ponds or elements with stagnant water, there is a risk of heating the surface level of the water, which consequently cannot contribute to cooling. From a microclimatic perspective, the psychological effect outweighs the actual contribution, even in these cases.

On the contrary, there are situations in which the effect of water is evident. The contribution provided by a large body of water, such as the sea or a lake, is well known and is related to the high thermal capacity of water. It must absorb and accumulate large amounts of solar radiation before releasing it back into the environment as thermal radiation (heat). The effect that we perceive, especially when comparing it to inland areas not too close to bodies of water, is the mitigation of both heat and cold extremes.

For all urban areas that require cooling, the solution is to incorporate moving or misted water configurations, which prevent the water from overheating (by continuously changing the surface in contact with solar radiation) and facilitates easy evaporation, reducing the air temperature.

There is also another crucial factor that should not be overlooked. It is not always possible or appropriate to suggest using water-based systems (WBS) for cooling purposes. Along with a decrease in air temperature, there is an increase in relative humidity that needs to be taken into consideration. While a WBS may be suitable for hot and generally temperate climates, it is also true that within the same city, there can be hot and dry or hot and humid summer days, discouraging water-based systems.

Mapping the urban heat vulnerability

For a few years now it has been possible to find resilience and adaptation plans containing quite detailed maps and open data of climate and environmental indicators of major European municipalities, such as the City of Rotterdam. The city of Milan, for instance, has made available on its Geoportal the Land Surface Temperature raster data from Landsat-8 Satellite and its aggregate in Census sectors. Even small Dutch cities now have the 'Temperature Wind Chill' comfort maps featuring the PET indicator (Physiological Equivalent Temperature). Upon careful observation, it becomes evident that nearly all compact urban areas exhibit high environmental vulnerability. Urban morphology and the materials used in buildings and pavements often contribute to the Urban Heat Island effect (UHI). On the other hand, small green spaces, parks, gardens, tree-lined streets, or areas close to significant bodies of water help alleviate extreme city temperatures and sometimes are on a small scale which does not show in LST Landsat-8 maps.

Consequently, identifying priorities becomes challenging since there are a myriad of hot cool spots in the city; therefore, efforts should focus on improving the microclimate of particularly vulnerable areas. Furthermore, in the absence of, or with limited measures, future scenarios suggest an increase in so-called vulnerabilities. In Milan, central and traditionally peripheral areas characterized by a strong presence of affordable and public housing are socially and environmentally vulnerable. Therefore, it may be appropriate to associate the criterion of environmental vulnerability with social and economic concerns. The most fragile segments of society also face the most significant difficulties in adapting and adjusting their private spaces to environmental stressors such extreme heat and air pollution. It is precisely here that public intervention could improve the conditions of the entire built environment, encompassing both public and private spaces and outdoor and indoor areas.

The research work of M. Pereira Guimaraes takes case studies of Milan, Rotterdam, and Madrid to investigate these relationships. In the first part of the research, at the city level, the goal is to identify the city's most vulnerable neighborhoods regarding extreme heat, given different parameters. In the Netherlands, it is easier to identify a trend related to specific urban morphologies given by the Dutch criteria for Neighborhood Typologies. In the case of the south of Europe, there is a big mix of typologies within the same neighborhoods. Thus, a simplified vulnerability Assessment was used as a first step to evaluate which these would be in the case of Milan. According to Preston et al. (2009), vulnerability maps can be used to open a dialogue around vulnerability, its meaning, and its causes (Preston et al., 2009). The objective is to help conceptualize rather than predict. The Vulnerability to Heat or the Heat Risk given in a city or region is usually a composition of the Heat Exposure (calculated for the area averages of surface temperatures –LST –and the Urban Heat Island intensity model) and the Heat Sensitivity (the average number of the population groups that are most affected by extreme heat:

the elderly, toddlers, low-income residents, and those living in poor quality housing) and the Adaptative Capacity, instances that can counteract and respond to extreme temperatures, in a given unit at the scale of the city that can be the census tracts, neighborhoods, boroughs or ZIP code areas. According to the IPCC Special Report on Extremes (IPCC, 2012) risk framework (also on the Fifth Assessment Report – AR5) and the later IPCC 2014 vulnerability definition: «Vulnerability is the propensity or predisposition to be adversely affected. It encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt». The map in Figure 1 shows the VITO UrbClim UHI intensity, a 100m resolution hourly temperature data (2008-2017), based on simulations with the urban climate model UrbClim as per the work of De Ridder et al. (2015), developed in the framework of the Copernicus European Health contract for the Copernicus Climate Change Service (C3S) (De Sherbinin et al., 2019). The surface temperatures and UHI intensities were averaged for the ISTAT's ACE unit (Aree di Censimento) to produce the Heat Exposure Map (Figure 2).

The Heat Exposure component was based on the UHI data, correlated to air temperature inside the city and the surface temperatures (LST). The first portion of the index, UHI intensity, is a model accounting for urban morphology, urban fabric, wind, and green masses. The second one directly correlates to the urban material's characteristics (including green and water). The combination of the two datasets allows a very

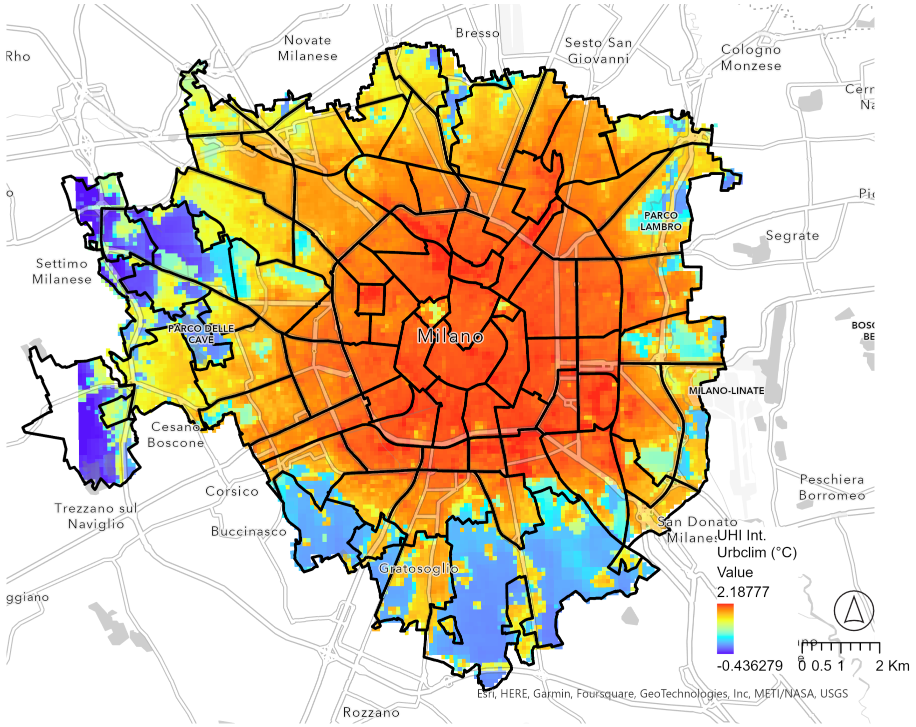


Figure 1. Average Urban Heat Island intensity is mapped for the summer (JJA), using the Urban climate model UrbClim (De Ridder et al., 2015). The UHI Intensity is calculated by subtracting the rural (non-water) spatial temperature value from the average temperature map.

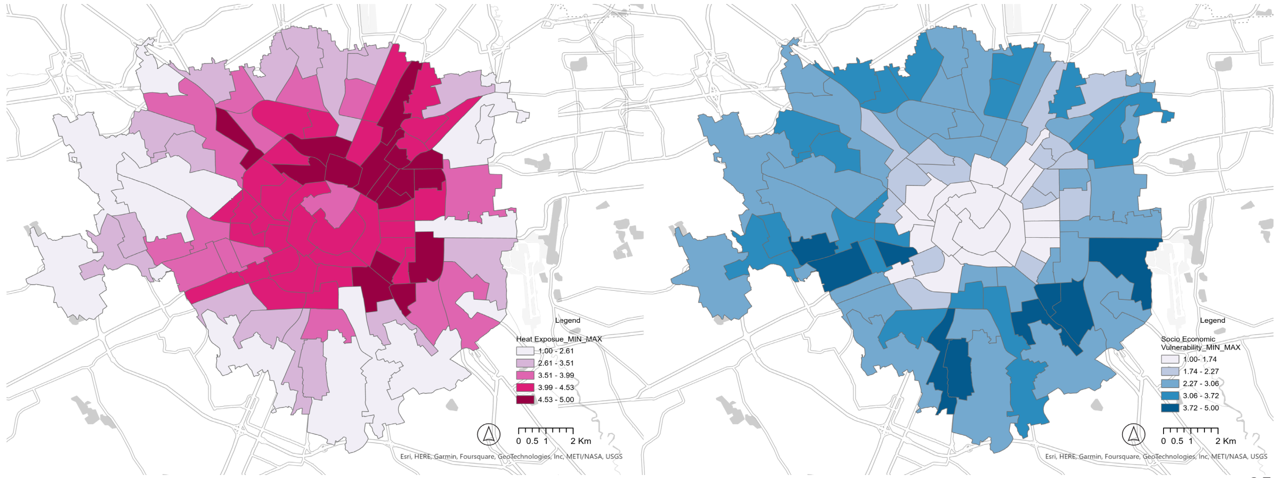


Figure 2. The Heat Exposure (left) is the average calculated from the Superficial and Intensity Urban Heat Island maps. It reveals the most heat-exposed areas in the city. The socio-economical vulnerability map (right) is the average calculated from the dependency index (2020), the income and the housing quality using the data coming from the ISTAT database.

comprehensive mapping of extreme heat in Milan.

From this map, we can observe that the railway areas, ex-industrial sites, and the city center (except Parco Sempione and Giardini Indro Montanelli urban parks) are the most exposed to heat. Moving out from the Centre to the periphery, we observe less exposure, even if still of uncomfortable levels. Nevertheless, in the frame of a possible future intervention, priorities need to be established, which cannot skip socio-economic factors for the Milanese case. This is related to income, dependency index, and housing quality; the fragility in these themes represents a necessity to intervene to reduce inequity and improve social inclusion, access to good open spaces and housing quality.

The combination of these elements generates a Socio-economic Vulnerability index. It is well known that in the city center, where we observe a big percentage of the dependent group (especially older people over seventy years old), the income and the housing quality are higher than the rest of the city. By combining the two data, environmental and social, it becomes evident that heat vulnerability for the City of Milan requires an angle from these two different points of view. Both help set the priority area. Finally, it emerges, indeed, that the most vulnerable areas are in specific peripheral areas (such as Corvetto, Scalo di Porta Romana, Lorenteggio, Forze Armate, Selinunte), while others present a correct balance between heat and vulnerability (Brera, Parco Sempione, Parco Forlanini San Siro, characterized by the presence of big

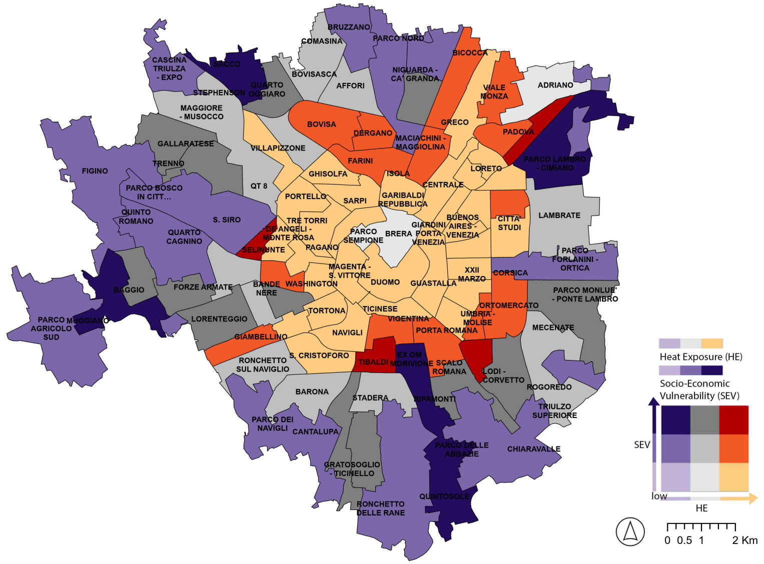


Figure 3. Heat vulnerability map of Milan. It is elaborated starting from heat exposure and the socio-economic vulnerability. As represented, the most vulnerable areas are the ones also most fragile from the socio-economic point of view, with some environmental heat issues probably due to the huge number of impervious surfaces and lack of green, and a compact urban fabric.

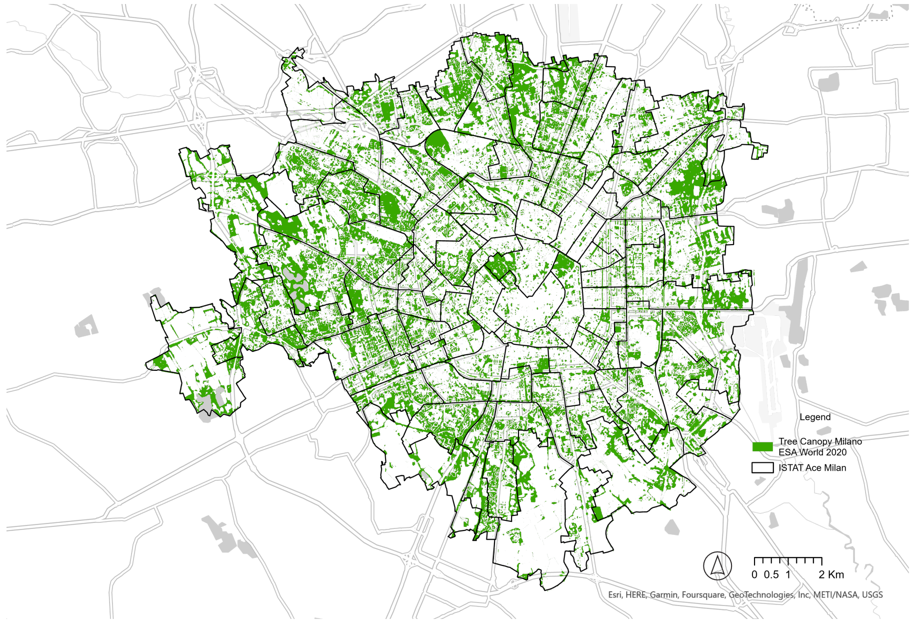
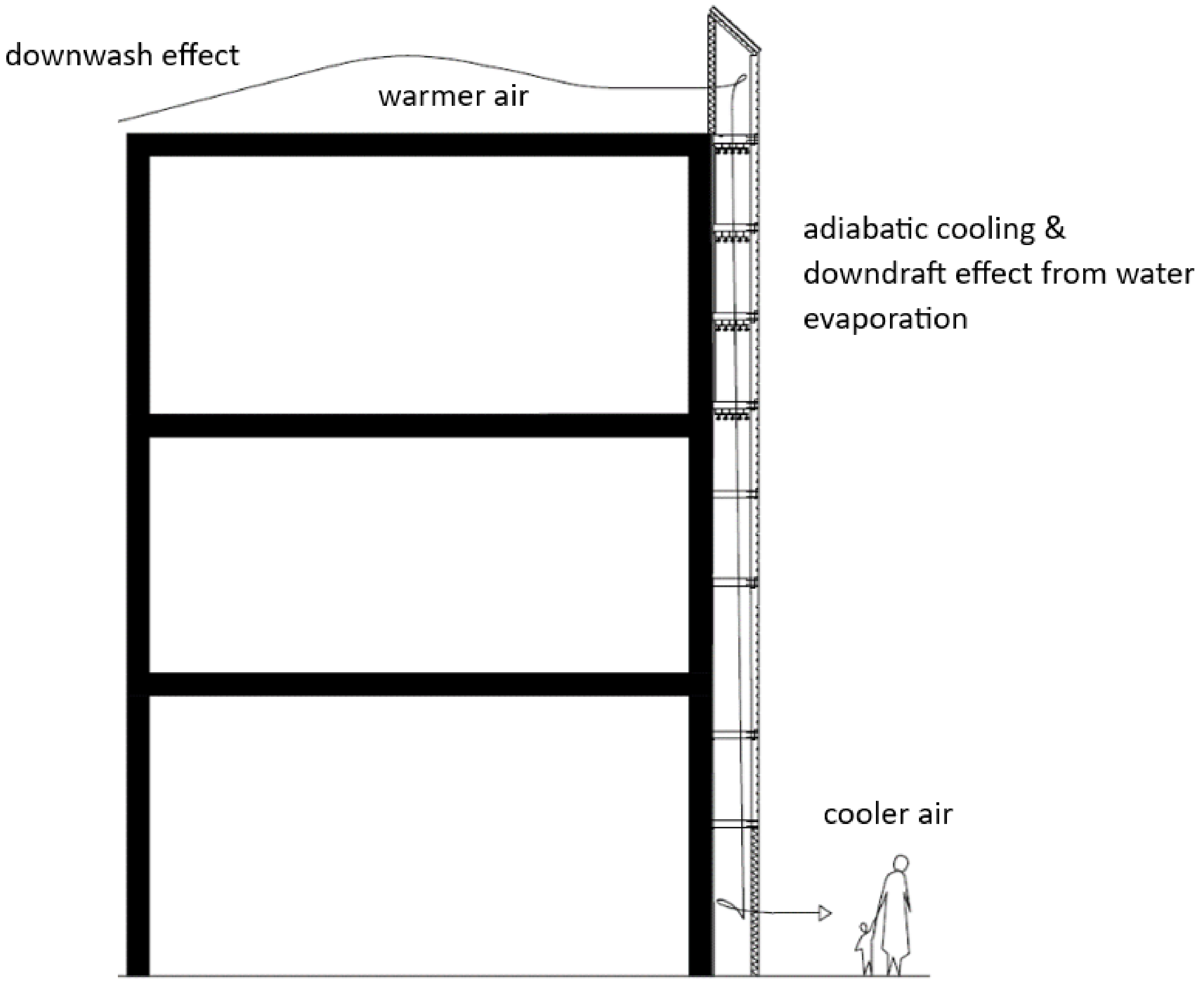


Figure 4. The trees canopy map of Milan. It reveals the presence of green, like parks, sparse green, and completely waterproofed areas, also the most superficially hot.

Figure 5. Schematic of the Cooling Facade: Exemplifying the Downwash Effect and Adiabatic Cooling Principles.



junks of green areas).

In parallel, it is possible to identify the adaptative capacity of these areas and select which ones need to be adapted with measures titled 'Nature Based Solutions', such as water-cooling systems as in water mists and fountains, small forests and street greening as in tree corridors (Figure 4). The ACE's

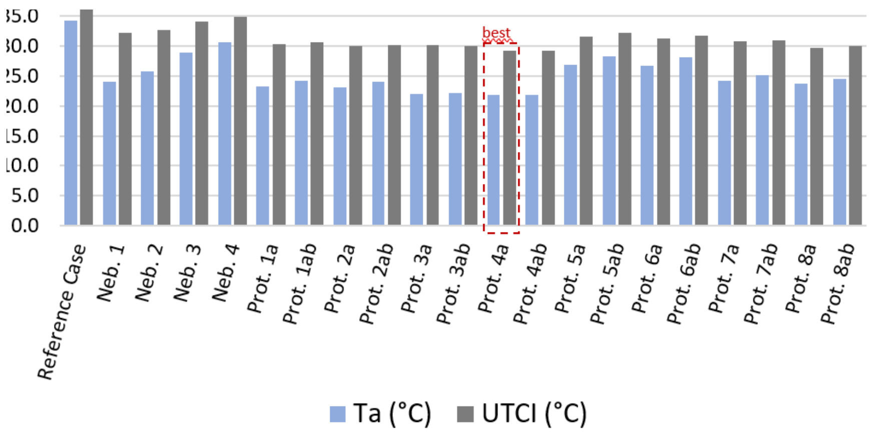


Figure 6. Digital Testbed: Comparative Analysis of Twenty-One Prototype Configurations. The results compare Ta and UTCI values across the different configurations.

Adaptative Capacity (Engle, 2010) as seen in the map is represented by the areas not covered by the tree canopy.

Next in the study is a zoom into a specific area where opportunities for intervention can be glanced when more details and variables come into the picture. There is thus a scaling down from the city to the neighborhood and a change in analysis. Within the neighborhood, the type of analysis complements the one developed at the urban level.

It allows identifying areas that are existing ‘cool refuges’ or ‘cool oases’ and where there is a need and lack of access to one of these outdoor refuges. Once identified, the areas that require intervention can receive, for example, a set of water fountains in a new reclaimed urban square or on the facade of buildings with misting systems.

The water-based cooling façade
The research work developed at the scale of the building by A. Moredia Valek resulted in the development of a water-based cooling system. During his research, he has developed a Cooling Facade as an innovative solution designed to improve thermal comfort in urban environments, particularly in areas experiencing high air temperatures and unpleasant thermal comfort.

The system employs a combination of passive and active cooling strategies to create a comfortable microclimate around buildings and public spaces. This innovative facade system aims to mitigate heat stress, promote outdoor activities, and enhance the overall well-being of residents in increasingly hot cities. Some examples already developed in this study field are the air tree from Ecosistema Urbano or the Fog assembly from Olafur Eliasson.

The cooling facade system is designed as a self-support modular system installed on a building facade as a second skin. Like a ventilated facade, it works regardless of the building’s new or existing conditions incorporating cooling principles such as the downwash effect, adiabatic cooling, and the downdraft effect.

Relying on water evaporation as a cooling technique where surface-area to volume ratio indicates the speed at which water changes from liquid to gas. Considering that water requires high amounts of energy to evaporate and that the higher the surface area exposure is, the higher the energy transfer due to heat exchange may be.

The key innovation of this system lies in integrating these principles in an outdoor cooling facade system that considers wind patterns and water evaporation to cool air and direct it towards leisure areas, enhancing the thermal comfort of people using them.

The cooling facade was analysed as a prototype using a digital testbed under various scenarios and climate conditions. The study explores 20 different configurations based on four variables: nebulization system output, facade width, outer panel materials, and nebulization system installation height. The digital testbed allowed for heat stress simulations and the assessment of multiple parameters related to people’s thermal comfort levels. The most effective configuration significantly reduced air temperature and improved thermal comfort conditions.

After completing the testbeds, the next step was to conduct a case study in the City of Milan which was chosen in order to analyze its effectiveness in a real-world scenario. This process

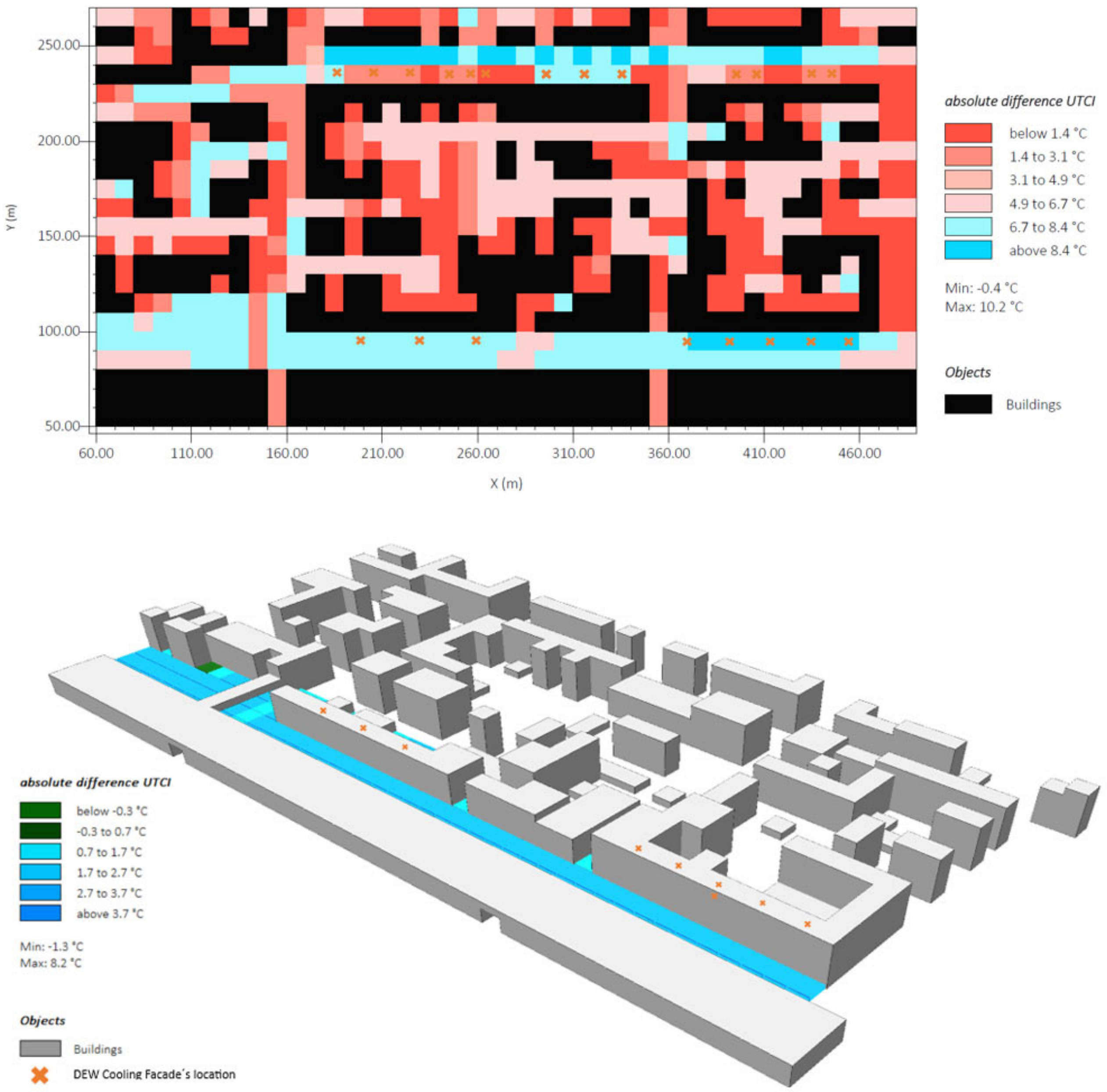


Figure 7. The two images show a simulation of the difference in the UTCI when utilizing the DEW Cooling Facade. Map showing the location with orange crosses. The figure presents both plan and 3D views of the absolute difference in the UTCI

provided valuable data on the system's practical viability and helped validate the feasibility and functionality of the developed system. The case study results are presented with empirical evidence obtained with multiple simulations.

The UTCI is one of the most important results to assess the research, as it incorporates all the necessary variables for determining thermal comfort, such as air temperature, wind speed, mean radiant temperature, and relative humidity.

Figure 7 demonstrates the Cooling Facade's ability to reduce thermal stress, with maximum reductions of up to 10.2˚C, a significant difference when assessing thermal comfort. The case study location was near the central station in Milan, where both Via Sammartini and Via Gluck show considerable improvements in thermal comfort.

This Ph.D. research has provided valuable insights into the potential of the cooling facade system for mitigating heat stress and enhancing thermal comfort in urban environments. The study has demonstrated the system's effectiveness in specific contexts and has outlined areas for further investigation to refine and optimize its performance. By building on the findings of this study, future research can contribute to the development of more effective, sustainable, and context-sensitive cooling strategies for urban planning and design, ultimately improving urban thermal comfort and overall quality of life for urban dwellers.

Conclusions

The effects of climate change, which we have been experiencing for years, such as the urban heat island effect, the management of excessive rainwater, and water scarcity, manifest themselves at different times but increasingly in the same contexts. This situation increasingly leads urban spaces to be considered multi-functional: urban areas designed to ensure high levels of livability but also places capable of contributing to environmental resilience, i.e., hosting cooling systems and accommodating excess water to help slow down runoff.

This contribution presented two ongoing research projects that propose solutions based on the use of water to mitigate the impacts of climate change at different scales of the city in its various forms. Thus, water is seen as a resource, not just a critical issue to manage.

This approach begins with an analysis of the environmental and socio-economic vulnerabilities of the entire city, leading to the definition of a microclimate improvement system that works in conjunction with buildings to create cool spaces. It also means seizing the opportunity to architecturally regenerate degraded neighborhoods, which are often the most vulnerable, and make them more livable.

These aspects, combined with the understanding that water

can be the missing link in a green and blue infrastructure when planting new trees is not feasible, help us comprehend how the city functions as an interconnected system of material and immaterial flows. It consists of environmental variables such as light, air, and physical elements, including water, vegetation, building facades, and pavements.

However, other types of energies are also necessary to determine where efforts should be directed to improve livability and thermal comfort in urban spaces. It is also important to note that when improvement interventions are replicated to intensify the green and blue infrastructure network, the air temperature decreases, and adaptation to the effects of climate change improves.

Acknowledgements

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PART II

SYSTEMS AND TOOLS FOR ENVIRONMENTAL EVALUATION, AND MODELLING

Using Open Source GIS to Support Energy and Carbon Flows Accounting in Urban Areas

Matteo Clementi and Marco Migliore

*This text focuses on the potential use of open source geographic information systems (GIS) and open data to develop project support maps, laying the foundation for a georeferenced database geared towards generative environmental design (*GED*).*
Starting from the awareness of the strategies normally used by a natural ecosystem in evolutionary processes, GED is mainly oriented towards the integrated management of the main dynamics that characterize the reference area with the dual goal of maximizing the energy efficiency of the system and at the same time guaranteeing circularity, basic conditions for achieving a zero emissions balance at the local scale.
To support the pursuit of these strategies, design tools should on the one hand help to know and map the salient features of the territory, and on the other understand the dynamics related to the main activities of the settled community. In particular the area as case study is the Corvetto - Chiaravalle district, in the southern part of Milan.

Introduction

The text briefly introduces a method and related tools useful for supporting regenerative design activities in an urban area. This paper focuses on the potential use of free and open source (FOS) Geographic Information Systems (GIS) and open data in order to develop project support maps, laying the foundations for a georeferenced database oriented to regenerative environmental design.

The regenerative environmental design, starting from the awareness of the strategies normally used by a natural ecosystem in the evolutionary processes (goal functions) (Fath et al., 2001), is mainly oriented towards the integrated management of the main dynamics that characterize a territorial reference area with a twofold goal:

- maximize the amount of local solar energy useful for doing work (Odum, 2006), in the specific case of the anthropized environment, useful for carrying out the main activities that characterize the local territorial metabolism, living and working, feeding and cleaning, transporting and communicating (Baccini, Brunner, 2012).
- ensure and maximize the circularity of matter. In fact, the inclusion of anthropic dynamics in natural dynamics implies maintaining the balance between production and consumption flows and stocks.

Both goals call into question the awareness of the main dynamics relating to local consumption activities and the resources available locally. In particular, the first asks us to

verify how much of the solar energy incident in a territorial area defined as local is directly involved in satisfying the local demand for energy and matter.

The second refers to the possibility of understanding and increasing the possibility of locally closing the production, consumption, and regeneration cycles associated with the use of the materials. In particular, the second goal provides for full compatibility between the regenerative cycles of local ecosystems and the dynamics relating to the local anthropized system, consistent with the principles of the Generative economy (Kelly, 2012).

The proposed method is divided into the following steps:

- Retrieval of open data that can be processed via GIS and referred to the local urban context.
- Processing and mapping of cartographic data useful to assess energy and carbon flows (Chrisoulakis, 2015).
- Mapping of specific indicators able to support strategies consistent with the main goal functions of a natural ecosystem.

The contribution presents some of the results of the application of the method to a portion of the urban fabric, in a portion of the south-eastern municipal area of Milan.

In particular, the work presented here intends to support the pursuit of the PGT's themes that strictly refer to the implementation of carbon-neutral strategies (Comune di

Milano, 2020). The term PGT stands for the Italian acronym for Territorial Governance Plan, the tool that regulates building activity within the municipality of Milan.

The area under consideration is a portion of the urban fabric that delimits the southeastern part of the Milan municipality near the Southern Agricultural Park of Milan, in particular Corvetto, Porto di Mare and Chiaravalle neighborhood.

Notes on the territorial governance (PGT)

An approach oriented to regenerative planning foresees an attitude of the designer and of the political decision-maker oriented not only to maintaining the cycles of local ecosystems but to improving their functioning. The Territorial Governance Plan approved in 2019 by the Municipality of Milan approaches this strategy by adopting some simplifications in order to make the law applicable immediately. The initiatives promoted refer to the accounting of carbon flows and water management in order to associate energy-saving strategies with reactivation strategies of local natural ecosystems. In particular, the PGT goals are aimed at ensuring that the building interventions subject to authorization are aimed at reducing and balancing CO_2 emissions and at the same time improving the functioning of local ecosystems. This second goal is achieved through the creation of incentives that favor the increase of vegetated and permeable surfaces and at the same time the creation of new green areas financed with compensation processes. These compensation processes are adopted if the building design does not comply with the requirements imposed by the law and are aimed at financing projects within the municipal area to enhance local natural ecosystems. The inclusion of new renaturalized areas provides the opportunity to increase the networks of relationships and also to encourage the involvement of the inhabitants and the flows managed by their activities in the dynamics of local ecosystems. While such strategies would increase local circular flows of matter on the one hand, on the other hand, it would allow associating strategies for emission reduction to the involvement of local manpower in these regenerative processes.

This text explores the possibilities offered by thematic maps created with FOS software and open data in the quantification and communication of such information to support strategies oriented to carbon-neutral scenarios. In particular, it does so starting from what has already been proposed within the PGT to understand how these thematic maps can support the strategies promoted in the PGT and at the same time support administrations and designers in identifying systemic aspects that can support the triggering of local micro-economies based on the regenerative cycles of sustainable territorial metabolism.

The themes of the PGT that strictly refer to the implementation of carbon-neutral strategies applied to new and existing buildings are:

1. Solutions with high-energy performance
2. Renaturalization interventions

3. Technologies for reduced water consumption and the reuse of rainwater
4. Use of sustainable and/or recycled content materials
5. Adoption of surface finishes with a high solar reflectance coefficient (Floors, Roofs)
6. Solutions for sustainable mobility

The following paragraphs illustrate how thematic maps developed with open source and local open data GIS sw can support the application of these strategies.)

Free Open Source FOS GIS

The current development of the open source software allows to carry out operations of equal complexity compared to the proprietary sw and at the same time gives the possibility of using complex data even to actors who cannot purchase a proprietary sw such as local administrations, especially minor ones, and designers who are not directly involved in urban planning. These tools represent an important opportunity to process and communicate information to support decisions aimed at both planners and local administrations. The open source feature of these tools allowed the creation of specific institutions and related websites that report news relating to the current level of development of such tools, such as the Open Geospatial Foundation (https://www.osgeo.org/). Among the open-source GIS tools made available, the elaborations of this work used Quantum GIS (https://www.qgis.org) and GRASS-GIS (https://grass.osgeo.org).

Available Open Data

The main georeferenced data available identify three main types of cartographic documentation:

- R1 - vector maps elaborated from aero-photogrammetric surveys, which show the geometry of the buildings, the relative heights of the eaves, and the different land uses (Figure 2).
- R2 - vector maps of census blocks that store data relating to the resident population and the present work activities (Figure 1).
- R3 - Lidar surveys at a resolution of 1 meter per pixel that add additional information to the geometry of existing buildings and greenery, in particular trees and roof geometries (Figure 3).

Tools to support the choice of high-energy performance solutions

The following is part of this set of strategies:

- all interventions related to increasing the energy performance of the opaque and transparent envelope;
- interventions on improving the energy efficiency of thermal systems;
- the installation of devices for the production of energy from renewable sources.

FOS GIS and open data can support the first and third set of strategies, in particular, namely 'interventions related to increasing the energy performance of the opaque and transparent envelope' and 'the installation of devices for the

Figure 1: Limits of the area considered in this work, in white the polygons of the various census blocks.

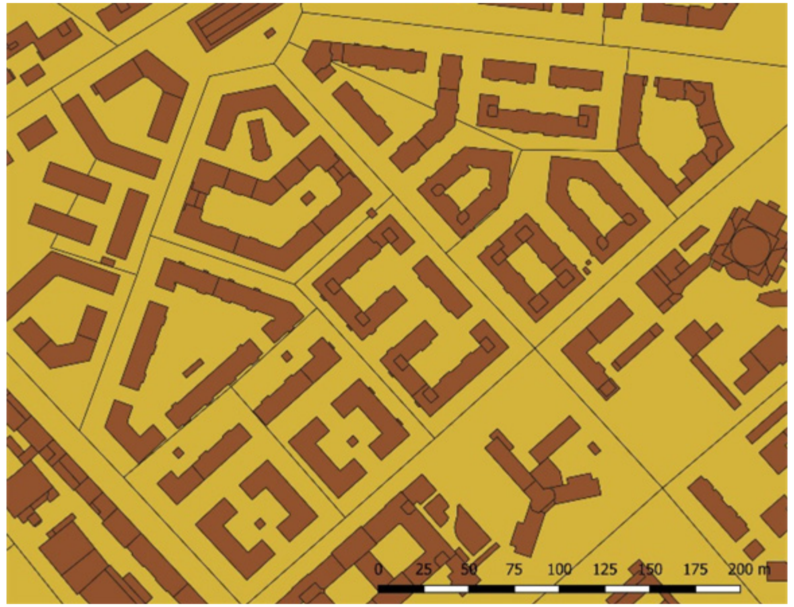


Figure 2: Portions of the area considered in this work, in brown polygons related to the volumetric units of the buildings, in light brown census blocks polygons.

Figure 3: Lidar model of the same area, resolution of 1 pixel/m2.

production of energy from renewable sources'. As regards the first, it is possible to map data relating to the shape of the building useful for estimating the energy needs of the building and for a summary assessment of the possibilities of intervention on the building envelope. Starting from the data relating to the aerial photogrammetric survey of the built urban area, made available by the Municipality of Milan, it is possible to associate specific indicators to the polygons relating to the individual buildings, summarizing information on the geometry of the building and urban form (Morganti et al, 2021).

This information, together with what has been made available by Istat (the Italian National Institute of Statistics) (ISTAT, 2022) relating to the population and housing census, allows for a preliminary assessment of energy consumption and, in the hypothesis of use of natural gas, the related CO_2 emissions and to publish such information in thematic maps to support political decision-makers and the designers. Those data can be associated with three different spatial scales using GIS:

- the volumetric unit of the buildings, or the polygon representative of the profile of a portion of the building characterized by the same eaves height;
- the building, the ground profile of a single building that includes multiple volumetric units;
- the census section, a portion of urbanized territory that includes both buildings and open spaces and constitutes the highest resolution at which the open census data on population, housing, industries, and facilities are made available.

Starting from what can be read and processed through FOS GIS, it is possible to create specific thematic maps that publish significant data on the shape of buildings and the relationships between them and outdoor areas:

- the number of vertical surfaces exposed to the outside (Figure 4);
- the combination of TM1 with data relating to the number of inhabitants associated with each census block makes it possible to map the availability of different amounts of building surfaces per person to assess the per capita weight of building efficiency measures;
- building shape indicators such as the Exposed Surface to Volume ratio ES/V.

Maps of the building's energy consumption, if combined with information relating to the type of energy sources, can be used to assess the CO_2 emissions into the air associated with building energy consumption.

Local availability of solar energy

The availability of information relating to the height of the volumetric units of the buildings together with the data relating to the orography of the terrain allow you to use FOS GIS to create a high-resolution Digital Elevation Model. These are raster maps in which a pixel corresponds to a square surface of 0.5 m side which represents in the form of gray tones the different heights of the artifacts present in the analyzed urban area. Starting from this model it is possible to represent particular urban form indicators as the Sky View Factor (Figure

Figure 4: Amount of building vertical surfaces exposed (m²/building).

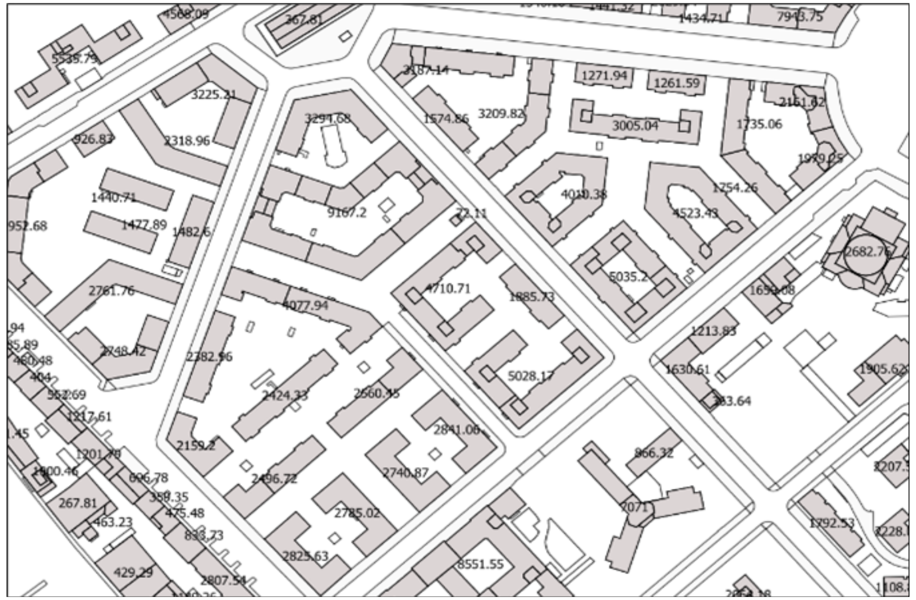
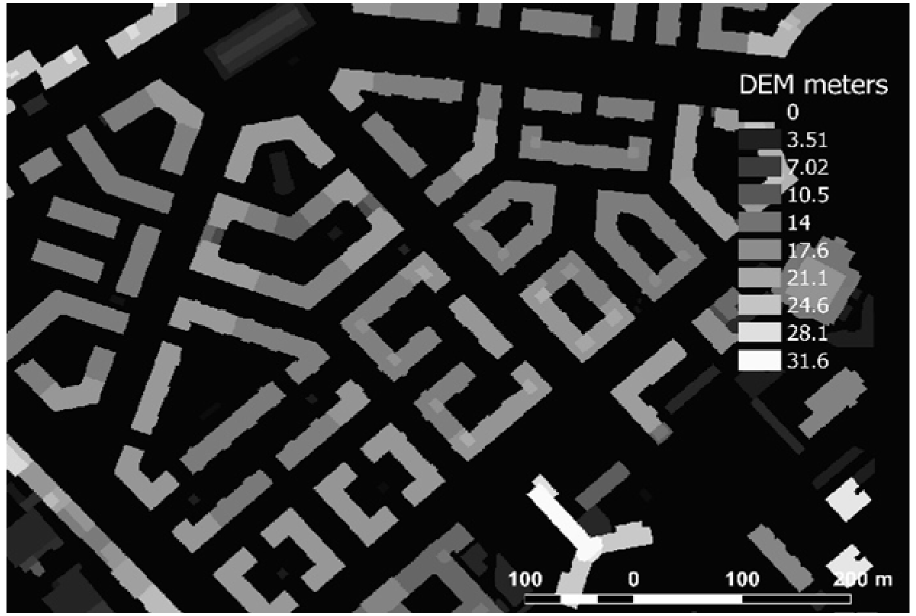


Figure 5: Digital Elevation Model of the area, 1 pixel side equal to 0,5m.



5) and then proceed with the mapping of the incident solar radiation (Hofierka, Suri, 2002) (Figures 6, 7, 8).

This processing allows the creation of various types of thematic maps:

- mapping of solar radiation on the horizontal plane to associate production capacities with the building's rooftops;
- mapping of solar radiation on the horizontal plane, at different heights from the ground, to estimate the possibility of installing solar collection devices on the building's facades;
- mapping of solar radiation on open spaces.

This processing allows to create various types of thematic maps, for instance:

- direct solar radiation mapping on the horizontal plane to associate production capacities with the building's rooftop and outdoor areas (Figure 6, 7) (all the maps refer to the average daily monthly irradiation);
- direct Solar radiation available per person on rooftop and outdoor areas for each census block.

Furthermore, by using lidar surveys, the georeferenced database (DOGD) is enriched with important new information such as the geometric configuration of the existing roofs and trees. These data are of fundamental importance to developing maps of the local renewable potential from solar energy. At the current state of the study, the elaborations carried out on

Figure 6: Sky View Factor map of the chosen area.

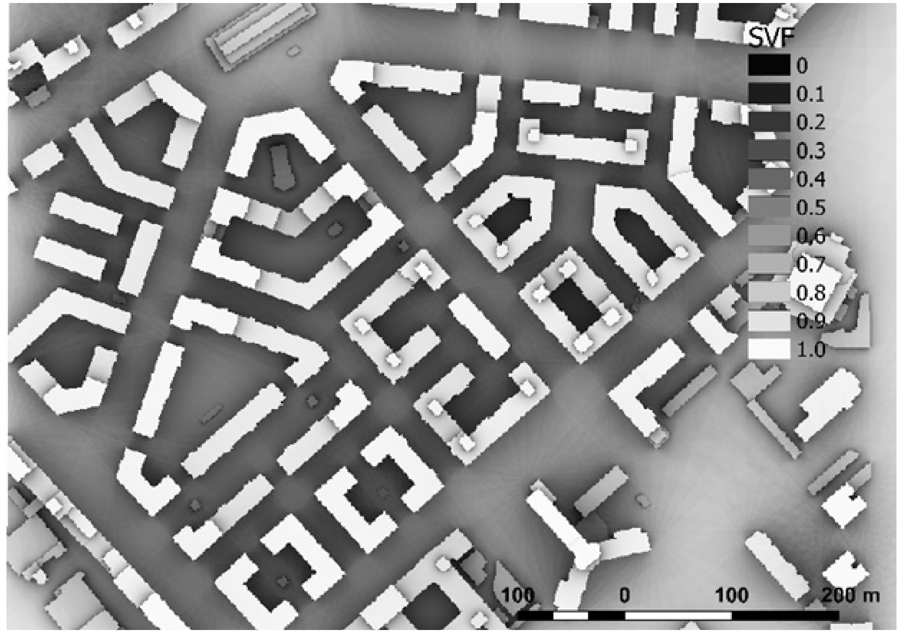
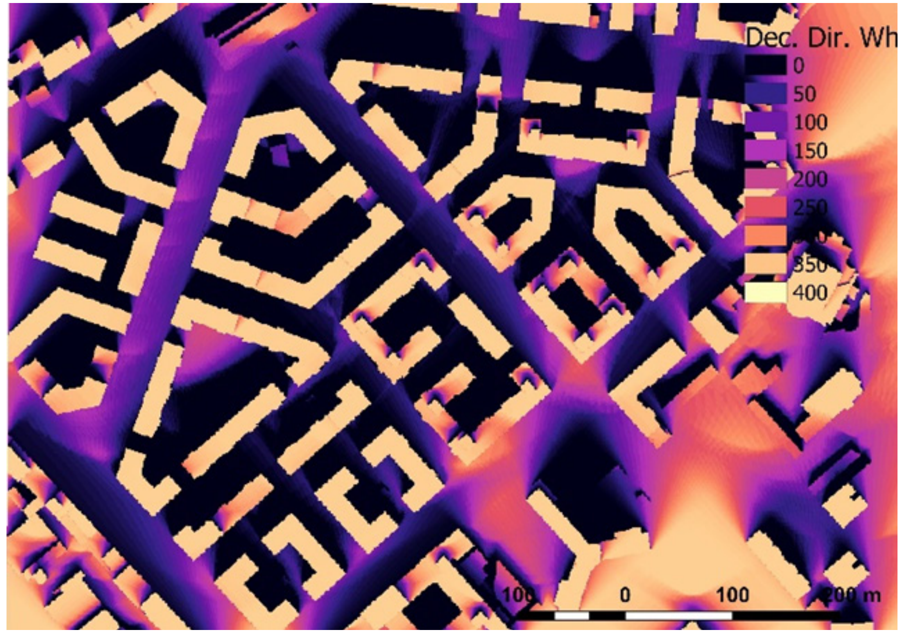


Figure 7: Direct solar irradiation representative of an average day in December (Wh/m²*day).



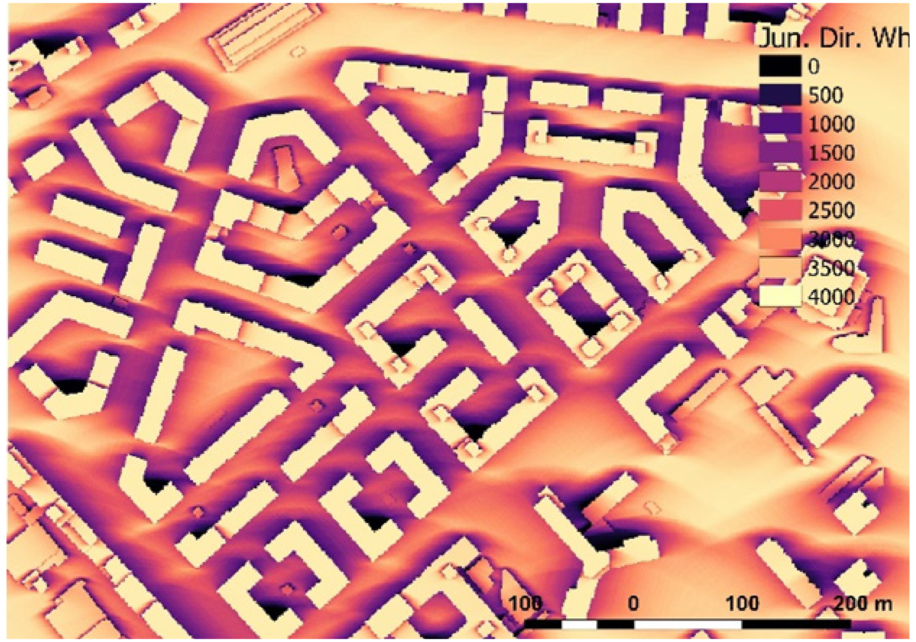


Figure 8: Direct solar irradiation representative of an average day in June (Wh/m²*day).

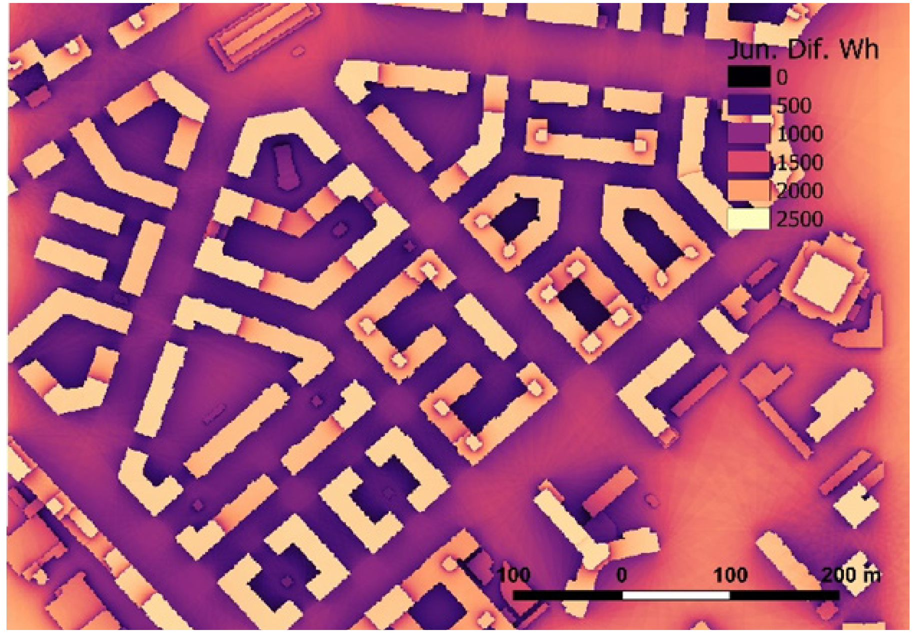


Figure 9: Diffuse solar irradiation representative of an average day in June (Wh/m²*day).

the lidar model have proved to be very effective in detecting the geometric consistency of the trees. As for those conducted on the roof coverings, they were found to be unusable due to the low resolution of the maps, 1pixel/m^2, they require future further elaborations, such as increasing the resolution in post production to one pixel/0,5 m (Figure 10, 11, 12).

Tools to support the choice of renaturalization interventions

The mapping of solar radiation on the ground, on the roofs, and on the facades can support the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. To facilitate the application of this strategy in the PGT, the green vegetated surface is currently associated with the ability to absorb annually 6 kg of CO_2 per square meter, and a tree with 50 kg of CO_2. Indeed, this capacity depends on the size of trees,

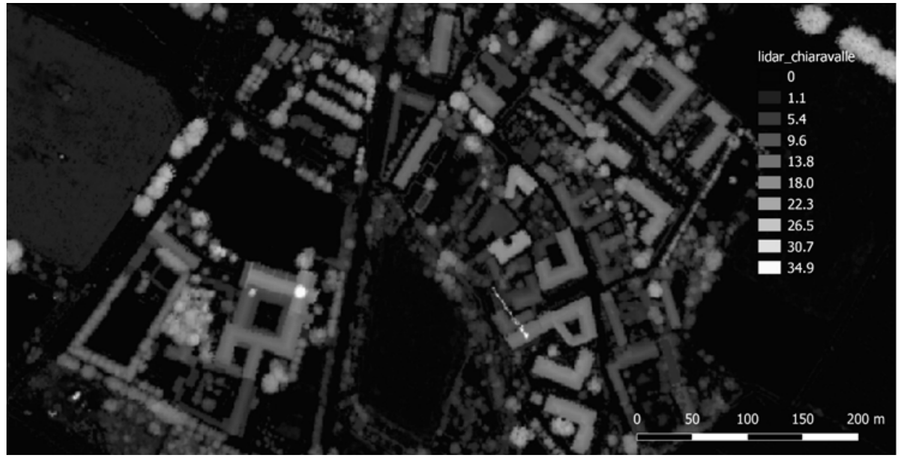


Figure 10. The portion of the lidar survey relating to the Chiaravalle area, the resolution is equal to 1pixel/m^2

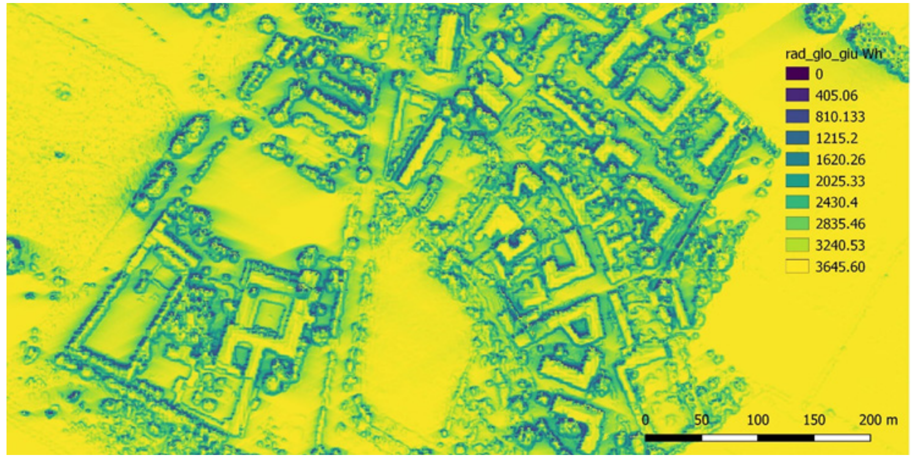


Figure 11. Map of global solar irradiation processed on a 1pixel/1 m^2 lidar survey, relative to a day in June.

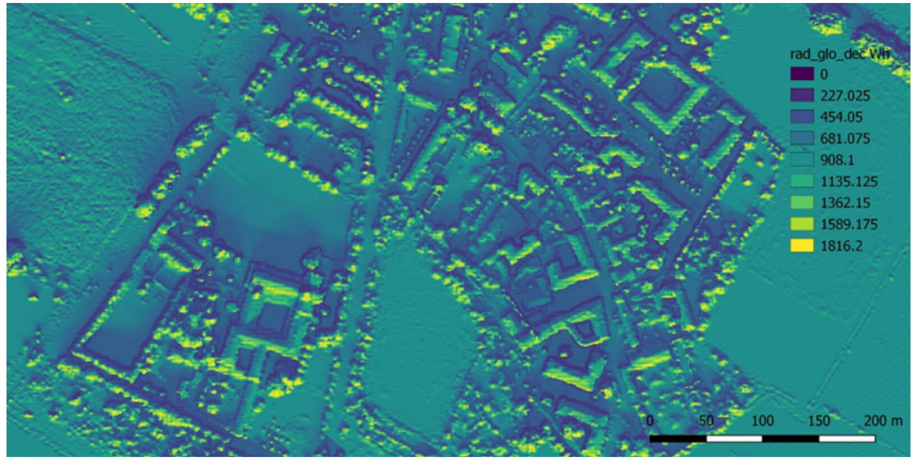


Figure 12. Map of global solar irradiation processed on a 1pixel/1 m^2 lidar survey, relative to a day in December.

Figure 13: Lidar map relating to tree volumes. To reduce the inaccuracies due to the low resolution, buildings have been eliminated from the map by using a mask increased by a buffer zone of 3 meters. To reduce some defects detected at higher altitudes, the interval from 1 to 20 m from the ground has been considered (the white parts of the trees refer to volumes above 20 m).

the availability of solar energy as well as on the availability of water and nutrients. Useful information on the geometric configuration of the trees can be mapped through the use of lidar surveys. Mapping of solar radiation on the ground and the roofs can support the choice of herbaceous or tree species to be cultivated and the effective possibility of absorbing CO_2 based on the available energy. The mapping of solar radiation conducted starting from these surveys also allows for identifying possible areas suitable for urban agricultural production, from planting fruit trees, installing productive green walls, rooftop agriculture devices, and other urban agriculture interventions that can favor the start-up of local productive activities.

Maps on local availability of rainwater and useful wastewater
The amount of rainwater incident monthly on roofs and open spaces represents important information in the choice of low energy-consuming strategies oriented not to use drinking water from the aqueduct. Making this information available requires associating information relating to the quantity of rain incident monthly and annually on the roofs and to the geometric data made available by the aerial photogrammetric survey relating to buildings and open spaces. This climatic data is made available by the local municipality and ARPA (Regional Environment Protection Agency) and refers to data representative of the annual average and data relating to extreme events (representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50 or 100 years). In the case of the data referring to the

monthly average, the open data portal of the municipality of Milan reports the monthly average of the atmospheric precipitation values (Comune di Milano, 2021). The data show an average annual quantity equal to 1006 mm, with monthly average values that fluctuate depending on the month from 50mm in August to 100mm in April, except for November where values around 170 mm are recorded.

Maps on the amount of carbon and nitrogen emitted through organic waste

Another aspect in which a systemic approach to design favors the implementation of carbon-neutral strategies is related to the possibility of locally producing nutrients. Buildings regularly export nutrients in the form of metabolic waste and organic waste. In the second case, the local treatment of the green component of organic waste would provide a contribution to the ability of local ecosystems to absorb CO_2, both in the soil and in the metabolic activity of plants (Chrisoulakis, 2015). Starting from the number of inhabitants associated with the census block, it is possible to map the potentially emitted flows of organic waste and therefore of the relative nutrients (starting from carbon and nitrogen flows).

Tools to support the applications of technologies to reduce water consumption and for the reuse of rainwater

In the specific case of the rules underlying the accounting of carbon flows associated with the PGT of the municipality of Milan, the CO_2 emissions include the emissions associated

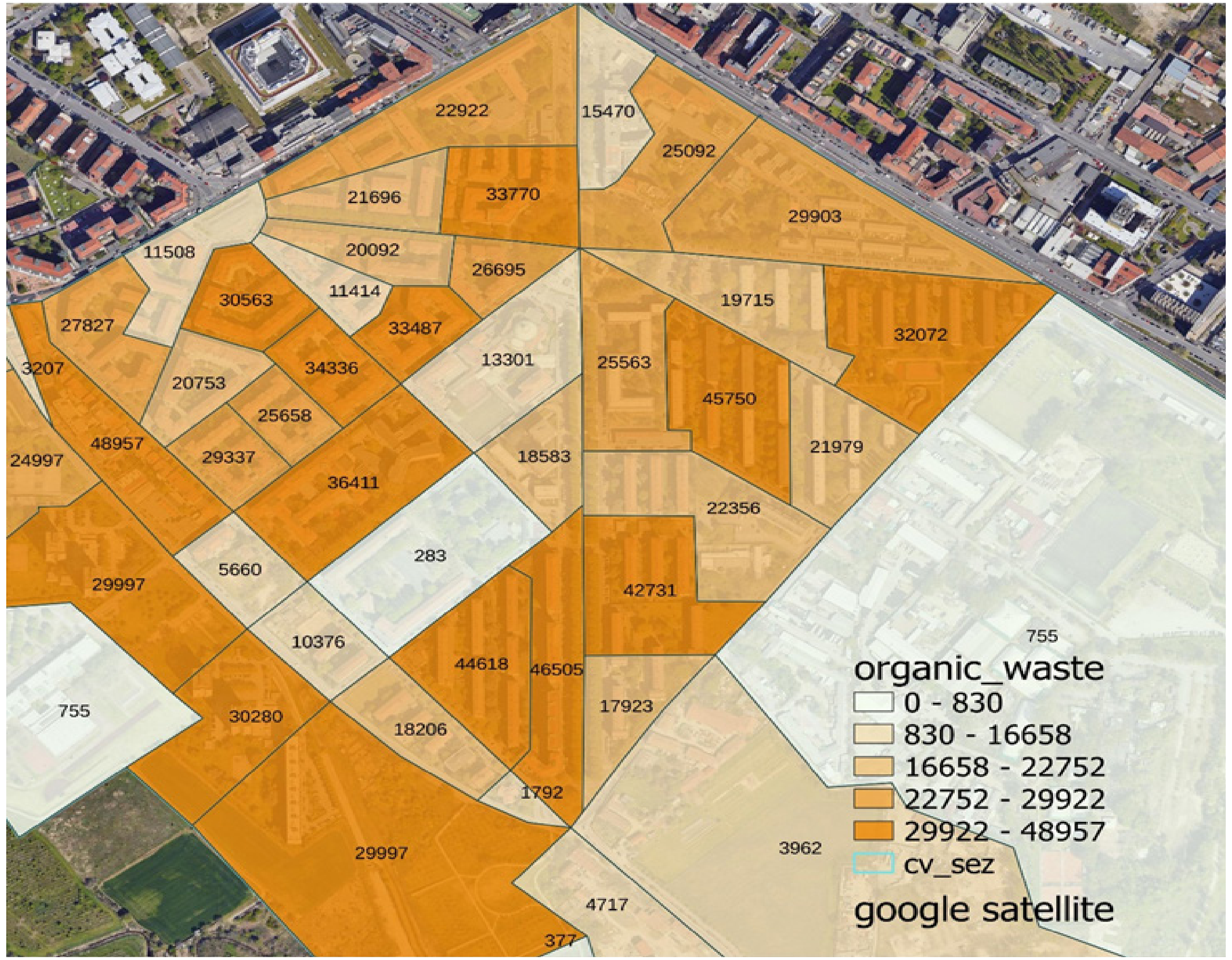


Figure 14: Amount of organic waste emitted from each census block each year.

with energy consumption for water supply and wastewater disposal. Mapping rainwater availability makes it possible to use these flows not only for irrigation but also to reduce the consumption of drinking water from the aqueduct. To understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. These types of maps can be elaborated starting from the number and characteristics of the inhabitants associated with each census block.

About Locally available rainwater, making this information available, requires associating information relating to the quantity of rain incident monthly and annually on the roofs to the geometric data provided in the aerial photogrammetric survey relating to buildings and open spaces. This information refers to data representative of the annual average and data relating to extreme events not representative of the average but representative of the possibility that an extreme event occurs in a multi-year interval of time usually 20, 50, or 100 years. In the case of the data referring to the monthly average, the open data website of the municipality of Milan reports the monthly average of the atmospheric precipitation values (Comune di Milano, 2022). Rainfall was measured in the urban area of Milan between 2008 and 2014, with values ranging from January 2008 to December 2014.

The mapping of rainwater availability makes it possible to use rainwater not only for irrigation but also to reduce the water consumption from the aqueduct. To understand the precise effectiveness of this solution it is important to compare the capture capacities of roofs and waterproof open spaces with the mapping of water consumption per building. As in the

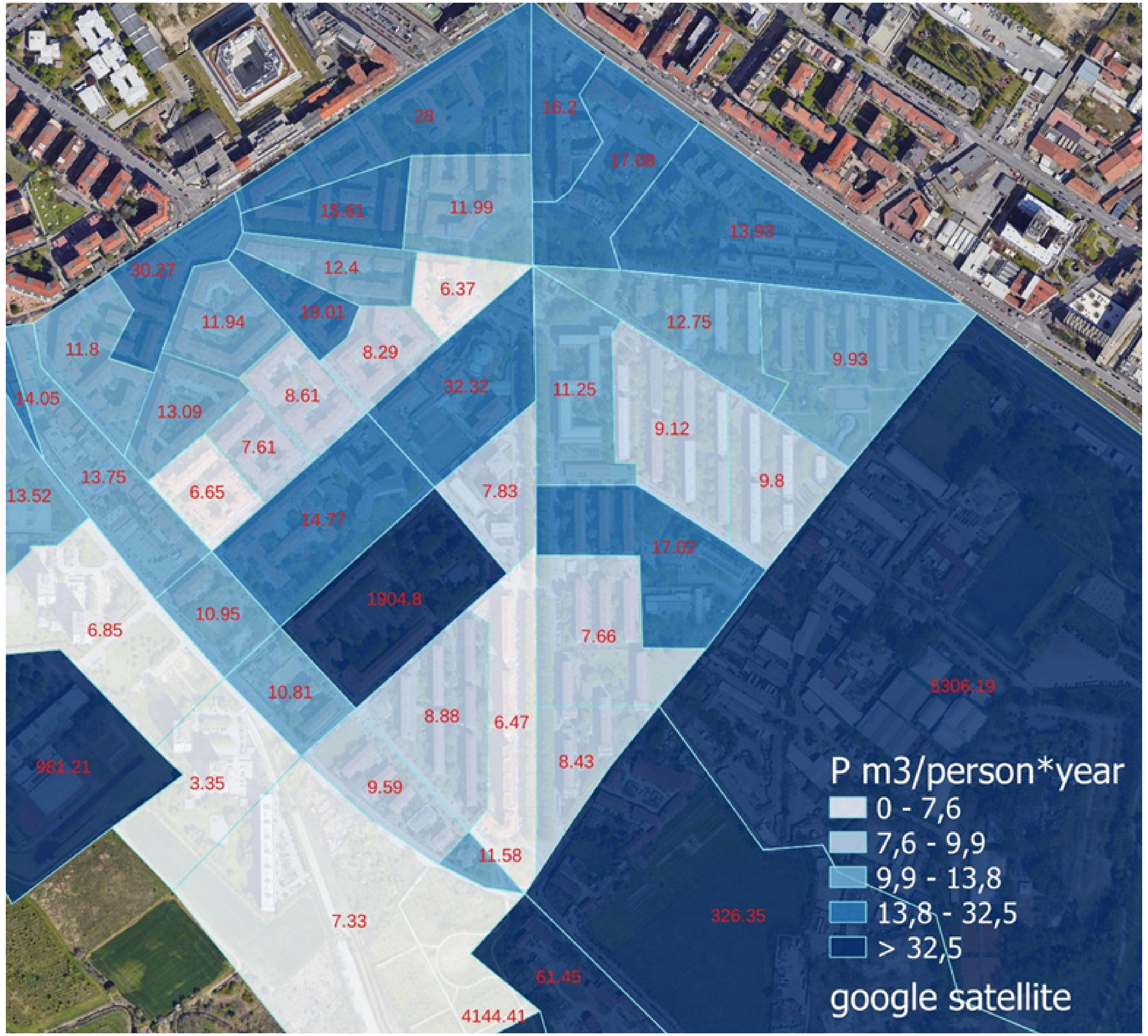


Figure 15: Quantity of water captured annually by the roof divided by the number of inhabitants present in the census section (unit of measurement, cubic meters/ person per year).

Figure 16: Maps of annual flows of polymeric waste from dwellings by census blocks.

case of solar energy mapping, starting from data concerning the climatic variables (in this case the pluviometry in the different months of the year), it is possible to enrich the database with information to support the design process. In particular maps about the amount of rainwater incident monthly and yearly on roofs and open spaces.

Tools to support the use of sustainable or recycled materials
The possibility of locally producing sustainable or recycled materials presupposes the mapping of possible emission flows of waste material from local production and residential activities. This availability of information could give rise to local collection and processing workshops. Among municipal solid waste, paper and textile waste could find use as building insulating material together with straw produced by peri-urban agricultural activities. Polymeric materials would find an interesting use in the construction of support devices for urban agriculture (for example tanks for cultivation and water storage).

Tools to support strategies for sustainable mobility
The thematic maps to support the application of these strategies at the current level of development include the availability of open spaces per person in the different census blocks (for bike parking and mobility). The reduction of CO_2 emissions is correlated to the per capita reduction of daily impacts and quantified in terms of avoided kilometers, a significant data is the availability of parking spaces per person. If these spaces coincide with those most affected by

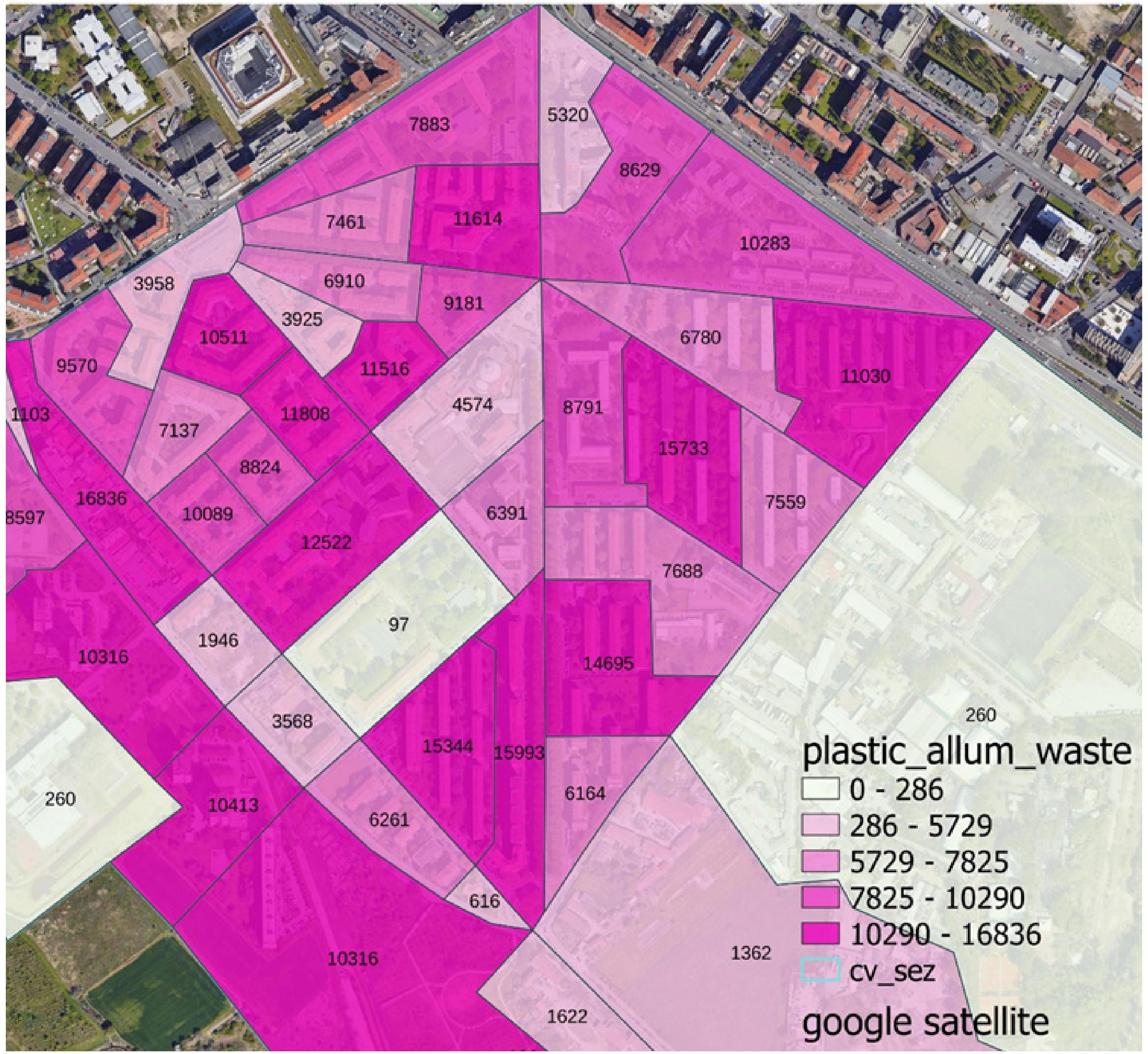


Figure 17: Maps of annual flows of paper waste from dwellings by census blocks

solar radiation then they could be suitable for the installation of photovoltaic canopies or photovoltaic pergolas suitable for generating shade and at the same time producing electricity for mobility.

Conclusions

The coexistence on the same GIS of different types of information, through the thematic maps developed to date and under development, has revealed the usefulness of associating to census blocks data relating to the local territorial metabolism. The information on local supply of energy and matter and on the local demand finds in the quantification per person a functional unit of reference capable of carrying out trans-scalar balances, both at the block scale, represented by the boundaries of the census blocks, and at a larger scale through the aggregation of the data associated with each block. The provision of this data on the same gis support allows for the development of scenarios relating to the possible activation of local circular micro-economies. A fundamental condition for local micro-economies to be activated is the possibility of intercepting existing spending flows, these dynamics are activated in the first place by the daily life of the established community, for example by the expenses for winter heating, together with the expenses for transport and food supply. The intention to intercept local spending flows further opens up the possibilities of intervention to reduce CO_2 emissions linked to lifestyle, giving the possibility to act on buildings and open spaces to reduce the energy consumption of buildings but at

the same time reduce the impacts of mobility and nutrition. In the latter case, the design of the vegetated spaces plays a multiple role, on the one hand, it favors the absorption of CO_2, on the other it lends itself to the activation of local production/consumption flows that can be promoted by local cooperatives, oriented towards the local management of nutrients and local food production.

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Social Acceptability of Technical Solutions and Role of Human's Behavior

Alessandro Rogora

Technology is important to reduce human impact on the planet, but changing in personal behavior is necessary and much more effective. People hardly accept to modify their lifestyle and the difficult to evaluate the impact of personal behavior is used as an excuse not to change anything.
The research TRACES was focused on the idea was that there is no chance to arrive at sustainability if people do not deeply change personal behavior.
The research TRACES is based on a game-based learning approach in which collaborative approaches and digital technologies support the performance response of design actions in building carbon neutral housing scenarios. TRACES can be played both at the Urban (or Community) level and at the Building (Personal) level referring to a building or a group of buildings in which a limited number of people can play in person. It is structured into six 'impact sections', with some subsections: clothing, mobility, food, home *(heating and cooling, electricity, domestic hot water, cooking),* leisure *and* communication, others *(education, health, and services), for each section impact values are given in terms of* m^2 *of surface area used and amount of* CO_2 *emitted.*
In these years the research project TRACES has revealed a great deal of growing potential even if the attempt to simulate the entire impact of our behaviors requires a significant work to reduce the complexity in analysis and communication.

We know the problem, we have the technology we need and we also have a clear view of the consequences of our delay; despite that nothing is really changing.
People are interested in changing the situation, but no one is willing to modify their lifestyle to help solve the problem because the effect of a single person represents a drop in the ocean of emissions and consumption, and each of us think: «*Why me? Why should I change my lifestyle if all the others are living the same way?...*» And then it is just a drop! Even if we know that an ocean is made of a sum of single, small drops. Most of us are waiting for a technical solution able to solve our problems without asking for a transformation of our behavior. As humans we believe in technology, we believe in efficiency and we believe in Providence; we are convinced that something will happen to save our species, because our destiny (at least in our belief) is to dominate the Planet.
To tell the truth I do not believe that technology, efficiency and providence will do anything special, and I am convinced that humans' behavior -as well as the entire structure of our society- should deeply change to give to our species a chance (*if any*) to survive and flourish again, rather than being involved in the next mass extinction (Harari 2014). The problem is that most people should be convinced of the need for change, should be involved in the change and should have clear in mind the impact of their own behavior and the distance between a series of small shared decisions and sustainability. As users, our goal is to achieve and maintain conditions of adequate environmental comfort (thermal conditions, lighting, health and wellbeing, but also clothing and nutrition) and social qualification (demonstration of a certain social status through the possession of goods and access to services that are considered adequate). Very broadly speaking, it could potentially indicate the former as elements of a physical nature and the latter as elements of a symbolic nature (Los, 2013), which «*must be satisfied without compromising the ability of future generations to meet their own needs*» (Brundtland, 1987; p. 16). On the other hand, the designers tend to provide a specific response to problems involving changes to an environment (on scales from a municipality to a single

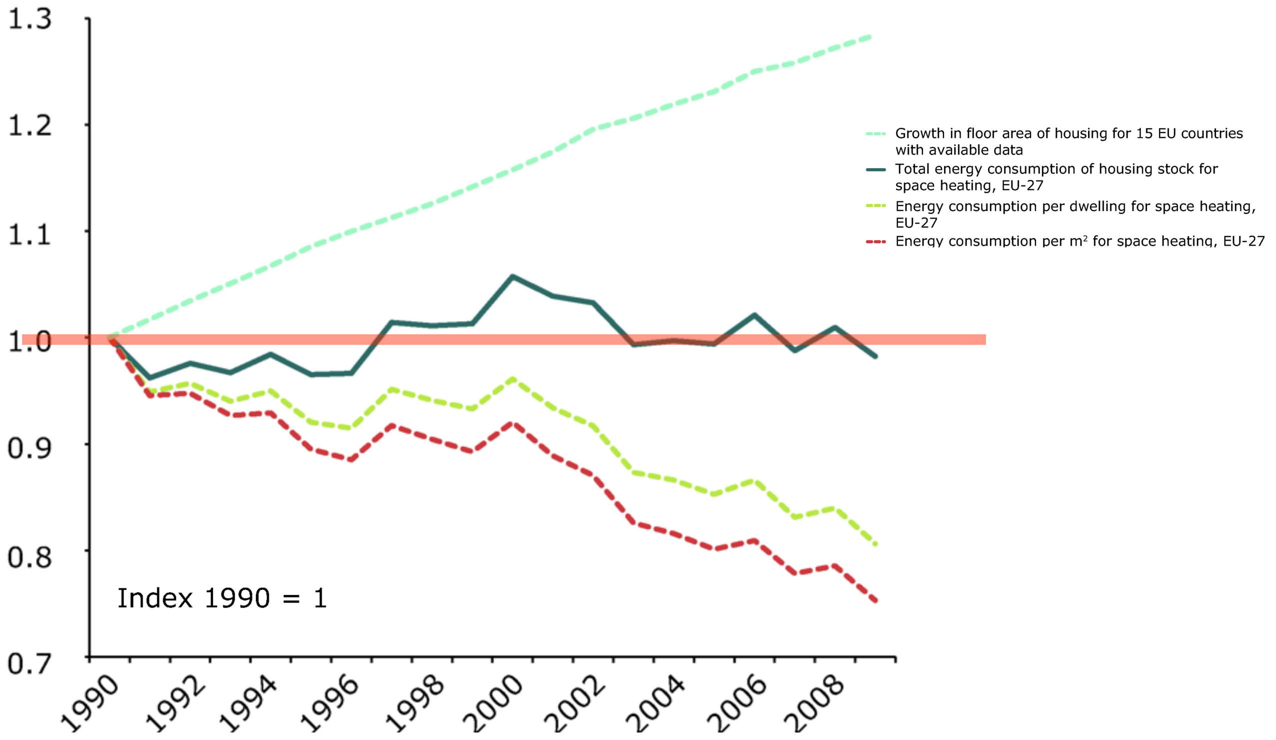


Figure 1: Trends in heating energy consumption and energy efficiency of housing, EU-27. Time series of the growth in floor area of housing in EU27 coupled with the energy demands for space heating per dwelling, per m2 and total.
Environmental Energy Agency https://www.eea.europa.eu/data-and-maps/figures/trends-in-heating-energy-consumption-2

building), at times favoring the needs of a physical nature, at others those of a symbolic nature, generally without having a clear insight into the effects that the choices cause to the environment and without being required to illustrate these effects to the clients.

The research TRACES was focused on this. The idea was that there is no chance to arrive at sustainability if people do not deeply change their behavior. There is not a single 'proper and correct' answer and different options are possible to approach sustainability. Some of us can pay more attention to transportation and nutrition, others to clothing or building insulation. The most effective mix depends on the culture and the climatic conditions in which we live, the shape and the age of the building, but also on our specificity as individuals who have different preferences and interests. We have several options, even if we have to guarantee that our impact remains within planetary limits, on the contrary we are not talking of sustainability.

Till now global efforts to reduce energy consumption and carbon dioxide emissions have not had the desired effects, despite significant increases in the energy efficiency levels of the manufacture of individual products and the provision of services. The policy initiatives promoted by governments have not proven capable of reversing the global trend, and there are very few concrete actions at the local level that attempt - even in their own small way - to address the overall problem of emissions and consumption by providing virtuous models to be followed.

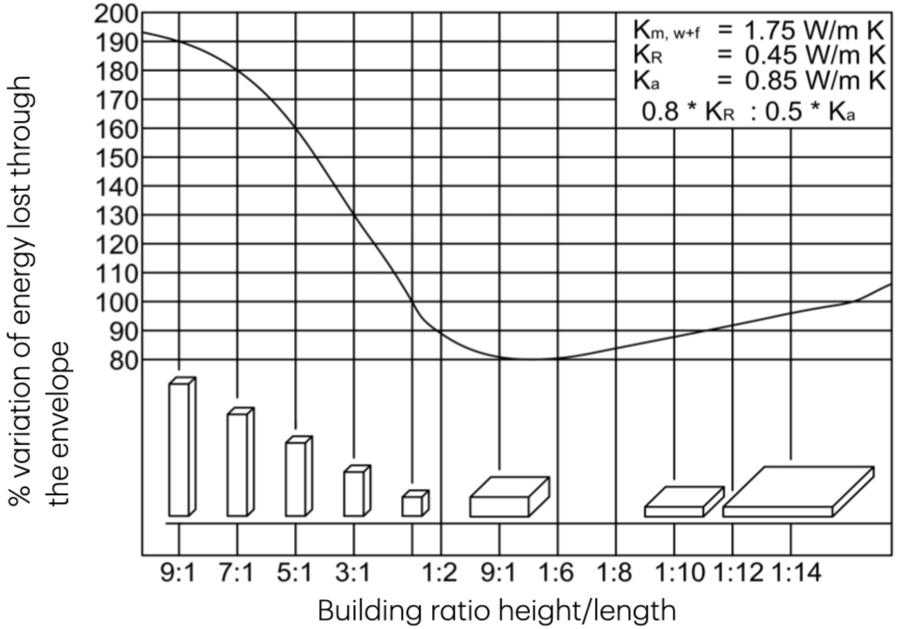


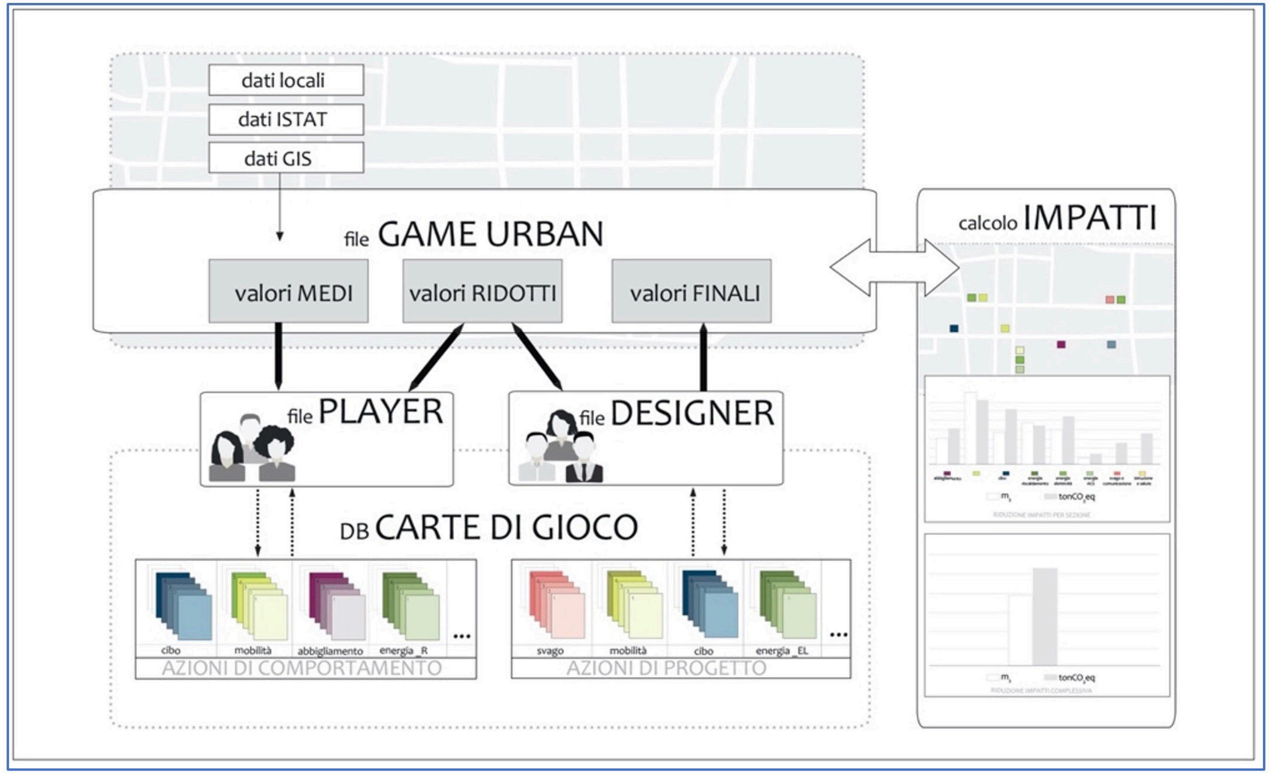
Figure 2: Variation of the heat losses through the envelope due to the building shape

The result is that the building transformations are extremely efficient if considered with reference to an individual problem (for example the conservation of thermal energy) without worrying about the amount of energy consumed for lighting or the energy necessary to create the set of elements, systems and components needed to achieve the energy-saving objective (LCA of the building). The organization of the urban structure presents, more or less, a similar problem. Some solutions seem quite efficient in terms of solar energy collection (for example in the case of single-family houses), but have an extremely important impact in terms of mobility, land consumption, etc. With the final result of being not sustainable in a global evaluation.

By carrying out simplified or more detailed analyses, it is possible to calculate the amount of energy necessary for a specific purpose, or to calculate the carbon dioxide emissions saved through some specific choices. However, these numerical values are understandable only to professionals in the field and are difficult for ordinary people to understand. This makes it particularly difficult to correlate causes with effects and thus get people to act correctly. This fact severely limits people's participation in transformation actions that aim to bring social behavior closer to global sustainability goals.
Attempts to move from point analysis of a single effect to analysis that include multiple sets of parameters (or let say to simulate the impact of people’s lifestyle) are by no means new (Wackernagel, Beyers, 2020), but such attempts are generally geared towards providing assessments of integrated comfort for individuals or environments, while at the opposite extreme other methods for these values have been developed for entire nations and populations (GDP, Happy Planet Index, etc.). The lack of an intermediate scale for assessing impacts - especially one in relation to environmental effects which encourages shared, informed design choices - has led the research team to work towards creating one; indeed, this issue represents an interesting field of work for the near future and has links with recent work on the subject (Clementi, 2019, Rogora 2020).
The search for impact prediction tools that can be used by administrators, planners and citizens alike and that involve and engage all stakeholders in deciding what action to take is the foundation of the research project formerly titled ‘The

Imitation Game’ and now TRACES (TRAnsition Society).
The basic experiment underpinning the research involves applying the logic of role-playing and simulation games and assessing their effectiveness in shared decision-making for sustainable planning choices which require significant changes to the lifestyle of those involved. This approach also represents a highly innovative method in terms of teaching and teacher-students interaction.
The method proposed in the research TRACES, is based on

Figure 3: Structure of the educational game TRAceS at Urban level. The initial values come from available average data (regional or national) or local information when available.



a game-based learning approach in which collaborative approaches and digital technologies support the performance response of design actions in building carbon neutral housing scenarios (Reference, xxxx). The design process is structured by sequential and iterative steps that augment project data and information until a final outcome is reached that is shared among the stakeholders. The resulting tool aims to configure a framework for the integration of technological and functional solutions in urban contexts which aims to highlight the potential of the transformations to be made in support of the transition of territories and communities with respect to a neutral equilibrium (sustainability). It also aims to build a framework for gaining knowledge related to project variables, contextualizing solutions applicable to the specific context. The basic framework relates variables that influence the design process concerning:

- urban fabric characteristics (morphology, infrastructure, services and their distribution, open space categories and uses);
- methods of use, lifestyles of the inhabitants, propensity to change the daily habits of travel and access to daily goods and services;
- scientifically recognized functional solutions and technologies;
- design performance in context, in terms of environmental, economic and social effects.

Each possible action is described through datasheets that represent the playing cards of the game. In these datasheets the performance of each proposed solution is made explicit through the description of the effects produced by the behavioral changes that the community accepts and - consequently - the structural changes of the built environment that the project requires and produces. Each action (card) has an effect both in terms of modification of the quantity of CO_2 emitted for the production of a good or service, and of the land surface used for the production of primary goods, but also the cost to carry out the specific action and the time commitment required for its implementation and/or management of this action. The cost is evaluated both in term of money and in term of time because each of us can use a given amount of these limited resources. The time variable gets more and more significant in case of behavior change, while money is more important in case of new technical solutions; the amount of available money at Urban level depends on the population and the taxes (is decided collectively at the start of the game).
An important activity in terms of time commitment and resources is the preparation of the playing field by the working group. This activity was almost as important and complex as the play itself and required months to collect information, define how to group and subdivide the necessary information and to give a graphic representation useful for the game.
During the game, players are asked to think on the effect that their daily habits produce on the environment (the TRACE) and to experiment actions able make their impact less unsustainable towards more responsible habits (the modified TRACES)
This phase (called Player in the game) is configured as a tool for

understanding the conditions that hinder the development of virtuous behavior by users and, consequently, for collectively deciding on the most appropriate set of solutions to make such behavior socially acceptable. In the next phase (in the game called Design) the interpretation of the data makes it possible to understand the effectiveness of the design actions which, in the specific context of the game, allow for concrete results to be obtained and for building shared scenarios of urban sustainability.
TRACES can be played both at the Urban (or Community) level -in which the playing field is a municipality, a mountain community or any administrative structure- and at the Building (Personal) level referring to a building or a group of buildings in which a limited number of people can play in person. We have two different strategies: the shared urban decision which must be acceptable to the community, and which first gives the main directives, the fine-tuning (optimization) referring to detailed choices made by a group of people on specific and real situations such as the second.
Actually, to give the best results, the game should be played first at the Community-Urban level and then at the Personal-Building level. This process should initially involve citizens as part of a larger community by comparing political choices and their degree of social acceptability. The next level should instead intervene at the level of personal choices by stimulating virtuous behaviours to be emulated.
TRACES offers a gaming experience where participants can simulate and experience different scenarios within a set of limited available resources (time, money, water, energy,

productive land, food, etc.) and where players represent the real-life stakeholders (community and people) of the social and geographical context in which the game is played. This allows you to simulate the effects and define the countermeasures to adopt to arrive at shared solutions with explicit and measurable effects.
The idea of interacting with students (or with citizens, stakeholder and politicians) as one would in a large-scale 'role-playing game' makes it possible to simulate both the social acceptability and the environmental consequences of a series of options for transforming the built environment, making the effects and weight of the choices implemented clear and explicit. The main objective is to change the users' behavior by increasing their level of awareness in order to build new shared values of sustainability.
The different design choices, technical solutions and behaviors adopted by the players (students of architecture, in our case) continuously modify the results, making the consequences of the choices with respect to two parameters: the quantity of land necessary to produce the basic materials necessary for support the lifestyles of the settled population and the amount of carbon dioxide emitted for their treatment and use.
The game is structured into six 'impact sections', with some subsections: clothing, mobility, food, home (heating and cooling, electricity, domestic hot water, cooking), leisure and communication, others (education, health and services), for each section impact values are given in terms of m^2 of surface area used and amount of CO_2 emitted.
The structure and organization of TRACES are rooted in the

assumption that without a deep shift in the behaviors of individuals - and therefore in the values of a settled society - any given collection of technical solutions is not sufficient to keep humanity's impact on the planet within sustainable limits.
The first hypothesis of the research was to represent this impact using a single parameter, namely the surface area needed to support any given lifestyle in order to make the discrepancy with the available surface area per capita in the defined environment immediately clear. The main problem was a double-edged sword: how to simplify the complexity of the real world to make the game playable, whilst at the same time maintaining its complexity to allow for specific, localized design operations.

Case study description

The first play was played in 2020 by the student of the Construction and Sustainability Design Studio -Master Degree in Architecture. The playground was the town of Rescaldina located in the north of Milan with a territory area of 8.20 square kilometers and a population of 13.920 inhabitants. The territory is more than 60% urbanized, with land use predominantly residential (28%) and tertiary (16%). The mobility system (roadways, car parking spaces and sidewalks) occupies a total of 10% of the total area, while only 1.6% and destined for green spaces.
Applying the simplified method to calculate the impact defined by TRACES we estimated that to support the lifestyles of the settled community in the municipality of Rescaldina,

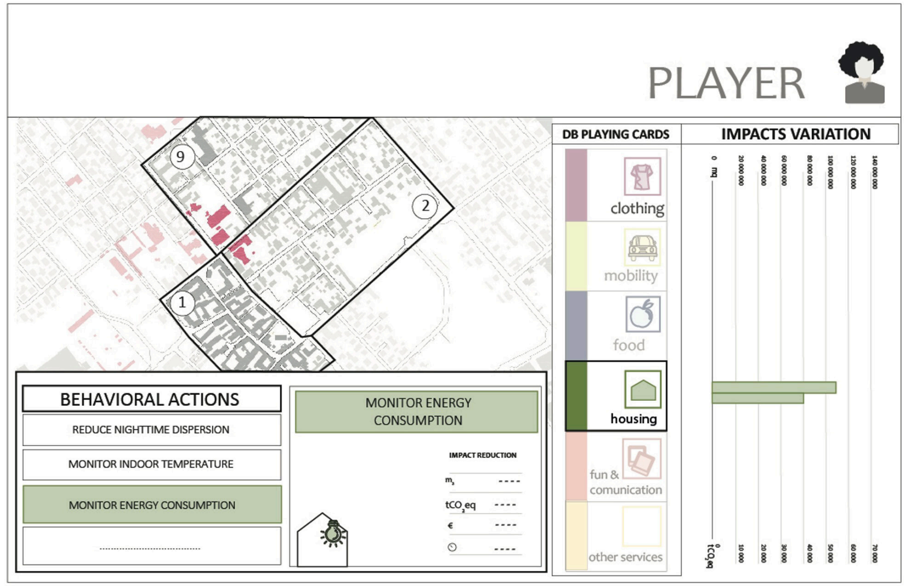


Figure 4a: Effect of the Behavior Card - Monitor Energy Consumption – in the game section *Housing*

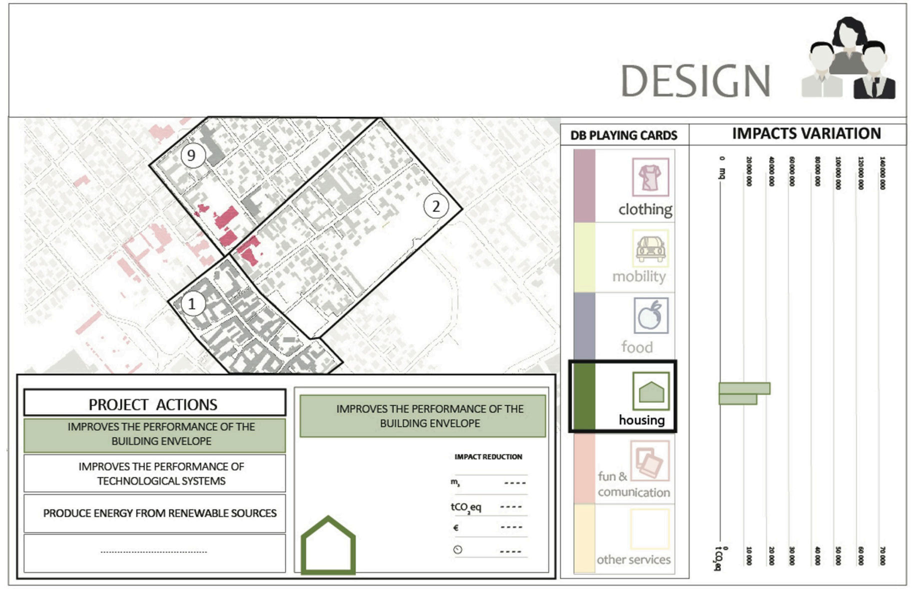


Figure 4b: Effect of the Design Card – Building insulation – in the game section *Housing*.

an area bigger than 40 times the existing was needed. The impacts have been divided into 6 sections that represent the main categories of expenditure that the population supports for access to goods and services of daily use (see above).
Focusing on the category 'mobility', a land consumption of 9.730 m^2 and an emission of 3,43 tCO_2eq are attributed per capita. The national statistics (ISTAT, ISFROT, ANFA) give information about the average distribution of journeys made by private transport (53.8%) and made by public transport (9.3%). The impacts are obtained from the average number of kilometers traveled annually in the municipality by applying conversion factors to transform the kilometers into m^2 of land consumed (for oil production obtained by sunflowers) and CO_2 emitted.
The impacts are calculated considering the average number of kilometers traveled annually in the municipality by applying proper conversion factors to transform the kilometers into m^2 of land consumed (we assumed the possibility to produce oil by planting sunflowers) and CO_2 emitted.
These factors take into account the number of journeys per inhabitant based on the total number of families residing in the municipality of Rescaldina, type of vehicle by type of fuel, average cost of travel, average consumption by type of vehicle and average impact on km travelled. The calculation is made using a rough, simplified calculation at Community-Urban level and a bit more precise evaluation at Personal-Building level.

Building scenarios and estimating the impact of project alternatives

The proposed strategies are part of a transformation scenario that involves the construction of an urban green infrastructure - for cycle and pedestrian use - that connects places of public interest and main interchanges with other forms of mobility (e.g., railway station) in the municipal area of Rescaldina. The location of the infrastructure is the result of an in-depth study of the characteristics of the urban fabric. The strategy is particularly aimed at improving the conditions of use of paths dedicated to sustainable mobility to encourage their use by the community by accommodating their daily needs. The bicycle and pedestrian path would be made accessible within a radius of 300 m. Parking spaces dedicated to the parking of 'traditional' vehicles converted with spaces intended for bike parking ('velostations'), cycle workshops, electric vehicles, charging stations, parking for shared-use and electric vehicles, and other proximity services.
Each proposed design solution must correspond to a card from the specific deck of 'design actions' cards. For each card in the deck, the effects and impact variations must first be calculated to allow the construction of alternative, plausible and comparable scenarios. If the card is not present in the deck, its effects must be calculated before it can be used. A first experimental test was conducted through simulations carried out by the research team to evaluate both the complexity of the procedure and the affordability of the results. In this first round of the game (we called it the Game zero), the results of design alternatives among those proposed were examined in order to understand the degree of effectiveness of the

proposed solutions.
In the simulated scenario, the mere creation of the cycle/pedestrian lane, if usable by the entire population, for journeys usually made by private means by the population, would lead to a reduction of the impact of about 50% in terms of occupied land, reducing the necessary surface of about 15,000 square meters. The reduction of private mobility would make it possible to eliminate part of the areas dedicated to the parking of private vehicles with a further reduction of the impact of around 37%. Finally, we can consider the reduction in the number of private vehicles powered by fossil fuels that would circulate in the municipal area by favoring the use of electric vehicles (not necessarily cars) and bicycles.
The results show different levels of uncertainty that express the need for robust experimentation with a wider audience to verify the calculation procedures and validate the impacts described in the individual actions. Developments in the research will be aimed at strengthening the methodological

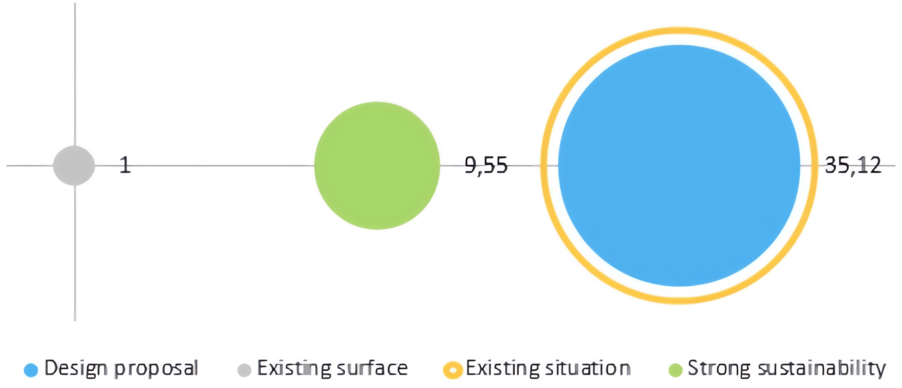


Figure 5: Results of one Play with TRAceS at Urban level

approach through openness to interdisciplinary collaborations aimed at improving the degree of effectiveness and practicability in the method, and further design solutions, which will be the subject of the in-depth investigations of the next stages of the research, preliminary to the testing of the game in the municipality of Rescaldina.

Conclusions

The impact of our society on the planet is not sustainable and the to increase the efficiency in the production of goods and services is not a viable solution by itself. A deep change in humans' behavior is necessary together with a clear perception of the environmental effect of our lifestyle. The three watchwords to be taken into consideration should be: sufficiency, parsimony and limits. We all must work together as society and as single persons in order to move versus a more sustainable or rather, using a more correct definition, a less unsustainable future.
In these years the research project TRACES has revealed a great deal of growing potential even if the attempt to simulate the entire impact of our behaviors requires a significant work to reduce the complexity in analysis and communication. The development at this early stage was largely focused on outlining the general structure of the game, seeking to simplify it more and more as the level of complexity increased.
We noted that moving the solution to a problem from a REMOTE level to a LOCAL one increases the degree of Resilience of the system, even though we have not yet found a way to exemplify and incorporate these considerations into the game. We have

not (yet) differentiated the effects of Money spent locally (Local Money) as against expenditure elsewhere, nor have we clearly defined the extent of the impact of goods and services being produced locally, which would bring about a further improvement in terms of closing the cycles involved.
As regards the initial objectives of the research project, we did not deal with the calculation of the level of Intangible Assets available, nor their variation within the context of the game. We strongly believe that an increase in the level of Intangible Assets of a settled society represents an initial indicator for estimating said society's level of Potential Happiness (Hy), but this part has yet to be fully developed.
Unfortunately, the research has no more financing support but there is the necessity to go on working to fix the many, huge problems that still remains in the calculation datasheet, as well as the deck of cards.
Aside from criticality and possible improvements of the dynamics of playability and, above all, of a modelling as likely as possible of the impacts and their measurement, TRACES remains mainly a serious game developed in the academic field for didactic-demonstrative purposes for students. Even if its ability to affect the lifestyles of active players, who therefore decide to accept the challenge of the game by changing their personal habits in favor of the common good for the community, has proved to be a powerful lever, so much so that it is worth trying to scale it also in other audiences of players, such as, for example, public administrators.

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Green Infrastructure Based on Smart Technology

Tae Han Kim

The world is facing various disaster risks due to climate change, and Korea is no exception. The increasing frequency and intensity of these disasters have caused significant damage in Korea. Energy is a crucial factor contributing to climate change. The Moon Jae-in administration promoted the construction of solar power facilities in mountainous areas, which led to forest resource damage and landslides. Additionally, transboundary fine dust from China significantly impacts Korea's environment.

To address these issues, nature-based solutions (NbS) such as urban ecosystem restoration are necessary. Our research team focuses on sustainable solutions to urban climate problems, divided into three areas: air, water, and energy. In the air sector, we focus on green wall technology to reduce fine dust. In the water sector, we develop LID technologies to mitigate urban flooding. In the energy sector, we research technologies to improve the efficiency of renewable energy generation. By integrating these approaches, we aim to develop sustainable solutions for urban environmental challenges.

Introduction

The world is currently facing various disaster risks as a result of climate change, and Korea is no exception. The increasing frequency and intensity of climate change disasters have led to significant damage in Korea. For example, on August 8, 2022, the Dongjak-gu area and Dorimcheon Stream in Seoul experienced heavy rainfall, resulting in extensive flooding and property damage.

Energy is another crucial factor contributing to climate change. In the past, the Moon Jae-in administration in Korea actively promoted the construction of solar power generation facilities in mountainous areas as a solution to the energy problem. However, this development has caused damage to forest resources and triggered continuous landslides, leading to a halt in further expansion.

Furthermore, transboundary fine dust originating from China has a significant environmental impact on Korea. Although there has been a decrease in nationwide PM10 levels since 2016, the levels of PM2.5 remain higher than those in developed countries. In the metropolitan area, two-thirds of the total PM2.5 generation comes from secondary fine dust generated through chemical reactions. Underground stations pose a particular health threat as they contain fine dust containing transition metals.

To address these urban climate change and environmental problems sustainably, it is necessary to implement counter-

measures such as nature-based solutions (NbS). NbS refers to the restoration of urban ecosystems and can be summarized as follows:

1. Restoration of the health of the ecosystem within the national territory and city center.
2. Creating a safe and smart green city.
3. Improving the quality of life through green living spaces.

Figure 1: Research Background

To enhance the resilience of cities through green infrastructure, technological advancements are required. Research teams are focusing on Green Infrastructure based on smart technology, which can be understood as a data-driven climate change response technology to improve air, water, and energy environments. It can be organized into the following categories:

1. Fine dust and atmospheric environment improvement technology.
2. Water circulation improvement technology.
3. Renewable Energy Connection Technology.

By leveraging these technologies, it is possible to develop sustainable solutions for climate change and environmental challenges in urban areas.

Based on the provided information, our research team is focusing on sustainable solutions to urban climate change and environmental problems, divided into three areas: air, water, and energy.

In the air sector, our team is focusing on bio wall technology to reduce fine dust and metallic particulate matter. We conduct time-series analysis using indoor air quality monitoring infrastructure linked to vegetation biofilters. By analyzing collected samples through chemical species analysis, we aim to identify the reduction effect of harmful substances to the human body through air purification plants.

Figure 2: Research Spectrum

In the water sector, our team is focusing on natural low-impact development (LID) technology to address urban flooding. We have established experimental infrastructure, including a laboratory and an experimental site, to quantitatively analyze the delay effect of vegetation-based LID technology on rainwater runoff during heavy rainfall. Using an artificial rainfall device with adjustable intensity, we analyze the mechanism for delaying rainwater runoff. Data from experimental plots installed in outdoor sites help identify the effect of delaying rainwater runoff.

Lastly, in the energy sector, we are researching green infrastructure technologies to improve the efficiency of renewable energy, specifically photovoltaic power generation systems. We aim to link solar power generation systems with a green roof system that can regulate the atmospheric temperature. By monitoring power generation efficiency and environmental data in real-time, we investigate the ambient temperature control effect of green roof system on power generation efficiency.

Air sector

In the air sector, our research team is conducting research on the application of vegetation biofilters to improve air quality in subway stations. Underground stations, which are representative multi-use facilities, are spaces with high concentrations of fine dust. It has been reported that large-scale stores have a concentration of 56.9 μg/m³, PC rooms have a concentration of 54.8 μg/m³, and academies have a concentration of 50.6 μg/m³.

Based on the provided information, our research team is conducting a study on the application of vegetation biofilters to improve air quality in subway stations. These underground stations are known to have high concentrations of fine dust, and previous studies have indicated that aerosol-type particles containing iron components contribute to a significant portion of the total air pollution in these stations. The iron components are generated through mechanical phenomena like friction and scratches between rails and wheels, which

then react with oxygen in the air and transform into iron oxide (Fe_3O_4, α-Fe_2O_3, γ-Fe_2O_3). These iron oxide particles diffuse into the underground space through thermal wind.

According to Maher et al., iron oxide generated from subway operations is inhaled through the mouth and nose, passes through the olfactory nerve or the trigeminal nerve, and then accumulates in the brain tissue. The accumulation of iron oxide has been suggested to cause neurodegenerative diseases

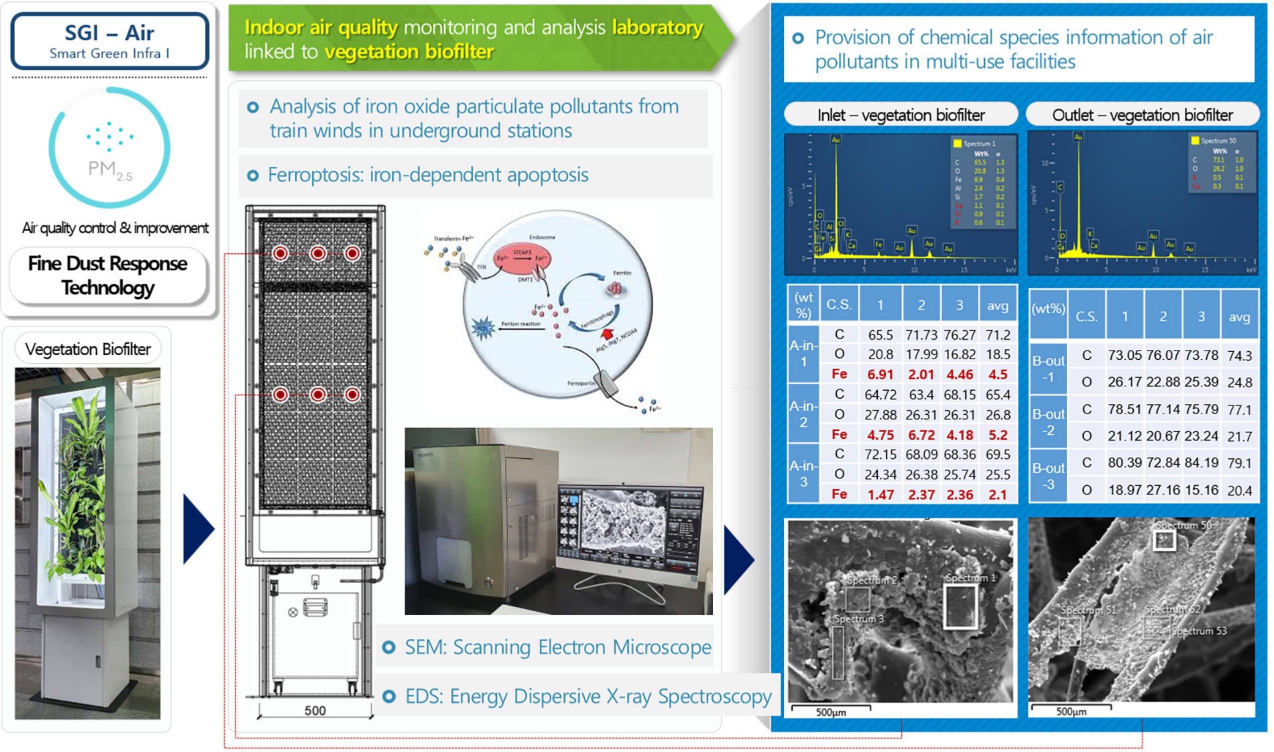

Figure 3: Smart Green Infrastructure-Air

(Ward et alt., 2014), such as Alzheimer's disease (Pankhurst et alt., 2008; Hautot et alt., 2003) and Parkinson's disease (Devos et alt., 2020) through long-term deformation of the nervous system.

To address this issue, our research team installed a vegetation biofilter in an underground station managed by Seoul Transportation Corporation. Over a period of 15 weeks, monitoring and sampling were conducted. The collected samples were analyzed using scanning electron microscope (SEM)-energy dispersive spectroscopy (EDS) to determine the weight ratio of iron (Fe) contained in the microparticles. The results showed that the intake part of the vegetation biofilter contained a significant amount of Fe, but the exhaust part exhibited an average weight ratio of less than 1% of Fe.

In particular, during cycle 3, there was a significant reduction in the weight ratio of Fe compared to the upper part of the intake (B) during the same period. The center of the exhaust part (A) showed a considerably lower average weight ratio of Fe. This reduction in Fe content suggests the effectiveness of the vegetation biofilter in removing iron oxide particles from the air.

Water sector

According to a study conducted by the Seoul Research Institute, it was found that 18.1% of areas in Seoul are situated below the planned flood water level, while 65.3% of the region consists of impervious areas (Sin et alt., 2011). These findings suggest that the increase in flood-prone spaces in the city center due to urbanization is a significant contributing factor to urban flooding.

In modern cities, floods are primarily characterized as inland water damage. The drainage pipe network system is divided into compartments with a limited design capacity, resulting in significant damage in urban spaces highly vulnerable to flood damage caused by concentrated rainfall. It is evident that concentrated rainfall on the increasing impervious surfaces due to urbanization leads to a heavy burden on the drainage pipe network, resulting in flood damage when the rainwater capacity exceeds the limit in flood-prone areas. The cause of urban flooding is not solely attributed to the design capacity of the centralized drainage system but is rooted in the escalating impermeable layer in the city center due to development. Therefore, it is advisable to consider disaster prevention measures against inland water damage by focusing on improving the city's infrastructure rather than solely relying on facility-oriented approaches. In other words, a sustainable plan from an ecological perspective is necessary.

Among various solutions, natural LID (Low Impact Development) can be presented as an effective alternative due to its positive functions, including mitigating the urban heat island effect, enhancing building ecological functionality, and providing rainwater runoff delay capabilities.

Inland water damage in the city is mainly caused by the excessive load on the drainage pipe network due to an increase in peak runoff resulting from localized heavy rain. Reducing the maximum storm runoff intensity and delaying its occurrence can be considered as crucial elements of flood disaster prevention strategies. Performance quantification is necessary to utilize vegetation-type LID systems for systematic flood prevention. However, ecological components such as plants and soil act as limiting factors in standardizing the performance of these systems compared to device-type devices. To overcome these limitations, our research team proposed a model and a reproduction method required for system design to objectively assess the rainwater runoff delay effect of the vegetation type LID system. In the model, LID controls supported by the Storm Water Management Model (SWMM) of the US EPA (Environmental Protection Agency) were applied, and a preliminary design method linking a rainfall and runoff simulator was proposed for reproduction.

We replicated artificial rainfall by inputting the rainfall column map corresponding to the Huff 3 quartile of the 20-year frequency 60-minute standard rainfall intensity in Cheonan City into the LabVIEW-based 'rainfall reproduction program'

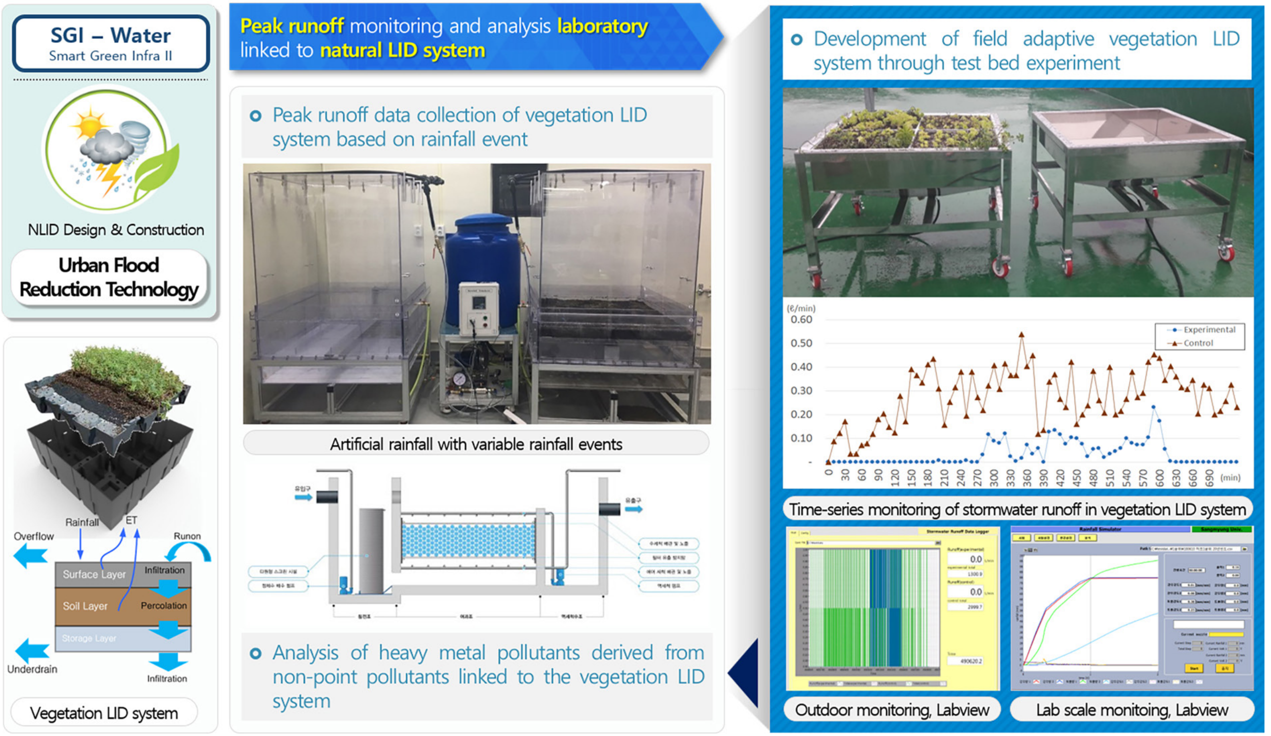

Figure 4: Smart Green Infrastructure-Water

linked with the rainfall simulator. Experimental and control groups, to which the vegetation type LID system was applied, were prepared under the same conditions. Rainfall was reproduced for 60 minutes, and runoff was measured and monitored for a total of 120 minutes. At the 70-minute point of the experiment, the experimental group recorded rainfall runoff intensities of 0.77 mm/min and 1.06 mm/min, respectively, following the same pattern as the artificial rainfall monitoring and SWMM computational simulation. In the control group, the maximum rainfall runoff intensities of 2.26 mm/min and

2.38 mm/min were recorded at the 50-minute point of the experiment, similar to the artificial rainfall monitoring and SWMM computational simulation. Through this, the ecological properties of the vegetation-type LID system were reflected in the rainfall/runoff simulator and SWMM computational simulation, confirming a statistically significant rainwater runoff delay effect.

Energy sector

Electricity rates, which have remained unchanged for an extended period, have recently increased due to the rise in oil prices caused by the war in Ukraine in 2022. However, these price increases have not been reflected in domestic energy costs and have had a significant impact on inflation. In the case of Korea, where achieving energy self-sufficiency is challenging, efforts are being made to advance the energy supply system. One of the measures being implemented is to enhance the generation efficiency of renewable energy.

Our research team has focused on improving the power conversion efficiency by integrating green roof to optimize the thermal characteristics of solar cells. We conducted an economic analysis of this approach. To monitor the improvement in photovoltaic power generation efficiency through green roof, we established a sensor network in the experimental and control zones capable of measuring horizontal surface insolation and instantaneous power. This network was based on the remote access system (eKEN820, KD Power).

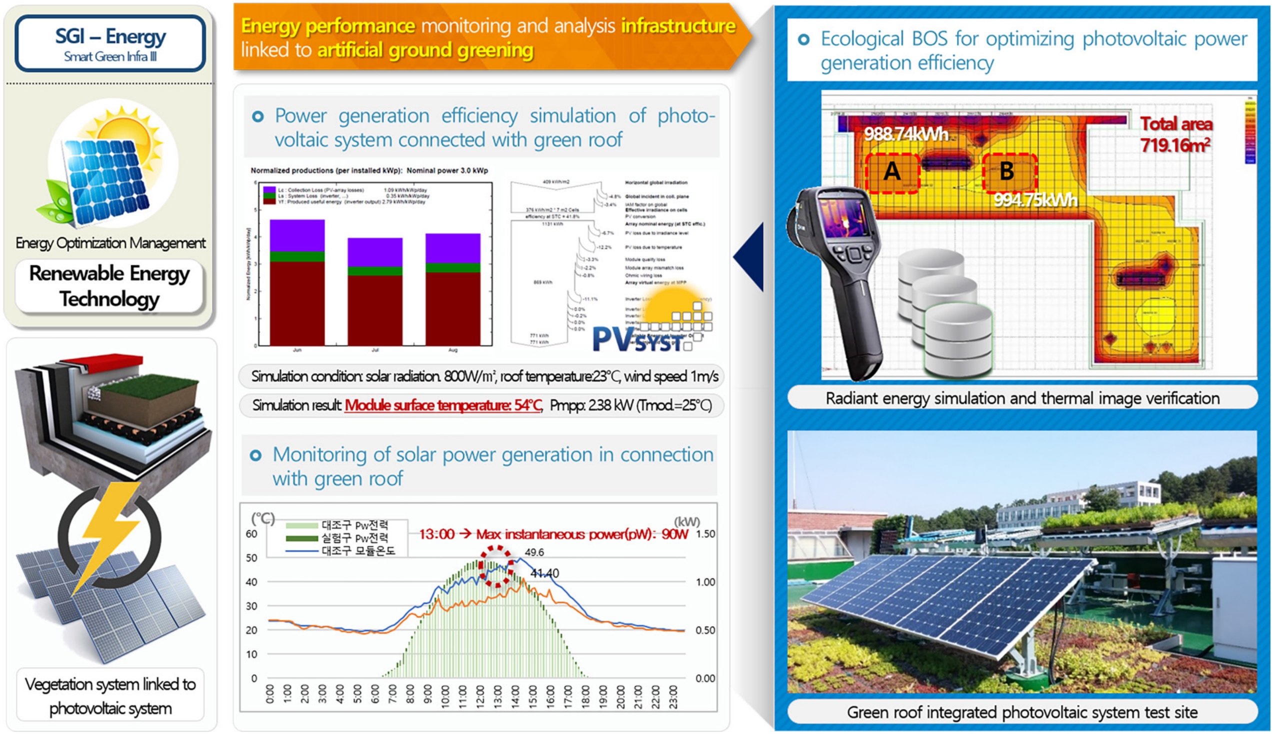

Figure 5: Smart Green Infrastructure-Energy

Based on this setup, we utilized Seoul city's sunlight map, the Renewable Portfolio Standard (RPS) system, and monitoring data to calculate the economic feasibility of an integrated system that combines solar power generation with green roof. The economic analysis focused on a 30kW solar power generation system by applying the average horizontal insolation amount for each grade specified in the Seoul sunlight map. The analysis revealed that the Net Present Value (NPV) remained positive up to the 4th grade, while the NPV for the 5th grade and beyond was negative, indicating inadequate business feasibility. However, when green roof was applied, the power improvement effect was confirmed. The monthly average power improvement efficiency ranged from 3.7% to 7.2%, with an annual average of 5.3%. The system exhibited particularly high efficiency during the summer season, including September and November. Furthermore, based on the average horizontal insolation of the first grade in the Seoul Sunshine Map, connecting rooftop greening to a 30kW photovoltaic power generation system resulted in an improved economic benefit, reducing the Simple Payback (SP) period by 0.2 years and the Equity Payback (EP) period by 0.5 years. The overall improved payback period was calculated as 8.3 years.

The integration of green roof with photovoltaic power generation improved the power conversion efficiency by up to 7% by reducing the ambient temperature and the surface temperature of the crystalline solar cell through greening. However, it should be noted that economic feasibility might be challenging during the winter and transitional seasons due to relatively low power conversion efficiency during those periods.

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S[m2]art Project: From Digital Island to Vertical Ring. Integration of Environmental Monitoring Technology into Street Furniture

Mónica Alexandra Muñoz Veloza, Lorenzo Savio and Stefano Bellintani

This chapter documents the research conducted as part of the S[m2]art (Smart Metro Quadro) project aimed at developing innovative street furniture that can deliver general and personalized services to the public administration (PA) and the citizens in an inclusive manner. Through an open design approach, S[m2]art seeks to provide urban solutions with recognizable aesthetics to monitor current urban phenomena and meet today's needs without banning the possibility of providing new services in the future. The primary outcome is a prototype installed on the campus of two of the main Universities in Italy: Politecnico di Milano and Politecnico di Torino. Due to its low maintenance and operating costs, the resulting prototype makes it possible to increase the number of aggregation and resting nodes in the city, expanding its physical and digital network. Moreover, the S[m2]art model can also provide the PA with tangible and intangible tools capable of collecting, monitoring, and analyzing data on environmental parameters through the various integrated sensors. To summarize, this landmark seeks to formally reference a design concept open to the ever-changing nature that characterizes smart cities.

Introduction. Thinking out of the telephone box

In recent years, digital reality has changed both the virtual space and our physical world. Urban areas, for instance, have had to adapt to the changes caused by virtualizing goods and services previously available only in person and through physical interaction. In addition, the use of stationary computers has been replaced by smart technology and mobile devices that facilitate portability and information transfer, making the ordinary citizen a key and constant participant in the global marketplace. On the other hand, the ease of accessing vast amounts of data in real time and its availability through the Web has revolutionized our perception of time. One main effect of the disappearance of the physical dimension's traditional limits is the need and desire for instantaneity and permanent connectivity. However, many cities' infrastructure continues to be inadequate for the needs that users on the move in it seek. The S[m2]art project aims to bridge this gap by equipping the city with physical and virtual tools that respond to the current citizens' needs, and that can be adapted, modified, or included to meet those future ones.

The 'S[m2]art (Smart Metro Quadro) Guardando la città metro per metro' research and development project was submitted on the 'Smart Cities and Communities and Social Innovation' call for proposals of the Ministry of Education, Universities and Research (MIUR) in 2012. The main intervention area in which the project sits is 'Welfare Technologies and Inclusion', but it also contributes to 'Territorial Security' as a secondary area. S[m2]art's main objective is to implement a new system of smart urban furniture that is scalable, adaptable, and <<connected as nodes of a network of data collection and processing, transmitted and processed by a digital platform, which aims to increase the urban well-being of citizens by implementing the efficiency, accessibility, and functionality of public services>> (S[m2]art team, Technical Specifications, 2021, p. 16).

S[m2]art reinterprets the traditional telephone booth: a small piece of street furniture that came into being in the late 1800s to help people communicate more quickly. This structure was part of the urban landscape worldwide during much of the last century. Although individually, it occupied one square meter of surface area, scattered throughout the city, it constituted a network. However, the arrival of private telephones and the latter wide spread of smartphones and wireless services led to the diminution of their usefulness and, consequently, their almost total disappearance. Based on an open design concept, S[m2]art seeks to revisit the telephone box's significance by integrating information technology and design features that allow the street furniture to adapt to current and future urban phenomena and new users' necessities. As a result, the research team built and installed two demonstrative prototypes called 'Vertical Ring' on the Politecnico di Torino and Politecnico di Milano campuses. This chapter presents an overview of the meta-project, the design and production stage, as well as the installation process and monitoring phase of the prototypes.

Type of actor	Partner	Activities and skills
Private: Companies	Telecom Italia	• Project coordination and organization. • Technology integration. • Communication of results.
	Santer Reply SpA	• Graphic design and layouts relating to the object and the tools for its visibility.
	Gruppo Thema Progetti	• Responsible for the aesthetic, functional, emotional, and communication design of the S[m2]art network. • Research and analysis of trends and benchmarks regarding furniture design and innovative tools. • Concept design and guidelines for developing urban spaces and furniture focus on well-being. • Concept design and guidelines for communication tools related to products and services.
	Metalco	• Prototyping, detailed design, testing, production, and installation of all finished product elements of the Vertical Ring.
	H&S Engineering	• Provision of innovative and high-quality technological services, products, and solutions. • Communication integration, software, and hardware research and implementation. • Interface software development. • Infrastructure installation and monitoring.
Public: Universities	Politecnico di Torino (Dipartimento di Automatica e Informatica - DAUIN)	• Data and systems analysis for database management, hardware and software design of networked embedded systems.
	Politecnico di Torino (Dipartimento di Architettura e Design - DAD)	• Technology meta-design, environmental sustainability assessment, and scenario definition. • Research and analysis of trends and benchmarks regarding furniture design and innovative tools. • Interactive mapping and sustainability analysis of street furniture in the Turin area. • User profile analysis for the S[m2]art furniture network. • Analysis of the needs, requirements, and performance for the S[m2]art furniture network.
	Politecnico di Milano (Dipartimento di Architettura, Ingegneria delle Costruzioni e Ambiente Costruito - DABC)	• Development of innovative business models for managing and installing new networks of S[m2]art furniture. • Research on the Milan area, development of product/service concept, monitoring of infrastructure. • Configuration of operational service management model with positive territorial spillover effects.

Table 1. Project partners' activities and expertise

An ensemble of energies for the city: private companies, entrepreneurs, universities, and Public Administrations:
To carry out the S[m2]art project, a consortium was formed with various public (universities) and private (companies) actors ensuring the development of strategies in the various fields of work. This teamwork based on the complementarity of knowledge enabled the project's successful outcome and contributed to the growth of each partner's skill domain by expanding their vision. In addition, the close relationship between the consortium and the public administration (PA) of the cities of Turin and Milan ensured that human capital was the first and most important resource for the project's development. Table 1 summarizes the activities and skills provided by the multidisciplinary nature of the final partners.

S[m2]art to bridge the digital divide
Not so long ago, we had to wait for a new edition of an encyclopedia to find up-to-date information on specific topics. Today, a connection to the World Wide Web is enough to find unlimited sources. This transformation has been made possible by the advent of the mobile Internet connection, which has promoted a fusion of the physical and digital worlds. It also has powerfully influenced our interaction with others and our surroundings, especially in cities, which are the daily reality for most of the world's population. Unfortunately, Information and Communication Technologies (ICTs) have not benefited everyone equally due to the social and economic gaps that separate the communities. In Italy, for instance, the public sector has been unable to keep up with the

digitalization and development of IT applications, negatively impacting people's lives as well as the relationship between them, the private sector, and PA. In the last two decades, the European and Italian normative frameworks have set some technological and informatics progress objectives[1]. However, one of the main reasons Italy is moving slowly on this path is the precarious state of its digital infrastructure.

Understanding the importance of bridging the digital divide and acknowledging the potential of public spaces and assets to drive technological innovation and digital transition, the collaborative efforts of the S[m2]art project partners have resulted in the proposal of the 'Vertical Ring' prototype, a smart urban furniture conceived not as a passive object but as a provider of physical and digital services. Vertical Ring aligns closely with the strategic framework and project guidelines of the National Technology Cluster 'Technologies for Smart Communities.' Furthermore, the proposal is entirely in line with the Cluster's primary focus on <<the development of the most advanced technology application solutions to enable innovative models of integrated solving for social problems of urban and metropolitan scale, (e.g., mobility, security, and land monitoring education, health, cultural heritage and tourism, green cloud computing, renewable energy, and energy efficiency, justice).>> (Ministero dell'Istruzione, dell'Università e della Ricerca, 2012, pp.5-6).

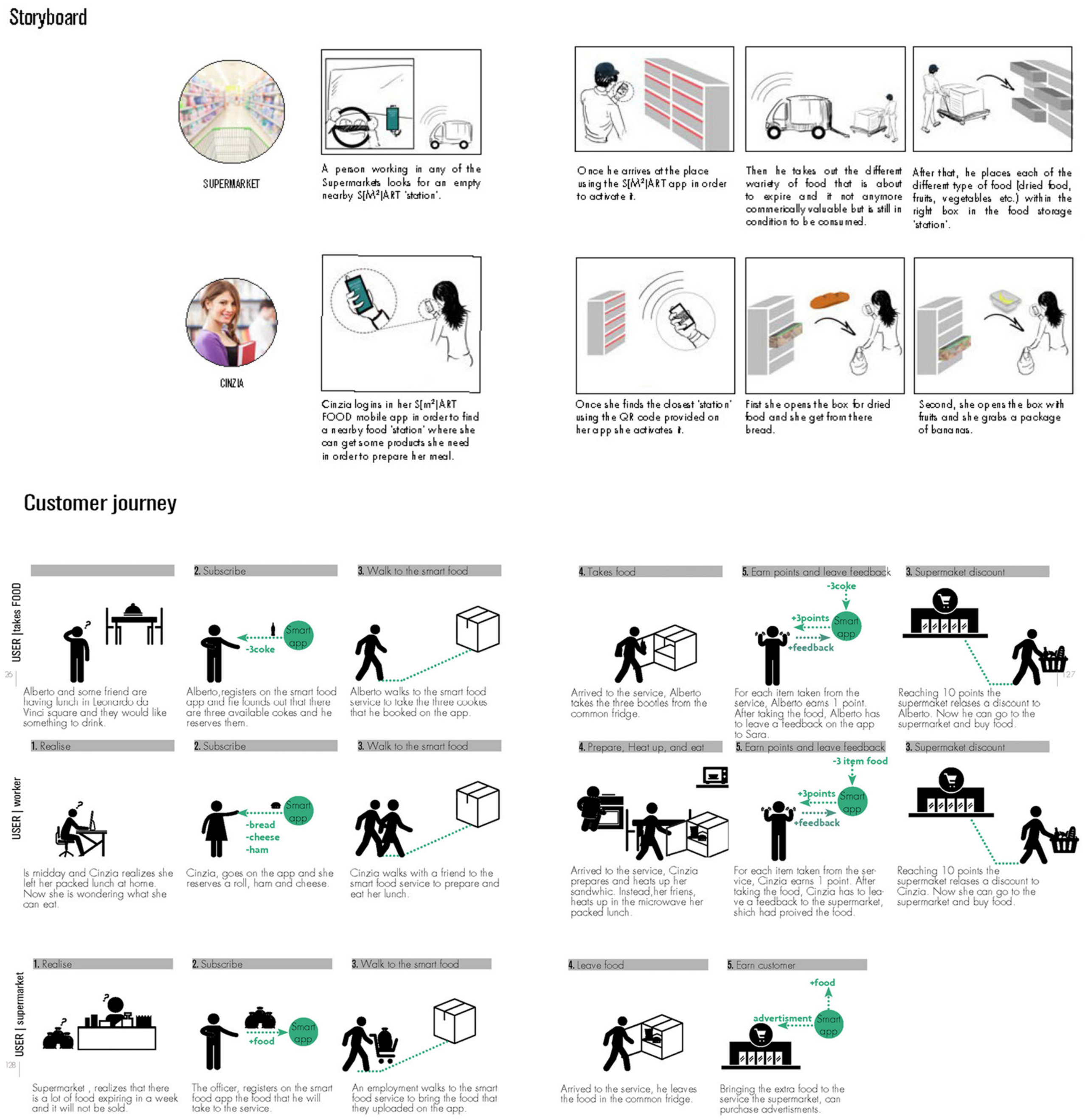
1 - The PNRR was approved in 2021 by the Italian government with two main goals: revitalizing the economy after the COVID-19 pandemic and enabling the so-called Twin Transitions, namely green and digital. It is part of the of the Next Generation EU program which intends to allocate 750 billion euros to help the economy of member countries.

Analysis activities and meta-design

Despite being a significant milestone within the S[m2art project, installing the Vertical Ring prototype is just one facet of its broader scope. This project encompasses diverse goals and outcomes, each coordinated by one of the partners involved. The primary role of the university partners (Politecnico di Torino and Politecnico di Milano) was to analyze the real possibilities of integrating S[m2]art infrastructures in the urban environment and to explore possible concepts of innovative services to be provided through the network of small infrastructures to stimulate the creative phase in alliance with the technological partners. The analysis activities have been partly developed by organizing workshops with architecture and engineering students in Italy and abroad, greatly expanding the foundation of creative thinking[2]. These collaborations have resulted in some cases also collecting the collection of potential future scenarios that may not be immediately applicable to the project's executive phase but are valuable as research outcomes in their own right (Figure 1).

Regarding the initial stage of the Vertical Ring development, the research group followed a simple and recognized methodology within the design and architectural technology disciplines to define service concepts: the user's needs/requirements/performance design approach. According to this approach, defining a precise 'picture' of the users and analyzing their needs is necessary before a design is developed. In this case, one of the most important activities

2- This partertships included the Alta Scuola Politecnica, a multidisciplinary training project active since 2004 in cooperation between Politecnico di Milano and Politecnico di Torino.



carried out was the analysis of the citizens' and PA's real needs and requirements to orient the design strategies toward the well-being of those who live or experience the city (Figure 2). Needs are the general or specific conditions necessary to carry out an activity or action (living, working, manufacturing, the fruition of urban services), and they can characterize management, safety, integration, well-being, accessibility, and environmental protection. The designer's task is to identify

Figure 1. Developed scenario for S[m2]art within the ASP project. Source: Politecnico di Milano and Politecnico di Torino students (Atanasovska Martina, Callegari Sandra, Chan Ho Yin William, Delvino Michele, Moreno Romero Juan Sebastian, Terraneo Emanuela).

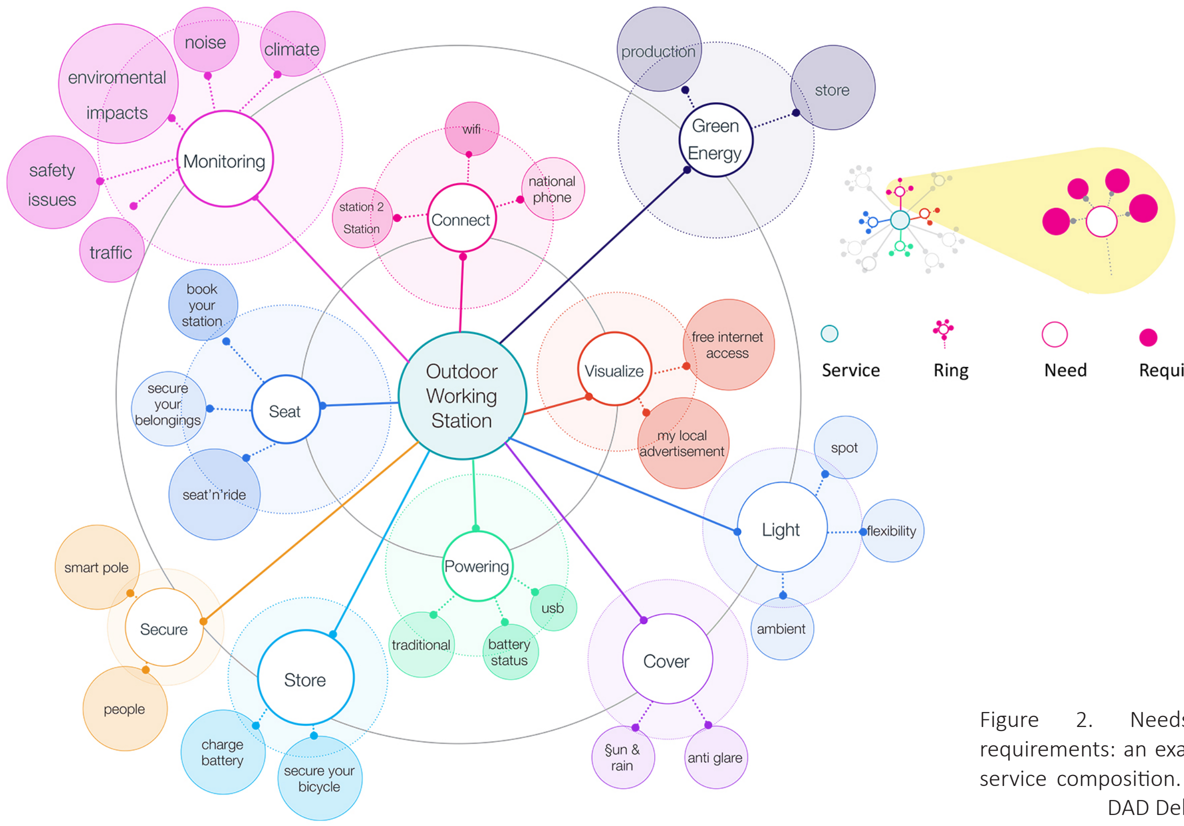


Figure 2. Needs and requirements: an example of service composition. Source: DAD Deliverable

the needs by engaging with the users. Subsequently, needs can be translated into design requirements, i.e., the expected behavior of the building or installation. These requirements can be met by various performances, such as specific design and technological solutions, which the designer will choose based on the opportunities available on the market, constraints related to the area of operation, and the overall economic sustainability of the project.

Learning from Others: best practices

Several pilot projects promoted by leading European and international cities have demonstrated the growing interest and emergence of potential new markets to increase widespread 'intelligence' in urban objects in recent years. In addition, they have highlighted how it is possible to envisage new ways of understanding the future smart city that can provide physical and digital services to the citizenry, such as Wi-Fi internet, the possibility of recharging mobile devices, defibrillators and first aid tools, information about services and the local area through augmented reality panels, state-of-the-art bike-parking stations, charging stations for electric and hybrid cars, among others.

During the meta-design phase (Savio, Cocina, Gariano, Giampetruzzi, Pagani, Pedrazzo & Pennacchio, 2017), the research team analyzed several best practices representing the sphere of innovative products and services offered to citizens from different geographical and cultural contexts. Some of these are collected in the following tables. The

examples were selected from innovative projects in street furniture, experiments with the city as their field of application, and objects that make up the urban landscape and city infrastructure.

The selection was made considering 'smart', not any project that includes an ICT component with the service provided, as is usually the case. In fact, from the end user's point of view, it would be inappropriate to call smart an interface that is only able to provide content without ever receiving feedback, acquiring data, and reacting accordingly, working in a one-way perspective: it would be in the condition of establishing a dialogue with a deaf entity, incapable of listening. In contrast, the examples in these sheets always have a data-gathering component that places them in a two-way dialogue space, where listening is central, and the service offered is specific in response to the stimuli of the city and the citizen.

Each information sheet identified key project data such as location, client, and site where available. The project description and status followed the latter to define its degree of maturity (is the project at the concept stage, prototype, or already a commercial application). In addition, a spider chart highlighted the main themes addressed: welfare, safety, leisure, mobility, tourism, and infrastructure. This was followed by a description of the main areas the project impacts: management, well-being, environmental protection, safety, and usability. Table 2 is an example of the type of information sheet produced for each project analyzed.

Link NYC			
Client	**Budget**	**Location**	**Designer**
NYC City Council	Unreported, self-funded through advertising	New York	Antenna, ABC Sidewalk Lab
Website	**Data production**	**Transmission**	**Implementation /feedback**
www.link.nyc	Map search data collection	Wi-Fi between users and bench, wired between artifact and central database	Return of context-aware publicity

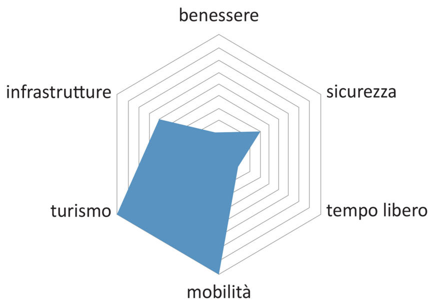
Legacy	**Privacy**	**Third-party data use**
Generation of a search history concerning geographic location	The data is entirely anonymous. Wi-Fi registration allows for tracking of MAC addresses	For advertising purposes

Description

Link NYC is the first phone booth 2.0 project to be fielded extensively. More than 7,500 New York phone booths have gradually been replaced by ABC's (Google) first actual project Sidewalk Lab.

They contain superfast Wi-Fi routers for public Wi-Fi, phone lines, charging for cellular devices and tablets, and access to maps and tourist information. On the security side, it gives direct access to 911, the US emergency number.

It is entirely self-funded through an ad hoc advertising system called "digital OOH advertising," which provides context-aware and functional directions to the user.



Management	**Security**
At the user experience level, it is the first example of a smartphone booth associated with a sustainable business model.	The phone booth allows rapid 911 calls.
Usability	**Technology**
The system is accessible to users with disabilities.	The system includes:
Project advancement	- two 55' screens, one of which is equipped with a touchscreen interface;
The phase of progressive deployment throughout the Manhattan project began in 2015.	- electrical outlets for charging devices; - a telephone interface; - a high-speed Wi-Fi router.

Table 2. Sample information sheet for an ICT best practice.

Table 3. Sample information sheet for a design and ergonomics best practice.

For developing the Vertical Ring prototype, it was equally important to analyze other case studies that considered the innovation in design and ergonomics, the reduction of the environmental impact, and the ability to harness renewable energy resources. Through this analysis, the research team was able to understand the services, components, and tools that the smart furniture designed at the end of the meta-project had to offer to facilitate the most efficient use of smart furniture by the general public, as well as to make urban space more enjoyable and of higher quality. One of these best practices is summarized in Table 3.

Solar Lounge	
Client	**Location**
Research project	Chandigarh, India
Designer	**Website**
Chitkara University (Anu Singla)	www.chitkara.edu.in/news/chitkara-university-receives-first-patent-design-project-solar-lounge/
Description	
This exterior space is designed as an outdoor room. The seat and backrest provide a comfortable position while working, and on the roof, a series of solar panels power a battery that allows personal devices to be recharged. During the night, the stored energy is used to illuminate the space. Part of the system was granted a specific patent in 2016. Unfortunately, this street furniture project has remained at the prototype stage.	

Landing in the local context

The analyzed good practices showcased a diverse range of urban furniture and smart services, ranging from comprehensive digital islands composed of multiple urban furnishings to compact elements like poles, digital totems, and even smaller devices or inconspicuous sensors integrated into existing urban structures. Reflecting upon the international case studies, the S[m2]art research group pondered the ideal infrastructure to serve as a reference for integrating services and technologies.

Given the analysis of the urban contexts of reference and Italian cities in general (compact, dense, rich in small-sized green areas, and often urban voids created by the relocation of production activities), a workshop was organized between the partners to establish the essential characteristics of S[m2]art project. Through primary sources and fieldwork conducted in Turin and Milan, it was possible to verify that one of the main issues was the lack of devices providing digital services in the city's public areas. At the same time, the scarcity of advanced visual and sensory surveillance equipment in the large open spaces of the city generated a sense of insecurity in the community. Regarding health and the environment, there was an increased interest in installing smart sensors for environmental control and monitoring rising air quality problems. Moreover, during this phase, adjectives such as multipurpose, innovative, accessible, non-invasive, customizable, scalable, adaptable, contextualized, secure, efficient, and dynamic were identified as particularly significant for the users.

It also became evident the importance of a network approach, distributing the services providers throughout the urban area in a capillary manner, especially targeting the under-served areas, where problems related to the accessibility of public services, social inclusion, and safety affect the population the most. Regarding the public sector, the improvement of technologies (physical and digital) with which local administrations collect, process, and communicate data can enable them to achieve better decision-making based on real-time pictures of the territory's dynamics (e.g., identification of main mobility flows, use of public services and their distribution, critical issues, among others). Based on this information, it was possible to define a set of tangible and intangible functions that formed the basis for the prototype's design phase.

At this stage, two models were considered: the 'extended' one of the digital island and the 'compact' one of the single-equipped element. The two compositional-spatial models can configure the same set of physical equipment (seats, fountains, distributors of goods) and digital devices (sensors and cameras, to name a few). In an initial phase, the project explored the digital island model, thanks to a prototype built by Telecom Italia in its Turin office. The island, occupying a large surface area, makes it possible to locate all the functions and services that can be provided in the urban environment to improve accessibility and social inclusion and reduce the digital divide. However, the island can be challenging to integrate into the urban environment precisely because of its size and the lack of opportunities for spaces and areas to intervene. Therefore, the work team chose the single-equipped element as the principle to design the Vertical Ring prototype.

The Vertical Ring and its open design concept

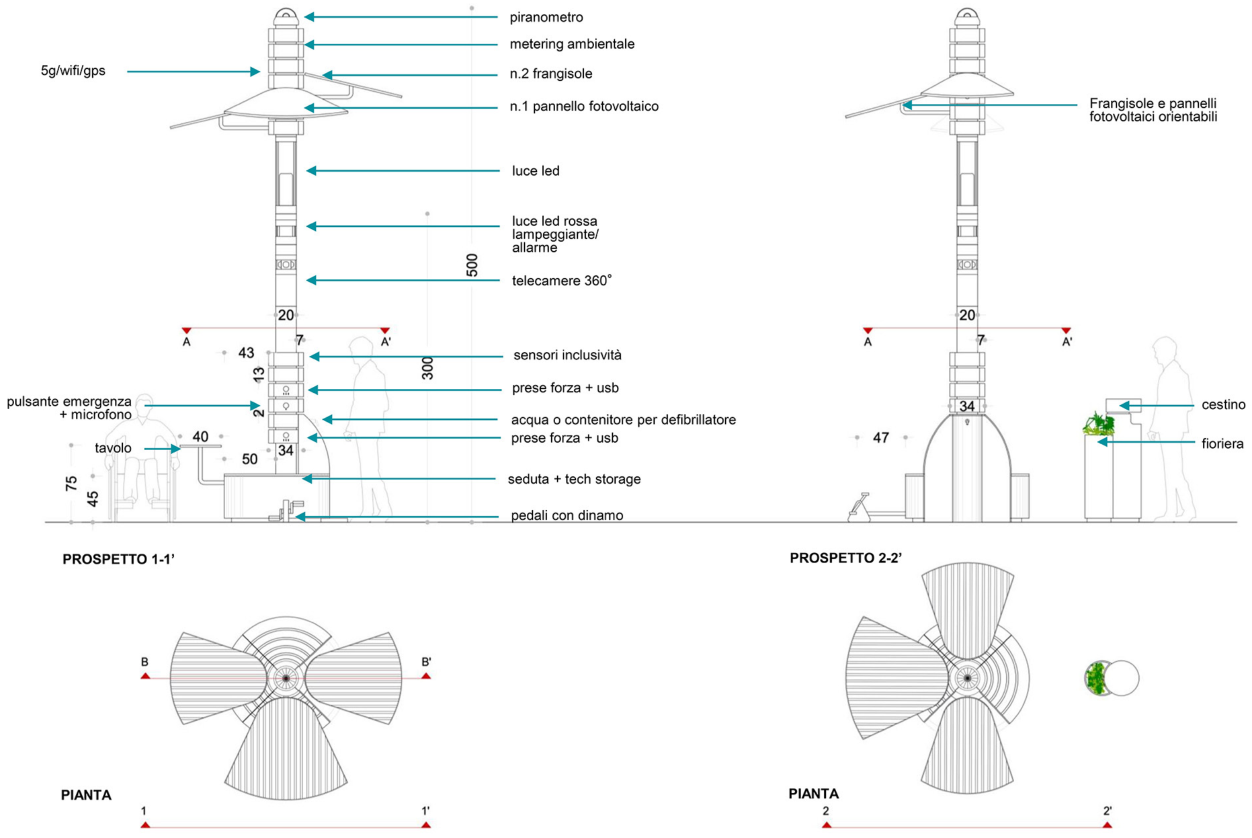
For defining the Vertical Ring concept, the Politecnico di Torino team collaborated with the Senseable Lab of the Massachusetts Institute of Technology (MIT) within the framework of the MITOR Project[3]. Some Senseable Lab students engaged in elaborating their thesis on a concept for the cities of Dallas and Turin (Figure 3). For instance, one of the ideas was to integrate trees as the support structure for minimal technological elements, which consisted of a pavement and a ring. The aim was to contribute to monitoring environmental data and urban phenomena with IoT sensors capable of interacting with users through smartphones. The different results of this significant experience supported the definition of the Vertical Ring final design.

The Vertical Ring prototype relied on an 'open design concept', a community-driven approach emphasizing openness, collaboration, inclusivity, and public engagement. This notion allowed the design of a formal model based on current urban conditions without removing the possibility of improving the provided services or proposing the implementation of new ones according to the feedback of the different types of users. In this phase, the project consists of two main components with different definition levels. The first involved the design of the basic prototype and defining its executive project (Figure 4). Simultaneously, a functional abacus was developed to provide a detailed overview of elements and functions that could be included in potential future scenarios (Figure 5), as well as possible additions to adapt the prototype for various urban settings (Figure 6).

3 - An international collaboration and eschange program between Massachusetts Institute of Technology (MIT) and the Politecnico di Torino (POLITO) For more information, see http://web.mit.edu/mitor/.

Figure 3- Proposal for the Turin's S[m2]art concept, developed in Alice Birolo's Master's Degree thesis entitled 'Urban furniture for senseable cities' in collaboration with MIT.

The vertical ring model can be better integrated due to its compactness and scalability. It is also potentially land-zero, as it could replace (rather than add to) the existing street lighting poles already integrated into the built environment. The basic prototype includes a support structure with a pole



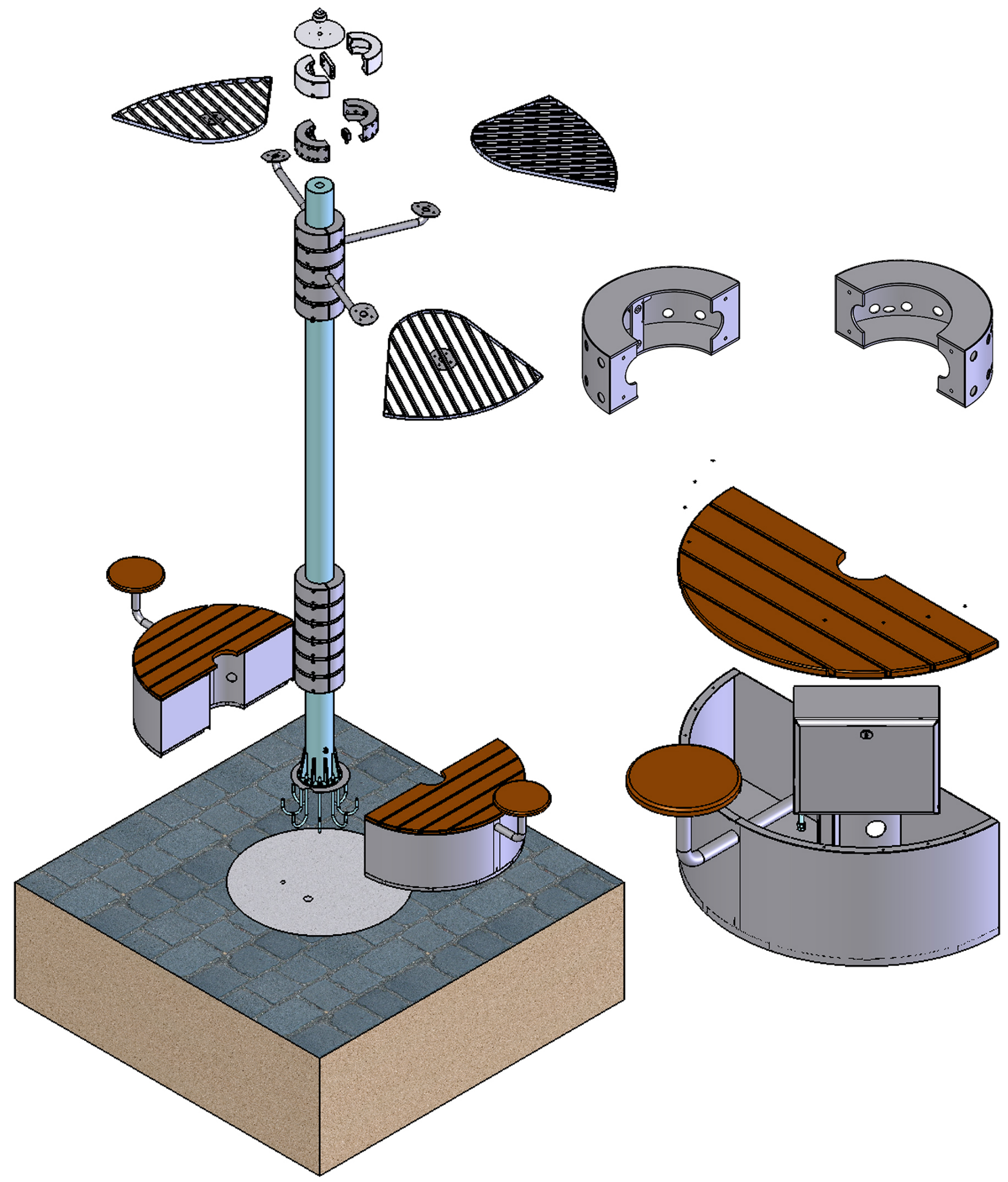


Figure 4. Plan, sections, plans (above), and axonometric exploded view of the basic prototype (right). Sources: GTP, DAD and Metalco Deliverables.

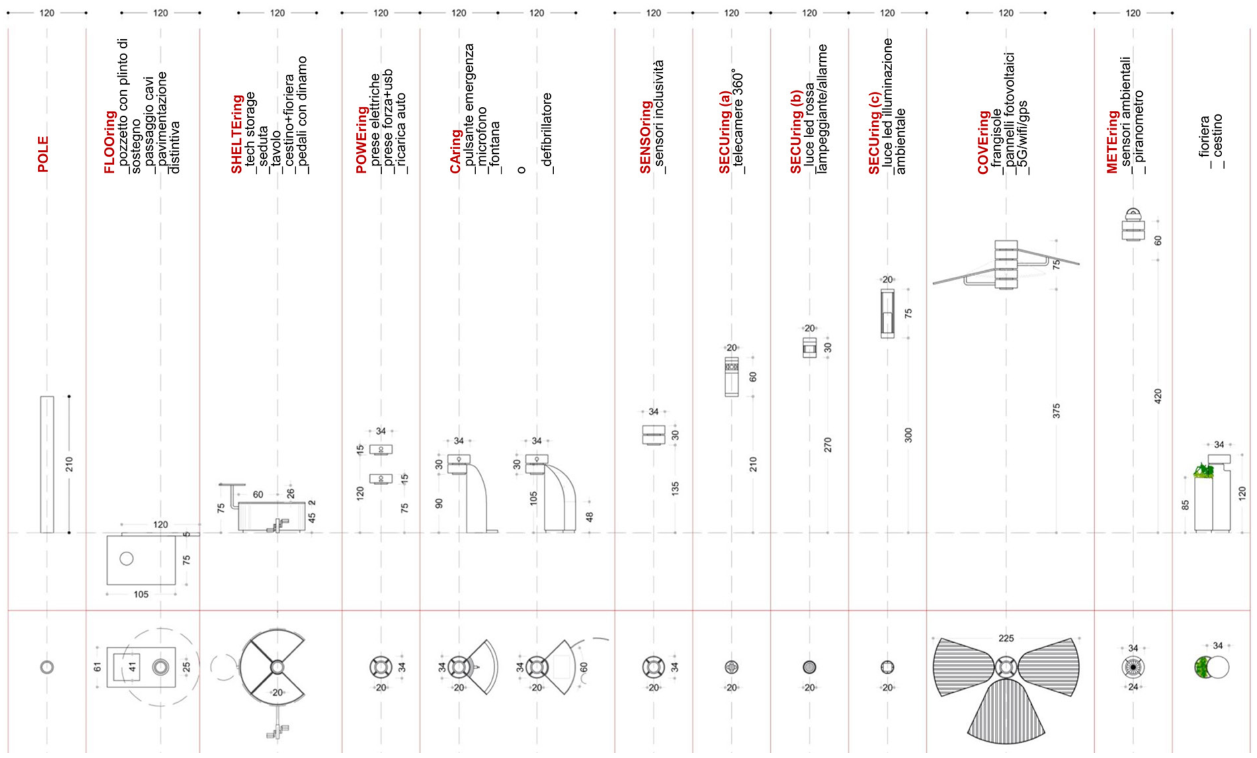


Figure 5. Functional abacus of elements. Sources: GTP and DAD Deliverables.

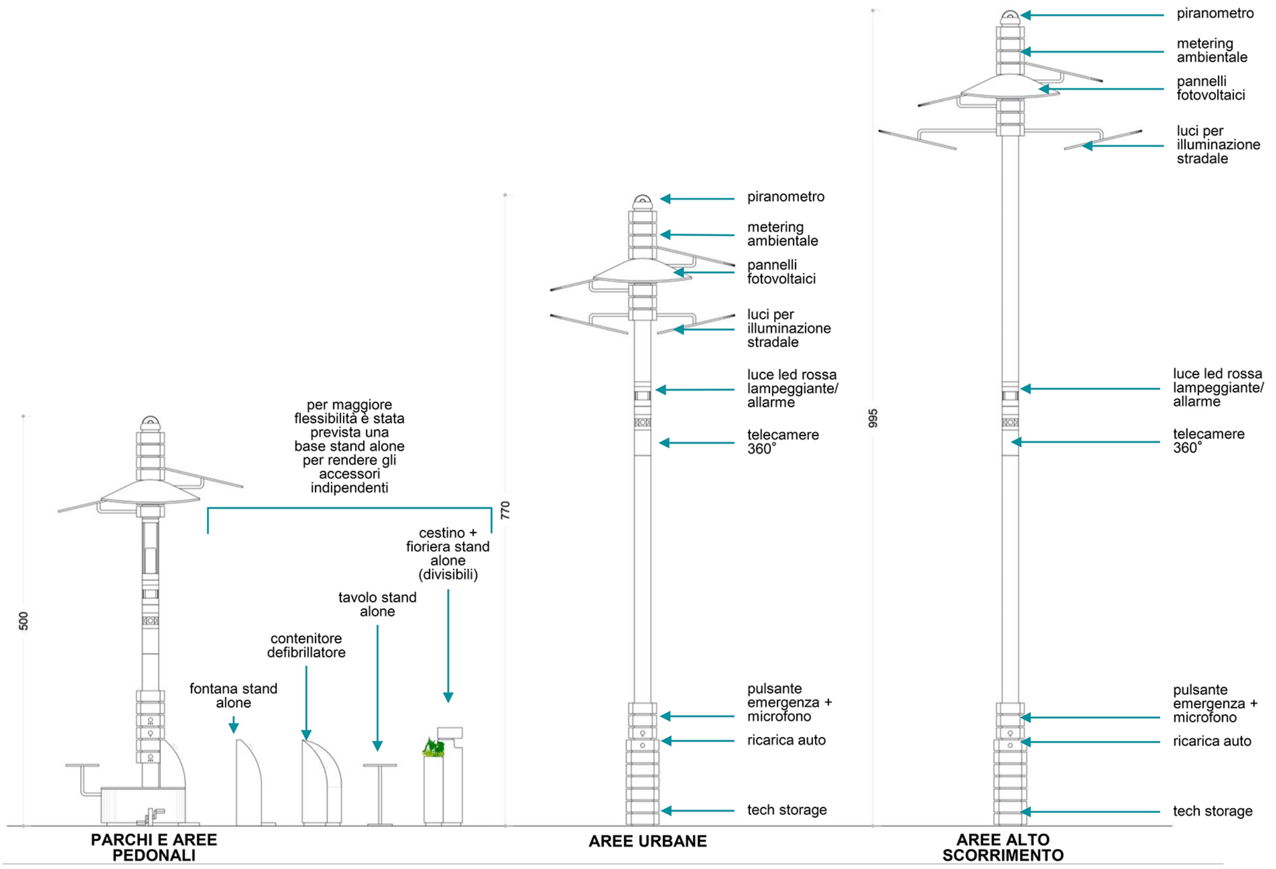


Figure 6. Possible integrations in different areas. Sources: GTP and DAD Deliverables.

that can progressively be equipped with specific devices for physical and digital services (the 'Rings'). Each Ring is a separate compartment structurally attached to the central pole, which contains the electrical system of the system as well as the hydraulic equipment in case there is the possibility of installing a drinking fountain. In each Ring, it is possible to install devices and sensors according to the changes in the urban environment and, therefore, in the needs of the citizens and the public administration.

As part of the last stage of the project, the prototype developed was built and installed in the Politecnico di Milano's Bovisa site (Figure 7) and the Politecnico di Torino's central campus. The integrated sensors will enable gathering a vast collection of heterogeneous data that, in various aspects, characterize the quality of the urban environment and the behavior of citizens.

Environmental and urban monitoring

Once the 1:1 scale prototype was built and installed in Turin and Milan, the team could start the monitoring phase. To achieve reliable data, the correct installation of the sensors was crucial. These IoT devices are currently measuring, collecting, and communicating information about several environmental factors (temperature, humidity, air quality, solar radiation). Regarding the prototype's acceptance, a user satisfaction button was activated to obtain information related to the use of the prototype. By scanning a QR code, users can access an online platform that provides information about

Figure 7. Vertical Ring at the Politecnico di Milano (left) and the Politecnico di Torino (right). Source: H&S Engineering S.r.l. (left); MultimediaLAB – Politecnico di Torino (right).

the various project phases. Furthermore, they can complete a brief questionnaire regarding the usefulness and benefits of the services (or Rings). This data will enable the research team to identify the most valued services and the users' preferences for integration into the Vertical Ring. (Figure 8).

The launch of the web portal aligns with the principles of FAIR Data and Citizen Science, enabling the ongoing enhancement of the Vertical Ring to meet the needs of both citizens and PA. Additionally, embracing an IoT approach will facilitate simple and immediate information sharing among diverse city stakeholders. Moreover, this integration will pave the way for future projects, ensuring the Vertical Ring remains adaptable and open to potential collaborations.

Further Steps

Moving forward through open planning requires a flexible and innovative approach to identifying new services. Although the Vertical Ring is an essential formal reference, it should allow for exploring and developing new solutions to respond to emerging urban phenomena. Thus, the future goals are to propose new services that adapt to the community's changing needs. Smart is not a static concept but is open and constantly evolving, and it needs to be developed in an active and participatory way. An opportunity to achieve this could be the organization of new workshops, offering the possibility to involve experts, citizens, and stakeholders and to explore the potential of 'digital twins' as a visualization and analysis tool to improve the planning and management of urban furniture.

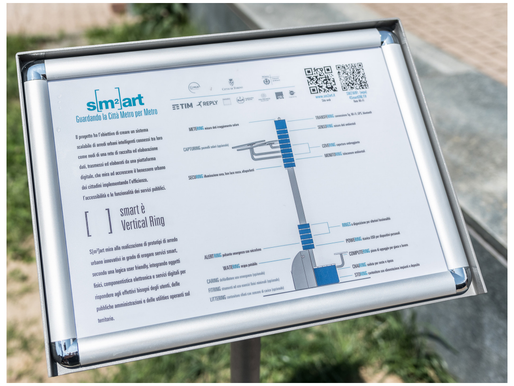


Figure 8. Explanatory display board with QR code and website for questionnaire https://sm2art-progetto.it/. Sources: MultimediaLAB – Politecnico di Torino (left); H&S Engineering S.r.l. (right).

Conclusions

In recent years, ICT systems capable of delivering services to citizens have significantly evolved due to the availability of new technologies and applications. The availability of distributed digital equipment, mobile devices equipped with sophisticated sensors, and the spread of social networking applications enable the collection of vast amounts of data. In addition, the development of innovative solutions for collecting and storing data, and processing it, makes it possible to extract a variety of helpful information to enhance the urban well-being of citizens.

The S[m2]art project sought to contribute to developing a network of intelligent and sensitive urban furnishings distributed throughout the territory. To achieve this, the research was based on an 'open design concept' which considers street assets as a system instead of as singular objects. This comprehensive approach, together with the specific competencies of the partners involved in the project, made developing the 'Vertical Ring' prototype possible. Moreover, the different international and local workshop experiences supported the elaboration of the compositional design of the Vertical Ring, stimulating the transition from the digital island to a minimalist urban intervention and a compact solution, more manageable from the point of view of integration with the built environment.

The S[m2]art project team installed two Vertical Ring base prototypes in different locations: the Bovisa campus of the Politecnico di Milano and the central campus of the Politecnico di Torino. Each generates a new point of reference and a place of socialization, reinforcing the social fabric and face-to-face interaction. They also contribute to the digital transition of the cities thanks to their technological characteristics and features. Vertical Ring went beyond its passive nature, becoming a provider of physical and digital services such as monitoring different environmental factors, including air quality and solar radiation. The integration of IoT devices makes the functions easily managed through a virtual platform, providing information and data exchange between citizens and the public administration. In addition, the division of the Rings makes it easier to change their composition, allowing the addition of new sensors and devices for future needs. By realizing what was in goal, the S[m2]art project stands as a powerful tool for disseminating the Smart City culture.

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Nature-Based Solutions as a Strategy for Adaptation to Climate Change

Roberto Giordano

Nature-based solutions (NBS) are 'solutions' for urban infrastructures that use greenery to address complex challenges related to the effects of climate change at the urban scale. From forests to Living Wall Systems (LWS), NBS integrate vegetation and urban materials.
In addition, within several frameworks, including urban planning and building detailing, NBS offers multiple environmental, social and economic benefits. With a focus on climate change adaptation, NBSs mitigate the urban heat island effect and improve stormwater management.
The chapter describes the results of a research study on the design and construction of an LWS. Some of its physical, technological and agronomic performances were monitored over about two years.
Based on the achievements, the chapter, finally, highlights some critical issues that must be addressed to promote and disseminate NBSs, particularly LWSs in the future.

The Nature-Based Solutions

A Nature-Based Solution can be defined as urban infrastructure based on greenery to simultaneously tackle sustainability challenges by maximising the benefits of nature (Sowińska-Świerkosz et al., 2022; European Commission, 2015; European Commission, 2022).

Nature-Based Solution encompasses many possibilities, ranging from urban and peri-urban forests to Living Wall Systems (to be understood as vertical enclosures or partitions that allow the rooting and growth of one or more plant species on its surface) (Dorst, H., 2019).

This means some Nature-Based Solutions are wholly and entirely made up of plant elements. In contrast, others require the integration of vegetation and materials, which, once fully integrated, make up a technology (i.e., a green roof solution). The materials perform several functions, such as filtration, control of root growth, drainage, and waterproofing. (Figure 1).

A Nature-Based Solution is used in several fields: i.e. urban planning, agriculture, water management, and infrastructure development.

The scientific literature provides an articulate picture of Nature-Based Solutions' features and properties.

First, Nature-Based solutions aim to provide many benefits concurrently, addressing multiple environmental, social and economic issues. For example, wetland renewal improves water quality and provides a habitat for wildlife and recreational opportunities for people (Sowińska-Świerkosz et al., 2022; Jessup, K. et al., 2021).

Figure 1. Examples of Nature-Based Solutions' integration in urban settlements. Author's source.

Besides, Nature-Based Solutions recognise the importance of local knowledge and empower communities to participate actively in decision-making processes. In other words, it emphasises community engagement and cooperation among several stakeholders (Adams et al., 2023; Wickenberg et al., 2022).

Finally, Nature-Based Solutions enhance the resilience of the natural and built environment to some climate change effects (Xi, 2022), as is also better described in the next paragraph.

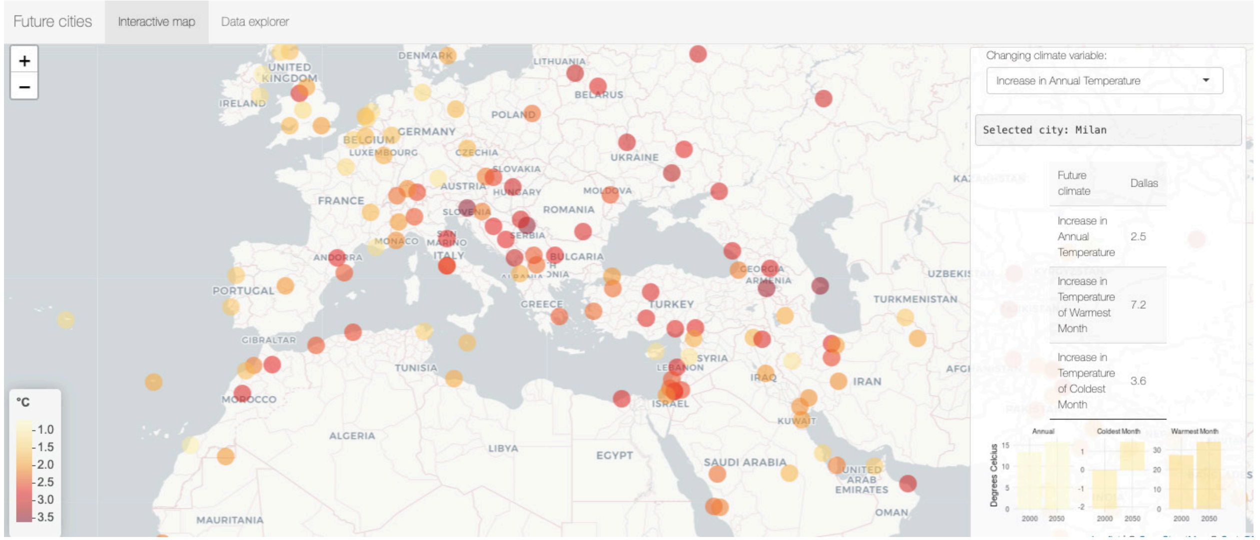
Figure 2. The City of Milan is changing in climate projection by 2050. The expected increase in temperature is about 7.2 °C more than in 2019. (source: https://hooge104.shinyapps.io/future_cities_app/)

Nature Based-Solutions as a strategy for climate change adaptation

Adapting cities to climate change means implementing a certain number of strategies to maintain a comfort and safety threshold in terms of temperature, rainfall, humidity, etc., that will no longer be the same in 20-30 years.

Looking at a City such as Milan in 2050 that will have a similar climate pattern to the City of Denver (Figure 2), there is no doubt that a gradual renovation of both outdoor and indoor environments will be necessary to maintain acceptable ecological and social standards (Bastin, 2019).

By reinventing or renovating the urban environment with Nature-Based Solutions, it is possible to turn cities and neighbourhoods into "urban ecosystems" that contribute



to climate change mitigation and adaptation. Nature-Based Solutions' role in climate change mitigation is mainly due to carbon sequestration. Particularly grasslands, wetlands, and forests (including urban forests) can capture and store atmospheric carbon dioxide through photosynthesis. Trees, in particular, are highly effective at carbon sequestration (FAO, 2016; FAO, 2020).

Nature-Based Solutions are a particularly effective climate adaptation strategy, as they can extend shaded surfaces and the evapotranspiration processes in the urban landscape. Simultaneously, they are suitable for reducing building enclosures' surface temperature and helping the rainwater drainage of collection systems. (FAO, 2016).

The effectiveness of Nature-Based Solutions (Figure 3) for climate change adaptation can be approached from several perspectives (IUCN, 2021). Particularly in the urban landscape, Nature-Based Solutions can be used for the following goals:

- **Urban resilience fostering.** By restoring, maintaining and planting forests, wetlands, and greenery, cities increase their ability to resist some climate-related events like heavy rains, floods, and droughts.
- **Urban Heat Island (UHI) mitigation.** Urban areas are particularly exposed to heat waves and increased temperatures due to the UHI effect (Xi, C. et al., 2022; Candelari E. et al., 2014). Nature-Based Solutions can mitigate the UHI by reducing the temperature locally and providing cooling benefits for citizens.
- **Rain Water management.** Nature-Based Solutions can contribute to effective rainwater management, regulating

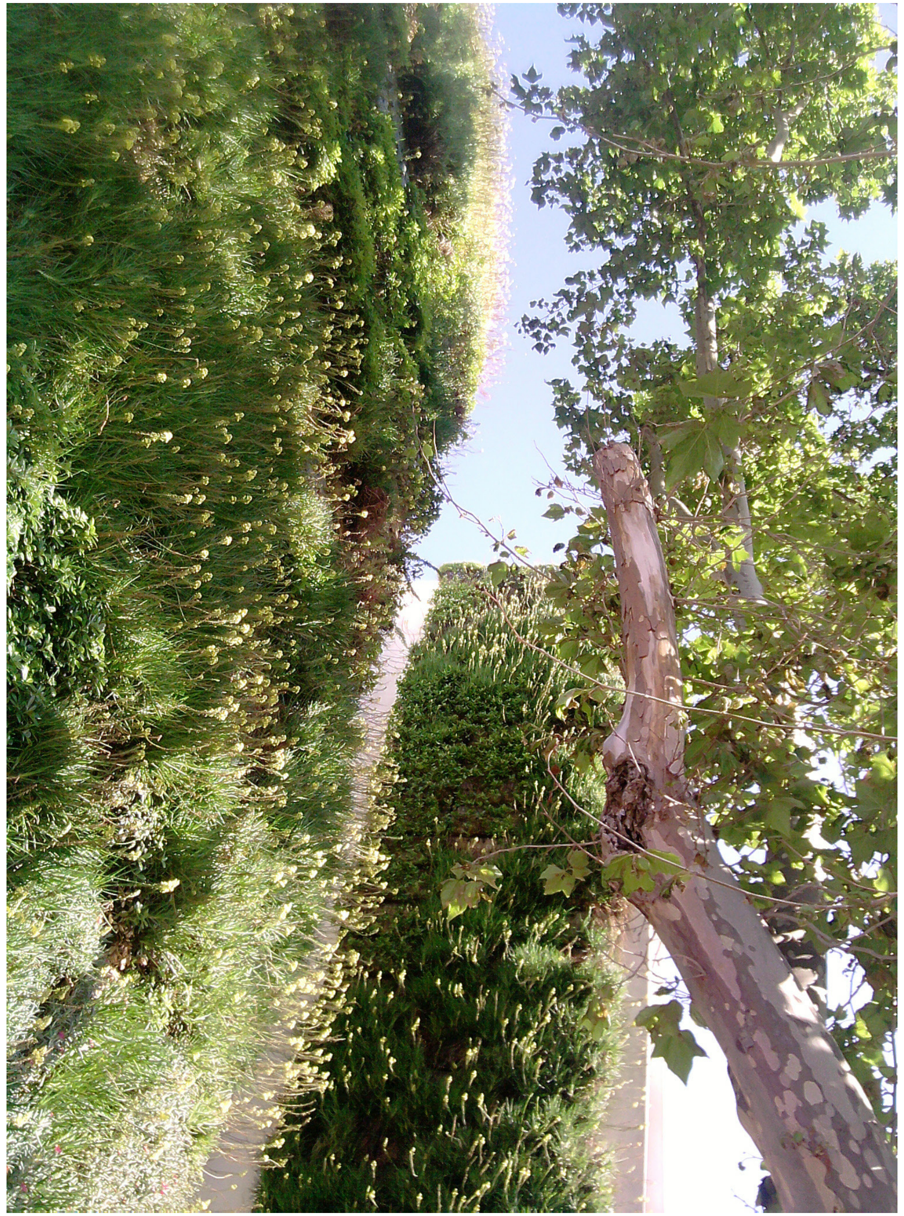


Figure 3. City of Valencia. Example of an integration of Nature-Based Solutions in the urban habitat.
Author's source.

water flows, filtering water, and reducing the risk of floods. They can also enhance water availability during dry periods and recharge groundwater reserves.

Table 1 summarises the significance of trees and greenery for climate change mitigation and adaptation in the urban landscape.

As shown in Table 1, vegetation - regardless of its design - is a compelling adaptation solution to climate change.

Table 1. Significance of urban forest type for climate change. Author's elaboration from the book Guidelines on Urban and peri-urban forestry.

Nature-Based Solutions	Significance on a scale of 1 to 5 (1 = very low significance; 5 = very high significance)	
	Climate change mitigation	Climate change adaptation
Peri-urban forest and woodlands	●●●●●	●●●●●
City parks and urban forest (> 0.5 ha)	●●●	●●●●●
Pocket parks and gardens with trees (< 0.5 ha)	●	●●●●
Trees on streets or in public squares	●●	●●●●
Other green spaces with trees and greenery (i.e. green roofs, green walls)	●●	●●●●

Living Wall Systems and climate change adaptation

The Technology and Environment research team of the Politecnico di Torino carried out some research projects in Nature-Based Solutions. One focuses on Living Wall Systems and some related environmental performances that were investigated and monitored.

Living Wall Systems is a specific vegetated façade solution for a building. The Living Wall Systems' features can be summarised as follows (Giordano et alt., 2017; Riley, 2017):

1. They generally include a modular or container system containing the plants and growing medium. Living Wall Systems are often fastened directly to walls and require a specific frame or vertical and horizontal mullions to support the plant and growing medium's weight.
2. They usually incorporate irrigation to water and provide plant nutrients.
3. They commonly have a higher planting density compared to green walls. The species are carefully planted, making dense vegetation on the wall.

GRE_EN_S (GREen ENvelope System) is the acronym of an EU-funded research project that was aimed at designing, prototyping and monitoring an advanced Living Wall System designed with modular container covered with vegetation, made of recycled and natural materials and characterised by a high-energy/environmental performance (Serra et al., 2018). Among other specific objectives, the research project aimed to assess the potential of the Living Wall System as an adaptation solution to climate change-related environmental effects, namely the UHI.

GRE_EN_S was divided into phases that dealt with the following tasks:

- the survey of existing Living Wall Systems solutions;
- the material sorting for the modular system (container) and the growing medium;
- the design and construction of prototypes;
- the assessment of technological, agronomic, and thermal and acoustic performance on a test cell and a sample building in Turin. (Figure 5).

Three Living Wall System prototypes were designed and built. The third and last prototype was a 50 by 50 cm module, about 6 cm thick (without vegetation). Each module had six pockets arranged in two lines to contain the plants. The module also had a few holes to allow the watering system to pass through. Once the prototype was verified to operate correctly on the test cell, the research team built around 90 modules, 80 of which were installed onto the sample building.
The sample building was aligned along the east-west axis, allowing it to have a south and a north façade. The absence of obstructions around the building permits, especially on the south façade total exposure to the sun in both the summer and winter seasons.

Figure 5. The GRE_EN_S sample building is located in Turin (I). Latitude: 45°04′13″. The picture shows the building's surface temperature sensors.

Figure 5 shows a building divided into two independent portions. The first (left) is the Living Wall System developed within the GRE_EN_S project. The second (right) is an insulated wood-clad façade. Both facades have the same theoretical U-value. The two sample building portions were equipped with radiant heating panels with temperature sensors for the winter period.

The monitoring was carried out for 18 months (2013-2015), covering two summers and one winter season. It has been handled by an interdisciplinary team organised as follows:

- The building technology researchers have investigated the water needs during the summer months (L/m² per day of water) and have checked, through regular inspections, for possible failures of materials and components.
- The agronomists have analysed the leaf apparatus of the plant species selected for the sample building (Leaf Area Index - LAI).
- The energy department researchers have monitored the surface temperature of south and north-facing façades (T °C).

The monitoring reports the following findings. It was checked that the water requirement in the hottest period (June to September) is at most 2 L/m² per day. Such value is less than that of an extensive green roof in a Mediterranean climate, for which an average daily water requirement is ranged between 2.6 and 9.0 L/m² per day (Pirouz, 2021).
Although the Living Wall System cross-section is only a few centimetres, thus enabling a small growing medium, the plant species tested (Bergenia crassifolia, Heuchera and Lonicera nitida) did not show any stress, keeping the LAI comparable to an analogue species, planted in soil, under the same climate (Serra et al., 2018).

The measurements in the summer season were carried out in free-floating conditions.

Free-floating conditions helped assess the surface temperature of the sample building walls in the absence of summer air-conditioning services. The outdoor surface temperature was measured on the south and north façades (Living Wall System vs wood cladding).
Particularly the peak temperature difference between the Living Wall System (covered with Lonicera nitida) and the wood cladding wall was found to be 23°C on the average sunny summer day, i.e. the daily hourly average temperature (24h) calculated in July. Such temperature variation is mainly due to the vegetation's evapotranspiration processes. Relative temperature differences were also found with the other plant species tested.

Achievements
The research shows that a Living Wall System with a module thickness of only a few centimetres (6 cm) can be recognised as a suitable technology to improve the adaptation of buildings to the effects of climate change in cities. The Living Wall System reduces the wall surface temperature, thus mitigating the Urban Heat Island (UHI).
However, the Living Wall System's thickness of a few centimetres (excluding the plant part) has another strength. The extra thickness of a wall does not usually exceed 10 cm (counting the 6 cm of the Living Wall System and the air space between the vegetated side and the wall outer side where the irrigation system is installed); this means that the Living Wall System typology, designed and developed within the GRE_EN_S project, has undoubtedly some potential for installation on new buildings, but above all, it is suitable for being easily integrated on existing buildings.
Based on the findings over the 30 months the sample building was monitored, leaf growth was not reduced by the small amount of growing medium in the modules' pockets. The drip-irrigation system, where nutrients were diluted daily, provided a little vegetative suffering (observed on three modules of 80) and good pest resistance.

During the monitoring, leaks in the irrigation system occurred a pair of times (mainly due to some installation difficulties during the construction of the sample building). However, these leaks did not cause any particular inconvenience to Living Wall System's functions. This is due to the air gap, which keeps the plants and the module away from the wall part, the reverse assembling modules' construction techniques, thanks to the bayonet mount to the aluminium frames, and, mainly, the small amount of irrigation used to water the Living Wall System (an annual average of 1.2 L/day/m^2), which avoids any stagnation processes.

No studies on the drainage capacity of the Living Wall System (i.e., its ability to retain rainwater for a prolonged period) were conducted as part of the research. Later studies (Boano et al., 2019; Prodanovic, 2019) conducted on Living Wall Systems with similar features to those described in this chapter have, however, demonstrated the potential capacity of plants and growing medium to remove certain substances, in particular nitrogen, usually contained in grey water and rainwater.

These scientific findings highlight another Living Wall System benefit from being considered once again as a solution to improve the climate resilience of the urban habitat.
In many geographical regions, long-term droughts are frequent, followed by extreme weather events during which many millimetres of water are released onto the ground quickly (from 15 minutes to an hour).
The first flush rainwater usually is rich in pollutants. These leach onto impervious surfaces (e.g. roofs and streets) and are rapidly carried to the sewage system without filtration. In some streets and squares, which are more exposed to certain pollutants, such as nitrogen dioxide (NO_2), green roofs, green walls, and Living Wall Systems could be placed to exploit their filtration and dilution properties.
Milan, for instance, has an interactive map that monitors the air NO_2 concentration, showing 50 by 50-metre pixel images. The map highlights the most high-risk city areas (https://www.cittadiniperlaria.org/dati-inquinamento-milano/) where the Nature-Based Solutions integration programmes could be launched.

Conclusions

Nature-Based Solutions, as pointed out by the European Commission, FAO and scientific literature, are technologies able to provide systemic benefits in the urban habitat. The outcomes described in the GRE_EN_S research also highlight the role of Living Wall Systems as an adaptation solution to tackle climate change. At the same time, it is also worth highlighting the constraints of Nature-Based Solutions deployment, also reported in some of the mentioned papers. One in particular in these conclusions is appropriate to remark. Nature-Based Solutions are predominantly viewed by various stakeholders (citizens, planners, agronomists, politicians) as solutions intended to make the urban landscape more attractive perceptually. It is a correct aim but must be regarded as something other than the leading urban landscape design and construction standard.
Most cities worldwide have a non-negotiable and delayable need to "put into practice" the climate resilience targets in many domestic and international pledges, particularly the Paris Agreement.
It is necessary to make the stakeholders aware of the changing scenarios ahead and the potential of Nature-Based Solutions.
Widespread dissemination to inform stakeholders, including this book, is a chance to raise awareness. Let us hope it works.

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To Have Urban Sustainability, Citizens Must Be Given a Nudge

Paolo Carli

The concept of urban sustainability is complex and multidimensional, and it cannot be reduced to simple improvements in energy performance or the adoption of more efficient technical solutions. Furthermore, also cities are complex and interconnected systems, and the sustainability of a city depends on different factors, including urban population growth, technological innovation, economic issues, the unpredictability of climate and socioeconomic changes.
Despite the challenges, it is possible to improve urban sustainability through an integrated approach involving all actors, including citizens. Because the involvement of citizens in local decision-making processes contributes to creating a sense of belonging and responsibility towards the environment and society itself.

New Energies for the City

This book is the natural development of the New Energies for the City study seminar, organized by Alessandro Rogora, at the DAStU Department of the Politecnico di Milano, in November 2022, whose aim was "to take stock of the methods, the ongoing researches on quantitative sustainability at the urban scale, and on urban modeling through physical parameters, with the aim of opening a discussion with some of the most important researchers on the topic, to stimulate profitable international research activities".
Unfortunately, I did not participate in the conference organized by Rogora with a speech, despite deeply sharing its two founding postulates. That is, that in the context of architecture and urban planning, the term "sustainability" is often used vaguely and imprecisely, referring to limited improvements in energy performance or the adoption of more efficient technical solutions. And equally, that sustainability is today a concept applied to a single building or to single parts/components, thus losing sight of the intrinsically holistic nature of architecture and, even more so, of the city; failing to recognize that the evaluation of individual buildings or individual components does not provide a complete vision of the impact of design choices on an urban or micro-urban scale.

If I had participated in the seminar, my contribution would probably have fallen in line with Alessandro Rogora's TRACES research, both for practical reasons since I contributed to it albeit minimally, and because TRACES is interested

in people's behaviors and lifestyles; but above all because my main research topic is about technologies and design for the production and regeneration of sustainable urban systems, through shared management methods of resilient communities.
This all-inclusive formulation, if on the one hand it allows for great transdisciplinarity, on the other however risks denying the founding postulates of the book and the conference themselves, falling within the qualitative horizon of a sustainability which only incidentally recalls the concept of energy, and which more and more often it concerns greenwashing strategies.
It is therefore good to reiterate and confirm adherence to the postulates proposed by Rogora, but adding a corollary: if any city can always be a little more sustainable, no city will ever be (completely) sustainable (Matthews, 2023).

Urban Sustainability and Sustainable Development Goals

There are many reasons why it would seem to be impossible for a city to achieve full sustainability, the main and most obvious ones are:
- the interconnection of systems: cities are made up of a vast network of interconnected infrastructures and systems (transport, construction, energy, waste, etc.). Changing one aspect can have impacts on other sectors, and ensuring sustainability in all these sectors requires very complex planning and management.
- The rapid growth of the urban population and urbanized areas which can make it very difficult to keep pace with the demand for resources and the increase in emissions, unless

there is an urgent transformation of lifestyles and the production paradigm of our society, which However, it still seems like there is a long way to go.
- Technology and innovation, which are fundamental to making cities more sustainable. However, adopting new technologies can require significant time and investment, and some necessary innovations are not yet available or applicable on a large scale.
- The economic issues linked to the adoption of sustainable practices and technologies which, having high initial costs, even if they bring economic savings and environmental benefits in the long term, discourage their application due to the permanent economic situation (especially for common goods and public spaces).
- The unpredictability of climate and environmental changes and the phenomena connected to them, which can make it difficult to create solutions that take into account all possible and increasingly indeterminable future scenarios.
- Interconnected to the previous one, the unpredictability of socioeconomic changes, due to financial crises, which can overturn the productive and social fabric of a city in a very short time, making current processes and methods unsustainable.

In summary, urban sustainability is a dynamic goal that can be continuously improved, but impossible to fully achieve due to the complexity of cities and ongoing challenges, as it requires a complex balance between different factors and continuous efforts over time.

From this point of view, the United Nations Sustainable Development Goals, introduced by Agenda 2030 in 2015, and signed by 193 countries (including Italy), are useful as categories based on which to evaluate the performance of a city, while at the same time revealing largely unattainable as goals.
The global Agenda has in fact defined 17 Sustainable Development Goals (SDGs) to be achieved by 2030, divided into 169 Targets, which represent a guide to set the signatory countries on a path aimed at sustainability. The process of changing the development model is then monitored through Goals, Targets and over 240 indicators; which unfortunately, as reported by The Sustainable Development Goals Report Special edition 2023, halfway through the implementation of Agenda 2030, remain largely unattainable. While some areas have seen progress, there remains a worrying percentage of the Goals that are progressing too slowly or even regressing.
If we look in detail, the situation is frightening: of the approximately 140 targets that can be evaluated today, half of them show moderate or severe deviations from the desired trajectory. Furthermore, over 30% of the 17 Goals saw no progress or, even worse, regressed below the 2015 baseline (UN, 2023).

Technological Innovation, Lifestyles and Active Citizen Participation

On the other hand, as already underlined at the beginning, as long as the market and the planning of large investors and producers, according to the rule of "hit-and-run" supply and demand, address the issue of sustainability only at the scale of materials and of products, in relation to fashions, technologies and standards, while still managing to derive great profit from them, the sustainability of methods and processes, which aims to improve the understanding of problems and the quality of decisions, will always take a back seat, in as an investment that is not immediately profitable (Chomsky, Polychroniou, 2021). Instead, innovation occurs only when a change reaches a critical mass capable of overcoming the inertia of the "orthodox system" (Pagani, 2012). Therefore, only through the adoption of new and innovative approaches and processes is it possible:

- strengthen the empowerment of actors who live and operate at local level;
- enhance the concepts of "partnership" and "involvement" focused on specific objectives.

This is why it therefore becomes fundamental to explore how citizens' actions and social dynamics can contribute to the sustainability of urban systems. In fact, citizens are key actors capable of positively influencing the urban fabric through: 1) their sustainable lifestyles and behaviors, 2) active participation in public life (from voting to urban planning choices), and 3) the their environmental awareness.

Sustainable lifestyles and behaviors play a fundamental role in shaping the urban fabric and influencing the way communities interact with the surrounding environment (Rogora, 2020).

Firstly, the preference for eco-friendly means of transport

constitutes a key element in promoting urban sustainability. The choice to use bicycles, public transport or low environmental impact vehicles instead of traditional combustion ones helps to reduce harmful emissions and traffic congestion. This not only improves air quality, but also urban liveability, promoting more efficient and sustainable travel.

Another crucial aspect is waste reduction. Citizens can adopt practices such as recycling, composting and reducing the use of single-use materials. These actions not only contribute to mitigating the waste problem, but also promote individual responsibility towards the environment, teaching sustainability right from everyday life.

Responsible consumption is a further pillar for a sustainable lifestyle. Buying local products, reducing the use of unnecessary packaging and making informed choices regarding goods and services are behaviors that can guide the local economy towards more sustainable practices. This not only reduces the environmental impact of producing and distributing goods, but also stimulates the growth of sustainable initiatives within the community.

Promoting sustainable lifestyles and behaviors among citizens is therefore essential to creating more ecologically balanced and resilient cities. The adoption of daily practices that reflect environmental awareness promotes a cultural change that translates into a positive impact on the urban environment, helping to build more aware and sustainability-oriented communities.

The active participation of citizens in politics, both at national

and local level, and in particular - obviously - when it comes to decisions on urban planning, is fundamental to achieving high levels of sustainability (Fioretti et al., 2020).
Citizen participation, in fact, helps to guarantee greater democratic legitimacy of the decisions taken. When citizens are involved in the decision-making process, there is greater confidence in the representativeness of the solutions identified.
Furthermore, residents of a community are those who live and directly experience the effects of urban planning decisions. Their participation ensures that decisions are based on local knowledge, taking into account the specific needs of the community and its social dynamics.
Obviously environmental sustainability benefits, since, by involving citizens in decisions on urban planning, the probability that measures that are more attentive to both social and environmental impacts will be adopted is increased. Residents may be particularly sensitive to environmental issues that affect their quality of life, and can help promote greener choices.
In this latter regard, active citizen participation helps ensure that urban planning decisions take into account the needs of all segments of society. This helps to promote social equity, avoiding disparities and ensuring that resources and opportunities are distributed fairly.
Furthermore, involving citizens in urban planning helps to promote active citizenship and civic responsibility. Because when people feel involved in decisions that affect their daily lives, they are more likely to actively participate in civic life and be responsible for their communities.
Communities that actively involve citizens in urban planning are often more resilient and able to adapt to change. The diversity of perspectives and skills contributes to finding more effective and flexible solutions in the face of challenges such as climate change, population growth and other social and economic dynamics (Hopkins, Astruc, 2016). Collaboration between government, local organizations and residents is therefore essential to create urban environments that meet current needs without compromising resources for future generations.

Environmental Awareness. The UNPark Experience

The cornerstone around which the two previous attitudes that the attentive and participatory citizen must implement to increase the true sustainability of their urban space revolve is the environmental awareness of their role, of the limits of living in the city and of its impacts on environment, which is fundamental for promoting responsible behavior towards society, nature and the economy. This concept underlines the relevance of environmental education and understanding the impacts of individual and collective actions on the overall health of the urban ecosystem, since awareness presupposes knowledge. And knowledge, especially in these times of greenwashing, is a fundamental tool for navigating the labyrinth of sustainability marketing.
Greater environmental awareness would allow citizens to fully understand the repercussions of their daily actions on the environment. This in-depth understanding can range from

conscious waste management to the usual choice of means of transport, from energy management to the consumption of natural resources. This awareness provides a solid basis for the adoption of more correct behaviors, helping to mitigate negative impacts on the urban environment.
Adopting more sustainable behaviors, in turn, helps create a healthier and more resilient urban environment. Reducing consumption and waste, combined with adopting more environmentally friendly practices, can improve air quality, reduce waste production and preserve natural resources. This translates into a healthier and more harmonious city, with direct benefits on the quality of life of citizens.
A crucial aspect of environmental awareness is its role in supporting environmental policies and initiatives at the local level. An aware population is more likely to be actively involved in discussions and actions aimed at promoting sustainability. This can positively influence the creation and application of urban policies aimed at protecting the environment and promoting sustainable solutions.
The risk is that someone may try to superimpose sharing with compliance, and participation with the anesthetization of social conflicts, in order to pursue their profit objectives in complete safety (Tozzi, 2023).

The UNPark (Urban Nudging Park) research dealt with precisely this.
Funded by the Polisocial Award 2019 competitive call as part of the social responsibility program of the Polytechnic of Milan, the UNPark research project, of which I was the proponent and

scientific director between March 2019 and December 2022, sought to increase the environmental awareness of citizens of a very critical area of Milan, cut in two by a vehicular overpass of almost 2 km, through their involvement to: 1) implement and animate with content a temporary intervention (1 week) of tactical urban planning under the overpass; 2) contribute to creating a shared collective imagination on the possibilities of transforming their overpass, thanks to the dissemination of other international experiences; 3) bring the attention of public administration to the problem by underlining the value of a multifunctional approach to the redevelopment of urban infrastructures.
In this case the area chosen was not an area already "tamed" or easy to imagine transformed permanently into a public space, as often happens with projects of this type inspired all over the world by the Bloomberg Foundation. On the contrary, UNPark was interested in an unpopular area, contested by parking, illicit uses, abandonment of waste and more, such as the Serra - Monte Ceneri overpass in Milan, not with the long-term aim of transforming it definitively, not having never had the necessary economic resources, but with several more immediate objectives. The project has in fact worked on different levels: theoretical research and the analysis of international case studies; field practice, through co-design and the involvement of local stakeholders in the design choices for the temporary intervention; participation and social inclusion thanks to an open discussion with citizens.
Although co-financed by them, UNPark was a project disliked by some sectors of public administration due to the

problems it raised: the conflict between private mobility and citizens in public space, the monofunctional approach to the redevelopment of urban infrastructures and the lack of technological innovation in their smart management, the scarcity or total absence of investments on these issues, the search for easy successes through top-down interventions of tactical urban planning.

Conclusions

In conclusion, the city can be considered an experimental laboratory for urban sustainability, where citizens can play a fundamental role as a continuous source of innovations and resources.

Indeed, citizens are themselves an inexhaustible source of new energy. In fact, through their sustainable lifestyles and behaviors, they can contribute to reducing the environmental impact of cities. For example, they can choose to use public or alternative transportation, reduce waste, and consume local, sustainable products; they can actively participate in public life, ensuring that cities are planned in a sustainable way, according to the needs of all citizens; they can acquire environmental awareness, to fully understand the repercussions of their daily actions on the environment.

This can help them make more sustainable choices and promote urban sustainability.

However, it is important that policy makers understand the value of involving citizens in sustainable urban planning, as it can provide valuable information and ideas, which help create more liveable, inclusive and sustainable cities.

We must therefore:

- promote citizen participation in sustainable urban planning, through consultation, co-planning and co-management mechanisms;
- develop environmental education and awareness-raising programs on urban sustainability, aimed at citizens of all ages;
- encourage innovation and experimentation with new sustainable solutions, involving citizens and local communities.

Only by adopting these measures will it be possible to create more sustainable cities, where citizens are active protagonists of change.

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Urban settlements are constantly increasing, and we are approaching a point where over half the human population will live in cities. This human concentration gives rise to complex problems, ranging from pollution to difficulties providing resources to sustain the inhabitants' lives. This situation results in low resilience of urban settlements to events that may affect the territory and the settled society. The complexity of consumption patterns and the flows of energy and matter in transit (inflows and outflows) require a profound rethinking compared to the past, as these flows differ in magnitude and complexity. This book, New Energies for the City, represents an initial attempt to reflect on the complexity and specificity of urban metabolism, as well as on potential solutions to address and transform the identified critical issues into possible elements for mitigating problems. New Energies for Cities explores the challenges and opportunities related to the transition towards more sustainable and resilient cities, with particular reference to Milan.

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