Lecture Notes in Information Systems and Organisation 86

Renata Paola Dameri
Monica Bruzzone *Editors*

Smart City Management for Wellbeing

Proceeding of the 2nd Conference on Smart Cities, Genoa, Italy

OPEN ACCESS

Springer

Lecture Notes in Information Systems and Organisation 86

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ISSN 2195-4968 ISSN 2195-4976 (electronic)
Lecture Notes in Information Systems and Organisation
ISBN 978-3-032-21841-4 ISBN 978-3-032-21842-1 (eBook)
https://doi.org/10.1007/978-3-032-21842-1

This work was supported by University of Genoa.

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

Contents

Smart City as an Interdisciplinary Topic. From Technological Platform to Participated Local Governance

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Abstract. Since the earliest moments when scholars, businesses, governments, and local administrators coined the term "Smart City", the concept has had an inherently interdisciplinary nature, as urban intelligence intersects with the various domains in which city life unfolds.

For this reason, the smart city must be studied from a multidisciplinary perspective, not only by examining its various components individually, but above all by analyzing the interrelations among them, as these dimensions mutually influence one another within the smart city context.

The second edition of the Smart City Conference organized by the University of Genoa aims primarily to foster dialogue and comparison of research findings in the field of smart cities from a multidisciplinary perspective.

This introductory chapter of the conference proceedings provides a unified perspective for examining the most significant contributions presented at the conference. The analysis of these scientific contributions is conducted from an evolutionary standpoint, taking into account the progressive transformation of the smart city concept over the years—from a technological platform to a model of good practice in urban governance.

Keywords: Smart City · Urban Governance · Giffinger's model · Smart policymaking · Interdisciplinary city

1 Introduction

Since the earliest moments when scholars, businesses, governments, and local administrators coined the term "Smart City", the concept has had an inherently interdisciplinary nature, as urban intelligence intersects with the various domains in which city life unfolds [1]. From Giffinger's model to more recent frameworks, every theorization of the smart city has consistently sought to integrate the diverse elements that constitute it [2, 3].

For this reason, the smart city must be studied from a multidisciplinary perspective, not only by examining its various components individually, but above all by analyzing the interrelations among them, as these dimensions mutually influence one another within the smart city context [4]. Although technological aspects—which underpin

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 1–9, 2026.
https://doi.org/10.1007/978-3-032-21842-1_1

smart city applications—are central, many other factors contribute to making a city 'smart': governance, local policymaking, citizen participation, and attention to social and environmental dimensions [5].

The second edition of the Smart City Conference organized by the University of Genoa aims primarily to foster dialogue and comparison of research findings in the field of smart cities from a multidisciplinary perspective. The conference promotes integration and exchange among scholars from various disciplines. Computer scientists and engineers, together with economists, legal scholars, and political scientists, engage in discussions on how to implement smarter cities, enriched by the contributions of sociologists and environmentalists who emphasize the importance of considering social and environmental dimensions.

This introductory chapter provides a unified perspective for examining the most significant contributions presented at the conference. The selection includes 11 papers that collectively offer an overview of the state of the art in smart city research across various disciplines. The analysis of these scientific contributions is conducted from an evolutionary standpoint, taking into account the progressive transformation of the smart city concept over the years—from a technological platform to a model of good practice in urban governance [3, 6].

2 The Smart City as an Interdisciplinary Concept

The concept of the "smart city" has emerged as a multifaceted and interdisciplinary framework aimed at enhancing urban quality of life through the integration of technology, governance, social inclusion, and environmental sustainability. Among the various theoretical approaches, the model developed by Giffinger et al. [2] stands out as a comprehensive and widely recognized framework that conceptualizes smart cities through six interconnected dimensions: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. This holistic perspective underscores the necessity of transcending purely technological solutions and emphasizes the interplay between diverse disciplinary domains to address complex urban challenges.

Giffinger's model advocates for a multidimensional understanding of urban intelligence, where advancements in information and communication technologies (ICT) are synergistically combined with social innovation, effective governance, and sustainable environmental practices [7]. By acknowledging that these domains mutually influence each other, the model highlights the importance of interdisciplinary collaboration among urban planners, engineers, social scientists, policymakers, and environmental experts [8].

The concept of the smart city has evolved as an interdisciplinary framework not only respect to the topics and applications, but also respect its crucial components, integrating technological, human, and institutional factors. Nam and Pardo [9] offer a pivotal model that conceptualizes smart cities through the interaction of these three core dimensions. This model moves beyond purely technological solutions by emphasizing the crucial roles played by human capital and institutional frameworks in shaping smart urban development.

The technological dimension encompasses the deployment of information and communication technologies (ICT) and digital infrastructure that enable data collection, analysis, and service delivery. However, Nam and Pardo highlight that technology alone is insufficient to achieve the goals of a smart city. The human dimension focuses on the skills, knowledge, and social participation of citizens, which are essential for fostering innovation and inclusive urban environments. Equally important is the institutional dimension, which refers to governance structures, policies, and administrative capacities that support coordination and collaboration among multiple stakeholders [10].

These two contributions, that are two pillars of the theoretical foundation of smart cities, define a two-dimensional multidisciplinary. The first dimension concerns the constitutive elements of the smart city. These elements, also acknowledged in other works—see, for example, Hollands [11] or Caragliu et al. [12]—consist of three components:

- technologies, whether informational or engineering;
- the role of institutions, governments, and policies;
- and finally, local actors, primarily citizens but also businesses.

The second dimension consists of the domains in which smart city implementations occur. Giffinger's model laid the foundational framework, and many subsequent studies have adopted the same thematic organization. However, these themes evolve over time and have fluid boundaries, as smart implementations increasingly integrate multiple aspects of urban life.

In recent years, the concept of smart cities has attracted significant academic interest, leading to comprehensive literature reviews aimed at clarifying its multiple dimensions.

The 2024 systematic review by Ulya et al. expands the analysis by examining 30 carefully selected articles from reputable academic sources. [13] Their research identifies 38 distinct smart city dimensions, categorized into six main groups, partially different respect to the Giffinger's ones: economy, people, environment, governance, living, and branding. This categorization highlights the multifaceted nature of smart cities, reflecting both technological and socio-economic aspects. Importantly, the study underscores the evolving and overlapping nature of these dimensions, which often integrate various aspects of urban life. Together, these articles provide a comprehensive overview of smart city frameworks, emphasizing the need for multidisciplinary approaches and adaptive models to address the complexity of modern urban challenges.

3 Technological Interdisciplinarity: From Basic ICT to Artificial Intelligence

The technological evolution underlying smart cities reflects a progressive shift from early digital infrastructures to advanced, data-driven systems powered by artificial intelligence. One of the foundational contributions to this discourse is provided by Dameri, who conceptualized the digital city as an early stage in smart urban development [14]. In her framework, digital cities were primarily characterized by the deployment of ICT infrastructures—such as broadband networks, e-government services, and digital databases—to improve administrative efficiency and citizen access to information [15].

As urban challenges became more complex, the focus moved beyond digitalization toward integration of urban systems, marking the transition to smart cities. This phase introduced technologies like IoT (Internet of Things), sensor networks, and big data analytics, enabling real-time monitoring of transportation, energy, waste, and security.

Today, the most advanced smart cities are increasingly shaped by artificial intelligence (AI), which allows predictive analysis, autonomous decision-making, and adaptive service delivery. AI applications range from traffic flow optimization and energy management to personalized public services and urban planning simulations.

This evolution—from basic ICT tools in the digital city to AI-driven ecosystems in the smart city—illustrates the deepening technological complexity and the growing need for interdisciplinary approaches that combine engineering, data science, governance, and social innovation.

This technological evolution generates a stratification of tools and methods that, within the framework of smart cities, are applied to diverse and heterogeneous domains. The two-dimensional model of analysis outlined in Sect. 2—focusing on constitutive factors and application domains—allows the contributions presented at the second edition of the Conference to be interpreted as a puzzle of tools with both temporal dimensions, linked to the evolution of technologies, and spatial dimensions, referring to the themes and smart applications involved.

Bruzzone et al. [16] examine a fundamental topic within the smart city domain: data processing applied to urban data, with the goal of developing decision support systems for local policymaking. The work is, in itself, an evolutionary analysis, as the proposed prototype integrates traditional database and data processing systems with advanced user interface techniques, including elements of artificial intelligence. Data processing is an integral part of many of the papers included in this volume. In several cases, it remains implicit, treated as an almost necessary activity for operating within the smart city context. However, different approaches to data processing emerge—from the use of traditional Excel spreadsheets in the work of Ambrosino and Mangano [17], to mobile applications discussed in the paper by Pirlone et al. [18]. In more than one paper (Bruzzone et al. [16], Gausa et al. [19], Peri et al. [20]), an urban dashboard is proposed as a platform that brings together data, themes, and users within a single knowledge environment. What emerges is the need to provide data and information with a unified urban identity.

The user interface plays a key role in many cases: both in enhancing the usability of urban dashboards, as seen in Bruzzone et al. [16], and in engaging citizens through living labs, as in the work by Gausa et al. [19]. In the latter, technology serves both as a tool and an objective, as the proposed living lab aims to identify the most suitable technologies for a citizen-centered smart city. As ICTs are increasingly regarded not only as tools for data processing but also as instruments of communication, user training takes on a central role. The contribution by Delzanno et al. [21] is in fact focused on an educational initiative.

Regarding non-ICT technologies, the papers presented at this II edition of the Smart city Conference focus primarily on mobility and energy issues. These themes are, in fact, interconnected: Fresia et al. [22] propose photovoltaic systems to power electric vehicles, while Peri et al. [20] address smart mobility, specifically electric vehicles, within the context of a historic city center. In these studies, engineering technologies are applied in conjunction with ICT: Fresia et al. [22] use them to optimize costs and performance, whereas Peri et al. [20] employ virtual and augmented reality to integrate electric mobility within the historic urban environment.

There are also several papers that explore the increasing use of AI within the context of smart cities. Bruzzone et al. mention AI as a tool for data processing and user interface in the case of urban dashboards, while other authors examine regulatory aspects related to AI use in urban settings. Notaristefano [23] addresses the distribution of data control among various actors in the urban context and their consequent roles in data-driven urban governance. Vipiana and Botto [24] investigate the application of AI to risk management within administrative actions. Di Gregorio and Turci [25] address the use of AI in local policy decisions, paying particular attention to issues of inclusion.

In conclusion, the contributions presented at the conference reveal a technological interdisciplinarity in which both traditional and more recent technological tools are constantly intertwined. ICT and engineering technologies mutually support each other; technology is increasingly less of a black box and more a tool for interface and communication between the city and its citizens. Competencies and participation play a key role, with respect for fundamental human rights, especially in light of the growing use of AI.

4 Thematic Interdisciplinarity: From the Centrality of Technology to the Centrality of the Citizen

As seen in the foundational models of smart cities, Giffinger's model proposed a multidisciplinary approach from the very beginning [2], which over time has progressively expanded to include as many as 38 thematic areas, as identified by the analysis of Ulya et al. in 2024 [13]. This aspect is evident in all eleven contributions presented at the Conference. Each of them, in fact, begins with an urban issue—covering a wide range of problems—and proposes a solution through the use of one or more technological tools. The list of topics addressed can be traced back to Giffinger's categories (see Sect. 2). However, a closer examination reveals that the themes explored in the contributions rarely fall within a single category; almost all of them span at least two, if not three, categories.

The most represented theme is *smart mobility*, with three contributions: Fresia et al. focus on electric mobility, as do Peri et al. [20], while Pirlone et al. address behaviors related to mobility [18]. However, Fresia et al. [22] also explore the topic of Renewable Energy Communities, which places their work within the domain of *smart people*, and they approach it in terms of economic savings, thus also touching on the *smart economy* dimension. Peri et al. [20] apply electric mobility within a historic city center, with particular attention to environmental concerns (*smart environment*) and the preservation of cultural heritage, which also situates their work within the *smart living* dimension. Pirlone et al. [18] address mobility with the aim of reducing environmental impact (*smart environment*) and influencing lifestyle changes (*smart living*).

The *smart government* dimension is also represented by three contributions: Bruzzone et al. [16] address urban dashboards for local policymaking; Gausa et al. [19] focus on participatory governance; and Notaristefano [23] explores data governance. These three papers appear to be primarily concentrated on this dimension.

The *smart environment* dimension emerges as a primary focus in at least three contributions: Ambrosino and Mangano address waste management [17]; Dameri and Bruzzone explore urban circular economy [26]; and Vipiana and Botto examine climate change and the related issue of risk management [24]. However, in the paper by Dameri and Bruzzone [26], the *smart economy* dimension is equally significant alongside environmental concerns. Ambrosino and Mangano [17] place the issue of waste management within the context of tourist cities, linking it also to *smart living*. In fact, the improvement of quality of life is also a key aspect in the work by Gausa et al. [19].

The *smart people* dimension plays a central role in several contributions. Delzanno et al. [21] focus on an educational initiative aimed at enhancing digital skills and civic engagement. Di Gregorio and Turci [25] explore the relationship between artificial intelligence and social inclusion, highlighting the importance of human-centered approaches to technology in local policy-making. Notaristefano [23], while addressing issues of data governance, also emphasizes the role of citizens through the use of dedicated applications, illustrating how technological tools can empower individuals and support participatory urban processes.

In summary, the interplay among the six dimensions proposed by Giffinger appears to be inextricable. This reflects the very nature of smart cities as platforms for both technological and social experimentation—a characteristic that continues to emerge strongly, even as the field reaches a stage of maturity.

By comparing the eleven papers in this volume with the scientific evolution of smart city studies and research, a somewhat circular trajectory can be observed. In the early stages of research, roughly between 2007 and 2012, the smart city was primarily approached as a theoretical concept focused on how technology could permeate urban activities to improve them—making them more efficient, more responsive to citizens' needs, and more promising from an economic perspective. In the most important theoretical models proposed by several authors - Giffinger et al. [2], Nam and Pardo [9], Caragliu et al. [11], just to name the main ones - the smart city arises from technologies as a tool, from policies as an activity and from quality of life as an end.

Over the years, however, research has predominantly focused on technological tools for smart cities, often overlooking the role of people. Only recently has the role of citizens regained prominence, as evident in nearly all the contributions presented at this Conference. The themes of participation and co-creation in smart cities strongly emerge, as will be discussed in the following paragraph.

5 Participation and Co-creation as Success Factors for Smarter Cities

When examining the eleven papers from the perspective of citizens, it becomes clear that people can play a dual role: as beneficiaries or as active participants. They are beneficiaries when smart actions are implemented to directly serve and improve citizens' lives. Five papers fall into this first category: Bruzzone et al. [16], whose proposed dashboard is developed to support local policies aimed at enhancing citizens' quality of life; Ambrosino and Mangano [17], who address improved waste management to mitigate the effects of overtourism; Peri et al. [20], who describe the use of electric mobility as a benefit for the community in terms of preserving the historic urban center; Vipiana and Botto [24], who apply risk management in the interest of citizens as a means of protection against climate change; and Di Gregorio and Turci [25], who analyze how AI can be used inclusively within smart cities. The concept of inclusion as a benefit for citizens is explicitly addressed in three of these papers: Bruzzone et al., Peri et al., and Di Gregorio and Turci.

The remaining six papers—the majority—consider citizens as actors, playing an active and leading role in the creation of the smart city. In some cases, this is due to the need for behavioral change, as in the work of Dameri and Bruzzone [26], who emphasize that an urban circular economy can only be achieved through the active contribution of all citizens, as well as businesses. Similarly, Pirlone et al. [18] argue that it is precisely through the interaction between the mobility app and citizens' mobility choices that a smarter city with a reduced environmental impact can emerge.

The key emerging concept in many of the papers—indeed, the majority—is participation, which in some cases evolves into co-creation: the co-creation of the smart city and the value it generates. The central contribution reflecting this approach is the paper by Gausa et al. [19], who experimented with a co-design framework for the smart city. This framework allows for the use of technologies not despite the citizens (as resistance to smart solutions is common), nor merely for the citizens [27]. Rather, their case study demonstrates that the most effective outcomes—particularly in terms of the city's capacity to enhance quality of life—arise when technologies are used with the citizens.

6 Conclusions

Although the term smart city often evokes technological solutions for urban environments, the evolution of research in this field has shown that the early theoretical models—based on the interaction between technology and people—are proving to be well-suited to describing the reality of implemented smart cities. The eleven best papers selected from the second edition of the Smart City Conference present a synthesis of technology and people, who now play an increasingly active role. Citizen participation in urban design emerges as the ideal outcome of a nearly two-decade-long process of smart city maturation, culminating in a value co-creation process in which citizens are both agents and beneficiaries.

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An ICT-Based Tool for Socio-economic Aware Governance of Urban Landscape (SEAGUL)

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Abstract. This research, in line with the goals of the RAISE innovation ecosystem, has the scope to empower the socio-economic quality of life in a Smart City, by combining the urban data potential with innovative technologies and artificial intelligence, to provide a tool for city governance and management. The paper describes the process of designing, developing and prototyping SEAGUL: an innovative and replicable ICT-based (tool) addressed to policy makers and PA technicians, which uses urban data related to the municipality of the italiani city of Genoa to measure and visualize the quality of life of the city districts and neighbourhoods. The study examines how urban data may be analysed and visualized in different ways using technologies and algorithms to create new knowledge about the city. The findings describe how the interactions between data about the people, human activities, and the territory may help measure and monitor the city's inclusivity. Further research will investigate the possibility of generalizing SEAGUL, moving from a pilot case to a replicable model capable of supporting data from many cities in the world.

Keywords: Smart City · Urban Dashboard · Governance · Social Inclusion ICT-tools

1 Introduction

In the era of the digital revolution, the exponential growth in urban data production mirrors the increasing complexity of the contemporary city [1]. The big size of contemporary cities may drive economic development, but it can also introduce vulnerabilities that adversely influence both environmental sustainability and social cohesion [2]. As a result, the gap of inequality is rising [3]. Today, especially in medium- and large-sized cities, social and economic inequalities are a major challenge, arising in many fields, such as education, income, employment, housing, health, and justice [4]. Inequalities are often linked to the disparities in lifestyles across the different city neighbourhoods and districts; the structural vulnerabilities inherent the urban morphology; to demographic

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 10–23, 2026.
https://doi.org/10.1007/978-3-032-21842-1_2

trends, and unequal accessibility to essential services [5]. Achieving sustainable urban development requires enhancing inclusive policies that address not only the city in its entirety, but also the sub-municipal dimension [6].

From this context, two key considerations emerge. Firstly, urban development and the reduction of inequalities within the city depend on a wide range of material and immaterial factors related to the urban communities' lifestyles and expectations, as well as to the local differences within the urban environment [7]. Secondly, each of these factors can produce impacts on urban sustainability both at the citywide scale and at the neighbourhood scale [8]. Moreover, in contemporary urban contexts, the majority of factors with an impact on the urban sustainable development can be detected and measured using urban data or indicators [9]. Public administrations are increasingly equipped to generate data that enable the monitoring of cities from a social, environmental, and economic perspective. The use of data and indicators is widely acknowledged as a strategic priority for the governance and management of local authorities. Nevertheless, a persistent gap remains between the data availability and their effective use in policymaking processes.

This research explores how to bridge this gap, by leveraging urban data to support sustainable local development. It promotes an integrated a data-informed approach to support the process of decision-making, enhancing the concept of aware governance. Urban data, generated or processed by the public administrations, can be used to detect and monitor the impact of a wide range of factors, conceptualizing the city as a system composed of diverse sub-municipal dimensions such as districts, neighbourhoods, and urban blocks. Data and indicators can be considered as synthetic measures that either directly describe observable phenomena (e.g., the environmental temperature) or infer the impacts of not-measurable phenomena trough measurable proxies (e.g., the variation in citizens' income as a proxy of economic growth)[1].

Since the late 1990s, and especially in recent years, scientific literature has documented the use of urban data to develop ICT-based tools for monitoring city dynamics and supporting evidence-based governance. Over time, the use of indicators as descriptors of the city's performances and trends has become a common practice to guide strategic planning, city management and resources allocation [10, 11]. The academic literature testifies that in recent years, a large amount of urban data has been used in the design of ICT-based tools aimed at supporting evidence-based governance [12, 13].

This research, aligned with the goals of the RAISE innovation ecosystem, has the scope of empowering the socio-economic quality of urban life, by designing an evaluation system for assessing urban quality of life at the neighbourhood scale, to inform and support local policy. The firs result is an innovative ICT-based tool powered with Artificial Intelligence, which uses administrative data to enable a more effective and aware sub-municipal governance. The tool, specifically targeted to policymakers and technicians, has the scope to measure the quality of life at the neighbourhoods level, starting from a socio-economic perspective, in order to give awareness about the diverse conditions that can emerge inside a medium or big city. Section 2 outlines the development process of building the tool, from an analysis of the scientific literature to the prototype of the Geo-dashboard. It focuses on three phases: the framework design process (2.1),

[1] (PA Quality Service - qualitapa.gov.it - Italian Ministry for Public Administration).

the selection of data and indicators (2.2) and the database creation (2.3). Section 3 introduces SEAGUL as an urban Geo-dashboard for promoting an aware socio-economic governance of the urban landscape. Section 4 summarizes the first results obtained and outlines the future developments of the tool.

2 A Tool for City Governance and Management

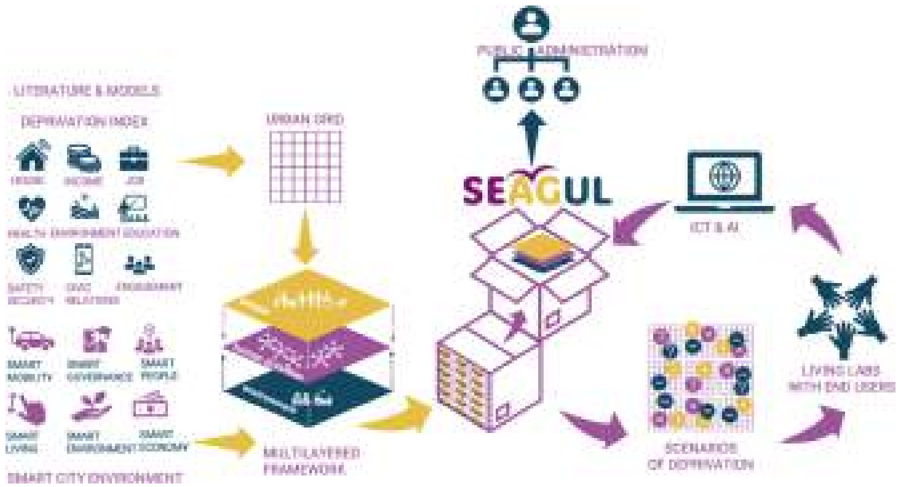

Fig. 1. The design process of the ICT-based tool (source: Authors)

The ICT-based tool has required a multi-step design process described in Fig. 1. The main purpose is to generate a dashboard aimed at monitoring the city's evolution, and supporting evidence-based governance. The dashboard uses administrative data to experience an innovative hybrid design methodology, integrating the top-down and bottom-up approaches. The process begins with a comprehensive review of the scientific literature about the topic: the research has explored the role of urban data and indicators in measuring and monitoring quality of life, with a particular focus on social inclusion in urban contexts; furthermore, it examinate the structure and functions of a wide range of urban dashboards designed for public administration [14]. This first phase was crucial for understanding indicators that can be used to measure the quality of life in cities, helping to assess the level of social inclusion. The research identifies a core set of indicators—such as income, housing, employment, health wellbeing, security, and education— and a selection of case studies, effective for evaluating urban quality of life. All these factors are considered in relation to the key Smart city dimensions: people, governance, economy, living, environment, and mobility [15].

The second phase of the process introduces a spatial grid for analysing the city at a sub-municipal level according with the administrative structure typical of European and Italian cities: the *Blocks*, as the smallest unit; the *Neighbourhoods*, very important for the proximity city model; and the *Districts*, as larger portions of city characterized by a degree of self-governance. This spatial grid supports the development of a multilevel framework organizing data into three analytical layers: the *Environment*, the *Human activities*, and the *People* composition. This framework can be defined as a neutral repository of raw data and indicators, implemented with datasets updated on a semi-annual basis, a suitable timeframe for describing the urban evolution over the medium term. The ultimate goal is to centre urban governance around the quality of life of citizens, focusing on the community composed of residents, who are also the main subjects of the inclusion policies. The dashboard is designed as a scalable and customizable model, suitable for different urban contexts, as it combines the two aspects of standard indicators for analysing the quality of life in cities, with city-specific characteristics such as morphology, density, demographics, and service provision.

The definition of the urban grid and the implementation of the framework make the dashboard customizable, identifying on the one hand the specific administrative borders, and on the other hand the morphological and demographic characteristics of each city, as well as the provision of services in all the city districts. According to this methodology, the standard selection of indicators is integrated with a tailored approach that allows the tool to identify the main characteristics of each city. At this stage of the project, it became essential to identify a city case study for the framework application, with the aim of developing a functional prototype to test this dual approach. The SEAGUL prototype was therefore parameterized on the city of Genoa, its neighbourhoods, its morphology and density, its population, and its services.

After designing the framework, datasets available at the neighbourhood level is identified and collected. All data are provided by the public administration, specifically the Municipality of Genoa, through an agreement with the University of Genoa. This agreement ensured that data processing complied with legal standards through anonymization algorithms. The data are then used to implement the database. During this phase, the most appropriate spatial, temporal, and social dimensions are established (as in Fig. 3).

Subsequently, the data were visualized through a geo-dashboard that supports dynamic querying and enables the aggregation of raw data using clustering techniques. The tool connects the data to the spatial grid of Genoa, structured on the three perimeters—blocks, neighbourhoods, and districts—allowing users to explore and to match the thematic dimensions: environment, services, and people (Fig. 2).

In addition, several fragility scenarios were developed to better identify the vulnerabilities of specific population groups, particularly children and young people, as well as the elderly.

A first prototype of the SEAGUL Geo-dashboard has been developed, focusing the visualization of a dynamic map of the city that uses innovative algorithms for clustering and improving the communication with end users.

With the release of the first ICT tool prototype in 2025, a series of Living Labs were launched involving end users: technicians and policymakers. In total, 40 participants took part in these sessions, comprising local government officials (from the Municipality, Metropolitan City, and Region Liguria), researchers, and university professors. The aim of these Living Labs is to enhance the participation process, not only to test the tool, but also to identify relevant use cases, and suggest improvements to enhance user experience. These activities contributed to refining the prototype in order to enhance its regular use in urban governance and decision-making processes. The Living Labs process is ongoing, involving senior officials and technical staff from the Municipality of Genoa's Department of Development and Department of Social Policies.

2.1 The Multilevel Framework

The framework described in Fig. 2 takes into account three layers that can be recognized in every city. The lower material level of the natural and built environment; the highest level, made up of people; and the intermediate level made up of human activities, connecting people with the environment. Each level is implemented with subsets of data and indicators.

Fig. 2. The Multilevel Framework (Source: Authors).

The Multilevel framework illustrated in Fig. 2 takes into account three layers that can be recognized in every city. Each level is implemented with subsets of data and indicators. At the basis of the model there is the urban environment, composed of the natural context, modified by man over the centuries, and the city's historical stratification. This layer encompasses data on urban morphology, including vulnerable areas, green spaces and the vertical variations that may be barriers to accessibility. This level incorporate the density of the built environment, covering residential and public buildings-as well as parks, squares, roads, railways, and other infrastructural elements.

At the top of the model are the citizens: people resident in the city, with their own individual and social attributes including their fragility. The analysis of people concerns demographic data, household composition, employment status, actual or expected income, educational attainment, ownership of personal property, use of social welfare services, and aggregated data concerning health and disability conditions.

At the centre of the model, between environment and people, is the level of human activities. This layer, as a connective interface, encompasses all the ways in which citizens interact with the urban environment, including accessibility to essential services, productive systems, mobility patterns, and more.

Integrating datasets across the three conceptual levels allows us to understand the quality of life in the city, especially if compared to the little clusters of blocks and districts. The development of the framework has considered general parameters with the aim of creating a standard but tailored tool, able to integrate standard indicators with context-specific elements. From this point, the prototype, is specifically designed for the city of Genoa.

2.2 Data Acquisition Process

The data acquisition process aimed at obtaining an ICT-based tool that could be robust and at the same time flexible, scalable, and implementable over time. To ensure robustness, all datasets are sourced exclusively from authoritative sources. In the prototype, data are obtained from the public administrations (Municipality, Metropolitan city, and Regional Government) as well as from other official sources such as the local Health Authority, the Regional Environment Protection Agency, law enforcement, and professional associations capable of producing datasets at the sub-municipal scale (encompassing blocks, neighbourhoods, and districts).

To facilitate data acquisition, the University of Genoa formalised an agreement with the local Municipality, which holds sensitive citizen-related information. This agreement ensured full compliance with privacy regulations throughout the data collection and anonymization. Access to information concerning local areas and public services was more straightforward, as the city council had already made these datasets publicly available, complete with geospatial references.

The target objective for developing a flexible dashboard is ensure availability of sufficient data to populate a comprehensive set of key indicators gathered from the scientific literature, with particular reference to international models. Among these the IMD (Index of Multiple Deprivation), widely adopted in Anglo-Saxon countries, assess the level of deprivation of citizens and the neighbourhood's fragility [16]. Another notable reference is the OECD's Better Life Index, which evaluates quality of life across countries at the national scale [17]. Both indices served as reference frameworks for defining the nine dimensions related to people: housing accessibility, employment, income, health and well-being, environment, education and professional training, safety, social relationships and political engagement. Additionally, the city ranking of European Medium-Sized Cities proposed by Giffinger, commonly used to measure development dynamics in Smart cities of medium-large size, was used to identify the 6 dimensions related to the Smart city: mobility, environment, governance, economy, living, and people [18, 19].

The development of a scalable dashboard requires the establishment of appropriate units of measurement to ensure suitable data granularity across three key dimensions. As illustrated in Fig. 3 these dimensions are conceptualized along a three-axis Cartesian graph: Space (from the city to the urban blocks), Time (from the real time to years) and People (from the individual to the society). SEAGUL, an ICT-based tool designed to assess the impacts of multiple factors over medium- and long-term horizons, adopt an approach where the space needs to delve into neighbourhood details, identifying the block as the optimal unit for data acquisition. The time can provide for a six-month

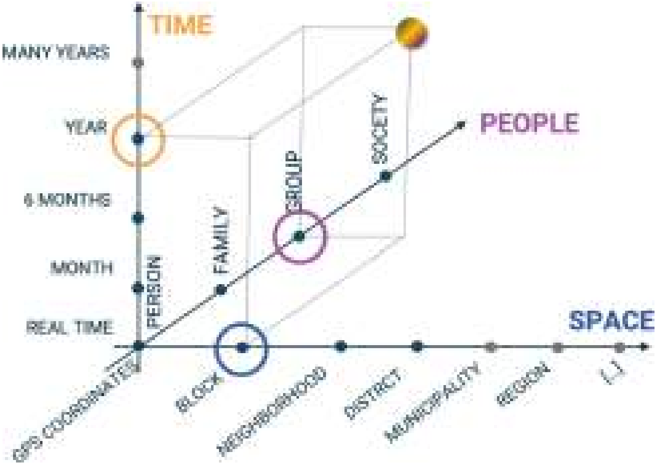

Fig. 3. The dataset granularity according with the three dimensions: time, space and people (source: Authors).

implementation horizon. The people is examined for groups with homogeneous characteristics, particularly in terms of fragility and deprivation. Upon completion of the data collection process, the research team proceeded the construction of the database, which serves as the foundation for the SEAGUL tool and enables its progressive implementation over time.

2.3 The Database

The database that serves SEAGUL contains data about all the three levels of the Multilevel framework (environment, human activities, and people) and referred these data onto an urban grid structured through a hierarchical composition of spaces.

For generating the urban grid, the database includes a table with information about the administrative subdivisions of the city.

The smallest unit is the Block (Sezioni di censimento), comprising 3,610 records. Blocks are aggregated into Neighbourhoods (Unità Urbanistiche), comprising 71 records. Neighbourhoods are further grouped into Districts (Municipi), comprising 9 records.

The database is structured around the Multilevel framework. At the environment level, it includes datasets describing the city's morphology—such as green spaces and hydrogeological risk zones—as well as characteristics of the built environment.

At the human activities level, the database contains tables covering key urban services, including schools, theatres, pharmacies, healthcare facilities, and museums. Each record includes precise GPS coordinates and its corresponding location within the three-tier urban grid: blocks, neighbourhoods, and districts.

At the people level, the database incorporates anonymized individual-level data provided by the by the Municipality of Genoa: specifically, from the Registry Office and the Directorate of Social Services. This includes demographic and socio-economic variables such as gender, year of birth, marital status, nationality, employment, education level, and household composition. Additional information is available for individuals receiving social assistance. All personal data are georeferenced to the block level and linked to the type of service received. Given the sensitive nature of this information, all records are anonymized in full compliance with privacy regulations and standards.

Furthermore, the database includes fragility indexes for each administrative subdivision of the city. These indexes are computed by assigning scores to characteristics indicative of social vulnerability (e.g., elderly individuals living alone, minors with unemployed parents, etc.). The scores are aggregated for each area and normalized by population density at the block level.

During the database construction phase, data pre-processing was required, particularly for the variable concerning citizens' professions. In the dataset provided by the Municipality of Genoa, this information was not standardised or certified, and the same profession could appear in multiple inconsistent formats. This inconsistency posed challenges for its integration into the data visualisation dashboard.

To address this issue, an initial step involved grouping all professional roles according to the standard occupational classifications defined by ISTAT[2], within the Jobs Units Database. In the current phase, the same classification process is redefined using an AI-based algorithm, which automated the categorisation of professional roles according to the ISTAT standard. Another essential preprocessing step involved calculating the number of family members for each individual. In the dataset provided by the Municipality of Genoa, each citizen was associated with a family code. By counting the number of individuals sharing the same code, the total number of family members per household was derived.

An additional preprocessing task focused on the nationalities of non-Italian citizens. Given the wide range of origins, strangers' residents were aggregated into four categories based on the Human Development Index (HDI) of the country of origin[3]. The HDI, developed by the United Nations Development Programme (UNDP), is updated annually and evaluates three core dimensions: health, education, and standard of living. This approach reflects the principle that human capabilities—not merely economic growth—should be the primary measure of a country's development.

3 The Urban Dashboard

SEAGUL is an Urban Geo-Dashboard under constant development. At the current stage, it offers a Graphical User Interface that allows the user to visualize through different Data Visualization idioms several attributes related to the citizens of Genoa, the position of some services on the landscape (e.g., pharmacies, schools, medical centres, sport facilities, theatres), and scalar functions describing the fragility of some profiles of interest. In this section, we describe in detail the layout of Seagul and how to use it to extract meaningful information concerning the performance of Genoa as a Smart city.

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[2] The ISTAT, Italian Institute of Statistics, Database can be explored at: https://professioni.istat.it/sistemainformativoprofessioni/cp/.

[3] The HDI of all the Countries can be explored at: https://hdr.undp.org/data-center/human-development-index#/indicies/HDI.

The bottom layer upon which all data are visualized is a map of Genoa consisting of buildings and roads, so that the user familiar with the toponymy of the city can easily orient themself when visualizing the map. Such a layer has been imported using the well-known library Leaflet. The administrative subdivisions mentioned in Sect. 2.3 are visualized as Scalable Vector Graphics upon the underlying map and according to the zoom level chosen by the user. Upon user request, three panels appear on the sides of the screen. In the following, we will refer to the three panels on the left as *control panels* while the panel on the right will be called *visualization panel* (see Fig. 4). The three control panels refer to the three levels defined in Sect. 2.2: people, human activities (particularly services) and territory. As explained above, the initial purpose of Seagul was to focus on the citizens. To this aim, one must be able to filter in several ways the attributes of the People dataset. For example, one might be interested in assessing how people with some characteristics (e.g., old people living alone, mid-forties people with no job, etc.) are distributed on the territory and, possibly, determine if some correlation exists between the amount of people that fit some given profile and the part of the city in which they live. To give the user the maximum degree of freedom in choosing these profiles, the control panel relative to the people consists of several sliders and multi-select checkboxes, which allow the user to define the profile of interest by filtering the attributes. Once the filters have been set, the user can visualize the result of the query with a *choropleth map*. In detail, once the user is satisfied with the chosen filters, a query is sent to the database, which returns the number of people that fit the profile selected by the user in every sub-municipal unit (block, neighbourhood or district) at the chosen level of granularity, which depends on the zoom level at which the user is visualizing the map or could be manually set by the user.

Every unit in the level under exam is coloured according to the number of people satisfying the query, and an indexed colormap is visualized on the top of the screen to give the user a quantitative estimate. An example is shown in Fig. 4.

The visualization panel on the right (see Fig. 5) has the purpose of giving the user an overview of the main attributes of interest in the People dataset: age, profession, nationality and number of family members. The user can choose which one of these attributes they want to visualize through a menu on the top of the control panel relative to the people. In the example of Fig. 5, the attribute is set to be "Profession", so every time the user clicks on a given region, the visualization panel shows the distribution of the professions of all the people living in that region. For professions, nationality and family members, a bar chart is used, while for the age distribution we use a histogram.

The yellow control panel in Fig. 5 thus gives the maximum possible leeway to the user to visualize the distribution of a given profile on the landscape. However, it is important to relate these profiles to services present on the territory. For this, include in our dashboard the possibility of visualizing several services. We started by considering the services needed by young and old people, thus prioritizing the part of population more "fragile" in some sense. The services included so far are schools of every degree, sport centres, paediatricians, pharmacies, doctors, and bus stops. All the services are visualized through clustered markers and, when the level of zoom is high enough to allow the pointwise visualization of them, they are endowed with tooltips giving information about the selected service (e.g., if a given sport centre has an entrance for an individual

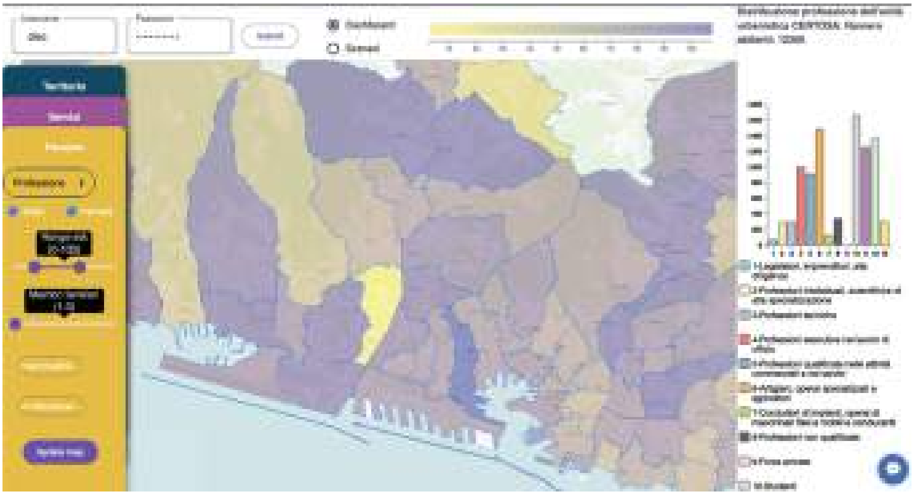

Fig. 4. Visualization of the query "people with an age between 20 and 66 that have no job and live alone". The choropleth map has been visualized by colouring the neighbourhoods according to the zoom level chosed by the user. The colobar at the top of the of the screen is updated according to the visualization and zoom level.

with disabilities or the name and address of doctor). An example of all the nurseries and nursery schools is shown in Fig. 5.

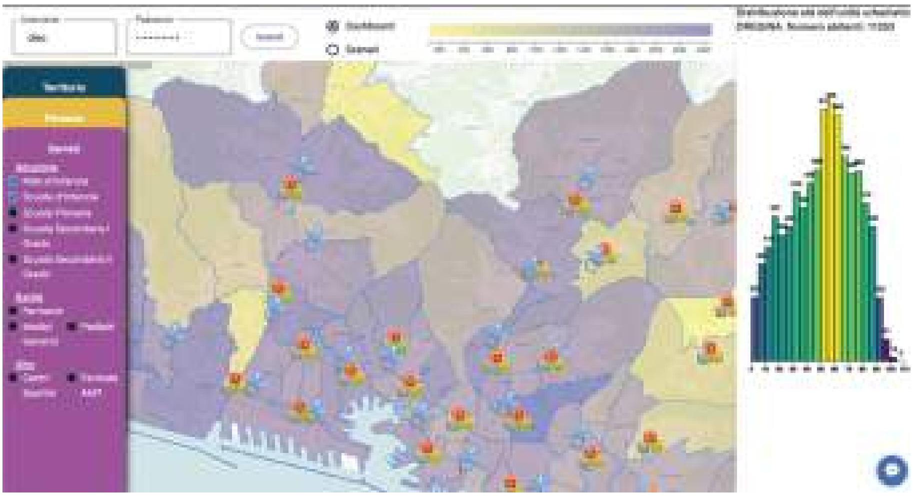

Fig. 5. Visualization of all the nurseries and nursery schools.

We have developed a set of fragility indexes for young and old people, and we tried to highlight regions in the city characterized by a high number of young or old people with some sort of fragility. To keep the user interface simple, the widgets controlling visualization can be accessed by using radio buttons that switch among a predefined sets of scenarios (see Fig. 6).

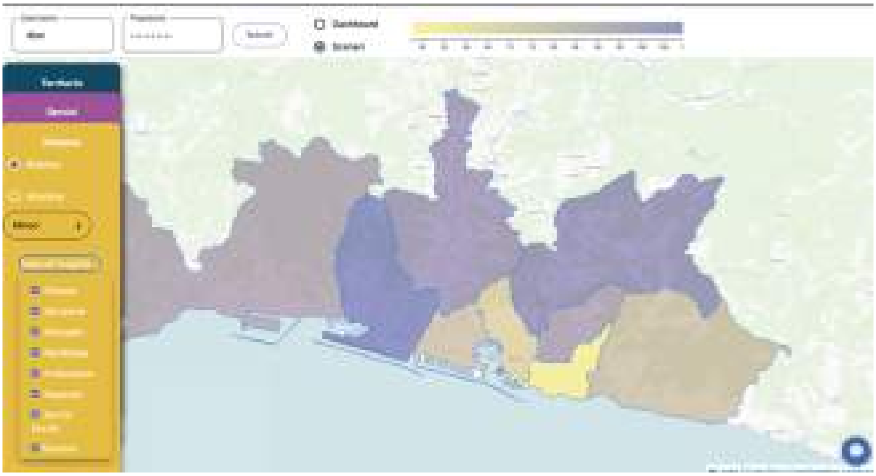

Fig. 6. Switch of mode for the control panel relative to the people: once the "Scenari" radio button is pressed, the yellow control panel allows the user to visualize through a choropleth map the fragility indicators of young and old people.

For both young and old people, we defined several score systems according to some indicators that can be related to a situation of distress. For example, take into account whether a young kid is living with both parents or not, if his family receives some sort of aid from the social services, and so on. The scores associated with these indicators can be computed separately and visualized one by one or aggregated. In this latter case, the ultimate fragility score will be the sum of all the indicators that the user selected using a combo box (see Fig. 6). The user can also choose to visualize the absolute value of the score resulting from his/her query, or the relative one, this latter being normalized with respect to the administrative level it is referring to (e.g., in the example shown in Fig. 6, the score of every district has been divided by the number of people living in that district).

4 First Results and Future Developments

The research, as a part of the PNRR RAISE Liguria Ecosystem, has developed a data-informed decision support system based on international indicators and tailored for local public administrations. The system is designed to address socio-economic empowerment within the urban context. It has been conceived and prototyped to enhance evidence-based policymaking by integrating heterogeneous data sources and providing intuitive visual analytics for institutional stakeholders.

This work constitutes a significant advancement in the application of data processing methodologies to the public sector, promoting transparency, efficiency, and strategic planning through advanced analytics. The research explored how an AI-supported ICT tool can bridge the gap between the growing availability of urban data produced and collected by public administrations and its effective use in policymaking, with the goal of promoting inclusive and sustainable governance at the local level. In response to this challenge, SEAGUL is designed as a geo-dashboard to support data-informed decision-making process, in the urban environments of medium and big cities.

The originality of SEAGUL is its ability to integrate standardized indicators to measure urban inclusiveness, with city-specific variables, enabling a detailed and up-to-date understanding of socio-economic inequalities at the sub-municipal level. Unlike many existing dashboards, SEAGUL adopts a Multilevel framework, encompassing environmental, demographic, and service-related dimensions, mapped onto a spatial grid that reflects the administrative and morphological complexity of cities. This structure facilitate a more nuanced analysis of urban dynamics and supports the development of targeted, evidence-based policies.

The development of the dashboard followed a user-centered design approach, grounded in scientific literature and refined through participatory methods such as Living Labs. These engages policymakers, technicians, and researchers in iterative feedback sessions to ensure the tool's usability, relevance, and alignment with real governance requirements and needs. Usability, both in terms of interface and content, was recognized a key factor in the effectiveness of urban dashboards. SEAGUL address this challenge by combining a robust analytical framework with intuitive interaction features.

A key innovation of SEAGUL is its integration of artificial intelligence. A large language model (LLM)-based assistant, is prototyped to enable natural language interaction via voice or text, making the dashboard more accessible to non-expert users. The future development is the implementation with clustering algorithms to identify spatial, social, and service-related vulnerabilities across city neighbourhoods, further enhancing the tool's capacity to support inclusive urban planning.

The ongoing implementation phase aims to evolve SEAGUL from a prototype into a scalable and replicable model for smart urban governance. The tool is designed to be adaptable to different urban contexts, while maintaining a consistent methodological core. In conclusion, the research has the aim to exemplifies, how digital innovation, when combined with participatory design and ICT and AI capabilities, may fill the gap between the production and availability of high quantities of administrative data, and their effective use for local management and governance.

Acknowledgments. This work was carried out within the framework of the project RAISE - Robotics and AI for Socio-economic Empowerment and has been supported by European Union - NextGenerationEU.

Author Contributions. Chapter 1, all the Authors; Chapter 2, 2.1 MB; Chapter 2.2 MB; Chapter 2.3 DO; Chapter 3 CM, EP; Chapter 4, all the Authors.

Conflict of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

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Analyzing Waste Management Strategies for "Cinque Terre" Area

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Abstract. This study presents a comprehensive analysis of urban solid waste management in Riomaggiore, located in the Cinque Terre National Park, a prominent Italian tourist destination. The municipality faces significant challenges due to overtourism, leading to increased waste production that threatens its socio-environmental integrity. This paper explores fluctuations in waste volume related to tourism growth, particularly in the post-pandemic context, while examining the local administration's efforts to rationalize waste collection. Through interviews with key stakeholders and secondary data collection, the study evaluates the relationship between tourist influx and municipal solid waste generation, identifying critical periods of heightened waste production. The study employs a quantitative modeling approach, implemented by the spreadsheet Excel, to assess current waste management practices, framing the issue as a transportation problem within a multi-level network. While this analysis serves as a partial examination, it establishes a vital foundation for future optimization strategies aimed at enhancing sustainability in waste management. Ultimately, Riomaggiore can act as a pilot case for broader applications within the Cinque Terre, emphasizing the importance of effective waste management in preserving both the environment and the local community's heritage.

Keywords: Urban Solid Waste Management· Overtourism Impact · Sustainability Strategies · Quantitative Modeling

1 Introduction and Methodology

This study provides a comprehensive analysis of the current urban solid waste management in the municipality of Riomaggiore, located in the Cinque Terre National Park. This area is a significant Italian tourist destination along the northwestern Mediterranean coast in the Liguria region. In recent years, it has faced substantial challenges due to overtourism, resulting in a dramatic increase in waste production that strains the integrity of its unique socio-environmental characteristics. These features have contributed to its designation as a UNESCO World Heritage site since 1997.

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 24–41, 2026.
https://doi.org/10.1007/978-3-032-21842-1_3

In addition to illustrating how the volume of urban solid waste has fluctuated due to the uncontrolled expansion of tourism [1], particularly in the post-pandemic period, this study examines how the local administration has begun to rationalize waste collection. It also explores potential areas for further improvement through the implementation of strategies aimed at optimizing existing waste management systems. These efforts seek to enhance the sustainability of a uniquely valuable yet highly fragile territorial context.

Primary data were collected through interviews with the Head of the Technical Office of Riomaggiore, providing insights into the existing waste management protocols. This allowed for an assessment of potential strategies to mitigate environmental impacts [2] and improve process efficiency while optimizing costs. Those data have been collected also through a series of interviews conducted with a group of local stakeholders employed in the tourism sector, as direct beneficiaries of the policies implemented by the Municipality.

Additionally, complementary secondary data were obtained from literature reviews, governmental and non-governmental reports, and statistical materials. This enabled an evaluation of the strong correlation between the increase in municipal solid waste and tourist influx, as well as the identification of the periods of the year when the issue is most severe. It is important to note that comparisons between different variables were not always possible with older data.

This study presents a quantitative approach to evaluate the current waste management practices in Riomaggiore, thereby establishing a basis for enhancing efficiency and sustainability in future waste management efforts.

Riomaggiore can thus serve as a pilot case for the other two municipalities within the Cinque Terre territory. In an area as complex as this, despite the presence of a National Park, the municipalities are the primary decision-makers in matters of municipal solid waste management. However, they do not always possess the material and immaterial resources necessary to implement management policies with uncertain outcomes, which could potentially lead to conflicts within the local population. The innovation of this work lies in proposing a data-driven approach to improve waste collection management through context-specific data collection combined with targeted optimization and monitoring tools tailored to the unique morphology of a Cinque Terre municipality. The proposed approach enables the evaluation of waste-management strategies to increase collection efficiency, reduce transport costs and environmental impact, and offers a transferable model for other complex contexts.

1.1 Waste Management

Waste management refers to the activities and processes involved in managing waste produced by communities and organizations. Key aspects include the collection and transportation of solid waste, separation and recycling of materials, treatment to reduce harmfulness, and proper disposal methods such as landfilling or incineration. Additionally, waste management aims to recover resources from waste and promote sustainable practices through community education and awareness. Effective waste management is essential for protecting the environment, public health, and promoting sustainability by reducing the environmental impact of human activities.

In heavily touristic areas, effective waste management is especially critical, as the influx of visitors significantly increases waste generation. A well-managed waste system not only protects the environment and public health but also enhances the experience for tourists, helping to maintain the local community's appeal and reputation.

Within the evolving framework of smart cities, waste management is a crucial area presenting both challenges and opportunities for sustainable urban development. Indeed, smart cities leverage technology and data to enhance urban living, prioritizing efficiency, sustainability, and citizen well-being. Key characteristics encompass connected infrastructure, data analytics, optimized public services (including smart waste management utilizing advanced technologies and artificial intelligence), environmental sustainability, citizen engagement, intelligent mobility, energy efficiency, security, resilience, and an innovative economy. Smart waste management, by leveraging new technologies and AI to enhance quality of life for residents and tourists while improving environmental quality, is therefore inherently aligned with and integrated into the smart city framework. Fundamentally, it represents employing technology to address urban challenges and elevate the quality of life for all [3].

In highly visited tourist areas, facing waste management challenges mirroring those in densely populated urban centers, traditional waste management systems increasingly struggle with inefficiencies, environmental impact, and social inequalities. Consequently, smart destinations are modernizing waste management through the integration of advanced digital technologies and computational intelligence tools [4]. Quantitative approaches, mathematical models applied to support solid waste management, have been revised in [5]. Mathematical programming has been widely applied to solid waste management issues, with many researchers focusing on multiple objectives. [6] highlights the inclusion of social aspects in solid waste management studies and the challenges of quantifying these aspects for optimization. Sustainable solid waste management frameworks must consider the interests of various stakeholders, including local authorities, residents, tourists, and all economic operators within the industry, thereby fostering a collaborative approach that supports environmental sustainability and community well-being. To address social factors, researchers employ methods such as interviews and surveys to gather insights from stakeholders. However, [6] stresses that only 10% of the reviewed studies involved stakeholders in defining social indicators for decision-making. A methodology for quantifying social metrics in solid waste management systems, addressing the challenges of integrating these indicators into optimization frameworks and highlighting the impact of employee turnover and exposure risks on operational efficiency and safety is developed in [7].

Solid waste management faces a critical global challenge, but the integration of artificial intelligence (AI) and information and communication technology (ICT) offers innovative solutions to enhance waste management practices supporting real-time data collection and monitoring. Smart bins equipped with sensors, for instance, can track fill levels and communicate with collection systems to dynamically schedule waste pickup, optimizing routes and minimizing fuel use and emissions [4, 8]. This not only results in operational cost savings but also contributes to the reduction of the city's environmental footprint.

AI-driven predictive models improve waste forecasting and recycling initiatives, while these technologies optimize collection routes and enable accurate waste sorting, significantly increasing recycling rates. A systematic review identifying challenges in implementing AI and ICT in solid waste management is presented in [9], while contributing to the conversation on sustainable waste management practices and future trends.

Recent literature presents integrated smart waste management (ISWM) as an innovative and technologically advanced method for waste management and collection. ISWM permits to improve both the efficiency and effectiveness of waste management, while also looking for sustainability and cost reduction. This comprehensive approach addresses the entire waste stream, from generation to final disposal. This approach is grounded in Internet of Things (IoT) technology, which involves a network of interconnected devices capable of communicating and exchanging data. The information gathered from IoT devices enables municipalities to enhance the efficiency of their waste management operations [10]. The authors of [10] propose a multi objective optimization approach for a multi-level network.

Digitalization and new technologies, essential components of smart destinations, play a crucial role in solid waste management. However, their application and integration must be tailored to the specific operational and social context of the community.

Transportation and logistics operations represent a substantial portion of the total costs within the waste management system [11]. As a result, the vehicle routing problem (VRP) has garnered significant attention as a means to reduce costs associated with this phase of the waste management process [12]. A two-stage model designed to optimize waste management by assisting a regional authority in locating sorting facilities and determining their capacities, while optimizing vehicle route lengths for waste collection and minimizing Greenhouse Gas emissions in presented in [13].

In this work, we present a preliminary attempt to utilize a spreadsheet-based modeling approach to evaluate the waste management strategy implemented by the Municipality of Riomaggiore for handling waste generated by accommodation facilities and second homes. We frame this issue as a transportation problem within a multi-level network. This modeling decision stems from the region's unique landscape and morphology, which often necessitate door-to-door collection conducted on foot, as vehicle access is impractical. Furthermore, the limited roadways require the use of small electric vehicles that are incapable of performing conventional waste collection routes. The proposed quantitative approach is designed to provide an initial framework for organizing waste management effectively, ultimately leading to the optimization of the entire process. Although it is a partial study, it marks a crucial first step toward more comprehensive solutions.

The rest of the paper is organized as follows: Sect. 2 provides an overview of the territory of Riomaggiore and its characteristics. Section 3 analyzes the impact of increased tourism on waste production in the area, while Sect. 4 details the waste management practices in Riomaggiore. Section 5 presents the quantitative approach employed in this study, and Sect. 6 outlines the conclusions and suggestions for future research.

2 Riomaggiore's Territorial Characteristics

The focus of this study is Riomaggiore, along with its settlements of Manarola, Volastra, and Groppo (Fig. 1). The municipality is situated in the province of La Spezia, within the Cinque Terre area, approximately 90 km east of the city of Genoa. An inset map shows the location of the area within Italy, marked with a red pin.

Fig. 1. Riomaggiore and its settlements: Manarola, Groppo and Volastra. Our elaboration from https://www.parconazionale5terre.it/map.php), https://www.google.it/maps.

As mentioned, this area was designated a UNESCO World Cultural and Natural Heritage Site in 1997, alongside Portovenere and the islands of Palmaria, Tino, and Tinetto. Two years later, on October 6, 1999, it was established as a National Park by a decree from the President of the Republic. Covering 3,868 hectares, it is the smallest park in Italy, yet it has the highest population density, with approximately 4,000 inhabitants. The park includes the municipalities of Monterosso al Mare, Vernazza and its hamlet of Corniglia, as well as Riomaggiore and its hamlet of Manarola. Riomaggiore, encompassing an area of 10.30 km2, is the southeasternmost municipality of the Cinque Terre. It is situated between the Ligurian Sea and the mountain range that branches off from the Apennines near Monte Zatta, extending southeastward and acting as the watershed between the Val di Vara and the coastal region.

The original core of its historic centre dates back to the 13th century and is situated in the valley of the Rio Maggiore stream. The settlement consists of parallel, tower-like houses built according to the Genoese tradition, following the steep course of the stream. The more recent *Stazione* district, developed in the second half of the 19th century, is situated in the adjacent valley of the Rio Finale. The two valleys, where the settlement extends, are separated by the steep *Campiòne* ridge, at the base of which lies the town’s castle.

According to ISTAT data, in 2023 Riomaggiore had a population of 1,313 residents, with approximately two-thirds residing in the main settlement of Riomaggiore and the remaining third in Manarola.

The geomorphological and settlement characteristics of Riomaggiore are crucial for understanding the challenges related to urban solid waste collection, especially when waste volumes surpass the territory’s actual absorption capacity as a result of overtourism. In order to better understand this situation, it is essential to analyze both the weather patterns and the impact of increased tourism on waste production, threatening the environmental, social and economic sustainability of the municipality and, more generally, of the entire Cinque Terre area.

3 Overtourism and Waste Production in Riomaggiore

The history of the massification of tourism in the Cinque Terre began with the construction of the coastal road in the 1950s and 1960s, which made accessible an area hitherto known for wine production [14]. Over time, accessibility and the region’s unique charm have transformed it from an agricultural area into one of the main overtourism areas in Italy. However, it is important to note that that while the area is accessible by car, train, and sea, navigating within the villages themselves is far from easy. This presents challenges not only for tourism supply but also for the management and disposal of urban solid waste.

According to a study conducted for the Cinque Terre National Park by [15, 16], which relied on a preliminary estimate of tourist flows into the park by correlating various data sources, historical records, and assumptions about park access, it was found that in 2023, nearly 3.5 million tourists were concentrated within an area of just 1 km2, representing only 3% of the park’s total area. The highest influx occurred during the spring and summer months, particularly from April to September, when over 85% of visitors were recorded (Fig. 2), reflecting an overall increase of approximately one million compared to 2022.

This situation indicates a high concentration of visitors in the municipality of Riomaggiore. Official tourism data, which track arrivals and overnight stays in hotels and other accommodation facilities (excluding second homes), although significantly lower than the estimates provided by [15] for the entire region, offer insight into the levels of tourist concentration and seasonality (Fig. 3).

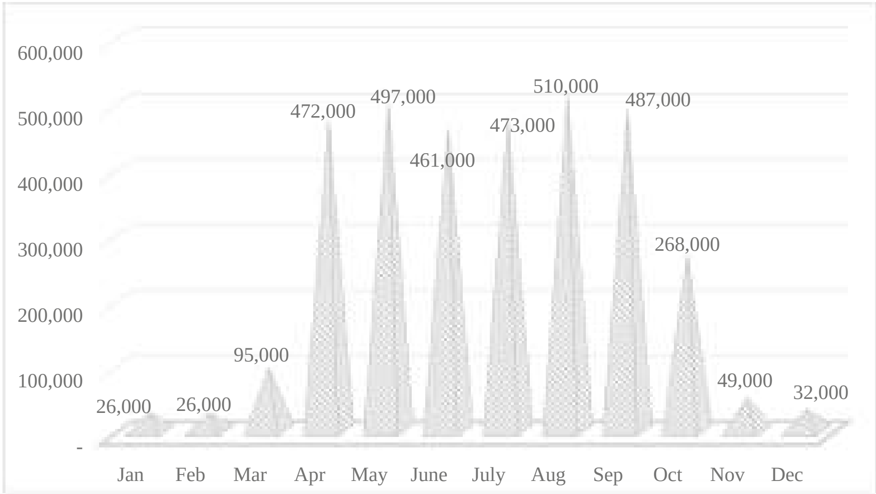


Fig. 2. Estimated visitors to the Cinque Terre in 2023. Source [6].

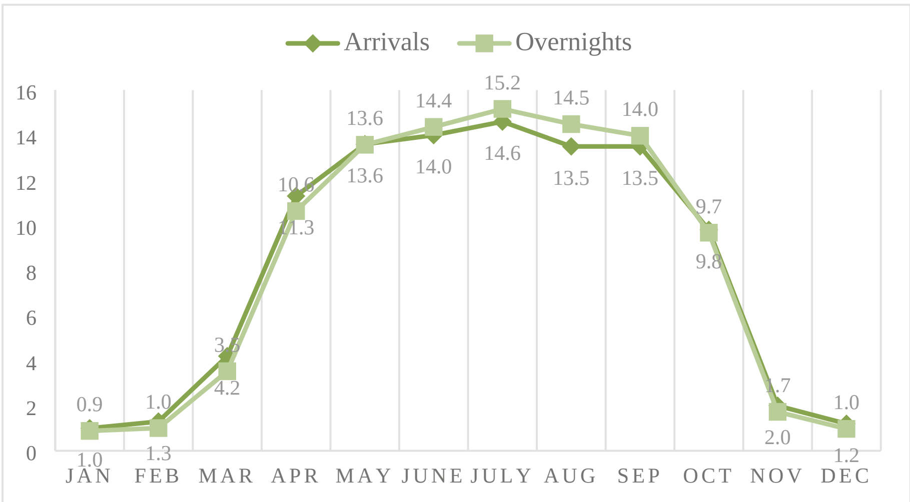


Fig. 3. Percentage trend of arrivals and presences in Riomaggiore in 2023. Source: ISTAT, 2025.

In 2023, tourist arrivals in Riomaggiore reached 107,739, while overnight stays totaled 259,076. Compared to 2019, these figures represent an increase, with overnight stays experiencing a higher percentage growth of approximately 12%, while arrivals saw a more modest rise of 1.3%. When compared to 2014, both metrics demonstrate significant growth, increasing by 87.9% for arrivals and 97.1% for overnight stays, equivalent to absolute increases of 57,325 and 131,452, respectively.

The provisional data for 2024 indicate a slight decline compared to the previous year, with arrivals decreasing by 2.1% and overnight stays falling by 2.7%. This trend may reflect the impact of policies aimed at redistributing tourist flows. Efforts are underway not only to regulate tourism but also to redirect it, encouraging tourism organizations to adopt alternative management strategies and to promote a deeper appreciation of the area’s natural and cultural heritage [17]. However, achieving this is not straightforward. While redirecting visitors to less frequented areas could be a potential solution, first-time visitors to the Cinque Terre are often reluctant to forgo the scenic paths overlooking the sea or the iconic “Via dell’Amore”. This highlights the necessity of managing the region as sustainably as possible, including effective waste management.

The trend in tourist flows significantly influences the generation of urban solid waste. Figure 4 illustrates the monthly trend of urban solid waste production in Riomaggiore for 2019 and 2023 (in tonnes), revealing an overall increase of nearly 30% between the two years. Furthermore, the monthly distribution closely aligns with the pattern of tourist flows (see Fig. 3).

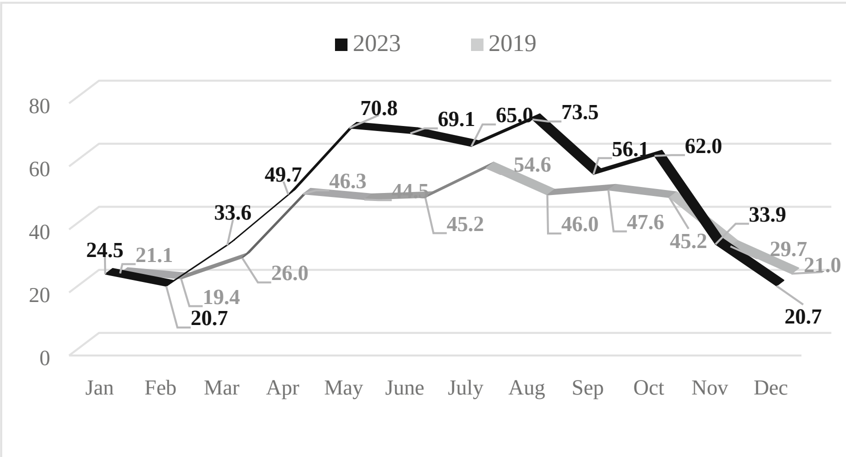


Fig. 4. Monthly trend of urban solid waste production in Riomaggiore in 2019 and 2023 in tonnes. Source: Regione Liguria, https://servizi.regione.liguria.it/page/welcome/RIFIUTI_URBANI

Figure 5 displays urban solid waste production per capita for the top 10 municipalities along with Riomaggiore for the years 2023, 2019, and 2007 (in kg). It highlights that per capita waste generation in Riomaggiore increased by approximately 21% between 2019 and 2023, and by about 45% when comparing 2023 to 2007.

The trend of these two variables indicates that the costs borne by the local population for waste management are significantly high—not necessarily from an economic standpoint, as the municipality provides support, but in terms of social and environmental well-being. The increasing number of tourists directly contributes to heightened waste production, necessitating efficient management strategies. In this context, the municipality has already implemented various policies and supported targeted actions.

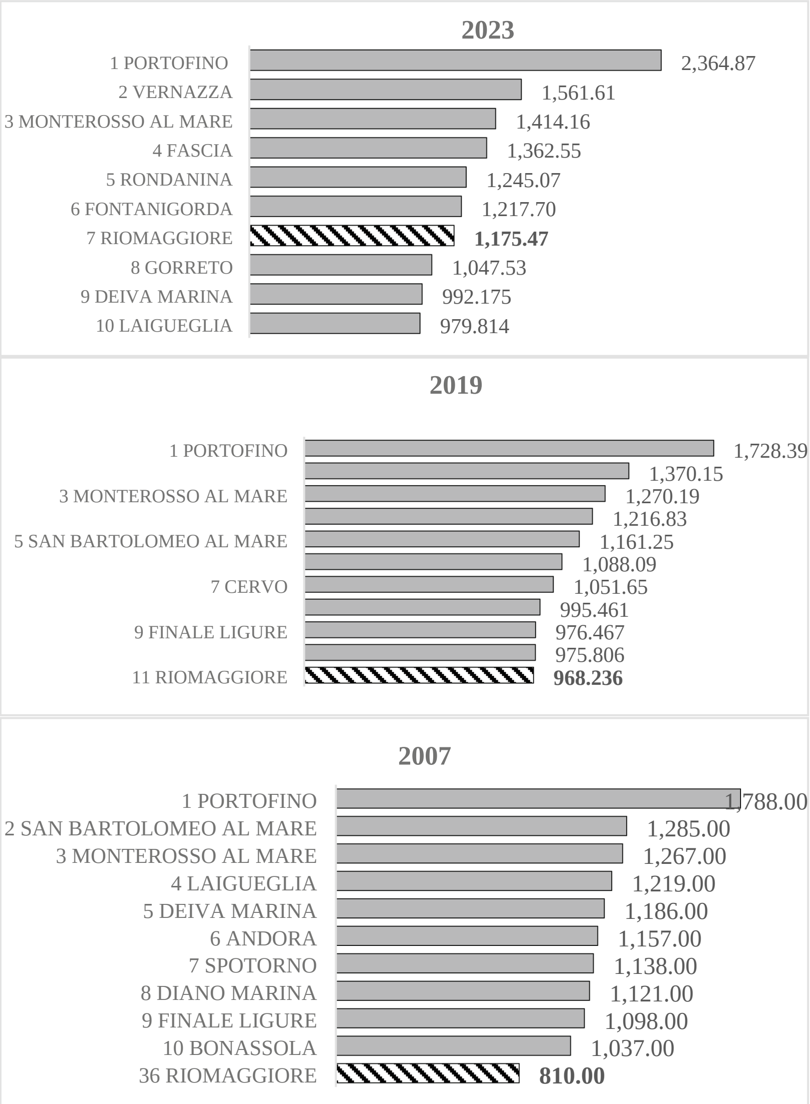


Fig. 5. Urban solid waste production per capita first 10 municipalities and Riomaggiore years 2023, 2019, 2007 in kg. Source: Regione Liguria, https://servizi.regione.liguria.it/page/welcome/RIFIUTI_URBANI

4 Waste Management in Riomaggiore

The in-deph interview with the Head of the Technical Office of the Municipality of Riomaggiore confirmed that best practices implemented in other tourist destinations are not effective here due to the area's unique morphological characteristics, which complicate waste flow management.

To address the situation described in the previous paragraph, Riomaggiore and its hamlets have adopted experimental and alternative waste collection methods to ensure higher cleanliness levels, particularly in areas frequently visited by tourists and hikers at various times of the day. As emphasized by the Head of the Technical Office, 2024 marks a transitional year for waste management strategies.

Micro waste collection islands have been established in the three villages specifically for accommodation facilities, as their waste disposal needs do not always align with the scheduled collection times due to guest check-out schedules. Bars and restaurants also benefit from a customized collection system, with waste pickups occurring in the evening and at dawn during the summer season for all types of waste. Additionally, most waste collection containers have been replaced, and a complete system renewal is planned for 2025.

Since spring 2024, waste collection services have been expanded to include evening pickups, even in areas near the Marina that are inaccessible to vehicles. Glass waste, in particular, is managed by a local craftsman who collects it overnight, transports it to a designated area, and coordinates its removal. These additional services were introduced because the area around the tourist harbor is often frequented by an increasing number of visitors who consume food and drinks by the sea after the last official collection. In residential areas, waste is collected through a door-to-door system that follows a specific schedule designating different collection days for various types of waste.

Additionally, to reduce plastic consumption —particularly from bottled water—three water stations will be installed. These stations will provide monitored drinking water in the three main villages of the municipality and will be managed by an external operator. Water will be available for a fee, with different rates for residents and tourists, sourced directly from the local water supply before undergoing purification.

Street cleaning has also been enhanced: during the summer months, streets and lifts are swept multiple times a day, thanks to the collaboration of local cooperatives working alongside the company responsible for routine waste management.

In conclusion, the comprehensive waste management strategies implemented in Riomaggiore—ranging from innovative collection methods and the establishment of micro waste collection islands to the installation of water stations and enhanced street cleaning—reflect a proactive approach to maintaining cleanliness and sustainability in this unique coastal municipality, especially in light of its increasing tourist activity.

A few months after the implementation of the initial measures described above, in August 2024, ten local stakeholders working in the tourism sector – particularly in tourist accommodation (e.g., short-term rental managers and B&B owners) and food service – were interviewed, as they represent the primary beneficiaries of the policies introduced. In general, the interviewees demonstrated good awareness of the initiatives undertaken by the municipality, such as the installation of dedicated ecological islands and the twice-daily collection of commercial waste. However, other measures – such as the collection of glass waste in the beach area or the planned installation of water dispensers aimed at reducing plastic use – were less well-known, highlighting a potential need for improved institutional communication.

The perception of tourist behaviour regarding waste management was largely negative: most respondents believed that visitors tend not to follow the rules and handle waste carelessly. Some also pointed out infrastructural shortcomings, including an insufficient number and size of public waste bins, as well as the excessive use of single-use packaging. Nonetheless, evaluations of municipal policies were not entirely critical. There was openness to the adoption of technological solutions, although half of the interviewees expressed scepticism. More prominently, there was a clear demand for increased citizen involvement, proposals for incentive-based systems to encourage virtuous behaviour, and a widely shared recognition of the need to redistribute tourist flows more evenly throughout the year in order to ease pressure during peak seasons.

From an operational standpoint, the priorities identified included enhancing street and beach cleaning services, increasing collection frequency, improving the availability and quality of public waste bins, and carrying out more frequent maintenance in peripheral or less well-maintained areas. The newly introduced waste bins were generally well received, both in terms of functionality and aesthetics.

Finally, some interviewees emphasized the need to simplify the waste disposal system and to design alternative solutions for elderly residents, who often face challenges in this regard. Given the geomorphological characteristics of the area, waste disposal is not always straightforward. In such cases, the adoption of smarter systems would undoubtedly be beneficial.

In the following section, we propose an Excel spreadsheet to conduct an initial assessment of the presence of ecological micro-islands for waste collection.

5 An Optimization Approach for Evaluating the Waste Management System Based on Micro Eco-Islands

Based on the spatial distribution of accommodation facilities and second homes within the territory of Riomaggiore, known the location of the ecological micro-islands and by analysing the available connections among them, we were able to create a graph to better analyse the waste collection problem. The graph permits to visualise the waste collection network and to implement a transportation model in such a way to optimize the collection costs by suggesting a waste delivery strategy to the central depot.

As already mentioned the door-to-door collection system evolved to a model where waste from the various operators is delivered to the eco-islands, which are subsequently serviced by small collection trucks that can easily navigate the streets of Riomaggiore, Manarola, Volastra and Groppo.

Due to the area's morphological characteristics and the fact that the distances and travel times—whether on foot or using a small electric vehicle—are generally very short, we have chosen to cluster accommodation facilities and second homes; each cluster serves as a production node in our network and is characterized by a specific production rate. Conversely, the micro eco-islands represent collection points with defined capacities. Additionally, the network includes two peripheral depots designated for the temporary storage of waste until it is transferred to a central depot, far away closed to the city of La Spezia (see Fig. 6).

The analysis began with the clusterization of the accommodation facilities and an assessment of the waste quantities delivered by each cluster to the eco-islands; six clusters have been defined for Manarola, six for Riomaggiore, one for Volastra and one for

Fig. 6. The region under investigation with 8 micro eco-islands and peripheral depots

Groppo. Each cluster, composed by a number of facilities ranging from 6 to 16, is connected to the micro eco-islands present in their respective locality. The resulting network is depicted in Fig. 7. Each micro eco-island is connected to both the depots and the last layer represents the connection of the depots to the central one in La Spezia.

The optimization problem consists in determining the flow of waste from production nodes, i.e., the clusters of accommodation facilities and second homes to the micro eco-islands, and at the second level of the network, from the micro eco-islands to the available depots, while the last transfer is from the depots to the central one. Please note that the capacities of eco-islands and peripheral depots (d1 and d2) must be respected; we assume the central depot of La Spezia has not a capacity limit.

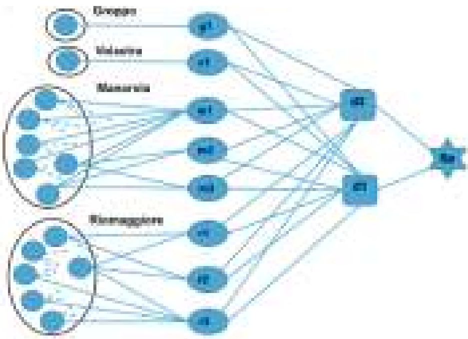
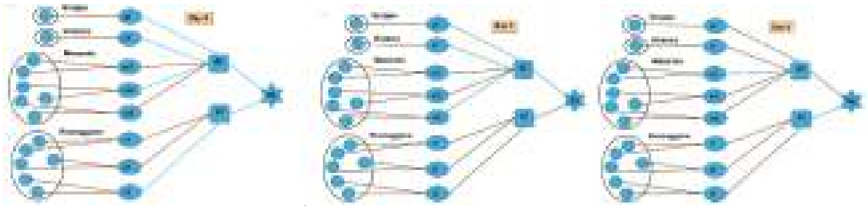


Fig. 7. The graph depicting the logistics of the waste collection system

The capacity of each micro eco-islands is limited and lower than the capacity of the peripheral depots; for this reason the waste flows are diversified day by day. This means that there may be a daily transfer of waste from the micro islands to the peripheral depots, while the peripheral depots will likely have biweekly transfers to the central depot in La Spezia, depending on the waste rate production and thus on the season and the flow of tourists. Therefore, the analysis consider a specific time frame, such as a week. An example of waste flows in the network during some days of a week is depicted in Fig. 8. For each reported day, the waste flows are represented thanks to brown arcs.



Day1 **Day2** **Day3**

Fig. 8. A feasible solution for the Riomaggiore waste collection system – 3 days planning

From a managerial perspective, this basic approach allows for the evaluation of both the network's and the vehicles' capacity to manage the waste produced, the identification of the most effective collection policies in terms of days/trips from micro eco-islands to the central depot, and finally, the assessment of the feasibility of managing other waste categories within this collection network (e.g., glass).

Regarding the optimization model, we have addressed a multiperiod, single product transportation problem using spreadsheets Excel. In this initial study, optimization is solely focused on defining the flows between the layers of the network to ensure compliance with the capacities of the eco-island and depots, while minimizing both total collection costs and, indirectly, the environmental impact of the collection activities. The use of electric vehicles for transporting waste from micro-islands to depots allows us to disregard emission costs within this layer of the network. However, this consideration is not applicable to waste transfer from depots to the central facility. Therefore, we adopted a weighted cost function that penalizes transportation costs in the last layer of the network.

The problem has been implemented and solved using Excel's Solver. The spreadsheet is organized into different sections, each corresponding to a layer of the network and a specific day within the planning horizon. For each layer, the data are presented in light blue cells. The section related to the first layer is shown in Fig. 9. For this layer, the sheet reports the distances between each pair of facilities, as well as the quantities to be delivered to the nodes of the second layer (note that these data vary for each day of the planning horizon). The capacities of the facilities within each layer are also displayed; specifically, the capacity of the micro eco-island is reported in Row 36.

The green cells represent the decision variables; upon completion of the optimization process, these cells display the optimal flow among nodes/facilities within the layer under consideration (e.g., from production nodes to micro eco-islands in Fig. 9) for the specific day analyzed (Day 1 in Fig. 9). The gray cells contain formulas that compute the outflows and inflows—referring again to the layer shown in Fig. 9, they represent the total quantity transferred from each production node (outflow) and the total quantity entering each micro eco-island (inflow).

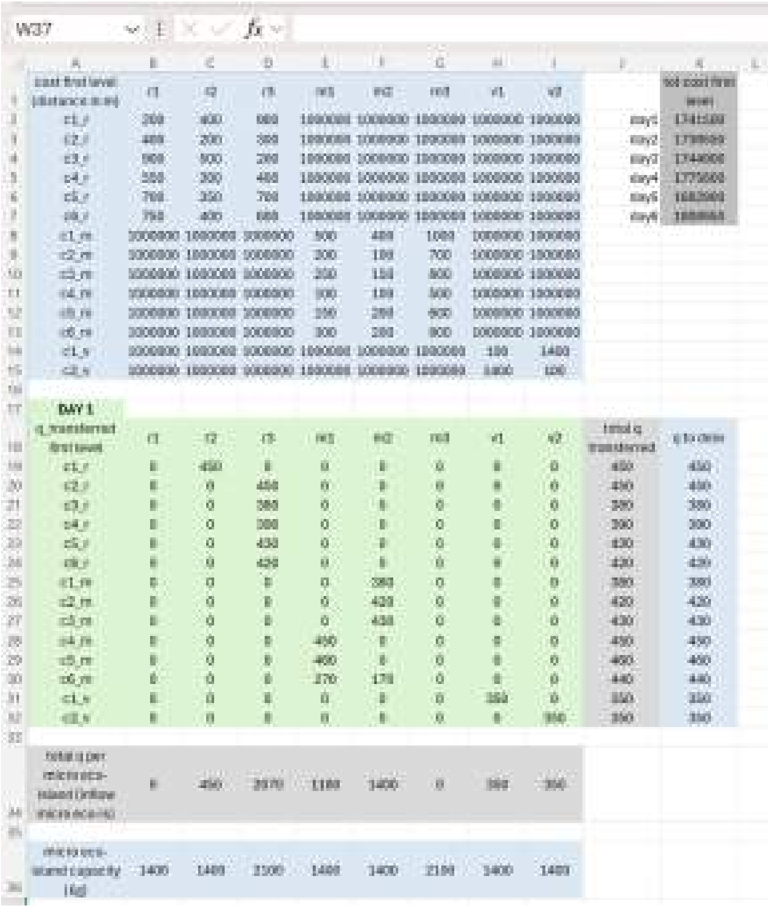


Fig. 9. The first level network in the spreadsheet Excel: data, decisions and formulas

Furthermore, the total cost associated with waste transportation in the first network layer is reported in the gray cells located in the top-right section of Fig. 9 (Column K). The same structure is applied to the second and third network layers (see Fig. 10). The second layer involves the micro eco-islands and peripheral depots (d1 and d2). At the end of each day, a waste stock may be present in each peripheral depot, calculated as the initial stock (for Day 1) or the stock at the end of the previous day (for subsequent days), plus the inflow from the micro eco-islands, minus the outflow sent to the central depot.

Moreover, Fig. 10 reports the total daily costs, calculated as the sum of the costs across all layers. The total cost is displayed in the yellow cell and serves as the criterion for evaluating the effectiveness of a collection solution within the given network. The total cost to be minimized is the weighted sum of the transportation costs across the three levels of the network over the considered time horizon. In more detail, we optimize the collection costs, identifying the optimal flows on the network while collecting all the produced waste. We assume that each operator prefers to ship its waste to the closest micro island, for this reason we minimize the total distance travelled for reaching the eco-islands; moreover, we minimize the total distance traveled for empty the eco-islands and transfer the waste to the depots. Finally, the last term to minimize is the cost for transferring waste to the central depot. This last component is weighted more than the others representing the most important element for the environmental aspects.

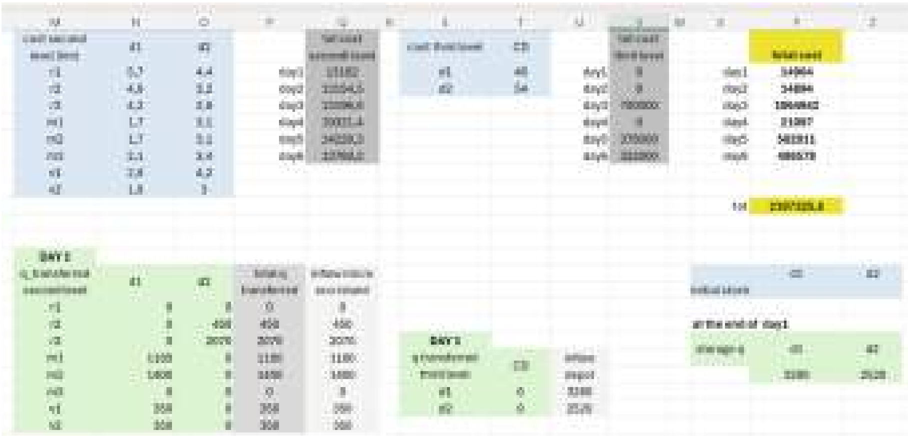


Fig. 10. The second and third levels in the spreadsheet Excel: data, decisions, formulas, and main objective.

Gray cells in Figs. 9 and 10 contain formulas used to enforce constraints related to capacity and flow conservation within the network in the optimization model. For example, at each micro eco-island, the total inflow must be equal to the total outflow; the total outflow from each production node must correspond to the quantity to be delivered; and the capacity of each micro eco-island must be respected (i.e., the total inflow to each micro eco-island on each day must not exceed its capacity). Regarding each peripheral depot, the total quantity stored at the end of each day must not exceed its storage capacity.

We have represented the transportation problem in such a way to find the best solution for transferring the waste during the considered planning horizon. Additionally, thanks to this spreadsheet we are able to identify the maximum amount of waste that the network is able to transfer from the production points to the La Spezia depot.

Paying attention to the collection network, with a focus on the relationships between the eco-islands and the downstream processes, which include peripheral depots and the central depot for waste disposal, we can observe that the actual network presents 2 depots (d1 and d2) both directly connected with La Spezia depot. Analysis of flows at the last level of the network revealed the potential to optimize waste transfers by implementing a single collection route that visits both peripheral depots before proceeding to the central depot in La Spezia. Given current flow volumes, this configuration also allows the peripheral depots to serve as interim storage for other waste types (e.g., glass), further optimizing their transfer to La Spezia.

Moreover, it is possible to use the spreadsheet to evaluate different networks, for example, a network with only one depot serving all eco-islands, or on the opposite, a network with more peripheral depots, defining the best number of depots, their capacities and their location.

6 Results and Conclusions

Preliminary results of the quantitative approach employed in this study indicate that the current waste management network, dedicated to a specific waste product, can effectively handle waste during peak summer periods. Using the Excel spreadsheet, we are able to identify the optimal collection strategies that minimize both overall costs and environmental impact. Furthermore, we are able to propose more promising strategies by modifying the collection process in the last layer of the network, which has the most significant environmental impact, and by integrating the collection of other waste streams, such as glass, which increase the total waste management costs within the municipality.

These results are important but remain a theoretical outcome, as tourism operators managing accommodation facilities are responsible for depositing their waste at the eco-islands, thus it does not guarantee proper management. The municipal incentives are crucial to ensure that operators efficiently deliver waste to the eco-islands. The municipality’s goal is undeniably to measure the quantity of waste delivered by various operators, enabling the development of appropriate pricing policies. This is an essential foundation for achieving an efficient waste collection system in the area.

Although numerous data regarding waste in Riomaggiore are available, a more detailed data collection system would facilitate the implementation of a more efficient management system. Therefore, from a data perspective, it is essential to design datasets to monitor and optimize waste management.

Effective monitoring of the waste management system relies on two pillars: quantitative and qualitative monitoring. By offering clear, evidence-based results, it enhances community awareness of the tangible benefits and fosters greater support for sustainable practices. Additionally, transparent and credible data serve as a compelling demonstration for other municipalities and stakeholders, encouraging them to adopt similar successful strategies and facilitating the dissemination of effective waste management models on a broader scale.

However, it is important to acknowledge that many smaller municipalities face significant challenges in organizing an accurate and systematic data collection process, which can impede effective monitoring and decision-making. In the case of the Cinque Terre, a unified shared system should be designed to address these difficulties, with Riomaggiore taking a leading role in guiding this digitalization process—an essential step toward establishing a smart waste management system appropriate for a smart city context.

Before concluding, we must remind that this preliminary study provides insights on optimizing a collection process that is a subsystem of the whole waste management system of Riomaggiore. Even if, in the previous section we mentioned the possibility of using the transportation system involving the micro eco-islands to other waste, i.e., glasses that has a specific collection process, a more comprehensive study addressing the overall waste management system is necessary for obtaining a sustainable waste management system. The possibility is to extend the optimization model to a multi-product, multi-period transport problem in such a way to define the most effective collection strategy for various types of waste managed within the micro eco-islands.

Finally, a general consideration regarding the potential to improve the collection cost and sustainability thanks to the usage of new technologies, for example by equipping the entire system with sensors would enable a more rational and efficient collection process.

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A Participatory Best Practice Supported by Technology for the Governance of University Sustainable Mobility

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Abstract. This paper presents a best practice developed within the PRINCE project "Rewards and Incentives for Modal Shift" ("PRemialità e INCEntivi per il cambiamento modale"), funded by the Ministry for the Environment, Land and Sea Protection of Italy (2018–2024), in which the University of Genoa is a partner. The initiative is proposed as a replicable model for participatory governance of sustainable mobility in academic contexts. Specifically, it focuses on the role that technology and incentive mechanisms played in achieving the project's goal: changing university students' mobility habits toward more sustainable forms of transport.

Given the significant impact of university mobility on overall urban mobility, the UniGe community was chosen as a test group for experimenting with new technologies and scalable best practices at the urban level.

The PRINCE project stands out for its integration of technological innovation (via a dedicated mobile App), participatory processes, and multi-stakeholder collaboration (Quintuple Helix), demonstrating how these elements can jointly contribute to effective urban policy.

The research, which recently concluded, stands out as a good participatory practice—involving various local stakeholders in Genoa—and is supported by innovative technological tools that contribute to the governance of sustainable university mobility.

Keywords: University community· Sustainable mobility · Technology

1 Introduction

In recent years, urban mobility systems have come under increasing strain due to rapid urbanization, rising travel demand, and a widespread reliance on unsustainable transport modes—particularly private car use. These trends have generated multiple negative impacts, such as road congestion, air pollution, land consumption, and social inequalities in access to services [1, 2]. In this context, the challenge facing urban planning is to build more efficient, equitable, and environmentally friendly mobility systems by promoting solutions that reduce dependence on private transport and encourage alternative modes such as public transit, active mobility (walking and cycling), and micromobility.

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 42–54, 2026.
https://doi.org/10.1007/978-3-032-21842-1_4

Urban areas are often viewed as laboratories for innovation, particularly in the context of sustainability transitions [3]. Cities have become strategic environments for testing new models of governance and technology integration, especially within the Smart City paradigm [4]. Technologies such as Big Data and the Internet of Things (IoT) are now central to urban mobility planning, offering real-time data collection, enhanced monitoring of travel flows, and more informed decision-making processes [5, 6].

However, the mere introduction of technological solutions is not sufficient to ensure a true transition toward a sustainable mobility model. Another key aspect to consider is the role of participatory and inclusive governance processes, capable of involving a wide range of stakeholders—the so-called Quintuple Helix: public sector, private sector, academia, the third sector, and citizens—in a shared process of defining goals and strategies [7–10]. It is therefore essential to accompany technological innovation with integrated and co-designed policies. Only through an integrated approach—combining digital tools with co-production practices in urban policymaking—can we hope to achieve lasting results in terms of sustainability, efficiency, and social justice.

Recent studies also emphasize the value of incentive-based strategies and behavioural tools, such as nudges and gamification, in steering mobility choices. These approaches are particularly effective when embedded in digital platforms like mobile applications, which can monitor user behavior and reward environmentally friendly decisions [10–12].

While the Smart City literature is vast, there is still limited research specifically focusing on university campuses as testbeds for sustainable mobility innovation. Yet universities are ideal microcosms for experimentation: they host diverse populations with varied travel needs and often concentrate significant daily mobility flows in compact urban areas [15]. Moreover, they align naturally with sustainability goals through their educational mission and increasing commitment to climate action.

This paper contributes to filling that gap by presenting the PRINCE project ("PRemialità e INCEntivi per il cambiamento modale") as a replicable best practice. Conducted in Genoa between 2018 and 2024 and involving a multi-actor partnership—including the University of Genoa, public agencies, transport operators, and ICT providers—the project aimed to promote modal shift among university students. It did so by combining a digital mobile App with a system of incentives, supported by participatory processes and stakeholder co-design.

Specifically, the PRINCE project, carried out between 2018 and 2024 in the city of Genoa, with the involvement of the University of Genoa and a diverse partnership made up of public institutions, transport companies, and private stakeholders, stands out as a significant case within this framework.

The project's main goal was to encourage a shift in the travel habits of the university community by promoting the adoption of sustainable mobility modes through the use of a mobile application (PRINCE App) based on a system of rewards and incentives [13, 14].

In this context, universities represent a privileged setting for experimenting with and applying innovative solutions for sustainable mobility governance. Characterized by high daily mobility and a wide variety of needs and behaviours, they form complex and dynamic communities that can serve as urban laboratories in which to test technological tools and civic engagement strategies [15].

This experience aims to highlight the importance of using technology, not only as a monitoring tool, but also as a lever to foster participation, awareness, and active citizen engagement. It reflects a model of governance based on collaboration among multiple stakeholders and the application of behavioural principles to guide individual choices toward more sustainable solutions.

The paper is structured to first provide a brief review of the scientific literature on sustainable mobility and participatory governance, with particular attention to the university context. It then discusses selected national best practices that integrate digital tools and incentive systems, before presenting the PRINCE project as a replicable model. Finally, the results are analysed and followed by conclusions on the potential of this approach for wider application.

This paper does not aim to provide an exhaustive account of all project phases. Rather, it focuses specifically on three key stages in the design and implementation of digital solutions: the co-development of ICT tools, the definition of incentive strategies, and the testing and monitoring of the PRINCE App. These phases are examined in depth to highlight the interplay between technology, participation, and behaviour change in the context of university mobility.

2 ICT and Incentives in University Mobility: Selected Italian Experiences

As previously mentioned, universities represent a privileged setting for experimenting with and applying innovative solutions for sustainable mobility governance. Furthermore, given their mission, they can be considered a driving force capable of raising awareness, educating, and ultimately contributing to the transformation of the cities and communities in which they operate, fostering both economic growth and social development [15]. Universities are, in fact, an integral part of the identity of cities, influencing their development and often shaping their cultural and social profile. In major university cities, both in Italy and abroad, the role of universities is clear, as they often serve as starting points for the testing of best practices. A common feature shared by universities—and relevant to urban areas—is the variety of information and situations that must be considered in order to develop effective strategies for improving sustainable mobility governance. What can be done, therefore, through various case studies and experiences, is to identify recurring, valuable concepts for the management and development of sustainable mobility systems to be promoted specifically for home-to-university travel.

Several initiatives, for example, promote the use of ICT tools to encourage sustainability. These tools are seen as a means to define, develop, and share strategies and solutions. In general, when it comes to mobility, information plays a crucial role—helping to organize trips, minimize travel time and reduce costs. Applications and sharing services complement public transport systems and make their use more efficient. The use of smartphones is increasingly emerging as a way to improve mobility and make it simpler and more sustainable [11, 12]. ICT today plays a strategic role within universities in enhancing the mobility experience. In this regard, academic institutions use data to make informed decisions about the services to offer students, the technologies to develop, and to launch and test projects and best practices. There are also other best practices—particularly relevant to the purpose of this contribution—that activate sustainable mobility processes through the use of technology, especially mobile applications.

In general, the objectives of these initiatives may include:

- Raise awareness among university users about sustainable mobility issues;
- Provide students and staff with useful information and services to access sustainable mobility options offered—potentially at subsidized prices—by the university and the municipality;
- Encourage and support an increase in environmentally friendly mobility choices, such as cycling and walking;
- Gather ideas and feedback directly from users to encourage participation in planning activities, helping to identify the most pressing issues and prioritize necessary interventions;
- Develop advanced information services to support user mobility;
- Provide data models and user profiles useful for building a database to support monitoring activities, data collection for the Home-to-Work Travel Plan, and the creation of origin-destination (OD) matrices.

Among these best practices, examples from Italian universities include the University of Naples L'Orientale, the University of Pavia, and the University of Turin. In June 2019, L'Orientale launched the UNIOR moveAPP, a sustainable mobility service that encourages users to share vehicles. This is a carpooling App that incentivizes sharing private cars with other users from the university community, generating benefits in terms of reducing the environmental, social, and economic impact of private car use. With this initiative, L'Orientale aims to contribute to the spread of best practices in sustainable mobility, raising awareness and educating users about environmental protection [16].

In 2022, the University of Pavia launched the sustainable mobility project "ActiveToWork@UNIPV", aimed at promoting active mobility (walking, cycling, or other sustainable modes) for the daily commuting of university staff and students. The project provides individual incentives (benefiting the individual) as well as collective incentives (for the academic community) in exchange for a commitment from staff and students to use active mobility for their home-to-work/home-to-university commutes.

The incentive aims to promote more sustainable transport modes, leading to a gradual reduction in the use of private vehicles, with positive effects on the environment, health, safety, and well-being of the population, as well as individual financial savings. Participation in the project is voluntary and open to the entire academic community: faculty, technical-administrative staff, and students.

To monitor the movements of project participants, the university decided to launch a free smartphone application that allows users to track the sustainable impact of their home-to-work commutes in terms of CO_2 savings. Based on the kilometers traveled using sustainable modes (carpooling, cycling, walking, public transport) and the CO_2 saved, the App automatically calculates credits that can be redeemed for rewards on a dedicated online shopping platform.

The credits accumulated by all participants will also help activate specific university projects for sustainable mobility (e.g., installation of new bike racks, activation of electric bikes, setting up a bike repair shop, etc.) [17].

Finally, regarding UniTO, during the European Mobility Week 2024, UniTO and its Green Office UniToGO launched a sustainable mobility challenge through the MUV App: "For one month, move sustainably, accumulate points, and try to win a Decathlon gift voucher. The more you move sustainably, the higher your chance of winning!" Points can be earned by traveling by bike, on foot, using electric vehicles (scooters, bicycles, e-scooters, and cars), public transport, and carpooling.

The challenge is part of the "Cycling, Campus & City" project, in which the University of Turin, together with the universities of Coimbra, Madrid, and Montpellier, and the International University Sports Federation (FISU), aims to promote sustainable mobility, particularly active mobility by bike, to enhance the health and well-being of the university community and help reduce the carbon footprint of the community's commuting [18].

From these experiences, it is already clear how ICT solutions are being used to improve, update, and connect all public transport operators, providing users (in a simple and quick way) with incentives to redirect their mobility choices. Moreover, these examples demonstrate how universities can serve as a fertile ground for experimenting with and implementing sustainable mobility strategies, thanks to the smart use of digital technologies and the active participation of the academic community. The analyzed experiences highlight the importance of an integrated approach, where ICT tools, incentives, and user engagement combine to bring about concrete and lasting changes in daily mobility behaviors.

Within this theoretical and operational framework, this paper discusses the PRINCE project not as an isolated case study, but as a participatory best practice.

Its relevance lies not only in the outcomes obtained in Genoa, but in the model's potential for transferability to other university contexts seeking to promote sustainable mobility through incentives, technology, and stakeholder engagement. The following section will be dedicated to analyzing this project, with a particular focus on the tools adopted, the objectives pursued, and the expected outcomes. The subsequent section will delve into the methodological and operational characteristics of the project, illustrating its objectives, development phases, and potential in terms of transferability and impact on both the urban and university context.

3 The PRINCE Project

The PRINCE project "PRemialità e INCEntivi per il cambiamento modale" is a "National experimental program for sustainable mobility in home-to-school and home-to-work commutes" funded by the Ministry of the Environment and the Protection of the Territory and the Sea. The project began in 2018 and was recently completed in December 2024. The lead partner of the project was the City of Genoa (Mobility Department), with partners including: UniGe-DICCA, AMT, Genova Parcheggi, Genova Car-Sharing, Softeco (now Algowatt), and Quaeryon. Specifically, the project involves strategic partners relevant to its goal, including public and private transport companies that manage sustainable mobility vehicles in Genoa, as well as some ICT companies. The project's general goal is to incentivize the use of sustainable transport (such as public transportation like buses, metro, car and bike-sharing, and bicycles) among students, particularly for home-to-university commutes. As mentioned earlier, university mobility has a significant impact on urban mobility, and thus the UniGe community has represented an excellent sample on which to test new technologies and best practices that can later be scaled to the urban level. To achieve this objective, the project defined and implemented integrated policies for incentives/loyalty/rewards/discounts linked to the use of sustainable transportation modes for urban commutes related to study activities [19]. The target requires a mix of different policies, so there is ongoing work to define various incentives that can integrate different types of sustainable transportation options, based on the concept of intermodality. Throughout the project, participatory processes for awareness-raising, involvement, and engagement were developed, and incentives and rewards (in-kind or monetary benefits) were defined as tools to steer students towards sustainable modes of transport. This approach aims to shift away from traditional restrictive/structural policies, such as circulation bans, access tariffs, or congestion charges. Moreover, the use of technology and participation were certainly the main innovations introduced across every phase of the project, which are summarized below:

– Phase 1 - Initial Knowledge: preparation and administration of online questionnaires to analyse the mobility habits of students and define tailored incentives and rules for the target group;
– Phase 2 - Co-Development of Technological Tools: study and definition of possible innovative ICT solutions to be used in service of the project's objective;
– Phase 3 - Incentive Policies: joint definition of policies, strategies, and rewards to be used for project purposes;
– Phase 4 - PRINCE App: testing period of the App with the student community and subsequent extraction of results;
– Phase 5 - Communication: planning and implementation of participatory and engagement processes to raise awareness/form/educate students on the importance of sustainable mobility and encourage them to participate in the initiative.

In particular, this paper focuses on the three central phases of studying and developing ICT solutions, specifically the development of the PRINCE app. During the project phases, ICT tools experimented with and implemented, leading to the creation of an App that allowed the registration and verification of students' virtuous behaviour regarding their mobility choices and the management of incentives.

In the context of the PRINCE project, the choice of technology represents a conscious evolution of previously initiated work. Specifically, it involves building upon a patent developed within a prior European Horizon project, promoted by the Municipality of Genoa, which now leads PRINCE. This decision carries significant implications, both operationally and strategically. On one hand, it allows for the valorization of existing expertise and results, reducing development time and providing a technological foundation that has already been tested in a real-world context. On the other hand, it requires a series of updates to adapt the technology to the project's new objectives, both functionally and in terms of integration with other systems. While this approach helps contain initial costs, it still demands targeted investments to ensure effective implementation and full compatibility with the current infrastructure.

The App uses Beacon technology, which consists of active sensors based on BLE (Bluetooth Low Energy) technology. These sensors can connect and transmit data to mobile devices such as tablets and smartphones. These devices, linked to the App, allow for the anonymous identification of the route and the type of transport used by the student for travel from home to university and vice versa, assigning points based on predefined rules.

The project first involved the selection of the type of Beacon to be used, based on the required characteristics (such as, weather resistance, dimension, power consumption, etc.), and then their installation on sustainable mobility vehicles participating in the project (AMT vehicles, ZenabyBike bike-sharing, and Elettra car-sharing).

The next step was to define the rules for assigning points; concurrently, additional stakeholders (beyond the core partners, including shops, bars, museums, etc.) were invited to participate and offer rewards.

As part of the PRINCE project, the points system was designed based on a preliminary phase involving a survey conducted among university users—students, faculty, and administrative staff—to map mobility habits and travel patterns to campus. The survey collected essential data such as origin (neighborhood or municipality), destination campus, mode of transport, travel time, and distance. This information was critical to understanding how public transport availability and place of residence influence mobility choices.

Based on the analysis, different mobility scenarios were created and assigned point values to encourage more sustainable behaviors. In particular, intermodality—using multiple forms of sustainable transport—was rewarded with higher point values. Additional point bonuses were also introduced during specific times of the year to promote events or targeted initiatives.

Some of the main rules supported by the app included:

- Points per trip: awarded when a minimum amount of time is spent using sustainable modes (bus, metro, bike sharing, car sharing);
- Points for changing transport modes: extra points for using more than one type of sustainable transport in a single trip;
- Points for car sharing: points for using car-sharing services, with additional points if more than one person is in the vehicle;
- CO_2 savings: while not rewarded with points, CO_2 reduction was tracked to assess environmental benefits.

These mechanisms were designed to guide users toward more sustainable mobility choices through an incentive-based approach.

Based on the identified incentives, a catalog of rewards was created (e.g., annual AMT subscriptions, free breakfasts, free museum tickets, vouchers for bike and car-sharing, etc.). Through various experiments developed with direct involvement from students, especially the UniGeco group, the PRINCE App was developed and launched. During the App's operational period (May – December 2022), students, by downloading the App on their mobile devices, would signal the start of their journey to the university or home and its completion. The App would then register points based on the route and the modes of transport used.

The point allocation was based on specific rules. For instance, points varied depending on the type of sustainable transport used and were increased if multiple modes of transport were used during the same journey, or if interchange parking was utilized, thus promoting the concept of intermodality. Once students accumulated the necessary points for a specific reward, they could claim it through the App, which issued vouchers redeemable for the rewards. For example, a total of 264 annual AMT subscriptions were provided by UniGe.

Thanks to the App, it was possible to monitor how the participation actions developed and the incentives offered were of interest to students by analyzing the trend in the number of registrations and their mobility choices: which modes of transport were preferred based on time of day and city zones. These data were then compared with the feedback and suggestions students had provided during surveys and participatory events. As an additional strength, the App allowed the evaluation of CO_2 savings associated with the use of sustainable transport compared to the emissions that would have been produced by a car covering the same distance, contributing to both an educational aspect and the third mission of the university.

The data collected through the app was managed with great care, both from a technical and regulatory perspective. Upon downloading the app, users were asked to sign a privacy notice, which was necessary to authorize data processing in accordance with applicable regulations. It is important to note that the app, through the use of beacons, did not track individual routes in detail. Instead, it only recorded aggregated information, such as the type of transport used and the total number of trips. This approach ensured that the data collected served the project's objectives without compromising user privacy. The management of personal data and privacy was centrally coordinated by the project lead, in collaboration with all PRINCE partners, ensuring a shared approach that complied with European data protection guidelines.

4 Results and Conclusions

In general, among the results obtained from the experimentation presented, it is possible to identify the successful use of incentive policies, technology, and participation. In particular, technology played an important role in the project, especially concerning the participatory and engagement processes, which were carried out to raise awareness, train, and educate students about the importance of sustainable mobility and to encourage them to participate in the initiative. Online questionnaires were created and administered, and statistical interpretation was used to draw representative conclusions from the collected data. Additionally, to manage participatory moments (meetings/focus groups), online platforms such as Wooclap and Miro were used, which allowed for the anonymous and rapid collection of participants' opinions, sharing of results in real-time, as well as enabling collaboration in a shared desktop environment.

The challenges faced during the research were several: first, the collapse of the Morandi Bridge (August 2018) and, later, the COVID-19 emergency (February 2020–2022), which seriously compromised mobility in Genoa. Furthermore, the risk of contagion, whether real or perceived, affected the use of public and sustainable transport modes, which were the focus of the project, for a long time. These events led to an extension of the project's duration (the original deadline was December 2021, which was then postponed to December 2024), but this also allowed for monitoring technological aspects that were initially not considered.

Participation was another important enabling factor in the project. In this aspect, the most strategic innovation of the project emerges: the collaboration of various Quintuple Helix actors within the partnership: Public Administration (Municipality of Genoa Mobility Office, lead partner), Research Institutions (UniGe, particularly the Urban Planning and Technique team), Public Companies (AMT and Bike and Car-sharing, managers of sustainable transport means), Private Companies (Algowatt and Queiron, who specialize in ICT), and the Population (student community), who shared their expertise and, through active participation, supported by technology, monitored and evaluated each stage of the project.

One of the weaknesses of the technology, however, is the speed at which it evolves, which led to the need for multiple cycles of app experimentation and revisiting the system to enable its use [20].

Given the complexity of the information presented in the following figures, additional clarifications are provided in the text to support interpretation. The data visualization has also been revised for improved readability, focusing on key trends and user behaviors during the testing period of the PRINCE App.

In particular, regarding the development and implementation of the App, the analysis of data related to the mobility choices made by users is now presented.

Figure 1 shows the histogram related to the mobility habits of students, with an analysis of the trend in the number of registrants and their mobility choices (for example, in blue are the users who chose to use the bus through the incentives provided by the project, in green those who travelled by subway, in red those who used the bus and an interchange parking lot, etc.). The data reveals a clear preference for public transport, especially the bus, followed by metro services. Multimodal behaviors were also recorded, particularly where students took advantage of intermodal incentives. This visualization helps to quantify the relative success of different incentive types and supports future refinements of the reward allocation logic within the App.

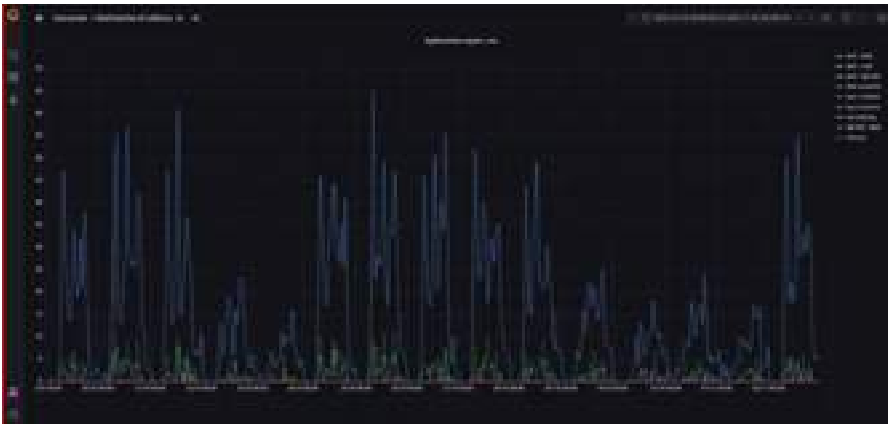

Fig. 1. Example of detailed histogram of users' mobility habits (Source: PRINCE project).

As mentioned, the experimentation period of the App ran from May to December 2022. Figure 2 shows the histogram for the September-December experimentation period of the App. It is possible to notice some peaks corresponding to initiatives that were implemented, such as during Sustainable Mobility Week (in September), the Science Festival (in October), and a pre-Christmas promotion (in November). In December, however, there is a decrease in points and user registrations, which coincides with the approaching holiday season and the closure of university campuses. Overall, the figure underscores the importance of aligning incentive policies with the university calendar and communication strategies to maximize impact.

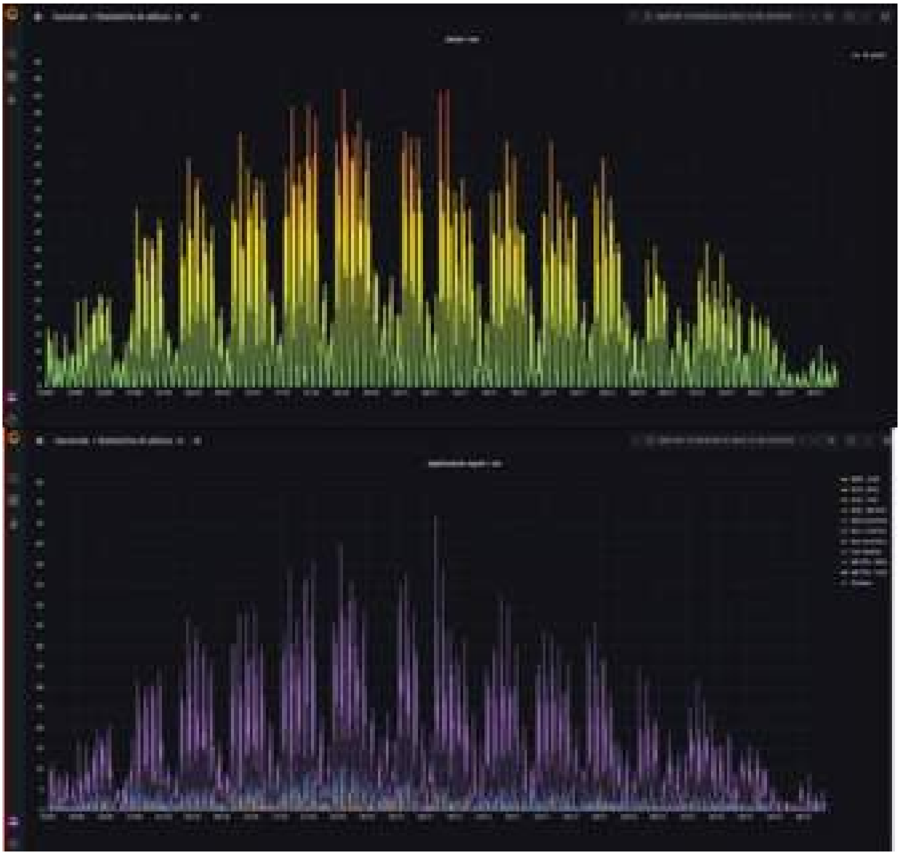

Fig. 2. Histograms of users and mobility habits from September to December 2022 (Source: PRINCE project).

In summary, the project had an initial impact in terms of numbers, both regarding the activated users (1,779 total users), accumulated points (430,826 total points), and the rewards distributed (e.g., annual subscriptions), but also in relation to the kilograms of CO_2 saved (20,588,281 g) (see Fig. 3).

Fig. 3. Activated users, accumulated points, and kg of CO_2 saved (Source: PRINCE project).

It also stood out for the participation of various key stakeholders from the Genoese territory, crucial for the project's success, boasting a Quintuple Helix partnership. The project also involved the experimentation of innovative technological tools (beacons and an App) for managing university sustainable mobility.

Initially, a structured post-project evaluation of the actual impact of the incentives on user behavior was planned, particularly through the launch of a second phase of the project, called PRINCE2, which would have involved other mobility organizations as well. However, due to the extension of the original project—which lasted about five years, partly as a result of challenges related to the pandemic—this second phase was not initiated.

In conclusion, the PRINCE initiative represents a structured best practice in the field of sustainable university mobility governance. Through an integrated approach that combines digital Apps, incentive mechanisms, and participatory processes the project demonstrated the potential to significantly contribute to the creation of more sustainable mobility practices. It also underscores the importance of adopting a systemic and collaborative method that enhances the role of all involved actors – public institutions, businesses, universities, and citizens – and integrates technological potential with shared planning tools. The inclusion of the PRINCE model in the University of Genoa's Home-University Travel Plan [21, 22] confirms its institutional value, but its true relevance lies in its replicability in other academic and urban contexts.

In fact, the effectiveness of such interventions is closely tied to the ability to address emerging challenges, such as the need to reduce digital barriers and ensure an equitable and inclusive involvement of all users. Furthermore, it is essential that technological solutions are embedded within a coherent urban policy context, oriented toward the long term and supported by ongoing monitoring of the results achieved.

Acknowledgement. The writing of section 1 was done by Federica Paoli and Francesca Pirlone; paragraph 2 was written by Federica Paoli and Ilenia Spadaro; paragraph 3 was written by Francesca Pirlone and Ilenia Spadaro; paragraph 4 was written by Federica Paoli, Francesca Pirlone and Ilenia Spadaro.

Data Availability Statement The lead partner of the PRINCE Project "PRemialità e INCEntivi per il cambiamento modale" is the Municipality of Genoa - Mobility Directorate. The University of Genoa is a partner (Scientific Responsible: Del Borghi A.; Scientific Responsible for Mobility: Pirlone F.; Scientific Responsible for Climate Change: Gallo M.; Research Group: Spadaro I.; Moreschi L.; UniGe Support Group: Marin V., Gallini R.). Further information on the research activities developed within the project are available on the website: https://unigesostenibile.unige.it/PRINCE.

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From Participation to Co-governance: Open Innovation Between Institutions, Citizens, and University in Urban Co-design Frameworks

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Abstract. This paper explores the integration of Open Innovation (OI) methodologies in urban planning and its implementation within the RAISE Spoke 1 WP5.4 project. The approach aims to overcome top-down decision-making by promoting collaborative ecosystems involving citizens, public administrations and local stakeholders through the implementation of Urban Living Labs (ULLs). The pilot case in the municipality of Cogorno (Liguria) is identified to implement scalable and replicable co-design processes empowered by digital technologies. The project identifies a co-managed governance strategy that enables citizens to take active roles in the co-production and co-management of public services. Beginning with the definition of multi-city clusters, the project envisions collaborative processes as the answer to shared needs. The proposed framework articulates four rounds of Urban Living Labs - needs assessment, technology co-assessment, policy co-definition and solution co-design - aimed at incorporating Urban Dashboard into governance structures. The overall goal is to foster inclusive practices and promote socio-economic empowerment. The conceptualization is presented as a transferable tool for municipalities in the Innovation Ecosystem to support digital transition strategies in polycentric, low-density spatial contexts.

Keywords: Urban Living Lab· Open Innovation · co-design

1 Open Innovation in Urban Context

1.1 Collaborative Ecosystems

Open Innovation (OI) represents a paradigm in urban planning, aimed at transforming traditional decision-making processes through the active inclusion of citizens (Arnkil, et al., 2014) and Public Administrations (PA) within collaborative ecosystems. OI implements skills among different actors, overcoming the limits of traditional hierarchical structures (Figenschou et al., 2024).

In recent years, OI has gained importance also in public contexts (Scozzi, et al., 2017) to allow the opening of decision-making processes towards inclusive and multidisciplinary collaborative forms, enabling Public Administrations to implement citizens'

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 55–69, 2026.
https://doi.org/10.1007/978-3-032-21842-1_5

daily experiences in the territories and enhance the quality of urban services and thus generate new relationships through the co-production of public services (Paskaleva, 2019), toward a continuous dialogue and interaction between citizens and administrations (Hilgers, Ihl, 2010).

Within the RAISE Spoke 1 WP 5.4 project[1], specific OI domains were defined to conceptualize a methodology for scaling and replicating the process using Urban Living Labs. A pilot case study was conducted in the Ligurian municipality of San Salvatore (Cogorno) to define a methodology applicable across multiple municipalities at the regional level. Generative AI tools were introduced to support the shared visualization of planning scenarios, acting as enablers in the co-definition of technological solutions.

This specific case fits into a broader perspective, where the adoption of new technologies and co-design processes open up to urban regeneration strategies shared with the citizens who inhabit and live the territories. As defined by Nambisan and Nambisan (2013, p. 10):

"Innovation ecosystem relates to the organizing structure for an ensemble of actors (e.g., citizens, government agency employees, nonprofits) to come together and co-create service offerings. It includes ways to:

- Build and sustain the community of innovators and promote a shared worldview among citizens and government employees.
- Define the architecture of participation to coordinate collaboration activities"

To identify participatory governance methodologies in open decision-making ecosystems, citizens can actively participate by taking on new roles (Nambisan, Nambisan, 2013):

- Explorer: citizens identify and define problems within public services
- Ideator: they propose innovative solutions to well-defined problems.
- Designer: They develop implementable solutions.
- Diffuser: Citizens contribute to the diffusion of innovations to facilitate the adoption of the identified solutions.

Co-production with users can be transformed into structured open governance processes, where citizens, administrations, and other stakeholders actively collaborate in the design, delivery, and evaluation of public services (Paskaleva et al., 2018): "citizens participation is the strategy by which these have-not stakeholder groups can join in determining how information is shared, goals and policies are set, tax resources are allocated, programs are operated and benefits, such as contracts and patronage, are distributed" (Konsti-Laakso, Rantala, 2018).

The development of competencies among both public administrators and citizens is key to implementing Open Innovation ecosystems. To structure an application methodology for the Ligurian context, three main categories were identified (Lee et al., 2012):

[1] RAISE is set to develop an active innovation ecosystem around Robotics&AI technologies, to support the innovativeness, economic and social development of the Liguria Region. The Liguria region's Innovation Ecosystem, part of PNRR mission 4 component 2, supports the application of new technologies. The project is included in Spoke 1 WP5 From Inclusive Technologies to Inclusive Smart Cities and aims to implement policy-making in living lab processes.

- Outside-in: the integration of external resources, such as citizen-sourcing practices where public tasks are opened up to citizen participation.
- Inside-out: the sharing of internal resources outside the organization to promote knowledge and technology diffusion
- Coupled: a hybrid model combining both approaches through strategic collaborations among complementary stakeholders.

Urban Living Labs (ULLs) emerge as coupled approaches—urban-level Open Innovation ecosystems that can be developed as Integrated Ecosystems (Almirall, et al., 2014). The focus of the early Living Labs was on how end users experience products and services in their daily life context. Their aim was to make their design a user-centric process, as opposed to a product-centric process" (Puerari, et al., 2018).

These labs involve multiple local stakeholders, promoting innovation through collaborative experimentation in specific socio-spatial contexts, combining academic knowledge, municipal needs, and insights from local communities. "The idea of Living Labs was originally developed at the end of the 1990s at the MIT Media Lab by computer science scholars. The concept complemented user-driven, human-centered, and participatory approaches to design challenges" (Puerari, et al., 2018).

1.2 Urban Co-decision Enabled by Living Labs

A framework is identified in which Living Lab processes become the cornerstone of the technological implementation system, aiming to overcome barriers and make not only public spaces and services accessible, but also the decision-making system for the identification and application of technology. The application of co-decisional processes and technologies "may contribute to overcome many of the spatial and temporal barriers that have traditionally haunted democracy: direct participation may occur without people having to share physical space and time" (Barandiaran, et al., 2024, p. 11). Within the project's case study, these spaces and processes prove essential for identifying multi-scalar needs and co-developing shared solutions.

According to Vidal (2009), two key processes need to be managed: the first concerns the problem-structuring process, the second concerns the relational modalities within the group. The problem-structuring process aims to envision future scenarios, represent needs, and identify the choices required for an operational strategy. The group process, instead, refers to the interactions among members: how they collaborate and engage with one another. The facilitation path connects both aspects, with the main objective of managing the collective dynamic. The facilitator plays a crucial role in preventing distortions and in fully valuing individual skills and potential (Konsti-Laakso and Rantala, 2018). In the case study, the researchers from the University involved in WP3 and WP4 took on the role of facilitators across the different Living Labs.

To identify the knowledge process of the territories based on the needs of the municipalities, stakeholder groups, and individual target citizens, it is necessary to structure multiple Living Labs to investigate the issues emerging in the territories at the municipal level, understand the needs of individual citizens, organize focus groups to identify the technological application domains at a collective level, and consequently structure decision-making Living Labs. In the Ligurian territory, the Tigullio area becomes a case study to explore the potential of Urban Living Labs, given its diverse territorial realities characterized by coastal environments and internal and rural areas. This heterogeneous territory makes it possible to define a methodology for replicability in different contexts.

The methodology foresees the identification of community needs, technological capacities, collaborative attitudes, and the skills available from both citizens and local administrations. Bellantuono et al. (2013) indicate that the quality of engagement from the community and institutions depends on the ability to define objectives, problems, and solutions in a shared and transparent manner. They identify three characteristics that influence the innovation context: the interest and ease of engaging external actors in the innovation process (IEP), the knowledge level of the recipients in understanding problems and evaluating proposed solutions (KDE), and the skills possessed by the recipients to address and solve the innovation problem (KA).

The process of replicability and scalability requires ongoing monitoring and evaluation activities, in order to produce methodological guidelines that can be applied in different territorial contexts, thus promoting the transfer of good practices and the dissemination of collaborative processes.

2 Multi-city Innovation Ecosystems: Approaches to Scalability and Replicability

2.1 From Metropolitan Areas to Granular Urban Systems

The main challenge in conceptualizing the processes of technology adoption within the Liguria Innovation Ecosystem lies in transitioning from the demonstrator case study identified by the WPs—namely, the city of Genoa with its 563,947 inhabitants and a complex structure in both data management and urban governance—to a primarily dispersed urban fabric composed mostly of small municipalities. Out of a total of 234 municipalities in Liguria, 183 (78%) have fewer than 5,000 inhabitants. So how can a process designed in the city of Genoa be replicated in a granular and dispersed urban system?

The coastal cities of the region underwent significant infrastructural development during the 20th century, which enabled local economies to grow around coastal nodes. In this context, populations living in inland areas maintain a relationship with the coastal cities: territories are thus structured through the connection between these two domains, enabled by citizen mobility along transversal corridors and their economic interdependence. The tourism accessibility of these territories differs: coastal areas experience intense seasonal tourism, while inland areas have a stronger connection with the Apennine system and the Alta Via dei Monti Liguri—forming a diffuse tourism network along ancient exchange routes toward the Po Valley.

The connection of citizens who move and work between inland areas and coastal cities is primarily observed along the fluvial valley networks, which are more densely infrastructured. Within this framework, it becomes essential to identify city systems spanning from coast to inland that already demonstrate infrastructural, economic, and social interconnection. Defining scalability and replicability logics means understanding how territorial characteristics can be identified in order to aggregate municipalities through the construction of multi-city decision-making ecosystems (Gausa, 2018), engaging multiple municipalities in the adoption process. This allows for the creation of collaborative and shared decision-making processes where the application of technology can bridge territorial disparities and ensure inclusive spaces and services.

The possibility of identifying a multi-urban system originates from reflections on the city of Barcelona outlined by the Generalitat de Catalunya, Consell Assessor per al Desenvolupament Sostenible (Gausa, 2011), where fifteen actions are proposed to build multi-urban processes based on a shared territorial contract capable of strategically and coherently connecting cities, landscapes, and infrastructures. The creation of multi-nodal structures between large centers and intermediate cities is emphasized, along with new tools of inter-municipal governance for the co-development of transversal areas and the articulation of interwoven mobility across different scales. At the urban level, regeneration passes through the activation of relational spaces in a vision that recognizes education, research, and innovation as key drivers of urban transformation.

The pilot case in the Cogorno area fits into this multi-city system, identified as a central node within the territorial structure that connects the coastal municipalities of Chiavari and Lavagna with the inland areas of Carasco and Leivi (see Fig. 1). This system generates a decision-making framework potentially capable of involving a total population of 54,529 inhabitants—comparable to the city of Savona.

Within this process, it becomes necessary to map existing collaborative processes between municipalities (e.g., park management, river infrastructures, shared tourism development goals) in order to integrate into a system that already shows potential for interrelation: an interwoven polycentrism, articulated through a sequence of medium and intermediate urban nodes. This possible model of low-density, discontinuous, and articulated development—referred to as Land-Links or Land-Grids—enables the identification of sub-systems that interconnect, in turn, the development channels and associated environmental corridors, generating networked relational spaces (Gausa, 2014, p. 47).

In this approach, it is possible to structure a system of digitization and understanding of users' needs along their daily activities, as in the pilot case of the city of Genoa. In the context of RAISE, the possibility of not working on single municipalities but on multiple systems guarantees the territories digitization processes that can optimize both economic and human resources, with the advantage of standardizing and unifying some processes that are currently disconnected.

The Tigullio territory presents some characteristics that can be identified in further territorial fabrics: river system and infrastructural system, historical relationship between coastal economy and inland economy, common territorial development objectives (Provincial Roads crossing the territories, possible hydrogeological risks of river structures, parks, touristic/cultural systems, daily movement of citizens between the different municipalities for school/work).

2.2 Identifying Multi-city Systems Within Liguria

Comb-shaped urban systems (coast–inland) are identified that present infrastructural, historical, economic, and cultural continuity, and that can collaborate on shared projects (for example services, mobility, tourism promotion, river and environmental management) through some characteristics of multi-city systems:

Fig. 1. Tigullio multiurban case study.

- Ridges and valleys as guiding lines: possibility of identifying aggregative systems along the main river axes (Roja, Nervia, Argentina, Impero, Centa, Bormida, Entella, Magra, Vara, etc.), already partially infrastructured (main roads and railways).
- Functional proximity: a cluster of municipalities has territorial and relational continuity (commuting, shared services, large area projects, etc.).
- Already initiated collaborations: Unions of Municipalities, Tourist Districts, Regional Parks, Conventions for the management of waste, water, roads. Integrating these networks can facilitate the co-design and governance of the systems.

The Unions of Municipalities – as defined by the Liguria Region – could be an already structured component for clustering the multi-city system, especially in inland areas, and include:

- Alta Val d'Aveto (2 municipalites: Rezzoaglio, Santo Stefano d'Aveto)
- Scrivia (9 municipalities: Busalla, Casella, Crocefieschi, Isola del Cantone, Montoggio, Ronco Scrivia, Savignone, Valbrevenna, Vobbia)
- Valli Stura, Orba e Leira (5 municipalities: Campo Ligure, Masone, Mele, Rossiglione, Tiglieto)
- Valle Impero e della Valle del Maro (6 municipalities: Aurigo, Borgomaro, Caravonica, Chiusavecchia, Lucinasco, Pontedassio)
- Alta Valle Arroscia (11 municipalities: Aquila d'Arroscia, Armo, Borghetto, Cosio d'Arroscia, Mendatica, Montegrosso Pian Latte, Pieve di Teco, Pornassio, Ranzo, Rezzo, Vessalico)
- Valli Argentina e Armea (6 municipalities: Badalucco, Bajardo, Ceriana, Molini di Triora, Triora)

- Valli Nervia e Roja (8 municipalities: Airole, Apricale, Castel Vittorio, Dolceacqua, Isolabona, Olivetta San Michele, Pigna, Rocchetta Nervina)
- Beigua (2 municipalities: Sassello, Urbe)

Potential configurations of local clusters within the regional ecosystem:

3. Bordighera - Ventimiglia – Airole - Vallecrosia - Camporosso – Ospedaletti – Dolceacqua – Pigna – Apricale – Perinaldo - Rocchetta Nervina - Pigna.

   Estimated total population: ~ 59.000. Linear urban system along the coast, densely populated and strongly infrastructured, extending inland through the Roya and Nervia valleys. The area has a strong touristic vocation, proximity to the French border, and a marked cross-border dimension with daily flows of workers and students. The inland municipalities, smaller in size, preserve a historical, natural, and cultural heritage with agricultural and artisanal traditions.
4. Sanremo – Bajardo - Ceriana - Taggia - Riva Ligure - Santo Stefano al Mare – Badalucco – Castellaro - Moltalto Carpasio – Triora.

   Estimated total population: ~75.000. Polycentric system served by a consolidated coastal infrastructure (Aurelia, railway), with connections to the hinterland along the Argentina and Carpasina valleys. The small mountain municipalities maintain strong historical, cultural, and economic ties with the coast. The territory is characterized by constant interaction between coastal cities and inland towns, with daily flows of school and work commuting.
5. Albenga - Alassio - Laigueglia - Ceriale – Andora, Garlenda, Villanova d'Albenga).

   Estimated total population: ~60.000. System structured around the plain of Albenga, which connects coastal municipalities with a strong tourist vocation (Alassio, Laigueglia, Ceriale, Andora) with inland centers linked to agricultural production, floriculture, and the agri-food supply chain (Albenga, Garlenda, Villanova d'Albenga). The territory features high accessibility thanks to the presence of the railway, the Aurelia road, and the A10 highway, with connections between coast and hinterland through the Neva and Pennavaira valleys.
6. Chiavari – Lavagna – Cogorno – Carasco – Leivi.

   Estimated total population: ~60.000. Integrated urban system of the middle Entella Valley, with a strong connection axis between the coastal centers of Chiavari and Lavagna and the nearby inland municipalities (Cogorno, Carasco, Leivi). The area is configured as a strategic node of eastern Tigullio, characterized by a consolidated infrastructural network (railway, Aurelia road, internal road system) and by a close socio-economic interdependence between coast and hillside. Presence of centralized services, daily commuting flows, and a tradition of institutional cooperation.
7. Sarzana – Lerici – Ameglia – Arcola – Vezzano Ligure

   Estimated total population: ~55.000–60.000. System of the eastern Gulf of La Spezia, with Sarzana as the historical hub in the inland area. The cluster integrates coastal areas with a tourist vocation (Lerici, Ameglia) with nearby inland municipalities (Arcola, Vezzano Ligure), connected by an efficient road and railway infrastructure along the Tyrrhenian backbone and towards the Magra Valley.

3 Conceptualizing the Pilot Case

3.1 Implementation Framework of Urban Living Labs

Starting from the activities carried out within Task 5.3 at the Villaggio del Ragazzo, the identified process and the investigative tools applied were conceptualized in order to enable the replicability of the methodology. The implementation of Living Lab activities for the identification of needs is articulated in its components addressing both citizens and public administrations (see Fig. 2).

The evaluation of technologies for their implementation through co-design processes defines a model of co-management in urban design decision-making.

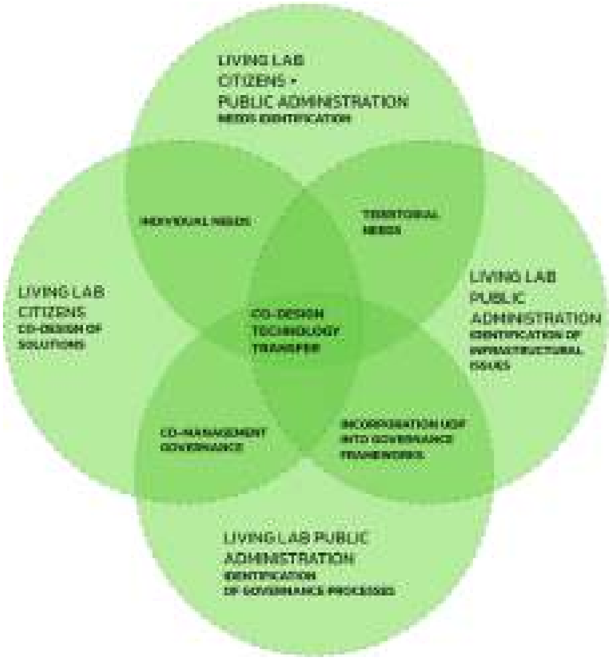

Fig. 2. Conceptual diagram of Urban Living Lab (ULL) interactions. The four quadrants represent different stakeholder—citizens, public administrations, or both—engaged in Living Lab process: needs identification, co-design of solutions, infrastructural and governance assessments. Each intersection illustrates shared thematic such as co-management governance, territorial and individual needs, and incorporation into governance frameworks.

From the resulting diagram, the main features of the methodology emerge:

- Co-management governance
- Incorporation of the Urban Dashboard into the governance framework
- Identification of territorial needs (infrastructure, data, technologies)
- Identification of the needs of target citizens

It is necessary to implement co-management and co-design logics between citizens and public administrations, through open decision-making ecosystems; the process of technological transfer in the specific application case between stakeholders and public administrations; and to integrate the platforms developed within the RAISE project into the governance systems of municipalities.

The design process is structured into several phases aimed at supporting Public Administration in defining strategic objectives aligned with the needs of local communities, while also promoting the adoption of innovative technologies to improve public services and the quality of urban space.

The first phase involves defining the objectives of the Public Administration, with a shared reflection on intervention priorities and key areas of action, with particular attention to inclusion, and digitalization. To support this activity, a phase of data collection and systematization is launched, which is used for building an Urban Dashboard[2] for monitoring territorial and social dynamics. The data collection includes information of various kinds, such as census data, accessibility indicators, territorial and environmental data, and data related to public services, the healthcare system, and urban mobility. This information forms the knowledge base for guiding decision-making and assessing the impact of policies. The project identifies four cycles of ULLs, which serve as spaces for participatory dialogue and experimentation, actively involving both citizens and the administration (see Fig. 3).

From the initial identification of territories already equipped with the necessary infrastructure (reference is made to the platform available at https://bandaultralarga.italia.it/mappa/, developed within the National Ultra-Broadband Strategic Plan, which aims to create a public infrastructure aligned with the goals of the European Digital Agenda), multi-city clusters are selected within the broader area—covering both coastal and inland zones—to identify territorial needs in relation to infrastructure, technological equipment, and local requirements.

The implementation activities of ULLs are then scheduled to identify needs, define strategic objectives for aligning the intentions of Public Administrations, and implement the Urban Dashboard within the framework of understanding inequalities, in order to identify possible technological solutions and consequently build multi-stakeholder design processes, so as to implement tools for citizens aimed at socio-economic empowerment. It becomes relevant to implement evaluative and validating ULLs with Public Administrations regarding the technologies implemented and their impact. As part of the Living Lab process, the *Urban Data Platform* developed within Spoke 1 is integrated to communicate both the human condition and the state of the city through devices that respond to the physical environment and guide users along personalized pathways.

[2] The main objective of the Urban Dashboard, developed within Work Packages 5.2, is to provide policymakers with a governance tool that introduces an innovative model for data implementation, organization, and user-platform interaction.The expected outcome is a platform that offers both exploratory and analytical services to support local decision-making processes.The system is based on a multi-level framework for collecting and organizing urban data, structured around three levels: territory, people, and activities, with a focus on public services. Data analysis begins at the micro-territorial scale of the neighborhood and is updated on a semi-annual basis. The analysis is centered on user profiles—represented through personas—to deliver a synthesized yet representative understanding of ongoing social and territorial dynamics.

- *Living Lab 1* Once the multi-urban system has been identified, an evaluation process is built together with Public Administrations. In particular, in this Living Lab it becomes important to understand the differences in digital management among the various municipalities (e.g. territorial data platforms, staff already trained on digital systems): this allows for the integration of processes and digital tools in order to read the territory with the most unified tools possible. Using data, understanding the territory, and thus building urban platforms that allow people to interact with the environment and public infrastructures through networks and remote monitoring is especially important in inland areas. Identification of the difficulties in applying technological knowledge in administered contexts—such as issues related to infrastructural development and the lack of territorial data.

  At this stage, it becomes relevant to understand the willingness of different municipalities for the application of integration of citizen-sourcing. Joint evaluation with administrators regarding the possibility of integration of technological tools with existing policy.
- *Living Lab 2* It is dedicated to user research activities aimed at identifying individual and collective needs. Through interviews and personas, user experience maps, and empathy maps, the everyday experiences and needs of citizens are collected. In parallel, focus groups are used to explore collective needs, promoting a shared vision of the critical issues and opportunities for intervention.
- *Living Lab 3* It includes a joint evaluation phase with the Public Administration, during which the results emerging from the previous phases are analyzed and reflections useful for defining policies and implementation actions are shared. This phase allows institutions to receive an updated overview of the community's needs and the most effective and sustainable technological solutions.
- *Living Lab 4* It focuses on co-design activities, with the aim of fostering collaboration between citizens and Public Administration in the design of innovative solutions. In this phase, participants take part in focus groups dedicated to technological transfer, during which available technologies and their application potential are presented and discussed. Subsequently, an individual experimentation phase is launched, in which citizens directly test certain technologies with the goal of improving their usability and assessing their contribution to enhancing public services and the quality of urban space.

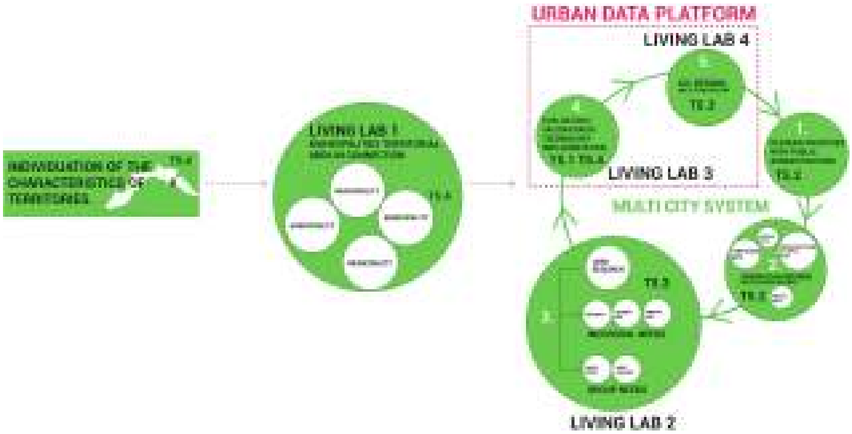

Fig. 3. Diagram of the multi-ULLs process implementation and technological co-design within the multi-city system.

3.2 Indicators for Monitoring Urban Living Lab Cycles

In the methodology for implementing ULLs, impact evaluation becomes necessary: a monitoring matrix is proposed to evaluate the different phases of the process. The European Network of Living Labs (Schuurman, et al., 2025; Schnurr, et al., 2022) identifies six components of Living Labs – *user-centricity, real-life environments, multi-stakeholder participation, multi-method and tools, co-creation* e *openness* – which represent dimensions that can be integrated into the evaluation system. Haug and Mergel (2021) highlight how the generation of public value within Living Labs derives from institutional mutual learning and collaborative networks. Based on these frameworks, the evaluation matrix and indicators are structured around the four main phases—*needs identification, technology evaluation, policy co-definition,* and *solution co-design*—with the integration of a monitoring phase. For each phase, in the Table 1 are indicated: the activities, the suggested indicators, and the operational responsibilities. Table 2 highlights the expected outcomes associated with each phase of the Urban Living Labs. The grid makes it possible to monitor the effectiveness of the participatory process, to strengthen the dialogue among stakeholders and to provide a tool for the scalability and transferability of the approach in other territorial contexts.

Table 1. Suggested indicators and monitoring dimensions for ULL phases.

ULL Phase	Activity	Suggested Indicators	Responsibility
1. Needs Identification	Focus groups, interviews, empathy mapping, including specific outreach to underrepresented or vulnerable groups (e.g. people with physical, cognitive, or digital access barriers)	– No. of participants per municipality – No. of identified needs (individual/collective) – Demographic diversity of participants	Municipalities, citizens, University facilitators
2. Technology Evaluation	Tool assessment sessions, prioritization with stakeholders	– No. of technologies assessed – Evaluation scores per solution – Tools selected for co-design	Tech. partners, citizens, University facilitators
3. Policy Co-definition	Strategic discussions with public administrations	– No. of shared policy directions – Cross-municipal goal alignment – No. of institutions involved	Policy makers, Working groups, University facilitators
4. Solution Co-design	Workshops, prototyping, citizen testing	– No. of solutions co-developed – No. of redesign iterations – User satisfaction/feedback rate	Citizens, Designers, Tech. partners
5. Post-Implementation Monitoring	Dashboard integration, ongoing observation	– Policy updates derived from ULLs – Citizen engagement post-implementation	Public Administrations

Table 2. Expected Outcomes for ULL phases.

ULL Phase	Expected Outcomes
1. Needs Identification	Needs mapped across territories that includes diverse ‘personas’; shared problem awareness, shared awareness of critical gaps in inclusion
2. Technology Evaluation	Selection of relevant, acceptable technologies
3. Policy Co-definition	Coherent strategic direction across municipalities

(continued)

Table 2. (*continued*)

ULL Phase	Expected Outcomes
4. Solution Co-design	Workshops and prototyping sessions involving citizens with varied abilities, languages, and access needs; testing sessions adapted for accessibility. Solutions iteratively developed and validated by a representative sample of the community, including users with specific accessibility challenges
5. Post-Implementation Monitoring	Long-term impact tracked, learning loops activated

4 Conclusions

Urban Living Lab (ULL)-based Open Innovation processes can become collaborative networks for supporting replicable and scalable metodology of urban governance in multi-municipality framework within the Liguria RAISE Innovation Ecosystem for the structuring of decision-making ecosystems that are responsive to both territorial specificities and social needs. The case study in the Tigullio multi-city system highlights the operational relevance of engaging citizens, local institutions, and academic stakeholders in co-defining objectives, evaluating technologies, formulating shared policies, and co-designing solutions. This ecosystemic perspective facilitates the identification of localised priorities and opportunities, overcoming the barriers of administrative fragmentation and infrastructural asymmetries typical of polycentric and low-density territories.

To strengthen the transferability of this model, future developments should aim to institutionalize the methodology within municipal planning regulations, facilitating long-term adoption through operational guidelines and shared governance protocols. These processes open up the possibility of integrating digital facilitation technologies, including urban dashboards and participatory platforms, to enhance collaborative decision-making and data-informed governance (Barandiaran, et al., 2024; Canessa, 2021).There is therefore a need to develop strategic alignment tools to support inter-municipal coordination across functional urban systems (Gausa, 2011; Goldsmith, Crawford, 2014). Future research should investigate how such frameworks can support long-term transformation within regional digital strategies and multi-level governance systems.

Acknowledgement. Funded by the European Union - NextGenerationEU and by the Ministry of University and Research (MUR), National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.5, project "RAISE - Robotics and AI for Socio-economic Empowerment" (ECS00000035).

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Digital Cultural Heritage and Smart Mobility in Genoa Beyond 2030. Integrated Approaches to Urban Regeneration

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Abstract. Genoa, a historic port city in northern Italy, is adopting smart city strategies to integrate cultural heritage with sustainable, urban mobility. This paper explores two interlinked initiatives: a digital regeneration project in the historic centre and a smart mobility plan focused on autonomous, electric transport.

Although operating in different domains, the two initiatives are conceived as complementary components of Genoa's urban strategy. Digital cultural heritage enhances cultural accessibility, while sustainable mobility ensures physical accessibility. Together, they outline an integrated model of urban regeneration beyond 2030. The first case, developed within the Genova Design Week "Metadistrict," uses augmented and virtual reality to preserve cultural identity and involve community participation. The second outlines Genoa's mobility vision beyond 2030, aiming to improve connectivity through inclusive, electric and intermodal transport tailored to the city's topography. Both projects align with the UN 2030 Agenda and exemplify a context-sensitive approach to innovation. By blending heritage preservation with technological advancement, Genoa offers a model for historic cities seeking to harmonise tradition with progress, emphasising co-creation, inclusivity, and environmental sustainability as pillars of urban regeneration.

Keywords: Smart City· Genoa 2030 · Urban Regeneration · Virtual Heritage · Smart Mobility · Shared Mobility · Autonomous Vehicles · Electric Vehicles (EV) · Mobility as a Service (MaaS) · Accessible Design · Sustainable Development Goals (SDGs)

1 Introduction

In the past two decades, "smart cities" have become central to urban development strategies worldwide. They use innovative technologies to improve life quality, optimize resource management and reduce environmental impacts [1]. Sustainable urban development shall include cultural dynamism, social inclusion and local identity.

Cities are complex systems, and effective innovation must balance advanced solutions while maintaining their character and engaging citizens [2]. Sociologist Richard

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 70–86, 2026.
https://doi.org/10.1007/978-3-032-21842-1_6

Sennett argues that urban change must be inclusive to prevent alienation or gentrification, ensuring benefits for existing communities [3]. Architect Juhani Pallasmaa emphasises the importance of human sensory experiences in architecture, stressing that technology should enhance human-scale qualities of each city [4].

Recent studies assert that "smart" urban regeneration must harmonise innovation with local identity, promoting community participation and social sustainability [1].

Genoa exemplifies the complexities and benefits of integrating modern smart city initiatives within a historic landscape. Famous for its medieval old town, characterised by a dense network of caruggi (narrow alleys) and stunning coastal hills, it addresses the challenge of preserving its cultural heritage while improving urban mobility. Collaborating with university partners, the municipality is actively working on both fronts. On one side, efforts are underway to use digital technologies to document, conserve, and revitalize the historic city centre's cultural landmarks and public areas. Conversely, Genoa is rethinking its transportation systems by implementing autonomous electric vehicles and smart infrastructure to create a more accessible and sustainable urban environment.

These initiatives align with the United Nations 2030 Agenda for Sustainable Development; for instance, Goal 11 emphasises the importance of making cities inclusive, safe, resilient, and sustainable —mirroring the need to protect cultural heritage [5] — while Goals 7, 9, and 13 promote clean energy, innovation, and climate action [6].

According to UNESCO's guidance, integrating culture into urban development is essential for achieving human-centred and inclusive growth. Furthermore, advancements in mobility technologies are essential for mitigating congestion, reducing emissions, and enhancing connectivity, particularly in historic cities where conventional methods often prove inadequate.

This paper examines two case studies in Genoa that together represent a holistic approach to smart and sustainable urban regeneration. The first case study focuses on Digital Cultural Heritage and Urban Identity, analysing the Genova Design Week "Metadistrict" initiative led by local academics and communities [7]. It explores how digital transformation can introduce new layers of meaning and accessibility into the historic centre, thereby strengthening urban identity through community-driven cultural innovation. The second case study addresses Smart and Inclusive Mobility Systems, detailing the development of an autonomous electric vehicle network for Genoa by 2030 [8].

The Discussion explores how cultural heritage and mobility initiatives reinforce each other in smart cities. In Genoa, preserving genius loci through digital heritage improves quality of life and city appeal, creating a favourable environment for innovative mobility services.

2 Smart City and Cultural Heritage: The Case of Genoa Design Week and the New Digital Meta-District (Davide Nicolini, Luca Parodi)

Genoa's historic centre, among Europe's largest medieval town centres, plays a crucial role in blending urban renewal with cultural heritage. Revitalisation efforts in the 1980s and 1990s transformed neglected areas into vibrant districts for art and commerce [9].

A notable 1990 project by the University of Genoa's Department of Architecture under Ignazio Gardella introduced new commercial and cultural spaces, showcasing culture's role in urban living. This initiative illustrated how historic re-evaluation can spur economic growth and strengthen community identity. Current projects in Genoa's centre emphasise cultural heritage as a catalyst for sustainable development.

Digital innovation plays a key role in preserving cultural heritage. Genova Distretto del Design (DiDe) is creating a "Metadistrict" in the historic city (Figure. 1), where local researchers explore how digital transformation enhances cultural engagement and urban revitalisation [7]. This digital, cultural district offers interactive experiences, promoting immersive interactions with historic sites through technologies like VR (virtual reality) and AR (augmented reality). High-resolution digitisation grants universal access to collections; VR recreations allow for exploration of heritage sites and AR overlays historical data onto current streetscapes.

AR can project historical maps or narratives over city structures, enriching visitor understanding. VR can simulate medieval Genoa, while digital archiving ensures long-term preservation of cultural knowledge beyond traditional institutions. The meta district model boosts Genoa's tangible heritage, creating a hybrid virtual-physical space for public engagement. Additionally, it fosters community involvement and local identity, envisioned as a collaborative cultural ecosystem led by urban planners and digital humanities specialists.

Founded in 2018, Distretto del Design (DiDe) was established by residents and professionals in the Piazza dei Giustiniani area. It aims to regenerate a historic quarter formerly known for furniture makers, use creativity for social and cultural development and promote design as a catalyst for economic renewal [10].

A major initiative of the Design District is the annual Genova BeDesign Week, which began in the same year. This week-long design and creativity celebration animates the streets and squares of the historic district with exhibitions, workshops, performances, and installations (Fig. 2, Fig. 3). The event encourages a dialogue among diverse artistic and design fields while promoting local development. Throughout BeDesign Week, traditional courtyards, vintage shop fronts, and plazas transform into pop-up galleries or stages, stimulating residents and visitors to explore spaces that may otherwise go underutilised year-round. The initiative rejuvenates public squares that once housed renowned Genoese furniture workshops in the 19th century, effectively restoring the legacy of craftsmanship to its roots. This process reconnects the modern community with local craftsmanship and design heritage. The city's cultural identity is preserved and dynamically reinterpreted "through a dialogue between tradition and innovation." This perspective aligns with architect Vinayak Bharne's view that historic cities should adapt their identities rather than freeze them, allowing new creative expressions to keep heritage alive.

The upcoming stage in developing this cultural district focuses on its digital upgrade, backed by Italy's National Recovery and Resilience Plan (PNRR). A new grant aimed at strengthening cultural and creative industries has propelled the Design Week project to advance its envisioned digital metadistrict. In collaboration with the Department of Architecture and Design (DAD) of the University of Genoa and partners such as

Fig. 1. Entrance students show 'Made in DAD', a project curated by the University of Genoa, Department of Architecture and Design (DAD)

the Industrial Design Association (ADI), the team is building a comprehensive digital platform and tools to enhance the district's on-site experience.

The goal is to create an open-air smart museum in the historic centre through cutting-edge technologies—including AR applications, 3D digitization of artworks and artifacts, interactive mobile maps, and potential IoT installations. For example, during BeDesign Week, a visitor could use their phone to scan a building and see archival photos depicting its condition a hundred years ago or watch a short video about a renowned craft workshop that once was situated there. Interactive maps could lead users through curated itineraries (e.g., "the furniture makers of Via dei Giustiniani") featuring multimedia content at each location.

Local inhabitants could engage by digitizing and sharing their personal stories, photographs, or design creations for a community archive, thus co-creating the cultural narrative. By integrating physical and digital realms, this initiative aims to connect younger audiences (digital natives) especially to Genoa's heritage, empowering the community to tell its own story.

In 2023, the project entered a new development phase, supported from Italy's National Recovery and Resilience Plan (PNRR). This funding falls under Mission 1, Component 3 – Investment 3.3, aimed at fostering innovation and digital transition in the cultural and creative industries. This assistance has facilitated enhancing the metadistrict's digital infrastructure, emphasising technological improvements and regional integration.

Fig. 2. Event communication throughout the historic centre of Genoa

The PNRR-funded program includes initiatives to develop a detailed, interactive geographic database that showcases cultural and commercial activities within the district, complete with multimedia elements. This database will integrate with municipal and regional geoportals, as well as national databases like CIVIS, offering users augmented reality experiences of the area. Additionally, a mobile app is in the works to assist visitors in navigating the district via themed routes while providing real-time updates on events and locations. The project extends beyond the world-renowned "Strade Nuove" and "Palazzi dei Rolli" to incorporate lesser-known yet culturally significant heritage sites, including medieval and Renaissance architecture throughout the historic centre.

A principal goal of this initiative is to enhance international visibility and draw a wider, global audience, ultimately creating a positive economic impact in both prominent and lesser-represented districts. The project aims to establish the Genoa Design District as part of a wider Ligurian Creative Metadistrict, positioning it competitively on a European level as a centre for culture, design, and digital innovation.

This initiative recognises urban identity and sense of place as vital for sustainable cities [11]. Genoa's cultural metadistrict is place-based and participatory, treating technology as a way to enhance human connections rather than an end goal. This echoes Pallasmaa's view that environments should engage all senses and cultural memory, not just focus on visual aspects of technology [4]. A key challenge for the project is ensuring that digital layers enhance rather than distract from the city's historic, tactile experience, avoiding a too-virtual feel that could undermine authenticity. By collaborating with local artists, designers, and historians, the metadistrict aims to provide interpretive depth that resonates with users emotionally and intellectually.

The research methodology combines comparative analysis with social research. The team has examined similar European digital heritage projects for best practices and conducted field studies in Genoa's old town through surveys, interviews, and observations. Early results are promising, indicating that smart technologies in the cultural district can drive urban regeneration by fostering an inclusive ecosystem. Integrating AR exhibits, interactive maps, and mobile apps enriches the public's heritage experience and encourages new participation forms. Pilot trials showed that visitors using an AR app spent more time at locations and engaged in discussions about historical content. At the same time, residents contributed stories to the digital archive after seeing their neighbourhood's history represented.

This demonstrates that technology can promote social interaction and local pride, acting as a catalyst for innovation that connects tradition and the future. It redefines the relationship between the city, its cultural heritage, and its citizens, by making heritage more accessible and participatory.

The project will analyse user survey and feedback data to refine its implementation strategies. Questions being explored include: Which digital features are most effective at engaging different age groups? How can we minimize the digital divide so that even the less tech-savvy or those without smartphones can benefit? How do we measure the economic impact on local businesses during these events? The ultimate aim is to develop a model that can be replicated in other cities seeking to blend innovation and sustainability in an integrated, community-driven way.

If successful, Genoa's digital cultural heritage metadistrict could become a model for "smart heritage" areas – regions where historical character lays the groundwork for growth in creative industries, high-tech educational tourism, and active citizen contributions to cultural production. This approach fosters not only cultural sustainability but also economic and social vitality, reflecting the idea that culture represents the "fourth pillar" of sustainable development, alongside economic, social, and environmental factors. Essentially, the Genoa example demonstrates that digital technology, shaped by human-centred design and local contexts, can enhance urban identity and revitalise historic neighbourhoods, establishing the smart city as a space of both memory and innovation.

The digital regeneration of Genoa's historic centre demonstrates how technological tools can expand cultural accessibility and strengthen collective identity. Yet cultural innovation cannot unfold in isolation from the urban system that sustains it. Physical accessibility and efficient mobility are indispensable conditions for ensuring that revitalised heritage becomes part of everyday urban life. For this reason, the transition from cultural platforms to mobility infrastructures is not a shift of topic but a continuation of the same integrated strategy.

Fig. 3. Setup of the Sustainable Mobility Room for the student show, a project curated by the University of Genoa, Department of Architecture and Design (DAD)

3 Genoa Beyond 2030: Designing the Future of Smart and Shared Urban Mobility (Massimo Musio-Sale, Angela Denise Peri)

Genoa is undertaking a significant transformation of its urban mobility system to address the challenges of the 21st century [12]. Like many cities around the globe, it faces issues such as traffic congestion, limited accessibility, pollution and the need for a more efficient public transportation system. These tasks are intensified by the city's unique geography, which features steep hills and a medieval street network in the centre that is largely inaccessible to conventional vehicles [13].

To address these matters, the Department of Architecture and Design (DAD) of the University of Genoa, in collaboration with engineering and urban mobility experts, has developed "Genoa beyond 2030: Designing the Future of Smart and Shared Urban Mobility." It imagines a holistic, intelligent mobility system that is autonomous, electric, shared, and smoothly incorporated into the city's current transit framework.

Genoa's mobility vision is explicitly aligned with the UN 2030 Agenda for Sustainable Development [14]. It embraces the principles of Sustainable Cities and Communities (SDG 11), Affordable and Clean Energy (SDG 7), Climate Action (SDG 13), and Industry, Innovation, and Infrastructure (SDG 9).

The project aims to provide accessible and equitable transportation (supporting inclusive cities), the use of clean electric energy, reduce emissions (addressing climate change) and drive innovation in vehicle design and infrastructure (supporting industry and innovation). The global context underscores the importance of such efforts. By 2030, spending on shared mobility services (from ride-sharing to micro-mobility) is projected to grow exponentially one report estimates the market could reach approximately $400 billion [15]. Major urban centres are already investing in autonomous shuttles, electric bus fleets, and mobility-as-a-service platforms to alleviate congestion and improve connectivity [16].

For Genoa, adopting smart mobility is not only an opportunity to modernise transport, but a necessity to remain sustainable and liveable. The historic city's narrow streets and piazzas cannot support unlimited private car use; thus, a shift to shared, automated vehicles and enhanced public transit is a logical path to reduce car dependency while improving access for all, including the elderly or disabled.

The Genoa 2030 smart mobility project approaches the challenge on multiple interconnected levels. First, it began with a thorough assessment of the urban landscape and traffic ecosystem. Researchers mapped the city's topology, street morphology and transit routes, identifying key pain points and gaps. They collected and analysed data on traffic patterns, congestion hotspots, public transportation usage and user behaviour (for example, how people move from periphery to centre, or from hilltop neighbourhoods down to the central city). This diagnostic phase highlighted several issues: for example, certain hilly residential areas are not well served by buses or the metro; the historic centre's congestion is partly due to delivery vehicles and taxis since buses cannot penetrate the caruggi; and there is under-utilization of some alternatives like funiculars and public lifts due to poor last-mile connectivity. By clearly understanding these strengths and weaknesses, the team could tailor solutions to Genoa's context, rather than importing a one-size-fits-all smart city idea.

At the heart of the design phase is the development of autonomous electric vehicles tailored to Genoa's conditions. The project envisions a fleet of vehicle types to address various mobility needs. There are micro-mobility vehicles for individual or small group travel (2–4–6 passengers); compact, electric shuttles or automated e-taxis can navigate the tight and winding lanes where larger vehicles are not permitted (Fig. 4, Fig. 6, Fig. 7). On the other hand, there are slightly larger mini-buses (Fig. 5) or shuttles accommodating around 16–20 passengers, designed for short-distance hops across neighbourhoods or linking transit hubs (for example, connecting a hilltop parking area to the city centre or circulating around the outskirts of the old town where a full-sized bus route is not practical). Notably, all these vehicles are envisioned as on-demand and shared, bridging the gap between private cars and traditional public transit [17].

This diversified approach reflects a key insight: improving urban mobility is not just about one mode of transport but creating a network of options that work together. In Genoa's case, the autonomous shuttles would complement existing modes (trains, buses, the metro line along the coast, the funiculars that scale the hills, and the elevators and cable cars in certain districts) rather than replace them.

A significant innovation in the project is its emphasis on vehicle design and technology tailor-made for the city's intricate urban form. Genoa's complex topography and street layout make it an ideal testing ground for advanced autonomous vehicle (AV) technology.

Fig. 4. Basil (AY 2021-22) Francesca Fiorini , Marta Garcia Piedrola, Crystal Padoan

Fig. 5. Genius (AY 2024-25) Michele Alloro, Nadia Baji, Eleonora Schella

Fig. 6. Toulì (AY 2024-25) Claudio Cervetto, Giorgia Grasso, Nicole Lomuscio

Fig. 7. amiGo (AY 2021-22) Benedetta Carro, Luca Galli, Matteo Pugliese

The autonomous shuttles are being designed with state-of-the-art sensor systems: LiDAR (Light Detection and Ranging) units [18], high-resolution cameras, and radar arrays enable the vehicle to perceive its surroundings in great detail, even in the maze-like alleys or around blind corners (Fig. 8).

These sensors feed into onboard AI algorithms by constantly scanning and creating precise 3D maps of the environment. Machine learning models, trained on large amounts of urban driving data, allow the shuttles to make real-time decisions – for instance, slowing for a pedestrian emerging from a narrow side alley or rerouting due to an unexpected road closure. Testing AVs in Genoa allows refining these algorithms under challenging conditions (narrow medieval streets, mixed traffic with pedestrians and scooters, steep gradients) beyond the scope of simpler grid-like city environments. In simulation and pilot trials, the team uses Genoa's conditions to improve the shuttles' navigation software, understanding that if it works here, it could work in many other old cities with irregular layouts.

Furthermore, the project incorporates sustainable energy and charging solutions from the outset. All vehicles are fully electric, supporting the city's transition from fossil fuels. To avoid adding visual clutter or requiring space for traditional charging stations in the historic city, the designers propose inductive wireless charging embedded in the infrastructure [19].

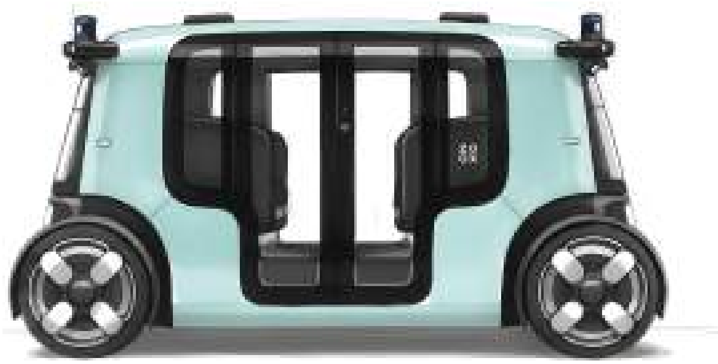

Fig. 8. Amazon Zoox autonomous vehicle (2020), original conceptual sketch (Musio-Sale, Peri)

For example, key shuttle stops or parking pads could have charging coils under the pavement, allowing vehicles to recharge automatically when they dwell at these points (say, during a passenger boarding or at an endpoint). This approach ensures the shuttles have sufficient battery life throughout the day without the need to be taken out of service for charging, and it keeps the streets free of extra equipment. It also exemplifies the project's ethos of minimizing the physical footprint of technology in a heritage city – maintaining aesthetics and avoiding obstruction, which is critical in narrow streets.

Several technological and design strategies for autonomous mobility were explored in academic settings, including research conducted in the course Design del Prodotto 2 of the Master's Degree program in Product Event Design at the University of Genoa. These explorations contributed to envisioning adaptable, context-sensitive mobility solutions that respond to Genoa's steep terrain and compact medieval street network.

The transition from internal combustion engines to electric propulsion is a cornerstone of Genoa's mobility redesign. This shift is expected to drastically cut the city's greenhouse gas emissions and air pollution, improving public health and contributing to climate goals. This development presents an opportunity to reconsider the design and functionality of vehicles. Traditional buses and cars often have large engine compartments and complex transmission systems, which impose specific design constraints. By contrast, electric vehicles (EVs) are mechanically more straightforward and flexible in layout.

The Genoa autonomous shuttles exploit this by using compact electric motors and batteries that free up space. Without a bulky front engine block, the vehicle's front and rear overhangs can be minimal, meaning more of the vehicle's length is usable interior space. The distance between the front end and the windshield is shortened, giving the vehicle a stubby nose and allowing a better field of view for sensors and any backup human operator.

The project uses in-wheel motor technology (Fig. 9) – electric motors integrated directly into the wheel hubs – which further reduces the size of the drivetrain and allows a flat floor design [20].

Fig. 9. In-wheel motor (Protean Electric system), original conceptual sketch (Musio-Sale, Peri)

Fig. 10. MG4 Electric car platform (MG Motor Europe), original conceptual sketch (Musio-Sale, Peri)

This modular chassis (Fig. 10) means the body (the passenger cabin) can be designed somewhat independently of the mechanical base, offering flexibility to create different body styles (e.g., a cargo vs. a passenger variant) on the same platform. An additional benefit is noise reduction; electric shuttles operate quietly due to having significantly fewer moving mechanical parts and no combustion. This is a significant advantage in a densely populated city where noise reverberates through narrow streets; smoother vehicles enhance the urban soundscape and lessen noise disturbances for residents.

Sustainable materials are given priority, such as incorporating solar panels on the roofs for auxiliary power and symbolic value, and using recycled or lightweight materials in the body to enhance energy efficiency. The autonomous shuttles are designed without a steering wheel or pedals, freeing internal space and offering greater design flexibility. Thanks to independent wheel control systems, the vehicles can also be bidirectional, capable of moving forward and backward with precision, which is especially advantageous in confined or nonlinear urban routes.

Inclusivity is at the forefront of the vehicle and service design. The interior layout of the autonomous shuttles is being crafted to accommodate a wide range of users, including those with reduced mobility. Low-floor designs and ramps (or level boarding platforms at stops) will allow easy entry for wheelchair users or strollers (Figs. 11 and 12).

Fig. 11. Geans (AY 2024-25) - Pietro Carena, Aurora Tenca, Xu Haoqi

Fig. 12. PiXi (AY 2024-25) - Desirèe Carrieri, Sofia Genesin, Ginevra Mignano

The seating is modular and reconfigurable (Figs. 13 and 14). For example, it can be arranged in a face-to-face bench style to encourage social interaction or configured to increase open space for wheelchairs or standing passengers during peak use. The design team tested configurations like a circle of seats or perimeter positioning to see what best balances comfort, capacity, and sociability in a small vehicle. Additionally, human-machine interfaces (HMI) are being developed with accessibility in mind.

Since these shuttles are autonomous, passengers will interact with them via digital interfaces to request a stop, get route information, or even dialogue with a virtual assistant for help. The project plans to implement voice-activated controls and conversational AI that understand multiple languages and even sign language commands (via camera-based gesture recognition).

For instance, a hearing-impaired person might sign a request or use a touch-screen; a visually impaired individual could use a voice interface. By incorporating universal design principles [21], the mobility system aims to be inclusive by design, ensuring that technological advancement does not inadvertently exclude anyone.

Beyond the nuts and bolts of vehicles, Genoa's mobility vision includes a strong focus on the user experience and service model. The autonomous vehicles are not imagined as bare-bones people movers, but as a new form of public space in motion. For example, the project proposes onboard information and entertainment systems to enhance rides, especially for tourists or during nighttime service. Interior, dynamic lighting can adjust to create a comfortable ambiance or provide extra illumination when traveling through dim alleyways at night. Screens or audio guides might share information about landmarks as the car passes, effectively combining transport and a guided tour. Free Wi-Fi connectivity on board would allow passengers to use travel apps or stay connected during their short trips.

Fig. 13. PiXi (AY 2024-25) Desirèe Carrieri, Sofia Genesin, Ginevra Mignano

Fig. 14. Toulì (AY 2024-25) Claudio Cervetto, Giorgia Grasso, Nicole Lomuscio

These features make riding the shuttle an attractive option compared to private cars and can enhance the tourism experience (imagine an evening “cultural pod” that takes people to museums or events with commentary along the way). Notably, the design also addresses safety in a novel manner: each autonomous vehicle is intended to serve as a “safe space” if needed.

In late-night operations or rare emergency situations, the shuttle can temporarily turn into a secure pod, locking its doors and directly communicating with authorities. For instance, if a passenger feels threatened by something outside or if there is a city-wide alert, the shuttle could shelter its occupants and have a direct line to police or emergency services. This feature is aimed at bolstering public confidence, ensuring that an autonomously run system is efficient but also trustworthy and safe for users at all times.

Crucially, the project integrates these vehicles into a broader intermodal network for Genoa. The planners identified strategic points in the city where different transport modes meet – for example, the base of a funicular, the terminus of a public elevator, or a coastal bus stop – and designed mobility hubs around them. At these hubs, an autonomous shuttle stop is collocated with other services, enabling passengers to transfer seamlessly. A likely scenario is a resident coming down from a hilltop on a funicular railway, then switching to an autonomous shuttle that takes them through the last mile to their workplace in the historic centre, where no regular bus goes. By linking previously disconnected nodes, the system improves last-mile connectivity and knits together Genoa’s existing transport infrastructure into a unified whole.

The project’s service design includes smartphone apps or kiosks for passengers to plan routes across multiple modes with a single ticket or payment, reflecting the Mobility-as-a-Service (MaaS) trend [22]. Someone could input their destination, and the system would suggest an itinerary: perhaps an elevator to shuttle to the metro, for example, optimizing for time or accessibility. The goal is for a person to navigate the city's vertical and horizontal complexities as easily as if it were a flat grid, without the need for a private car.

As with the cultural project, rigorous testing and validation are part of the mobility initiative. Simulations are run to simulate how a fleet of autonomous shuttles would interact with traffic and pedestrians and anticipate potential issues like vehicle bunching or software edge cases on Genoa's roads. The city's challenging terrain is being used as a laboratory to fine-tune navigation algorithms—for instance, handling steep slope parking or tight turning radii in the old town.

Pilot deployments of a few shuttles on controlled routes are planned to collect real-world performance data. Researchers are also considering the regulatory context: Italian laws (like those in many countries) are still catching up to fully driverless operations. Current regulations often require a safety operator on board and limit speeds (some EU projects cap AV shuttles at 20–30 km/h for safety) [23].

Public engagement is a key component of the project. Demonstration events, potentially tied to exhibitions such as Genova BeDesign Week, will allow residents to explore and ride prototype shuttles, provide feedback, and become familiar with the new system. This participatory approach fosters transparency and community trust, which are essential to successfully adopting autonomous mobility services in heritage cities like Genoa.

4 Discussion

The two case studies—digital cultural heritage and smart mobility—highlight distinct yet deeply interconnected aspects of Genoa's smart city transformation. Together, they offer an integrated vision for innovation that honours local identity, promotes social inclusion, and aligns with sustainability objectives. Several key themes arise from the projects.

First, both initiatives actively seek to balance technological advancement with the preservation of Genoa's urban and cultural identity. Rather than imposing technology indiscriminately, they adapt it to the city's context. The metadistrict uses digital tools to enrich physical spaces through AR/VR storytelling rooted in local history. Similarly, the smart mobility system introduces quiet, small-scale autonomous vehicles that respect the medieval urban fabric. This approach reflects a shift from rigid, top-down smart city paradigms to more nuanced, context-aware strategies, echoing Sennett's (2018) call for "wise cities" that value flexibility, complexity, and human experience.

Second, both projects place a strong emphasis on community engagement and inclusivity. In the metadistrict, local associations curate cultural events, and residents contribute to digital archives. In the mobility project, inclusive design principles ensure accessibility for all, particularly underserved groups. Genoa has cultivated trust, ownership, and long-term viability by involving citizens throughout design and implementation. These examples align with UN-Habitat's concept of people-centred smart cities, where technology is co-designed with the communities it serves.

Third, a multidisciplinary and collaborative approach is central to success. The cultural and mobility projects draw on architecture, urban design, engineering, ICT, and the social sciences. The University of Genoa serves as a bridge between domains, fostering cross-sectoral innovation and a shared vision. This collaboration allows for creative synergies—for instance, using smart mobility infrastructure to connect cultural sites or drawing aesthetic inspiration for shuttle design from local heritage.

Another insight is that technology is treated as a means rather than an end. In both cases, tools such as AR or autonomous vehicles are selected for their ability to solve real problems and enrich human experiences. Genoa's approach avoids the common pitfall of implementing advanced technologies simply because they are available. Instead, careful piloting, monitoring, and iterative refinement ensure that innovation remains relevant and effective.

The dual projects also address various aspects of sustainability. The cultural initiative strengthens social and economic sustainability by reinforcing community identity, supporting local creative industries, and promoting inclusive participation. The mobility project fosters environmental and social sustainability through reduced emissions, improved accessibility, and adaptive infrastructure. Together, they enhance the city's resilience—culturally, economically, and operationally.

Of course, challenges remain. Long-term maintenance, equitable access to technology and data privacy must be continually addressed. Genoa mitigates these risks through hybrid access models, public outreach, and regulatory alignment. Ensuring scalability, sustainability of funding, and integration with urban policies will be critical in the coming years.

Finally, the coexistence of these initiatives presents unique opportunities for synergy. Cultural events increase demand for flexible transport, and improved mobility broadens access to heritage experiences. These reciprocal benefits demonstrate how integrated planning across domains can amplify impact. Genoa thus models an interdisciplinary and interdependent smart city strategy.

5 Conclusion

Genoa's twin digital cultural heritage initiatives and smart mobility demonstrate how a historic city can pursue technological innovation without compromising its identity. The projects show that tradition and technology can form a virtuous cycle, where digital tools enhance cultural understanding and heritage context shapes more meaningful innovations.

By actively involving citizens, embracing inclusive design, and fostering cross-sector collaboration, Genoa has created socially grounded and future-oriented initiatives. This approach confirms that a smart city is defined not only by its infrastructure but also by its ability to serve its people.

Moreover, Genoa illustrates how historic cities, often viewed as resistant to innovation, can become laboratories for forward-thinking solutions. The challenges of constrained space, layered history, and social diversity demand creative responses that may prove replicable elsewhere. As such, Genoa contributes to a growing body of evidence that digital innovation and cultural preservation are not mutually exclusive but mutually reinforcing.

As cities worldwide grapple with digital transitions, climate goals, and the need for more inclusive urban systems, Genoa stands as a compelling model. Its strategy demonstrates that progress and preservation coexist, and meaningful innovation is rooted not in erasing the past, but in building upon it. In this way, Genoa shows how a city can become smarter by becoming more deeply itself.

At the same time, several challenges remain open and deserve further attention. The risk of digital exclusion may undermine the inclusiveness of cultural platforms if access is not broadly guaranteed; the long-term economic sustainability of large-scale mobility infrastructures requires careful planning and continuous investment and the governance of such integrated strategies demands coordination across multiple institutional levels. Far from weakening the proposed framework, acknowledging these unresolved issues enhances its robustness, outlining clear directions for future research and policy experimentation. In this sense, Genoa's experience not only inspires but also cautions, offering a laboratory in which the promises and limits of smart city innovation can be critically tested.

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Data Governance in Action: The Role of Data Norms in Smart Cities Innovation

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Abstract. This paper explores the role of data norms in the governance of smart cities, with a focus on how these norms shape innovation and collaborative value creation. Data norms are defined as the rules that govern the distribution of data control rights among stakeholders, particularly in relation to civic data sharing, data monetization, and personal data protection. Using the case of Rome's evolving smart city initiatives, including the Rome Data Platform, RomApp, and the newly launched Julia App, this study examines how these norms are enacted in practice. By analyzing these cases, we highlight the tensions and challenges that emerge when data governance initiatives are deployed in urban settings. The findings offer insights into how data norms influence the development and innovation of smart cities. Future research will expand on these themes through in-depth case studies, investigating the long-term impacts of data governance on the growth of smart cities.

Keywords: Smart City· Data Protection · Roma Data Platform · Data sharing · Monetization

1 Introduction

It is commonly accepted that smart cities feed on data, with circulation, sharing, portability and interoperability being their fundamental bases (Paolucci & Pollicino, 2023). Indeed, the contemporary smart cities rely on a continuous flow of data to deliver personalized and increasingly sophisticated services to citizens (Guggenberger et al., 2025; Vigorito, 2023; Tripodi 2024). This growing dependence on data brings to the forefront the critical issue of data governance – that is, how data are accessed, processed and stored across a complex network of public and private actors (Spagnoletti et al. 2025). The relevance of data governance in smart cities is further amplified by the central role that data play in AI-enabled urban architectures (Di Gregorio, 2025).

There is little doubt that the more data are collected and processed, the more effective and personalized the services offered to citizens become. In particular, personal data are of high value to smart cities, as they are rich in information essential for both the delivery and continuous optimization of urban services. It has been noted that collaboration, data sharing and coordination among stakeholders serve as an innovation engine for a smart city, especially through the data generated by various smart city applications (Voorwinden, 2021). Among other things, data collaborations make it possible

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 87–101, 2026.
https://doi.org/10.1007/978-3-032-21842-1_7

to direct data, which are in the domain of private entities (companies, in particular), toward instances of collective interest. Moreover, the companies that share their data in these inter-organizational and interaction forms also need new forms of governance (Kazemargi & Ceci, 2025). But these are still insufficiently tested practices, given that – especially in the private sector – data are predominantly used within organizations. It is noted that traditionally the exchange of data in the private sector is hindered by two main causes.[1] Companies tend to process data for their exclusive use and to maintain a competitive advantage over their competitors. After that, individuals keep the data they own within their organization and are unwilling to share it when the benefits to the public are unclear or when its use is not sufficiently rewarding with respect to their business missions (Grimaldi & Fernandez, 2019; Mossberger et al., 2023).

Therefore, to reverse this trend, in addition to putting pressure on companies (by improving the exchange of data according to the "Business to Government data sharing" and "Government to Business data sharing" formulas) the sharing of data directly by citizens (so-called "Civic data sharing") should certainly be encouraged.[2] The latter, in fact, through the rights granted by the GDPR[3] and now also by the Data Act[4] (as will be seen below) can once again dispose of the data processed by companies (social networks, various applications, Telco, etc.) and can then dispose of them for the benefit of smart cities, also instead of companies. Their data, moreover, are strategic for the governance of smart cities, as they are rich in the information needed to improve their decision-making processes and to deliver and get better services. Smart cities must, then, strive to attract data empowerment from citizens by fructifying in the best possible way the data norms we will discuss and designing a participatory context where the citizens themselves aim at a shared goal of public interest, made desirable also a return in terms of economic, personal or collective benefits, such as better public health, less traffic, more efficient mobility, etc. (Mossberger et al., 2023).[5]

Moving, however, from theory to practice, there are many smart city projects that have not experimented with or have found it difficult to put into practice valid forms of

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[1] European Commission. Towards a European strategy on business-to-government data sharing for the public interest. Final report prepared by the High-Level Expert Group on Business-to-Government Data Sharing (2020).

[2] As ENISA (2023) highlighted: "*Personal data protection is an integral element of the trust individuals and organizations should have in the development of data sharing ecosystems… Success will also rely on the establishment of a strong data governance and effective safeguards for the rights and interests of natural persons that are fully compliant with the GDPR. Data protection engineering … can be a key factor for building a trusted sharing environment, where organizations may submit data without disclosing personal data or sensitive business information or disclosing personal data with an adequate level of protection*".

[3] Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016.

[4] Regulation (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023.

[5] Casiddu et al. (2023) state that "*Citizen interaction and participation are key elements of evidence-based urban planning, as they are capable of providing tools for developing new personalized, adaptive and responsive services*".

data sharing and, therefore, also to stably maintain their vocation of offering useful services to citizens and businesses by promoting data sharing among various stakeholders, characterized by trust, transparency and usefulness (Dameri & Bruzzone, 2023).

It often happens that many projects that go by the name of smart cities end up being implemented only as prototypes or have a short duration, which is why it is important to evaluate the development of concrete data-driven solutions that serve to give them stability and durability (Aguilera et al., 2017; Cicirelli et al., 2017; Lim et al., 2018).

In this paper, we investigate data governance in smart cities to examine how data norms shape the evolution of collaborative value creation. We define data norms as the rules that allocate data control rights among smart city stakeholders (Spagnoletti et al., 2025). Specifically, we argue that three types of data norms play a critical role in the governance of smart cities.

The one related to the European Data Strategy (Grimaldi & Fernandez, 2019; Mossberger et al., 2023; Caggiano, 2024); the one that recognizes the "monetization" and economic value of data (Ritala, 2024; Gambino, 2020; Bolognini, 2024); and, finally, the one related to the protection of personal data to be used in a virtuous way, rather than letting it be perceived and/or stand, in practice, as a brake on the development and improvement of our modern smart cities.

2 Data Norms for Smart City Data Collaboration

2.1 Civic Data Sharing

The norms related to the European Data Strategy (Data Governance Act and Data Act) create opportunities to stimulate innovation and development in smart cities by fostering the availability of more data, both from businesses and citizens (Di Gregorio, 2025), in the form of "data sharing," i.e., the "*provision of data by a data subject or data owner to a data user for the purpose of joint or individual use of such data, on the basis of voluntary agreements or Union or national law, either directly or through an intermediary, e.g., under open or commercial licenses, for remuneration or free of charge*" (art. 2, par. 10 of the Data Governance Act, European Regulation 2022/868 of May 30, 2022). By the provision of a monetization, the European Data Strategy itself marks an important discontinuity in the data governance system, compared to the past in which – among others – incentives for data sharing were lacking (Poletti, 2024; Resta, 2023).

While the Data Governance Act can be leveraged to improve data sharing in the public sector (Government to Business Data Sharing) – which is a more tried practice than in the private sector but has nevertheless remained underutilized for a variety of reasons, including, lack of trust, obstacles, and little interest in sharing as such (without some economic return or other utility)[6] – the Data Act could, then, be usefully leveraged for Civic data sharing, which we are interested in.[7]

The article 5 of the Data Act states that *"Upon request by a user, or by a party acting on behalf of a user, the data holder shall make available readily available data, as well as the relevant metadata necessary to interpret and use those data, to a third party without undue delay, of the same quality as is available to the data holder, easily, securely, free of charge to the user, in a comprehensive, structured, commonly used and machine-readable format and, where relevant and technically feasible, continuously and in real-time"*.

Data subject's right to share data with third parties under the Data Act is an extension of the right to portability, already provided for in art. 20 of the GDPR, and could have relevant applications in the context we are dealing with, strengthening the tools that individuals can use to get back possession of information about themselves and to dispose of it for the benefit of data users, through contractual instruments and/or acts of disposition alternative to traditional public-private partnership agreements, which are the forms of data sharing still most widely used in the context of smart cities.[8]

Ultimately, the above-mentioned regulation - aimed at stimulating the European economy through greater use of data and to position the EU competitively vis-à-vis the United States and China – also formalized the concept of the data intermediary. A few years later, this role was institutionalized, reflecting business models that had already emerged with early services like Lumeria and, two decades on, with the Italian app Weople, developed by the start-up Hoda. The app had a clear purpose*: "to use the right to data portability to make it so that any user could manage his or her data, digital capital, as he or she does with his or her money through the bank: that is, to keep it safely stored away or to make it profitable by investing it in the market. This symbology of the bank was not just a marketing gimmick. The Weople app, in fact, allowed the user to have his or her digital data held by any platform applied for in his or her name*

[6] Data Gorvernance Act states *"to share or jointly process data for, inter alia, the development of new products and services, scientific research or civil society initiatives. Data intermediation services could include bilateral or multilateral sharing of data or the creation of platforms or databases enabling the sharing or joint use of data, as well as the establishment of specific infrastructure for the interconnection of data subjects and data holders with data users"* (preamble 27).

[7] Conversely, the Data Act cannot be used to support voluntary Business to Government type forms of data sharing. Indeed, on closer inspection, this long-awaited regulatory intervention does not introduce any new elements with respect to voluntary "Business to Government" type data sharing initiatives (see preambles 65 and 66), which remain excluded from its scope, focused on data sharing obligations for reasons of public emergency (Masnada, 2025).

[8] Di Gregorio (2025) says "*The content of the activity of intermediaries thus concerns the use, reuse, exchange, sharing, and exploitation of data (including for consideration, see Art. 12 lett. b, regarding the conditions for the provision of intermediary services and Art. 20, for the altruism of data) between the entities identified in the new figures of the data holder and the data user who hold the data thanks to the right to portability (directly or from other companies that have acquired them) and who act on the basis of a contractual relationship that can be traced to the scheme of service contract or mandate"*.

under Article 20 and "safely and anonymously 'deposit' it with Weople's servers, in a 'personal bank account' just as one does with money" (Rinaldi, 2025).

These models have, however, stopped in the face of skepticism from data protection authorities. In the request for an opinion on the subject of the commercialization of personal data and the right of portability, addressed by the Chair of the Italian Data Protection Authority to the Chair of the European Data Protection Board, it is stated that *"(...) this is a very relevant issue that, although it has come to the fore in Italy, calls for a general reflection that cannot be referred to individual data protection authorities. The case concerns the application of the right to data portability: in fact, an Italian company has proposed itself as an intermediary in the relationship between data controllers and data subjects by requesting, on the latter's proxy, to obtain personal information held by important business entities, particularly in the large-scale retail sector in order to bring them together within its own database to be subjected to enrichment. The issue is thus related to the "marketability" of the data, with the added complication of the exercise by proxy of the right and the consequent not remote risk of possible duplication of the databases subject to portability (...)".*[9]

The perplexities that had accompanied the introduction of this data sharing model were, therefore, definitively overcome, on the one hand, with article 5 of the Data Act, providing that the data subject can request, including through data intermediation services providers, that he be given a copy of the data concerning him and can dispose of it in favor of other users for the most varied purposes; on the other hand, by implementing the EU Directive 2019/770, which amends the Legislative Decree 206/2005, the so-called Consumer Code, providing without a doubt that digital services can also be payed with the provision of one's personal data.

Moreover, precisely on the assumption that the services of social networks are only apparently "free," the Milan Public Prosecutor's Office charged Meta Platforms Ireland Limited and X Corporation with € 877 million and € 12.5 million in vat evasion, respectively, claiming that the provision of their digital services to users does not constitute a 'free' service but, in fact, realizes a "barter" in which the platforms' digital services are paid with their users' personal data (Galimberti, 2025; Carinci, 2025).

2.2 Data Monetization

The fact that the Consumer Code provides that digital services can be paid with personal data open the way for practices in which *"these data and the metadata associated with them*" can constitute *"an object good of economic and legal relations"* (Resta & Zencovich, 2018).

Pursuant to article 135 octies of the Legislative Decree. 206/2005, the provisions on digital content contracts *"shall also apply where the trader provides or undertakes to provide a digital content or digital service to the consumer and the consumer provides or undertakes to provide personal data to the trader, except where the personal data provided by the consumer are processed exclusively by the trader for the purpose of*

[9] Letter by the Chair of Italian Supervisory Authority to the Chair of European Data Protection Board - Request for opinion on the subject of marketability of personal data and the right to data portability. www.garanteprivacy.it, doc. web 9126725, last accessed 2025/03/27 (2019).

providing the digital content or digital service in accordance with this chapter or to enable the performance of legal obligations to which the trader is subject and the trader does not process such data for purposes other than those intended”.

This means admitting, in general, that users’ personal data have economic value and that they can dispose of it to purchase goods and services. After all, data have become an extremely important resource for the economies of our Countries and, with good reason, have been called the “new oil”,[10] although – compared to this precious natural resource – data have the characteristic of being intangible assets that do not consume and can be used and reused simultaneously by multiple parties and for multiple purposes, without the use of one excluding that of the other (Rinaldi, 2025; Ducuing, 2024).

Although it may seem difficult to admit that personal data can be used as a bargaining chip, since they also constitute attributes of the person,[11] it should not be forgotten that the right to the image also undoubtedly constitutes a right of the person but it is, likewise, established that it equally constitutes an asset that can be exploited in its patrimonial values for commercial purposes, at least for famous people.[12]

However, there are many business models, involving personal data, that exploit their monetization potential and are finding increasing diffusion and application. Ultimately, they can be traced to three types (Ducci, 2025): the “zero cost” model, typical of social networks; the “personal data economy” model, which consists of the direct exchange of data for a monetary consideration, as in the case of the Weople App; and the “pay or consent” model, typically applied by online newspapers (Trovato, 2022). It has, however, been highlighted that these models, in order to be applicable, must comply with GDPR, on the protection of personal data, as a necessary condition of lawfulness (Moretti, 2022).

All of these models are also abstractly useful and usable in smart city data sharing ecosystems to encourage citizens’ data empowerment (Civic data sharing) or a virtuous exchange of their data with public administrations that provide services and companies (d’Ippolito, 2022; Bravo, 2021). It has been in this regard correctly noted that the “*the transformation into a data monetizing system creates a tremendous opportunity for all the stakeholders and a motivation for city officials to collect and feed appropriate data into the system”* (Samuel & Gupta, 2022).

2.3 Data Protection

There is no doubt that different frameworks of data sharing work in smart cities if they also ensure the protection of citizens’ personal data.

So, new data norms and data sharing tools that implement the European strategy for data and its monetization are welcome – provided that people’s fundamental rights

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[10] The Economist: The World’s Most Valuable Resource Is No Longer Oil, but Data. https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data, last accessed 2025/03/29 (2017).

[11] European Data Protection Supervisor: Opinion 4/2017 on the Proposal for a Directive on certain aspects concerning contracts for the supply of digital content. https://www.edps.europa.eu/sites/default/files/publication/17-03-14_opinion_digital_content_en.pdf, last accessed 2025/03/20 (2017).

[12] Ex multis Trib. Monza 20 June, 1999. *Dir. Autore*, 74–78 (2021).

are always safeguarded in the smart city (Turci, 2023). After all - by the express will of the European legislator - the GDPR remains fully applicable and protected, without being limited or overridden by other intersecting legislation. Ultimately, the European legislator aimed to strengthen the instruments that enable broader access to data, while at the same time preserving the centrality of fundamental rights. Among these, the right to the protection of personal data – and the corollary rights that allow individuals to maintain control over their data – are positioned to play a primary role (Di Gregorio, 2025).

Precisely, in order to avoid the complexities of GDPR compliance – a data norm often, though mistakenly, perceived as an obstacle to the development of data ecosystems - a model based solely on anonymized data is frequently adopted. This model applies "privacy" measures, rather than security measures, to safeguard the confidentiality, availability and integrity of data. While such an approach certainly eliminates any concerns regarding data protection – since anonymized data do not qualify as personal data and therefore fall outside the scope of the GDPR – it also raises questions about the broader implications for accountability and data governance.

It was, however, noted that – even with respect to anonymized data – not every issue of personal data protection is always resolved, if sufficiently robust techniques aimed at eliminating the identification component of the data are not implemented, as the risk of reidentification of data subjects may remain high.

For instance, users were reidentified against data that were believed to have been irreversibly anonymized, due to incidents involving some databases on users' browsing data (in Germany), health data (in Italy and in Australia), and public transport data (in Latvia) (De Cordes, 2019).

It was, then, further pointed out that anonymization of data leads to the loss of much important information. Ultimately, anonymized data become less rich in information and, therefore, less useful for smart city goals (De Cordes, 2019).

Here, then, a part of the doctrine proposes the use of synthetic data, understood as *"a privacy optimization technology (PET), since it serves as a mechanism to implement a data protection approach by design in scenarios that require the processing of personal data"*, that is, data that allow for the implementation of even sufficiently complex treatments, eliminating the need to use real personal data (D'Acquisto, 2024; Brozzetti, 2024; Finocchiaro, 2024)·[13] Although tested in other sectors (healthcare, pharmacology, training of artificial intelligence and machine learning algorithms), synthetic data could be a valid alternative tool to data anonymization (of which, moreover, recurring limitations have been highlighted), allowing work with rich datasets of information and attributes and eliminating the risks of reidentification of data subjects.

Synthetic data could, then, also be used by data intermediation services providers as measures to facilitate the exchange of data in smart cities, improving governance and personal data protection outcomes (art. 12, lett. e) of the Data Governance act).

[13] ENISA (2022): "*Synthetic data is a new area of data processing in which data are elaborated in a way that they realistically resemble real data (both personal and non-personal), but actually they do not refer to any specific identified or identifiable individual, or to the real measure of an observable parameter in the case of non-personal data"*.

Furthermore, synthetic data could be not only a means to protect personal information of data subjects,[14] but also a measure to promote the innovation and progress we are seeking in smart cities.

An alternative model to the one above consists in the definition of specific contractual agreements on data, which define the subjects and the responsibilities related to the processing of personal data. In this model, "privacy" issues remain in all their scope and require the enforcement of the GDPR, defining the roles of the subjects involved in the processing of personal data, the information to be given to the interested parties, the legal bases necessary to process the data, the impact assessments on the protection of the rights and fundamental freedoms of the interested parties (de Montjoye, 2018).

Compared to the approaches seen above, there are additional solutions that promote the exchange of data in smart cities under the control of users, who will be able to selectively choose the companies or public entities that will have access to all or part of their data, as well as the duration of their use and all other conditions for using them (De Cordes, 2019). It is the model seen above of the Weople App[15] and data vaults in which interested parties collect and archive their data which are then used and valued on the market, in various forms, by giving a mandate to the data intermediary, now explicitly provided for by the European legislature (Thopam et al., 2023). It is, in fact, the same model proposed by the Data Governance Act.[16] In any case, through the exercise of the rights of interested parties (articles 15–22 of the GDPR) citizens will be able, after their provision, to follow their data and also control how they are used.

Achieving the right balance between protection of data subjects' personal data and optimizing the forms of data sharing remains, in fact, a considerable challenge in the landscape of smart city development, still poorly addressed from a theoretical point of view and even less from a concrete point of view (Joyce & Javidroozi, 2024).

3 Data Norms in Action: Insights from the City of Rome

To explore how data norms take shape in practice and to uncover the tensions that may arise during their implementation, we examine the case of data governance in the city of Rome. Drawing on three key components of the city's data ecosystem – the Rome Data Platform, the RomApp, and the Julia App – we illustrate how different data norms are instantiated, negotiated, and sometimes contested. These examples provide empirical grounding for the theoretical categories introduced above, offering insights into the complex interplay between civic data sharing, data monetization, and data protection in a smart city context.

[14] Finocchiaro, G. et al. (2024) state that synthetic data *"represent the result of synthesizing processes that exploit machine learning and artificial intelligence algorithms to create novel datasets that 'mimic' the characteristics and statistical relationships of real datasets, but do not contain any direct identifying features. In other words, synthetic data, when properly generated, not only faithfully reflect the distribution, trends and patterns of the original data, but do so in a way that negates any risk of tracing information back to individuals"*.

[15] Available at https://weople.space/, last accessed 2025/03/23.

[16] Data Governance Act, *"Data intermediation services providers should be allowed to offer additional specific tools and services to data holders or data subjects for the specific purpose of facilitating the exchange of data, such as temporary storage, curation, conversion, anonymization and pseudonymization"* (preamble 32).

Speaking about the methodology used to gain useful insights from the field, primary data were collected that consisted of discussions and meetings with key figures involved in the projects in order to gain a comprehensive understanding of the phased development and their operation in terms of system design and data governance. Primary data collection was also particularly valuable in understanding the challenges, current limitations of the system, and recognizing areas that need to be addressed and current barriers that have prevented RDP and other applications from operating at full capacity. Secondary data, on the other hand, consisted of an extensive literature review on the topics of data sharing (especially, in the form of Civic data sharing), data monetization, and personal data protection, and the tools that enact them to fully absolve the development and progress of smart cities.

Rome Data Platform. The Rome Data Platform (hereinafter for brevity, "RDP") is a digital smart city platform of the City of Rome. The RDP has its own infrastructure, its own datasets, its own data processing logics, and sensors distributed across the territory. It can collect and process different kinds of data and is a useful governance tool for the Municipality of Rome. The RDP consists of a centralized "dashboard" for observing and managing information related to essential aspects of daily urban life in the city of Rome (Ariano, 2021).

The Rome Data Platform was launched in 2020, precisely with the ambitious goal of becoming the city's dashboard and enhancing the vast amounts of information produced by the City of Rome and its citizens using connected devices. The purpose of RDP was evidently to improve the data-driven governance of the city, making it evolve at great speed.

Designed to support multiple frameworks of data sharing, not only between public entities but also with companies, the RDP has an ICT architecture capable of collecting, recording and integrating multiple streams of information from different sources, managing to incorporate them into a single system. All this information is processed by the RDP, which returns "data insights" that are useful for city governance and for the citizens themselves. In fact, the further goal of the RDP was precisely to promote the active participation of citizens in data sharing (Civic data sharing), so that this participation could add value for the entire data ecosystem, further supporting smart city governance and its services.

However, over the years, its use has been limited to city governance, lacking direct interoperability and connections with external actors. The current configuration, databases and interoperability between IoT systems are effective only for internal use and do not communicate adequately with each other.

In 2024, however, in collaboration with key figures involved in the creation and administration of the platform, it was possible to conduct a strategic assessment of its capabilities and the possibility of opening to the exchange of data with external entities such as private organizations, companies and, above all, citizens, as well as to define suitable measures to encourage it. Ultimately, RDP intends to extend its scope to an interconnected system of data sharing among various entities, to improve its services to citizens by harnessing public information (stored now in a large "distributed data lake"), but also by attracting the contribution of data from private entities and, above all, citizens. It will, then, be interesting to see whether the new "Evoluzione Roma Data

Platform" project (relaunched by the City of Rome in December 2024) will take these assessments into account and how it will want to and/or succeed in using data norms to push innovation and development in its smart city.

At the moment, the pages of the City's website report that the goal of this new project is to *"create an enabling tool for the Smart City, operating as a Decision Support System (DSS) to support administrative and stakeholder activities. The platform acts as a centralized" virtual repository "of data generated by Roma Capitale, allowing their aggregation and exchange with other systems in an organized way. The RDP makes digital services available to citizens, such as apps, data visualization dashboards, APIs and web services. (…) The RDP project will have an impact also extended to the municipalities involved, providing a solid basis for improving administrative and economic management. Data interoperability will create an ecosystem of cooperation between municipalities, allowing the development of data-driven strategies. City users will benefit from updated digital services based on forecasts and actual data, enriching the experience of residents, tourists and pilgrims, especially in view of the Jubilee of 2025".*[17]

RomApp. RomApp was, on the other hand, an application that allowed citizens to actively participate in the governance of the city by reporting various urban problems and needs (e.g., need to remove bulky waste; existence of potholes and other issues related to roads, transportation, and so on).

RomApp allowed, as well, to acquire information about the state of the city and services, which was useful for interpreting data provided by other ecosystems (economy, transportation, culture, tourism, welfare, and others) and IoT sensors. RomApp was fully integrated into the overall design and standards of RDP and had functional modules that supported the entire process, from report collection to data processing and analysis. Available for Apple and Android users, it featured a simple design and a strong call-to-action for submitting reports and proposals.

Its uniqueness lay in the fact that there was no need to register and any form of tracking was absent, which encouraged massive citizen adherence and the collection of anonymous, but sufficiently large, data to build models based on which to define citizens' needs and feelings of liking or disliking. RomApp, was shut down on 20 September 2024, due to operating costs. Despite the support of citizens who helped solve multiple problems and successes in improving services, the closure was inevitable. The group that managed the App expressed deep gratitude for the many active participation and the hope that other similar initiatives will continue this path of civic collaboration for the improvement of the city.

Taking advantage of data norms related to data sharing, monetization, and data protection (moreover, already adequately considered in terms of data anonymization and lack of any tracking of user activities), new development scenarios could also be opened for RomApp.

App Julia. Julia is the City of Rome's new virtual assistant, which uses generative Artificial Intelligence algorithms to help visitors to explore the city and experience it in

[17] Available at https://www.comune.roma.it/web/it/attivita-progetto.page?contentId=PRG1163717, last accessed 2025/03/27.

an easy and pleasant way.[18] Julia also constitutes an interesting application in which it is intended to enhance the sharing and exchange of data among various stakeholders while safeguarding the protection of personal data, above all, using data norms (in this case, also the AI Act)[19] to shelter citizens and users from cognitive bias and hallucinations of the artificial intelligence system used (Spagnoletti & Baskerville, 2025).

Specifically, Julia is based on the generative Artificial Intelligence of OpenAI/ChatGPT, developed through the collaboration of the City of Rome, assisted by the Foundation for Attraction and partners such as Microsoft /OpenAI, Ntt Data and Intellera. Julia allows direct entry of information by operators (hosts, restaurant owners, municipal offices, etc.) and is queried by users through questions posed through special chatbot. Julia represents a unique opportunity for the city's merchants who can enter special databases and actively participate in its platform designed to optimize the management of tourist flows, improve visitor satisfaction and strengthen Rome's image as a destination of excellence and sustainability. Thanks to Julia, Rome can offer tourists a personalized and innovative welcome, and local operators can promote their services more effectively and immediately.

The information and responses Julia provides are generated through direct and guaranteed control of data sources, which should ensure relevance, completeness, and accuracy. Julia relies, then, in addition to the RDP's significant information assets (drawing from its large "data lake"), on data sharing by various stakeholders and claims to operate in compliance with data protection regulations (Palmieri, 2025).

At the time of writing, the Julia App has just been released and represents a promising example of innovation enabled by collaborative data governance (Spagnoletti & Volpentesta, 2024; Manzocchi & Spagnoletti, 2024) The App allows users to query databases from different actors—such as those related to mobility, commerce, and other urban services—using natural language. However, given its recent deployment, it is not yet possible to assess the limitations of this solution. Future research will be needed to critically evaluate its long-term implications and effectiveness.

4 Conclusions and Future Developments

The recent data norms, relating to the European Data Strategy (the Data Act and the Data Governance Act), provide useful means to incentivize data sharing in smart cities, as demonstrated by the activities that are assigned to data intermediation services providers, which can certainly be directed to converge citizens' data towards the implementation of the collective interests of modern smart cities (mobility, tourism, healthcare).

This article considers, then, the Civic data sharing which – if effectively utilized – can make an important contribution to the needs of modern, crowded urban areas. Specifically, it is noted that by taking advantage of the norms governing data collaborations (the Data Act, in particular), sharing activities can be made attractive and interesting to citizens as well, leading to the desirable result of overcoming the abandonment of many

[18] Available at https://julia.comune.roma.it/it/, last accessed 2025/03/27.

[19] Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024.

smart city projects that are observed in practice because they are not very profitable or not very attractive to the administrations implementing them.

The monetization of data can also be a useful lever to encourage the exchange and collection of large volumes of data (big data), which – as mentioned above – are the "main engine" of smart city governance and the AI algorithms that make them work.

The above solutions, in any case, cannot absolutely ignore the application of the data protection regulation (the GDPR and national law on the personal data protection), both in terms of their anchoring to solid principles that justify positive conclusions regarding the legitimacy of the economic exploitation of personal data, and in terms of the definition of forms of data sharing that will also have to rigorously apply the data norms on the personal data protection.

Future developments of this research will further explore these themes by conducting in-depth case studies within the evolving smart city ecosystem of Rome. Particular attention will be given to how data norms related to data sharing, monetization, and personal data protection are being applied in emerging initiatives – such as the evolution of the Rome Data Platform and the Julia App – and to what extent they influence the development and innovation of smart cities.

Acknowledgments. We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.1, Call for tender No. 1409 published on 14.9.2022 by the Italian Ministry of University and Research (MUR), funded by the European Union –NextGenerationEU–Project Title Data4Innovation- Data ecosystem governance toward enhancing data sharing for innovation: implications for organizations – CUP D53D23017780001 - Grant Assignment Decree n. 1376 on 01/09/2023 by the Italian Ministry of Ministry of University and Research (MUR).

The authors have no competing interests to declare that are relevant to the content of this article.

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Planning and Management Tools for Renewable Energy Communities in Smart and Sustainable Urban Districts

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Abstract. Renewable Energy Communities (RECs), introduced by the RED-II EU Directive, represent a promising mechanism to facilitate the integration of Renewable Energy Sources (RESs) in compliance with European targets. Based on the principles of virtually shared energy and geographical proximity, RECs enable energy exchange among members without direct physical connections, relying instead on simultaneous energy injection and withdrawal through the public distribution network. This paper presents a comprehensive methodology for both the optimal design and management of RECs, improving their technical and economic performances. The optimal design identifies the best mix of REC members and determines the appropriate sizing of Photovoltaic (PV) and Battery Energy Storage Systems (BESS), aiming to minimise the total costs (purchase and installation costs, operation and maintenance costs, electricity costs) and to maximise the incentives on the shared energy, considering also Electric Vehicle (EV) charging infrastructure. Regarding the optimal management, a bi-level Energy Management System (EMS) is proposed. The upper level, controlled by the REC manager, seeks to maximize the shared energy, while the lower-level EMSs, located at members' premises, perform detailed resource dispatch under both cooperative and non-cooperative behavioural models. Optimization results highlight that including mainly larger members improves economic viability, while the inclusion of a large number of residential users may not always generate benefits, due to increased REC management costs.

Keywords: Renewable Energy Community · Energy Management System · Optimal design · Electric mobility · Photovoltaic · Battery Energy Storage System

1 Introduction

To reduce the environmental impact of human activities in cities, the European Commission has taken several actions. The main ones are based on the use of Renewable Energy Sources (RESs) to meet the energy needs, i.e. electricity and heat, of buildings, both residential and office, but also industrial. It is worth mentioning the Clean Energy for all

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 102–121, 2026.
https://doi.org/10.1007/978-3-032-21842-1_8

Europeans Package, adopted in 2019 to decarbonise EU's energy system and act against climate change in line with the European Green Deal objectives [1]. The package includes different regulations aimed to promote energy performance in buildings and sustainable living, renewable energy use and energy efficiency, as well as electricity market design and innovative governance policies. Within this regulatory framework, the Renewable Energy Directive (EU) 2018/2001 (RED-II) [2] defines Renewable Energy Communities (RECs), while the Electricity Market Directive (EU) 2019/944 [3] introduces Citizen Energy Communities (CECs), whose joint purpose is to provide environmental, economic or social benefits for their members or to the local areas where they operate, by producing, consuming, storing and exchanging renewable energy.

This paper focuses on RECs [4], which are aggregations of users underlying the same primary electrical substation who decide to share locally produced energy from RESs, and proposes a set of tools used to optimally plan and manage RECs with the aim of reducing the energy costs of citizens, as well as to minimize the environmental impact of the urban districts where the aforesaid citizens live [5–7].

In literature, many papers deal either with the optimal design of RECs, as [8–11], or with the optimal management of RECs [12–14]: nevertheless, they do not provide a comprehensive approach involving both aspects. Reference [8] explores the optimal design of RECs in Italy, analysing factors such as community composition, market signals, building characteristics, location and incentives, considering as possible technologies PV units and BESSs. The authors of [9] analyse the impact of the levelized cost of electricity by different technologies on the optimal design of RECs. In [10], the authors investigate also the role of hydrogen-based systems in RECs, considering the possible installation of fuel cells in addition to PV units, wind turbines and BESSs. A similar approach is adopted in [11], where the authors apply particle swarm optimization to solve the optimal planning problem for RECs. On the side of energy management applied to RECs, reference [12] compares the economic performances of two REC configurations (centralised and decentralised, depending whether the PV has a dedicated point of delivery or not). Multi-vector RECs are considered in [13], providing intelligent management solutions. The trade-off between individual physical self-consumption and community virtual energy consumption are investigated in [14], providing advanced battery management solution to guarantee greater REC energy independence and a better investment for all REC participants.

Within this state of art, the developed tools proposed in this paper can be used to determine the optimal size of renewable power plants to be installed in sustainable prosumer buildings, as well as to manage dispatchable power generation plants, Battery Energy Storage Systems (BESSs) and charging infrastructures for Electric Vehicles (EVs), aiming to maximise the shared energy within the REC, for which the Italian company *Gestore Servizi Energetici*[1] (GSE) also recognises an incentive and a valorisation contribution due to the avoided transmission network losses. In particular, regarding electric mobility, new innovative technologies such as Vehicle-to-Grid (V2G) and Vehicle-to-Building (V2B) [15] are investigated in order to assess how urban districts characterized by the implementation of green energy policies and transportation systems can lead to

[1] Company responsible for promoting and managing renewable energy and energy efficiency initiatives in Italy, under the control of the Ministry of Economy and Finance.

more liveable cities and economic savings for citizens [16], defining different EV smart charging strategies and optimising the integration of electric mobility and RESs [17].

The present paper is organized as follows: Sect. 2 describes the concept of physical and virtual self-consumption, that are at the base of RECs; Sect. 3 provides an insight on the Italian regulation of RECs; Sect. 4 describes the developed methodology; Sect. 5 highlights the main input data necessary to run the optimization tools; Sect. 6 discusses the most important results of the study and Sect. 7 provides some conclusive remarks.

2 The Concept of Self-Consumption

The essence of self-consumption is the ability to use electrical energy generated by a production facility located in proximity of a user in order to meet its own energy needs or the energy needs of neighbouring users.

Physical self-consumption (in Italian, *Autoconsumo fisico*) is a configuration where the production unit is directly connected (by cable) to the consumption unit and the use of part of the energy produced by the end customer is instantaneous. The portion of energy produced and not self-consumed instantly flows into the grid. From a technical point of view this is the most efficient mechanism, since the energy directly self-consumed at the site minimizes system losses. From the economic point of view, self-consumed energy is directly valued as savings in the bill. The portion of energy produced and not self-consumed is handed over (sold) to the GSE or to the market. A physical self-consumption scheme is provided in Fig. 1.

On the other hand, virtual self-consumption (in Italian, *Autoconsumo diffuso*) is a configuration where the energy produced by a production unit is shared virtually between two or more units of consumption that are not directly connected to the production plant but are connected to the network through two different Points of Delivery (PODs) and have the characteristics for a beneficial sharing of that energy through the public distribution network. The technical definition of *"Autoconsumo diffuso"* is that energy produced at one location and consumed at nearby locations (all connected to the same primary High Voltage (HV) – Medium Voltage (MV) substation) does not transit at higher network voltage levels and has lower transport losses than energy produced at far locations, which impacts all network stages of the national electricity grid. Because of this, the Italian regulation authority (*Autorità di Regolazione per Energia, Reti e Ambiente* – ARERA) has also provided an economic definition of the expenses prevented in the distribution and transportation of virtual self-consumption [13]. A scheme of virtual self-consumption configuration is shown in Fig. 2.

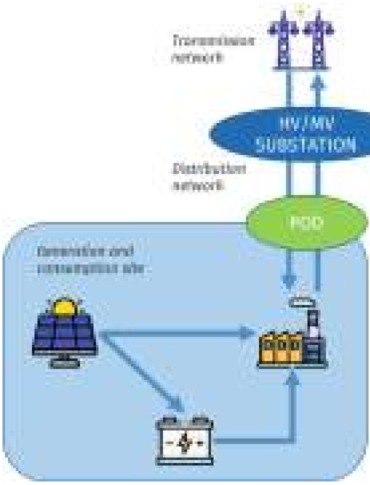

Fig. 1. Physical self-consumption.

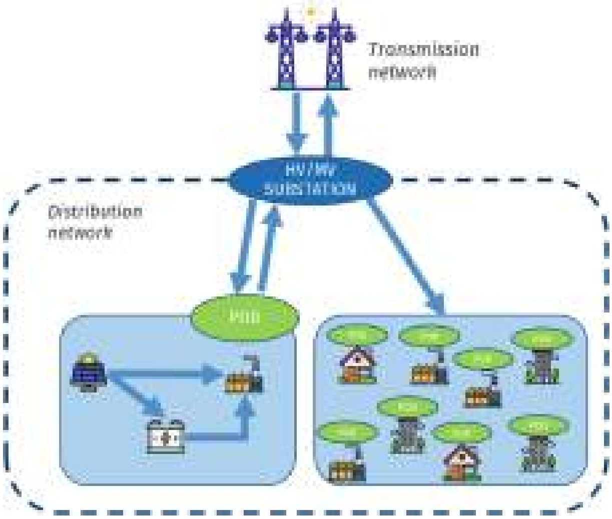

Fig. 2. Virtual self-consumption configuration.

3 Italian Regulatory Framework for RECs

3.1 Legislative Actions

As aforesaid, the concept of RECs was first introduced at European level through the RED-II directive in 2018. The transposition of RECs in Italy followed a long path from a temporary transposition to a full transposition.

Law Decree 162/2019 and Law 8/2020 were the first attempt to transpose RED-II directive into the Italian regulatory framework. Those two provisions imposed that self-consumption configurations had to be confined within a single market zone[2] and had to be connected to the portion of low voltage network pertaining to the same secondary substation (medium-to-low voltage), and that the capacity of each RES generator owned by a member of the REC could not exceed 200 kW. These limitations severely reduced the scope and importance of RECs, and as a result, few initiatives were put in place.

The first criteria for regulating the remuneration of energy sharing inside self-consumption configurations were set by the Italian regulation authority ARERA with the Resolution of August 4th, 2020, 318/2020/R/eel, followed by Ministerial Decree 16/09/2020 of the Ministry for Economic Development (*Ministero dello Sviluppo Economico* – MiSE).

Legislative Decree 199/2021, which was passed into law in November 2021, furtherly transposed RED-II directive's provisions, loosening certain restrictions. Self-consumption configurations were then restricted to a certain market zone, and the members had to belong to the same portion of distribution network pertaining to the same primary substation (high-to-medium voltage). Additionally, RES power plants with a maximum capacity of 1 MW were made eligible for incentives.

Testo Integrato Autoconsumo Diffuso (TIAD) was then approved by ARERA in December 2022 with Resolution 727/2022/R/eel, governing the valorisation mechanism for the configurations defined in Legislative Decree 199/2021.

Finally, Ministerial Decree 414/2023 of the 7th December 2023 (so-called *Decreto CACER*[3]), delivered by the Italian Ministry of Environment and Energy Security, introduced the final transposition of RED-II directive in terms of self-consumption configurations. In January 2024, the regulating agency ARERA modified TIAD in order to take into account the prescriptions of Ministerial Decree 414/2023, followed by the publication of the operating rules for accessing incentives (in Italian, *Regole operative per l'accesso al servizio per l'autoconsumo diffuso e al contributo PNRR*) by GSE.

3.2 Self-Consumption Configurations

The Italian transposition of RED-II Directive, culminated with Ministerial Decree 414/2023, proposed three schemes of self-consumption configurations:

- Remote individual self-consumers (in Italian, *Autoconsumatori individuali a distanza*)
- Groups of collective self-consumers (in Italian, *Gruppi di Autoconsumatori Collettivi*)
- RECs

[2] A market zone is a subdivision of the Italian transmission network in accordance with some market congestion criteria. The subdivision is defined by Terna, the Italian Transmission System Operator.

[3] CACER stands for *Configurazioni di Autoconsumo per la Condivisione dell'Energia Rinnovabile* (i.e., Self-consumption configurations for renewable energy sharing).

3.3 Remote Individual Self-Consumers.

A remote individual self-consumer is an end-user who shares the renewable energy produced in areas of its ownership to virtually self-consume it at some consumption units of which it is owner.

An example is given by a company that owns two warehouses, connected to the network by means of two distinct PODs, A and B: if a Photovoltaic (PV) plant is installed on the roof of Warehouse A, the surplus production can be injected into the public distribution network and virtually shared with Warehouse B.

3.4 Groups of Collective Self-Consumers.

It is a group of at least two consumers and/or producers of renewable energy who are in the same condominium or building. The production plants may be located in the building or condominium or even at other sites owned by one of the members of the group.

An example is given by a condominium with a RES plant (e.g. a PV plant on the roof) connected to the meter of the utilities (e.g. stair lights, elevator, etc.) and capable of producing electricity in excess of the consumption of the common utilities: the energy produced in excess, can be either sold to the grid or virtually shared with the apartments.

Buildings owned by large enterprises can participate to this configuration, too.

3.5 RECs

When the self-consumption configuration goes beyond a single end-user (Remote individual self-consumers) or a single condominium/building (Groups of collective self-consumers), we are dealing with a REC.

RECs involve a combination of citizens, small and medium-sized enterprises and local authorities, like municipal administrations.

3.6 Technical Requirements

As previously mentioned, all the members of self-consumption configurations have to be connected to the portion of distribution network pertaining the same primary substation (high-to-medium voltage). Self-consumption configurations may manage the supply of both electrical and thermal energy, given that energy is produced from RESs: thus, the eligible technologies are PV power plants, wind turbine power plants, hydroelectric power plants, biomass power plants, biogas/sewage gas power plants and hydrogen-fed power plants (i.e., fuel cells and combined heat and power units). For the latter three technologies, requirements on the CO_2 emission involved in the production of the primary energy source are present. Also BESSs and EVs can participate in self-consumption schemes. The size of the power plants has to be lower than 1 MW and they must be new power plants or new sections of already-existing power plants. To be eligible for incentives, the power plants must have entered into activity after the 16th December 2021.

3.7 Shared Energy and Remuneration Mechanisms

The incentivization for self-consumption schemes is remunerated on the base of the so-called "shared energy". It represents the hourly minimum between the energy produced and injected into the grid by the renewable power plants of the configuration and the energy withdrawn from the grid by the members of the configuration. In other words, it is the hourly minimum between the energy sold and the energy withdrawn to/from the local distribution network by the members of the configuration. Only the portion of shared energy that is produced by RES power plants satisfying the requirements detailed in Subsection 3.3 is incentivized. A graphical representation of the concept of shared energy is reported in Fig. 3.

Fig. 3. Hierarchical scheme of the shared energy concept.

The incentive on shared energy is called premium tariff (in Italian, *Tariffa premio*). It is composed of a fixed tariff, varying on the base of the nominal power of the power plant, and of a variable tariff, that is inversely proportional to the zonal market clearing price. Moreover, a further premium is remunerated to PV power plants located in the North and in the Centre of Italy: indeed, in these zones, the PV production yield is lower compared to the South of Italy, due to a smaller number of equivalent operating hours and reduced solar irradiance. The incentivization scheme is summarised in Table 1.

A further remuneration (in Italian, *Contributo di valorizzazione*) is provided to self-consumption configurations to refund transmission and distribution usage tariffs and avoided network losses: indeed, all the members of self-consumption schemes are pertaining to the same portion of distribution network, thus avoiding transmission losses. Moreover, groups of collective self-consumers avoid also distribution losses, since they are composed of members located within the same building. This remuneration scheme is summarised in Table 2, as defined in the operating rules published by GSE in February 2024.

Table 1. Premium tariff on shared energy.

Nominal power	Fixed tariff	Variable Tariff	Premium for PV power plants		
			North	Centre	South
P $\leq$ 200 kW	80 [€/MWh]	0÷40 [€/MWh]	10 [€/MWh]	4 [€/MWh]	0 [€/MWh]
200 kW < P $\leq$ 600 kW	70 [€/MWh]	0÷40 [€/MWh]			
P > 600 kW	60 [€/MWh]	0÷40 [€/MWh]			

Table 2. *Contributo di valorizzazione.*

	Remote individual self-consumers	Groups of collective self-consumers	RECs
Transmission tariff	10.57 [€/MWh]	10.57 [€/MWh]	10.57 [€/MWh]
Distribution tariff	–	0.65 [€/MWh]	–
Avoided losses	–	% of zonal electricity market clearing price	–

According to the Italian regulatory framework, the energy injected into the distribution network by the RES power plants is still available for the owners of the power plants: thus, in addition to the possible incentive related to the shared energy, power plants owners receive a remuneration for the sold energy.

On the demand side, each REC member is allowed to have its own electricity supply contract. Alternatively, RECs are entitled to be energy suppliers for their own members: in this case, RECs may participate in the day-ahead market to exchange energy volumes.

4 Mathematical Models

From a planning point of view, the optimal design model allows to choose the best mix of users, among a certain number of eligible REC members, and technologies in order to maximize techno-economic and environmental indicators. Different types of users are considered (residential, tertiary and industrial), each one characterized by specific daily load profiles and annual energy demands. Planning models consider current and future REC's incentive mechanisms adopted at the national level, as well as different price scenarios for energy carriers.

Regarding optimal management, Energy Management Systems (EMSs) with varying degrees of detail and complexity, have been developed to determine the optimal operation of generation and storage systems installed at the site of REC users. These EMSs can present a different complexity in modelling electric networks (single-busbar models and Optimal Power Flow (OPF) models [18], both for AC [19] and DC networks [20]).

Particular focus is on the modelling of electric mobility infrastructures, with the aim of analysing how appropriate smart charging strategies for EVs, including the use of V2G and V2B technologies, can bring economic benefits to users and contribute to better management of electric distribution networks. In particular, a bi-level EMS structure is adopted, with an upper-level EMS, supposed to be adopted by the REC manager, used to define the optimal profile of active power that each REC member should exchange with the local distribution network in order to maximize the energy shared within the REC. The lower-level EMSs are the ones actually managing the facility of each user. These local EMSs take as input the profiles deriving from the upper-level EMS. REC members are supposed to adopt either a "non-cooperative" approach, if they decide to minimize just their electricity bill, or a "cooperative" approach, if they decide to minimize both the electricity bill and the deviation from the active power exchange profiles defined by the upper-level EMS: in this latter way, local EMSs contribute to the maximization of the shared energy within the REC.

In both the optimal design and the bi-level EMS, given that the current Italian regulatory framework about the participation of EVs and BESSs to the shared energy is not clear, the authors decided to prevent the discharge of EVs and BESSs directly into the network: thus, EVs can be operated only in V2B mode.

In the following, the main mathematical formulation of the optimization problems will be presented. All the optimization problems have been formalised as Mixed-Integer Linear Programming (MILP) problems.

4.1 Optimal Design

The goal of the optimal design procedure is to choose the best mix of REC members, starting from a set of U possible candidates, and to define, for each selected member, the optimal size of PV and BESS units allowing to minimize an economic objective function. A schematic representation of the optimal design is presented in Fig. 4, in which the possible REC members are identified with the index u (with $u = 1,\ldots,U$).

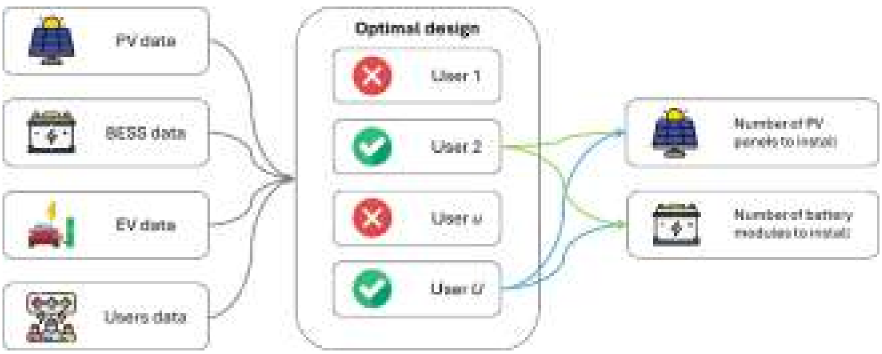

Fig. 4. Scheme of optimal design procedure.

The objective function to be minimized is formulated as:

$$Obj^{OD} = CAPEX^{PLANTS} + OPEX^{PLANTS} + OPEX^{GRID} + OPEX^{EV} + C^{CER} - BEN^{CER} \quad (1)$$

where $CAPEX^{PLANTS}$ are the purchase and installation costs of PV and BESS power plants, $OPEX^{PLANTS}$ are the operation & maintenance costs of PV and BESS power plants, $OPEX^{GRID}$ are the net costs related to the sale and purchase of electricity with the distribution network, $OPEX^{EV}$ are the costs related to charging of EVs at charging stations not owned by the members of the REC (e.g., a charging station located on a highway), C^{CER} are the REC management costs and BEN^{CER} are the incentives provided on the shared energy.

The EVs and relevant charging infrastructure are supposed to be already owned by the REC members (indeed, it would be unreasonable to state that a REC could impose to the members to purchase an EV).

To reduce the computation burden, the optimal design problem exploits the so-called "typical days": not each calendar day is considered in the mathematical formulation but the calendar days are grouped together considering affinity and clustering criteria, allowing to define "typical days", each one representative of a set of calendar days.

4.2 EMSs

As anticipated in Sect. 4, two EMSs have been developed to model the management of a REC. Indeed, the upper-level EMS has the aim of coordinating the operation of the REC members to maximize the collective welfare represented by the shared energy, while the lower-level EMSs have the aim of balancing collective objective (provided by the upper-level EMS) with each member's objective. The bi-level architecture is developed since the lower-level EMS of a single member is not able to access information about other members.

4.3 Upper-Level EMS

The objective of the first-level EMS is to maximize the energy shared within the REC: thus, the objective function to be minimized is defined as:

$$Obj^{FL} = -\sum\nolimits_{h=1}^{H} E_h^{REC,sh} \quad (2)$$

where $E_h^{REC,sh}$ is the energy shared within the REC at each hour h, with $h = 1,...,H$, where H is the total number of hours in the considered time horizon.

The upper-level EMS models each member in an aggregate way, with different decision variables and constraints that model the behaviour of RESs, BESSs and EVs, optimizing them in order to maximize the shared energy.

The interaction between upper-level EMS and lower-level EMSs is shown in Fig. 5. As previously explained, for each member m of the REC (with $m = 1,...,M$, being M the total number of REC members), the upper-level EMS provides the optimal values of the active power to be withdrawn (i.e., purchased) from the network, $P_{m,t}^{grid,b}$, and to be injected (i.e., sold) into the network, $P_{m,t}^{grid,s}$, at each time interval t ($t = 1,\ldots,T$, where T is the number of time intervals into which the optimization horizon is subdivided). If each user exchanged with the network the profiles given by the upper-level EMS, the energy shared within the REC would be maximized.

Among the other main decision variables, there are the charging/discharging power of the BESS of each member and the charging/discharging power of each EV of each member.

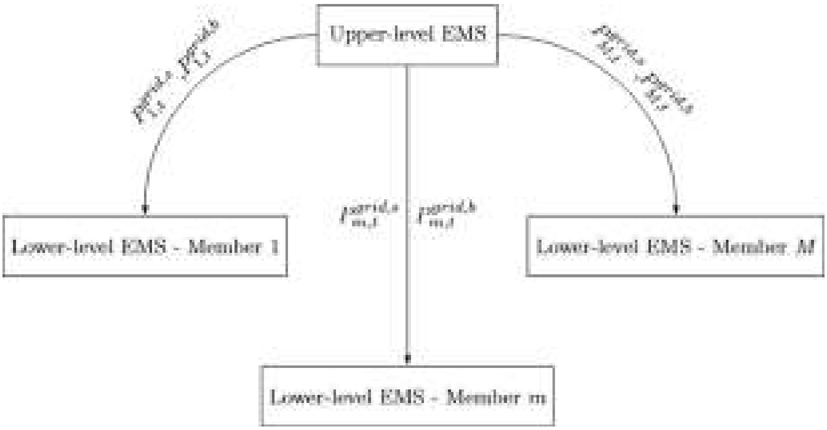

Fig. 5. Interaction between upper-level EMS and lower-level EMSs.

4.4 Lower-Level EMSs

The lower-level EMSs may adopt a multi-objective approach. Indeed, the objective function Obj^{SL} to be minimised is made of two terms, that may be in conflict with each other. In formulas:

$$Obj^{SL} = \Delta \cdot \sum\nolimits_{t=1}^{T} \left(p_t^{el} \cdot P_t^{grid,b} - r_t^{el} \cdot P_t^{grid,s} \right) + \beta^{grid} \cdot \left(\Delta \cdot \sum\nolimits_{t=1}^{T} \left(U_t^{grid,b} + U_t^{grid,s} \right) \right) \quad (3)$$

where $P_t^{grid,b}$ and $P_t^{grid,s}$ are the active power actually exchanged by the considered REC member with the distribution network at each time interval t, p_t^{el} and r_t^{el} are the unitary electricity purchase price and electricity selling price, $U_t^{grid,b}$ and $U_t^{grid,s}$ are the deviation of $P_t^{grid,b}$ and $P_t^{grid,s}$ with respect to the input profiles provided by the upper-level EMS, as shown in Fig. 5, β^{grid} is a weight coefficient and Δ is the time interval duration.

The first addendum of (3) represents the net cost related to the exchange of electricity with the distribution network, while the second term is related to the deviation of the behaviour of the single member from the "desired" one provided by the upper-level EMS. If the REC members adopt a non-cooperative approach, only the first term of (3) is considered in the objective function (thus assuming $\beta^{grid} = 0$), while if they adopt a cooperative approach both the terms of (3) are considered ($\beta^{grid} \neq 0$).

Lower-level EMSs are modelled with a more detailed characterization of each member's facility, thus being able to provide a more detailed dispatchment of the local resources. Advanced features involve the modelling of inverters' capability curves, shiftable loads, dependence of the maximum charging and discharging power on the state of charge of the BESS and EV batteries and optimal power flow equations, in case some members were characterized by a microgrid configuration.

5 Input Data and Case Studies

Two different case studies have been considered, one for the optimal design and one for the EMSs: the former will be called "REC-1", the latter "REC-2". They are described in the following subsections.

5.1 General Input Data

General input data involve the economic aspects. Given that each REC potential/effective member is entitled to keep its own electricity supply contract, it is supposed that each user has different tariffs (also to take into account the impact that the fixed tariff component has on each user's bill, depending on the amount of electricity exchanged). Time-of-use tariffs have been considered, in accordance with the Italian regulatory framework, that defines three different time slots tariffs (peak hours, intermediate hours and off-peak hours, differentiating also between working days and holidays). Regarding the selling price, it has been considered equal to the zonal electricity price, as holds for dedicated power purchase agreements (in Italian, *Ritiro Dedicato*).

5.2 Optimal Design Case Study

The considered case study is made of a set of 15 users, considering producers, consumers and prosumers (i.e., an entity both producing and consuming electricity), equally distributed between residential, public and commercial entities. Each member is supposed to be available for the installation of PV and BESS units, while only some members are supposed to own EVs and relevant charging infrastructure. The maximum number of PV and BESS modules depends respectively on the available area on the rooftops of the facilities and on the available volumes.

REC-1 is supposed to be located in Italy, more precisely in the province of Savona of the Liguria region. The location is needed in order to evaluate the available production by PV units and zonal electricity prices.

The considered optimization horizon is 1 year, subdivided into a set of 12 representative typical days (two for each bimester). Each typical day is subdivided into 24 time intervals with duration of 1 h.

5.3 EMS Case Study

The EMS is conceived for a REC made of 8 members, considering again a mix of producers, consumers and prosumers, both residential and non-residential. An industrial user is considered in the configuration, too. While flexible technologies such as BESSs and EVs are considered, loads are considered as not flexible (i.e., neither shiftable in time nor controllable in terms of power modulation). The characteristics of the members are summarised in Table 3, with the interaction between upper-level EMS and lower-level EMSs being depicted in Fig. 6. It is important to highlight that, for those members who are simple consumers or simple producers, it is not necessary an EMS for the optimal management of the facility, since they can rely only on the distribution network for the purchase or sale of electricity.

Again, REC-2 is supposed to be operating in the Italian province of Savona.

The considered optimization horizon is 1 week, subdivided into 672 time intervals with a duration of 15 min ($\Delta = 0.25$ h), for both the EMS levels.

Fig. 6. REC-2 configuration for EMSs application.

Table 3. REC-2 members for EMSs application[a].

Member	Typology	PV	Wind turbine	BESS	EV	Loads
1	Consumer	x	x	x	x	✓
2	Consumer	x	x	x	x	✓
3	Prosumer	✓	x	✓	✓	✓
4	Prosumer	✓	x	x	x	✓
5	Prosumer	✓	x	✓	x	✓
6	Prosumer	✓	x	✓	✓	✓
7	Prosumer	✓	x	x	✓	✓
8	Producer	x	✓	x	x	x

[a]✓ = included, x=not included

6 Results

This section summarises and discusses the results of the optimal design procedure and of the bi-level EMS. The optimization problems have been implemented in a Matlab R2023B/Yalmip R20230622 [21] environment and solved with a Gurobi solver [22].

6.1 Optimal Design

The optimal configuration of the REC-1 involves the inclusion as members of 5 candidates, that are two offices, a supermarket, a school and a residential prosumer. The other possible members are not included into the configuration since, due to the management costs, for them it would not be beneficial to enter the REC.

The optimal results in terms of installation of PV and BESS units are summarised in Table 4. All the members of REC-1 are suggested to install PV plants, while only for two of them the installation of BESS units is favourable. This is due to their load profiles: indeed, the load profiles of the two offices well align with the PV production, reaching the peak during the central hours of the day. On the other hand, the supermarket has a significant power absorption also during the nights, due to presence of fridges: thus, the daily PV surplus production is stored in the BESS and exploited during the night. The same for the residential prosumer: the inhabitants may not be at home during the day and the PV production is stored in order to exploit it during the evening or to sold it to provide revenues to the users.

Table 4. Optimal design results for REC-1.

	PV size		BESS size		CAPEX		OPEX	
Office 1	90.40	[kW]	0	[kWh]	122,320	[€]	−3,528	[€]
Office 2	44.80	[kW]	0	[kWh]	80,640	[€]	3,846	[€]
Supermarket	181.6	[kW]	238.08	[kWh]	212,315	[€]	126,750	[€]
School	90.40	[kW]	0	[kWh]	122,320	[€]	77,081	[€]
Residential	13.60	[kW]	2.56	[kWh]	24,796	[€]	−1,615	[€]
REC	420.8	[kW]	240.64	[kWh]	562,392	[€]	202,534	[€]

Figure 7 shows the comparison between the production of the PV plants and the shared energy within REC-1 for each typical day. The difference between the two quantities is given by the fact that there is not a complete simultaneity between the withdrawal of energy from the network by loads, BESS units and EVs and injection into the network by PV plants.

Table 5 reports the annual energy shared within REC-1 and the relevant incentives, separately for working days (WD) and weekend days (WE).

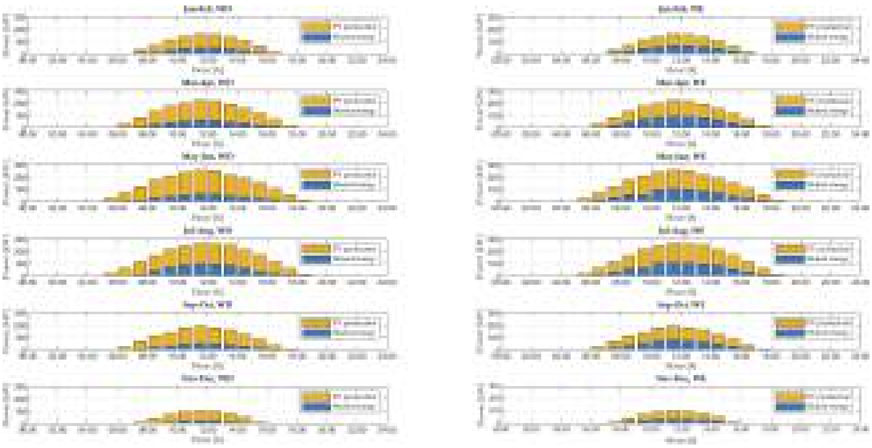

Fig. 7. Trend of shared energy (in blue) vs. PV production (in yellow) for each typical day.

Table 5. Shared energy and relevant incentives.

	Shared energy		*Tariffa premio*		*Contributo di valorizzazione*	
REC-1	140,940	[kWh]	19,731	[€]	1,490	[€]

6.2 Bi-Level EMS

The analysis has been performed for two representative weeks, one in May and one in December.

For brevity reasons, only the results related to a residential prosumer (REC-2 member no.6) will be shown. The following figures show the optimal active power dispatchment of the REC member, where the produced active power is represented on the positive y-axis, while absorbed active power is shown on the negative y-axis. In the graphs, the range of values on the y-axis is related to the user's committed power.

Figure 8 represents the optimal active power dispatchment for user no. 6 in the week of May, as dictated by the upper-level EMS. When the PV production is significant, it exceeds the load demand and thus surplus production is either stored or sold to the network. Sale of electricity is preferred, since the goal of the upper-level EMS is to maximize the energy shared within the network. For the same reason, in some periods of the day the local demand is satisfied by withdrawing power from the network. The charging of the EVs has the dual aim of satisfying the transportation demand and of increasing the energy that is shared within REC-2.

On Sunday, both the BESS and EVs are being charged in the early afternoon, given that the content of energy of the BESS has to reach a certain level before the end of the week and the EVs need to be sufficiently charged to satisfy its travel consumption required for the midafternoon.

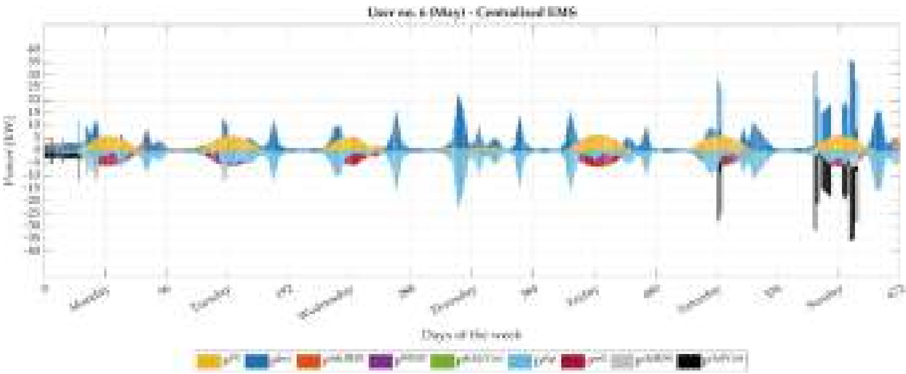

Fig. 8. Results of the upper-level EMS for user no. 6 – May scenario (P^{PV}=PV production, P^{buy} = power withdrawn from the distribution network, $P^{dch,BESS}$=BESS discharging power, P^{WIND} = wind turbine production, $P^{dch,EV,tot}$ = EV total discharging power, $D^{el,p}$ = load demand, P^{sell} = power injected into the distribution network, $P^{ch,BESS}$=BESS charging power, $P^{ch,EV,tot}$ = EV total charging power.).

Figure 9 shows the optimal dispatchment for user no. 6 in December. The reduced PV production forces the user to withdraw energy from the distribution network over the whole week. Moreover, the increased production of the wind turbine producer (user no.8) invites the other users to withdraw energy from the network, in order to account the wind turbine production as shared energy. That is also the reason for the massive charging of EVs during the night between Friday and Saturday, also exploiting the lower prices.

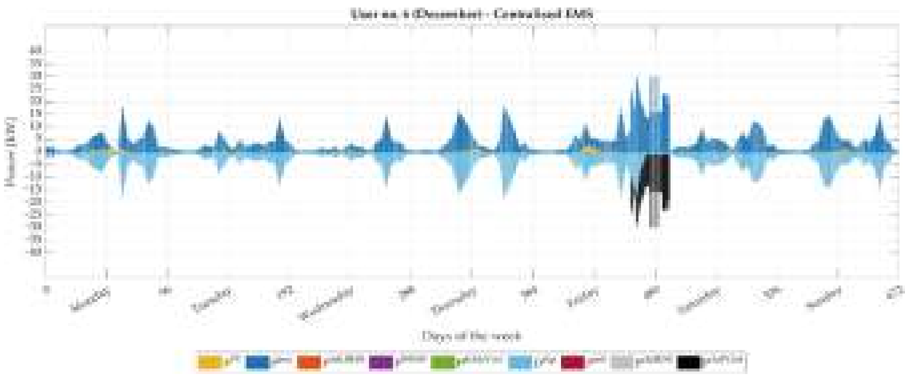

Fig. 9. Results of the upper-level EMS for user no. 6 - December scenario.

Figures 10 and 11 present a comparison for user no.6 between the profile of active power withdrawal from the distribution network as output of the upper-level EMS and the actual one, output of the lower-level EMS, for both May and December. The results are obtained considering a cooperative approach for user no.6 (i.e., $\beta^{grid} \neq 0$). The focus is on the purchased active power that is much more significant for user no.6 than the sold one. It is evident that, even with a cooperative approach, in both months user no.6 is not able to follow perfectly the reference power exchange profile provided by the upper-level EMS, thus not fully contributing to the maximization of the energy shared within REC-2. This behaviour is due to the fact that, even with a cooperative approach, REC-2 members try to minimize their own electricity costs, thus withdrawing energy when the purchase price is lower and injecting energy when the selling prices are higher. Moreover, the deviation of the actual power exchange profile of user no.6 from the reference one is furtherly exacerbated by the fact that user no.6 owns flexible loads that can be shifted in time during the day: the upper-level EMS is not aware of the presence of these loads, so when computing the optimal power exchange profiles it considers a forecasted "non-shiftable" load profile.

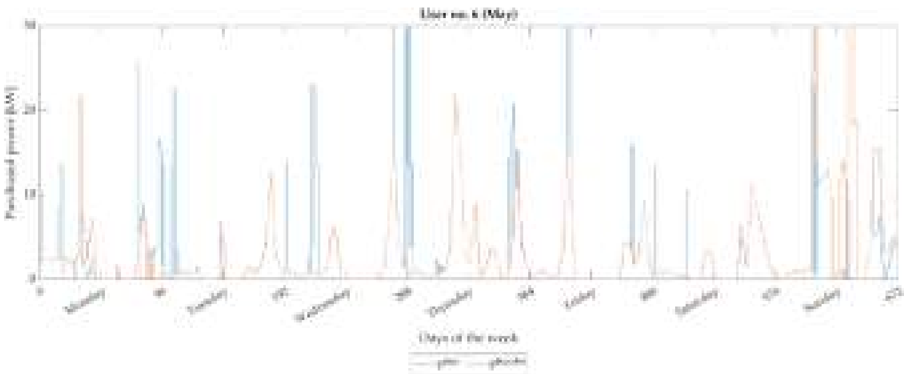

Fig. 10. Comparison between the desired withdrawal of active power from the distribution network (output of the upper-level EMS) and the actual one (output of lower-level EMS) – May scenario (P^{buy} = active power actually withdrawn (i.e., bought) from the distribution network by each REC-2 member, $P^{buy,des}$ = reference active power withdrawal output of the upper-level EMS of REC-2 manager.).

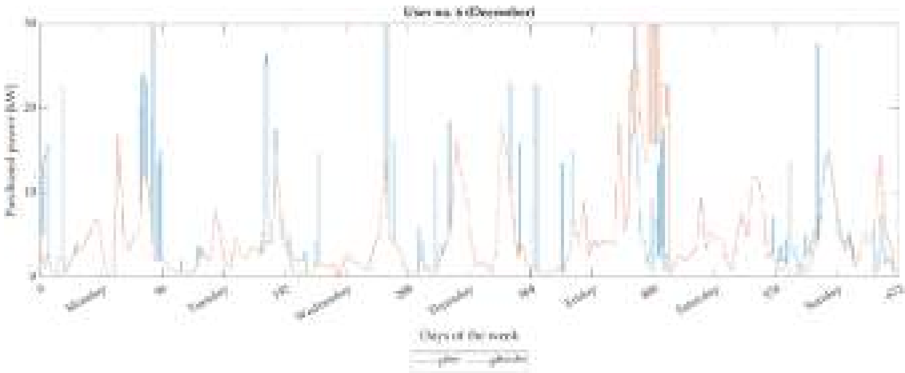

Fig. 11. Comparison between the desired withdrawal of active power from the distribution network (output of the upper-level EMS) and the actual one (output of lower-level EMS) – December scenario.

7 Conclusions

In order to comply with European goals in terms of penetration of RESs into power systems, RECs may play a fundamental role. These entities, introduced with the RED-II Directive in 2018, are based on the concept of "virtually shared energy" and "proximity": indeed, the aim is to share energy not through a direct electrical connection but through a simultaneous absorption and withdrawal of electricity by the members of the configuration, located in a confined geographical area.

To achieve effective performance of RECs, optimal design and optimal management tools are fundamental. The former allows to choose the optimal mix of REC members starting from a set of possible candidates, along with the size of PV and BESS units to locally install: the choice should be made in order to have a good alignment of injection and absorption profiles, necessary to increase the shared energy and the relevant incentive. The latter instead allows to dispatch the members' resources with the aim of maximizing the collective welfare represented by the shared energy: to this aim, a bi-level EMS was developed, with the first-level one (pertinent to the REC manager) targeting the maximization of the shared energy within the REC and the second-level ones (installed at members' facilities) providing the detailed optimal dispatchment of the local resources. In particular, two approaches for REC members' behaviour were modelled: a non-cooperative one, in which each members aims at minimising its own electricity bill, and a cooperative one in which, along with the minimisation of its own operating costs, each member tries to follow a reference signal of active power to be exchanged with the external network, output of the first-level EMS: tracking this signal, the members contribute to the maximization of the shared energy.

The results of the optimal design procedure showed that the inclusion of a lot of residential users may not be the best solution from an economic point of view: indeed, for them, the REC participation cost may be greater than the repartition of the shared energy incentive. Thus, in the optimal configuration, just larger users were included, ensuring a significant amount of shared energy over the year.

The results of the bi-level EMS showed that for the single user it may be not always convenient to follow the reference signal of active power exchange with the network provided by the REC manager, since it could be in contrast with the minimisation of the electricity bill.

Future developments of the study may involve the participation of aggregate of RECs in flexibility services markets, like the ancillary services market, further improving the beneficial impact that these configurations may have on the flexibility of the system.

Acknowledgements. This research was funded by ENEA, grant Project 1.7 "Technologies for the efficient penetration of the electric vector in the final uses" within the "Electrical System Research" Program Agreement 22-24 between ENEA and the Ministry of the Environment (PTR 22-24).

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BotBid 2025: Bridging Technology, Participatory Science, and Science Outreach

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Abstract. The BotBid (From Botany to Big Data) project is an educational initiative that aims at promoting data literacy, scientific and research methods, and participatory science practice based on a network of sustainable and smart school gardens. Since July 2023, the project is part of the dissemination activities of the RAISE Innovation Ecosystem, a NRRP initiative funded by the Italian Ministry of University and Research. In this paper, we present the overall organization of the initiative, methods and technologies adopted in the different phases of the project, and current and expected results of the 2024–25 edition.

Keywords: Scientific Method· Participatory Science · Internet of Things (IoT) · Edge Device · Data Education · Environmental Biomonitoring

1 Motivations and Goals

Attention to the environment and climate change together with the adoption of big data technologies is becoming increasingly widespread in various fields. At the same time, there is growing recognition of the crucial role played by data education [3, 10] in the life of every citizen. In this context, the BotBid (From Botany to Big Data) project is a citizen science initiative that focuses on the creation of innovative and sustainable school gardens, with the aim of promoting data literacy, scientific and research methods, and citizen science practices [4]. BotBid is an initiative of an interdisciplinary group at the University of Genoa, in the context of the STACY[1] community of Spoke 5 of the NRRP RAISE Ecosystem. The BotBid project started in May 2022 to support schools that won the "Edugreen" project of the Italian Ministry of Education, aimed at the establishment of innovative and sustainable educational school gardens. Since July 2023, the project became part of the dissemination activities of the RAISE Innovation Ecosystem, a NRRP initiative funded by the Italian Ministry of University and Research. The general goal of the BotBid initiative is to provide teachers, and thus their students, with perspectives and tools to make the green experience of the school garden an opportunity to exercise a plurality of skills in the STEM area. The project is closely linked to the digital and ecological transition themes supporting the transformation of each school garden into a widespread biomonitoring experiment. Furthermore, it can be viewed as a starting point for building a citizen science network involving schools of different levels.

[1] The STACY Community Website, https://stacy-community.it/

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 122–136, 2026.
https://doi.org/10.1007/978-3-032-21842-1_9

More specifically, the experiment involves setting up in each school a garden with 30 control plants and 30 treated plants (submitted to stressful soil conditions), and kits for collecting and transmitting environmental data. The BotBid WebApp[2] has been developed for this purpose to enable the collection of data associated with both environmental parameters and useful for monitoring plant growth. The project is supported by an Internet of Things/Big Data infrastructure used to collect observation data (e.g., plant biomass, plant growth, soil pH, temperature, etc.) from the school gardens to a central repository. The platform plays the role of digital accelerator for sharing data and knowledge with domain experts and project participants. Furthermore, it enables the creation of a dashboard for data visualization and aggregation. Engagement is stimulated by learning how to use digital tools to transform the school garden into a living laboratory and how to become a proactive agent of a citizen's science experience. The proposed initiative is therefore not only an educational proposal for teachers, but, at the same time, a community building experiment involving several schools over a wide territory. The educational proposal, that is increasingly participatory thanks to the adoption of digital tools such as Web and cloud platforms, encompasses diverse learning outcomes for participants: 1) learning the fundamentals of environmental and applied botany; 2) acquiring a scientific method by participating in a citizen science project; 3) learning how to use digital devices and applications; 4) learning how to process, interpret, and graphically represent the data from their observations. On a dedicated portal, teachers find all the resources to complete the activities in their schools: in-depth resources, video-tutorials, and recordings of the seminars. The proposed material guides schools in collaborative research activities during the entire school year. Using the BotBid WebApp, it is possible to visualize monitoring data from control and treated plants, following the expert's instructions to simulate soil stressful conditions (e.g. by increasing soil salinity) from different schools and make comparisons and aggregate analyses using business intelligence tools as a concrete example of education on the importance of data, its manipulation and interpretation [6, 7]. Worksheets are also made available to support the implementation of activities with students, exercising skills in the pedagogical use of digital technologies according to the DigCompEdu framework. In terms of community building, the initiative supports the creation of a thematic community within a Moodle portal that multiplies the value of individual experiences through discussion with researchers and among schools engaged in the implementation of smart school gardens. Moreover, the schools are asked to be part of a citizen science initiative by sharing data with other schools, interpreting them with the help of experts and combining them with other types of observations (weather data, images, satellite data, etc.).

The 2025 edition was launched through online meetings with teachers between November and December 2024 and has already involved five secondary schools from Liguria and one secondary school from Sardinia (Sassari) and involves 10 different classes. The project also includes 9 first-cycle classes in a parallel activity using simplified tools and methods. Including previous editions, the project has reached over 3000 students and around 200 STEM teachers to date. In February 2025, the BotBid project has been selected among the 14 outreach case-studies submitted to the Italian Universities Evaluation process. In this paper, we present the overall organization of the initiative,

[2] The BotBid portal, https://botbid.dibris.unige.it/

the methods and technologies adopted in the 2024–25 edition, and the corresponding results obtained so far.

2 Background and Related Work

Citizen science [11] can foster an understanding of engagement with science as well as the perception of the relevance of scientific topics, thus enabling earlier learning in formal science education. Citizen science can indeed enhance aspects including pupils' motivation, interest and knowledge as well as their scientific and communication skills. A high level of student involvement is found to be particularly promising in terms of achieving learning objectives [17]. The main benefits of participatory science conducted in formal K–12 settings (also referred to as school-based participatory science, SBPS) are identified as the potential to engage teachers and students authentically in the scientific enterprise and to make learning more meaningful by Smith et al. in [16]. The advantages reported in [18] also include renewed sense of confidence in their science abilities and a deepened sense of place in the science community. From the smart school garden perspective, experiences exist [14] focused on education for sustainable development to make students become more sensible to natural environment, more responsible for their consumption, more aware about waste reduction and recycling, more conscious of the sustainable use of natural resources and, at the same time, more 'digitally competent'.

A study using the network of urban gardens to grow vegetables and to monitor air quality and evaluating whether food grown on a clean, unpolluted substrate in an urban environment is safe for consumption, using lettuce as in BotBid, is reported in [12].

Specifically, lettuce has been widely used as a biomonitor due to its sensitivity to atmospheric pollutants and its rapid growth cycle. Izquierdo-Díaz et al. [8] demonstrated that lettuces grown in urban areas can accumulate trace elements linked to air pollution, making them suitable indicators for environmental quality and potential food safety risks. Similar findings were reported by Kováts et al.in [9], who measured polycyclic aromatic hydrocarbon (PAH) accumulation in rural garden lettuces, and by Amato-Lourenco et al. in [1], who used urban garden vegetables to evaluate genotoxic effects from airborne contaminants. In addition, it was demonstrated that the uptake of lead and aluminum by lettuce cultivated in contaminated urban soils demonstrated limited lead transfer from soil to lettuce leaves, suggesting that while soil contamination levels were high, the actual uptake by lettuce was relatively low [13]. Similarly, another study assessed human health risks from consuming lettuce grown in soils contaminated with trace elements and heavy metals. The study concluded that lettuce accumulated higher levels of cadmium and arsenic, posing potential health risks to consumers [15]. Moreover, another study evaluated the uptake of DDT, and some heavy metals by lettuce and radish grown in contaminated horticultural soils, highlighting the varying accumulation patterns of these contaminants in different plant species and emphasized the importance of monitoring and managing soil quality to ensure food safety [5]. These studies underscore the critical role of lettuce in biomonitoring programs aimed at assessing soil contamination and its potential impact on human health. When integrated into citizen science frameworks, such approaches not only provide valuable environmental data but also empower communities and students to engage directly with issues of urban sustainability and public health.

3 Project Structure

Being targeted at schools, BotBid configures as a citizen science educational initiative. Citizen science refers to the involvement of ordinary people, often referred to as citizen scientists, in scientific research activities [2]. In citizen science projects, citizens collaborate with professional scientists to collect, analyze, and contribute to scientific data. In this setting, citizen scientists (i.e., students and teachers) actively contribute to scientific research by collecting data, making observations, or performing other tasks defined by the research project. Citizen science projects often involve collaboration between professional scientists and participants, fostering a sense of community and shared effort. Participants collect data using standardized protocols provided by scientists, ensuring the reliability and consistency of the information gathered. Citizen science projects aim to make scientific research more accessible to the public, allowing individuals without formal scientific training to contribute meaningfully to the scientific process. Like many citizen science initiatives, BotBid incorporates an educational component, providing participants with opportunities to learn about the scientific method, data analysis, and the specific topic of the project.

3.1 Structure and Timeline

The overall structure and timeline of the project is described in Fig. 1.

Phase	Goal	Contents	Timing
Network formation	Creation of the network of schools, classes and teachers	Call for participation Online launch of the project	October-November
Training	Methodology	Introduction to the scientific method; biomonitoring best practices; setup of the experiment	December
	Data acquisition	Introduction to edge components and IoT platforms with a focus on biomonitoring case-study (e.g., environmental sensors)	January
	Data education	How to organize, prepare, and interpret data	February
	Data analysis	How to validate the experiment hypothesis	March
Monitoring	Data collection	Use the BotBid platform to collect data: for 12 weeks, once a week	March-May
Restitution	Data analysis	Use of statistical analysis to validate the experiment hypothesis, compare data and results of different nodes, comparisons and correlations with external data sources (meteorological data, etc.)	June

Fig. 1. The BotBid timeline

The initial phase is dedicated to the formation of a network of schools and classes via contacts with teachers and online launch meetings. After the formation of the network, a training phase based on a series of online meetings is used to present goals, principles, methods, and tools adopted in the project. Specifically, we have prepared material for the online meetings listed below.

- The online meeting on methodology is focused on the best practices for the set-up of a biomonitoring experiment according to the scientific method principles. Participants receive detailed guidelines from a domain expert to set up a monitoring laboratory with thirty control plants and thirty plants in which the soil is subjected to salt stress. This set-up allows for multiple observations in each repetition of the observation phase, providing robust data for statistical analysis. In addition, the expert domain presents the hypothesis to be experimentally validated via the data collection campaign. In our case, the objective of the experiment is to evaluate the plants' response to soil stress by measuring their growth (i.e., leaf and root length and plant biomass) over time.
- The online meeting on data acquisition introduces to the edge components that can be used to automate the data acquisition and processing phase with a focus on the biomonitoring case-study (e.g., environmental sensors such as pH-meters), to illustrate Internet of Things (IoT) architectures that can be used to interconnect the different nodes of the network, and how to use IoT platform to support data acquisitions.
- The online meeting on data education is dedicated to the introduction of the basic concepts of data education including the importance of data quality, data preparation and different tools that can be used to interpret data, e.g., visualization and data warehousing.
- Finally, the online meeting on data analysis is focused to the analysis of the collected data during and at the end of the experiment. In our case we introduce data visualization tools and statistical tests to validate the experiment hypothesis.

In the third phase, participants collect data on a weekly basis for twelve weeks (i.e., average time required to obtain the complete growth of tested species, specifically lettuce). Data collection is supported by the BotBid platform. The platform provides a WebApp where data can be inserted for each monitored plant. To simplify the procedure, the BotBid WebApp was designed to create a digital twin of the physical laboratory to facilitate data entry at this stage. Each plant, controlled or treated, is represented by its own digital version in a palette that guides students and teachers as they observe the growth data. The platform also enables automated acquisition of data produced by the BotBid edge devices.

The final phase is dedicated to the restitution of the results of the common experiment using data visualization and statistical tools. The BotBid platform provides preconfigured data analysis tools, sort of business intelligence services such as queries on collected data, etc. The collected data can also be downloaded, e.g., in csv format, for further analysis using external tools, e.g., Jupyter Notebook, Google Colab, Python/R, Excel, to discover correlations with open data, e.g., meteorological data, perform comparisons among data of different schools, and perform advanced analysis of interest for botany experts and environmental monitoring.

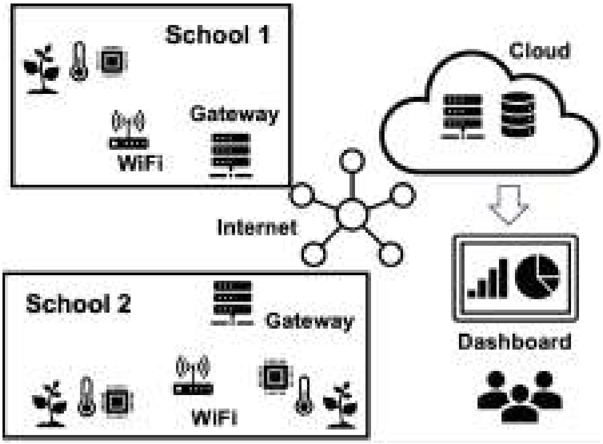

Fig. 2. The BotBid IoT architecture

4 IoT Architecture and BotBid Platform

The data collected from the various nodes of the network are made available in the dashboard of the Botany expert via an IoT architecture, depicted in Fig. 2, that includes edge computing components connected to the Internet via local Wi-Fi networks, Web and mobile applications, and cloud services to store data. The different components of the platform are described in the remainder of the section.

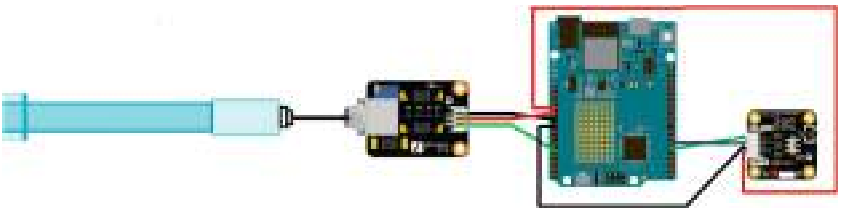

Fig. 3. The circuit project of the edge device

4.1 Edge Devices

The kit includes an Arduino board equipped with a Wi-Fi communication interface with the possibility of connecting to its pins a multifunctional sensor for environmental data (temperature, humidity, light intensity, ultraviolet light) and a probe to measure soil acidity (pH-meter).

The logic diagram of the kit together with the source code needed to program the Arduino controller, see Fig. 3, is provided to each school to build a kit to automate the collection of environmental data. An example of the physical configuration of the use

Fig. 4. The BotBid Arduino kit

of our kit is illustrated in Fig. 4. More in detail, the kit consists of the following components. The hardware controller is based on an Arduino UNO R4 Wi-Fi board. Arduin UNO R4 is based on the RA4M1 microcontroller and is equipped with an ESP32-S3 module, thus allowing connection with the outside world via Wi-Fi and Bluetooth. It also has an EEPROM memory available, necessary, e.g., for calibrating some types of sensors. The board is linked to two different types of environmental sensors. The Gravity Multifunctional Environmental Sensor comprises SHTC3 temperature & humidity sensor, BMP280 atmospheric pressure sensor, VEML7700 light sensor, and ultraviolet sensor ML8511 therefore producing 5 kinds of environmental parameters. Professional sensor chips are selected for each kind of parameter measurement. The device has an MCU processing chip onboard that converts the raw sensor data into values with the standard unit so you can directly use them. For example, °C and °F for temperature, % for humidity, Kpa for atmospheric pressure, lx for light illuminance, and mw/cm^2 for ultraviolet. The environmental sensor supports two communication methods, UART and I2C. The Gravity Analog pH Sensor/Meter Ki is a device specially designed for Arduino controllers. It provides an LED which works as the Power Indicator, a BNC connector and pH 2.0 sensor interface. The pH 2.0 interface can be plugged into the analog input port of any Arduino controller. The board must be pre-programmed to extract the pH value from the data produced by the probe. Each school will be able to use its own Wi-Fi network to connect the Arduino kit to an Internet gateway. The kit is automatically connected to the WebApp via credentials provided when the school registers on the BotBid portal. The data acquired in the schools via the WebApp, and the kit are transmitted to the servers installed on virtual machines at DIBRIS at the University of Genoa according to the paradigm typical of the Internet of Things (IoT).

The adoption of the kit allows possible further investigations into microprocessors, sensors and their programming in languages such as C and C++. For instance, the sensor used to measure soil pH comes with a dedicated protocol that can be a possible starting point for introducing the basic principles of calibration methods (calibration curve, slope of the interpolation line, etc.) to students.

4.2 The BotBid App

The BotBid WebApp is an application that aims to help the users throughout the experiment process, guiding them step by step. After registration and log-in, users can set up a digital twin of their smart school garden by entering the name of the experiment, the name of the plant species, the number of plants and their type/group (control/treatments), the type of cultivation (in soil or in pot) and the day they will begin biomonitoring. Once the experiment has been set up, the user is guided in each activity by a series of sections in which the monitoring workflow is organized. In the first chapter, "Create your virtual garden", the user creates a digital twin of the physical experiment mimicking the physical arrangement of the plants in the garden. In the second section, "Start monitoring", the user can insert the biomonitoring data of each plant. Once the first collected set of data is available, users can access the third section, "View your data", where they can check the progress of the experiment via dashboards and tabular data. When the biomonitoring phase is completed, the fourth and final section is unlocked: "Analyze aggregate data", where the results of the experiment are studied. To best achieve the objectives set at the requirements specification, it was decided that the software architecture that is right for us is a Rich Internet Application; RIA (Rich Internet Applications) are a special breed of Web Applications where the user interface has much richer functionality than the first-and second-generation Web Applications. This architectural pattern uses the client-server model that can be organized in three tiers. The presentation tier is the user interface and communication layer of the application, where the end user interacts with the application. Its main purpose is to display information to and collect information from the user. This top-level tier runs in the browser. Web presentation tiers are usually developed using HTML, CSS and JavaScript. Because the Rich Internet Application requires that the logic of the presentation layer must stay on the client browser, we decided to use React Js. This library grants a lot of benefits, first of all it works on separate components and makes it easy for developers if they want to add, remove or work on a component. In the application tier, the information collected in the presentation tier is processed using our business logic. The application tier can also add, delete or modify data in the data tier. The data tier is where the information processed by the application is stored and managed. In a three-tier application, all communication goes through the application tier. The presentation tier and the data tier cannot communicate directly with one another. To develop the different parts of the architecture, we rely on component-based design, which focuses on the decomposition of the design into individual functional or logical components that represent well-defined communication interfaces containing methods, events, and properties. It provides a higher level of abstraction and divides the problem into sub-problems, each associated with component partitions. This pattern has some advantages that will help us with the work. It is easy to develop, the components will implement interfaces well known to provide defined functionality, without impacting other parts of the system. It is reusable, that means that we can spread the development and maintenance cost across several applications or systems. Following the "*divide et impera*" criterion, this pattern reduces complexity of the system, dividing big problems into smaller ones. Furthermore, using this pattern it's easy to change and update the implementation without affecting the rest of the system, this also helps maintain and modify the code after deployment in case there are bugs to fix or new features to implement.

Fig. 5. The BotBid Web portal

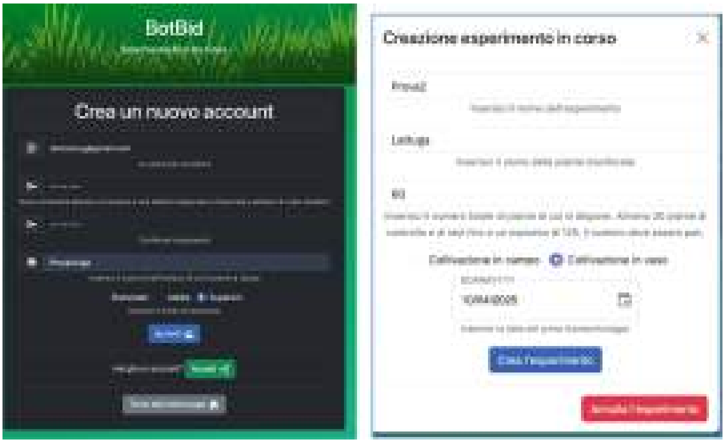

Fig. 6. Registration form: user and experiment data

The Web portal of the application is shown in Fig. 5. The registration form is shown in Fig. 6. Each participant creates user credential and the data of the first experiment such as: number of control and treated plants, type of plants, and starting date of the biomonitoring period. Other experiments can be added after registration.

The user can then create a digital twin of the smart garden using the dashboard in Fig. 7. Each plant item can be moved to reconstruct the physical configuration of the garden.

The form in Fig. 8 is used to insert the observation data of each plant. The platform provides all necessary instructions and source code to configure the BotBid Arduino kit. The source code can be downloaded from the platform.

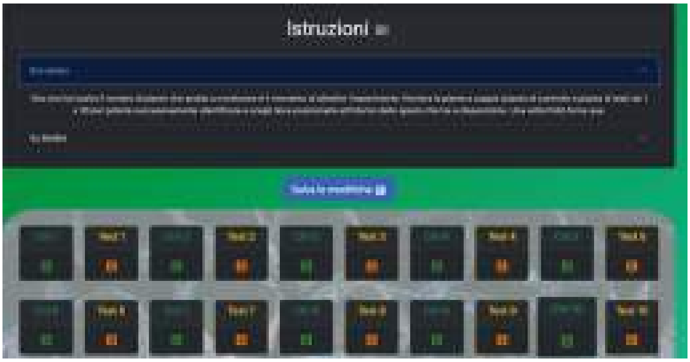

Fig. 7. Digital twin of the school garden

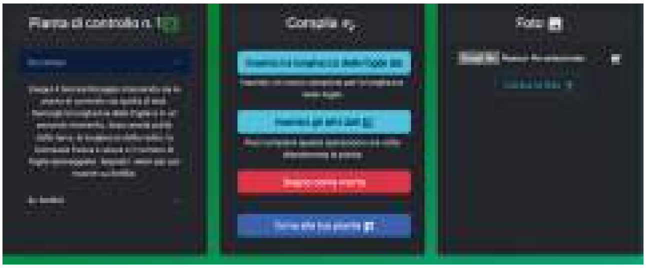

Fig. 8. Form to insert monitored data

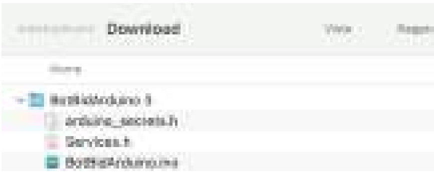

Fig. 9. Files for configuring the Arduino kit

It consists of a single program, in the C language, and two header files, as shown in Fig. 9. The arduino_secret.h header file contains the macro needed for the user to configure a own device with the Wi-Fi credential of the local network, user and experiment credentials.

```
//Recuperare dal proprio WiFi SECRET_SSID e SECRET_PASS.
//USER_ID e EXP_ID sono disponibili nella pagina dell'esperimento
#define SECRET_SSID "My-WIFI"  //nome del WiFi
#define SECRET_PASS "PippoPlutoPaperino"  //password del WiFi
#define USER_ID "m3RvA5iGMYKqOTRJlsUrKiwUv9r2"  // utente BotBid
#define EXP_ID "-My4kl9yzwFrplj5K_"      // esperimento in corso
```

The configuration is very simple. SSID and password of the Wi-Fi network must be specified as values of the SECRET_SSID and SECRET_PASS macro definitions. The unique user and experiments ids' generated by the platform must be specified as values of the USER_ID and EXP_ID macro definitions. The source code can be compiled and installed on Arduino using tools such as the Arduino IDE. The BotBid Arduino software is programmed to collect data from the environmental sensors and send them to the Firebase cloud platforms that is used to collect user and experimental data. The resulting cloud database is the actual backend for the BotBid client.

Fig. 10. Form to insert monitored data

Users can manually insert environmental data using the form in Fig. 10.

Fig. 11. Dashboard for the environmental data

The real-time dashboard of Fig. 11 can be used to visualize the last acquired sensor data. The data can also be visualized in tabular and graphical format. The platform also provides a dashboard for visualizing the historical data of the experiment.

5 Data Education in BotBid

At each stage of the project, the data can be entered via a graphic card associated with each plant available in the BotBid WebApp. The WebApp provides different visualization tools to monitor the experiment of each participant. It is also possible to query historical data using a simple query language that allows user to select periods, plant identifiers, value ranges, etc. In addition, for each week, the WebApp provides a visualization of the data of control and test groups using boxplots in order to identify possible outliers.

Preliminary experiments showed us that it is not possible to rely on the assumption that data are normally distributed even when restricting the attention to a single time point. For this reason, to validate the hypothesis of our experiment (compare the growth of control and treatment plants), we decided to adopt the non-parametric Mann-Whitney statistical method, U-test. The Mann-Whitney U-test is used to compare differences between two independent groups when the dependent variable is either ordinal or continuous and data are not normally distributed. Our WebApp applies the U-test to each batch of data collected during the biomonitoring process, visualizes the resulting P-value and whether the P-value satisfies or rejects the null hypothesis. This way, participants can observe possible trends related to the validation of their experimental hypothesis.

The data can also be downloaded in .csv format for further study in the classroom using tools such as Excel and Python.

6 Last Year Edition 2024–2025

The 2024–25 edition of the BotBid project has been launched together with STACY on April 3, 2024. The project has also been presented in the event OrientaMenti at the Festival of Science of Genoa on October 25, 2024. Six first grade secondary school classes and two second grade secondary school classes, from Genoa and Imperia, attended the event for a total of 200 participants. The project has also been presented at the RAISE Village in the 2024 Science Festival of Genoa on November 3, 2024, with 2 teachers (secondary school) and 8 researchers attending the meeting.

Fig. 12. Experimental school gardens' installations of two different schools.

The first online meeting took place on November 28, 2024 with 19 participating teachers, 9 from the first cycle (primary and secondary I grade) and 10 from the second cycle (secondary II grade) from 6 different high schools: IIS Majorana-Giorgi, IIS Calvino and IIS Gastaldi Abba of Genoa; ITIS Ferraris Pancaldo and Liceo Issel of Savona; and IIS N. Pellegrini of Sassari. After three other online meetings between January and March to set up the physical configuration of the experiment in their garden, the 10 registered schools have started using the BotBid WebApp to collect the growth data of the two groups of 30 plants, see e.g. Fig. 12. Four schools decided to use the Arduino kit. They are currently collecting environmental data together with plant growth data. The experiment ends at the end of May 2025. We plan to organize further meetings to interpret the data collected during the project together with teachers and students. In addition to the visualization and statistical tools provided in the BotBid Web Application, we also plan to use Google Colab's Data Science Agent to guide the creation of data analysis reports from raw data sets. This is an interesting topic to consider to evaluate the use of generative AI in interdisciplinary projects such as BotBid.

7 Conclusions and Future Work

The BotBid project effectively combines scientific education, technological innovation, and active participation. Through a citizen science approach, it involved students and teachers in all phases of scientific research, from hypothesis formulation to data collection and analysis. The modular structure of the project, supported by an advanced IoT infrastructure and an interactive Web platform, allowed participants to engage in a hands-on research experience. The educational path emphasized active learning, promoting skills in science, technology, and statistics. Moreover, the creation of a "digital twin" of the school garden helped participants grasp the concept of digitizing physical environments. The results show how a well-designed platform can stimulate interest in science, encourage critical thinking, and enhance scientific literacy. BotBid has thus demonstrated the transformative potential of citizen science within school education.

Future developments of BotBid include expanding the network of participating schools at both national and international levels, fostering a growing community of "citizen scientists." From a technological standpoint, future improvements may involve the integration of new types of sensors and enhanced platform functionalities using artificial intelligence to detect patterns in the collected data. Educationally, the project aims to strengthen collaboration with teachers and researchers to co-design interdisciplinary lab experiences, where real data and digital tools become an integral part of the curriculum. Additionally, the analysis of aggregated data on a territorial scale could provide valuable insights for urban environmental monitoring, creating a tangible link between schools, scientific research, and civic engagement.

Acknowledgments. Funded by the European Union – NextGenerationEU and by the Ministry of University and Research (MUR), National Recovery and Resilience Plan (NRRP), Mission 4, Component 2, Investment 1.5, project "RAISE – Robotics and AI for Socio-economic Empowerment" (ECS00000035).

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AI Technologies for Inclusive Smart Cities: Safeguarding Elderly and Disabled Citizens

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Abstract. This article examines the role of AI and digital technologies in promoting inclusive Smart Cities, with a particular emphasis on safeguarding the rights and accessibility of elderly and disabled individuals. It examines the legal and ethical challenges posed by technological advancements, such as algorithmic discrimination and the digital divide, which can exacerbate social inequalities. The authors highlight key European and Italian regulations, including the AI Act and the Web Accessibility Directive, aimed at ensuring accessibility and non-discrimination. The study underscores the importance of balancing innovation with fundamental rights, advocating for universal design and digital literacy to empower vulnerable groups. By analysing case studies and legislative frameworks, the article proposes strategies to integrate technology into urban planning while safeguarding inclusivity and human dignity.

Keywords: Smart Cities· Artificial Intelligence · Inclusivity · Disability Rights · Elderly Care · Algorithmic Discrimination · Digital Divide · Accessibility · Urban Planning · European Regulations

1 Introduction

This article delves into the transformative role of Artificial Intelligence (AI) and digital technologies in shaping the modern urban landscape, particularly within the evolving paradigm of 'Smart Cities'. While these technological advancements promise enhanced efficiency, sustainability, and quality of life, a critical examination is necessary to ensure their inclusive application, especially for vulnerable populations such as the elderly and individuals with disabilities. We begin by outlining the inherent fragilities within the Smart City context that can exacerbate social inequalities, including algorithmic discrimination and the digital divide. Subsequently, the article explores the current legislative frameworks at both European and Italian levels, such as the AI Act and the Web Accessibility Directive, designed to uphold fundamental rights, promote accessibility, and prevent discrimination in the digital realm. Through an analysis of these legal instruments and relevant case studies, we advocate for a balanced approach that

This chapter is based on a joint analysis by the two authors. Sections 1, 2, 2.1, 3 and 6 have been written by V. Di Gregorio and Sects. 2.2, 4 and 5 by M. Turci.

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 137–155, 2026.
https://doi.org/10.1007/978-3-032-21842-1_10

integrates technological innovation with principles of universal design and digital literacy, ultimately proposing strategies to foster human-centric urban development that safeguards inclusivity and human dignity.

2 Fragilities in the Smart City

Over time, the integration of technology in the management of the city has transformed the vision of urban space, shifting its centre of gravity towards the so-called 'Smart city', a notion that aims to summarise the urban context's tension towards innovation in territorial and economic policy, in the use of resources and in the protection of the environment.[1] Indeed, the city appears to be increasingly populated, not only by citizens, but also by technological tools that are gradually redesigning an unprecedented urban dimension in which traditional models of the city (and of human living) are called upon to coexist with the network in a constant integration between digital space and real space.[2]

The Smart City paradigm aims to enhance the quality and usability of urban services while ensuring the effective realization of individual rights. The expansion and efficiency of the potential for access to the city's resources and services must be pursued taking into account the fact that some subjective conditions, such as persons with disabilities, the elderly, the incapacitated or those who find it difficult to move within a new and different context from the one they come from, such as foreigners or immigrants, may benefit less from urban automation and digitisation and even be discriminated against. The new technologies must therefore operate in a way that allows everyone to improve their standard of living in the city and foster inclusion. It is therefore of paramount importance that the development of the smart city and its technologies turn its attention to the fragilities of citizens, in order to (also) target their inclusion and participation (social, economic and political) in the civitas vitae.

According to the World Health Organisation, about 15 percent of the world's population has some form of vulnerability that limits their ability to benefit from the prosperity resulting from urban revitalisation, as is evident from the fact that not all residents are able to have equal access to city services, participate in municipal decision-making and benefit from the city's economic growth. The fundamental rights of people, and in particular of those in fragile conditions, constitute the criterion for evaluating both the

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[1] Antoniazzi (2019), *Smart city: diritto, competenze e obiettivi (realizzabili?) di innovazione*, in Federalismi, 10/2019, p. 2 ff. Assuming and not conceding that the phenomenon can assume a univocal definition, the Smart city seems to identify that set of urban planning strategies, correlated with innovation and the potential of new technologies, aimed at improving the quality of life of citizens, nurturing sustainable economic growth, through a wise management of resources and resorting to participatory governance. For a more complete definition, please refer to M. Turci, *Le nuove tecnologie al servizio del cittadino: Smart city e diritti fondamentali*, in P. Dameri, M. Bruzzone (eds.), *Smart City. Prospettive di ricerca*, Genoa, 2024, p. 143 ff.

[2] Paolucci, Pollicino, *Intelligenza urbana e tutela dei diritti fondamentali. Antinomia o complementarità nella nuova stagione algoritmica?* In https://www.medialaws.eu/rivista/intelligenza-urbana-e-tutela-dei-diritti-fondamentali-antinomia-o-complementarita-nella-nuova-stagione-algoritmica/

effectiveness of the measures adopted and based on new technologies: either because they offer better access to places and services that can be easily and safely used, and facilitate mobility and amplify the network of social relations,[3] or because these rights represent, conversely, the limit within which urban technological development can affect people's lives.

Among the situations of fragility two stand out in terms of relevance and diffusion: disability and senility. In Italy, according to ISTAT data, in 2019, people with disabilities - i.e. those who suffer, due to health problems, from serious limitations that prevent them from carrying out habitual activities - are 3 million 150 thousand (5.2% of the population). Demographic ageing is also a relevant phenomenon, with Italy and Liguria in particular standing above the European average for the progressive increase in the elderly population (in Liguria the average age is 49.7 years). The two frailties are moreover likely to combine: the elderly are in fact the subjects most affected by disability with almost 1.5 million over 75 year olds (22% of the population in that age group) affected by one or more disability conditions.[4] It is, therefore, precisely the inclusion of these frailties that represents the priority challenge of the Inclusive Smart City.

2.1 Disability and Inclusion

The first legislative interventions aimed at rescuing persons with intellectual and physical disabilities from the material and legal isolation in which they found themselves have been implemented since the 1960s with instruments of an assistance and protection type, gradually replaced by active instruments aimed at promoting the equalisation and inclusion of persons with disabilities and guaranteeing their integration. Fundamental in this context were the anti-discrimination regulations of European and international matrix that gave rise to a system of structured rules allowed for a "regenerated" reading of the constitutional norms with recourse to the principles of domestic, international and European sources.[5]

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3 https://www.irpa.eu/accessibilita-urbana-disabilita-e-smart-cities/

4 Istat Hearing at the Technical Scientific Committee of the National Observatory on the Condition of Persons with Disabilities Hearing of the President of the National Institute of Statistics Prof. Gian Carlo Blangiardo available at the link: https://www.istat.it/it/files/2021/03/Istat-Audizione-Osservatorio-Disabilit%C3%A0_24-marzo-2021.pdf

5 S. Rodotà, *Il diritto di avere diritti*, Bari, 2012, p. 61, assigns the judge a decisive role in intervening in the protection of fundamental rights with a correct jurisprudential argumentation based on constitutional principles, in the event of legislator or political inertia. On the multilevel regulation of disability see. A. Venchiarutti, *Sistema multilivello delle fonti e divieto di discriminazione per disabilità in ambito europeo*, in *NGCC*, 2014, 409; ID., *I diritti delle persone disabili*, in *Il governo del corpo*, in *Trattato di Biodiritto*, directed by Rodotà and Zatti, I, Milano, 2011, p. 176. The perception of disability as a phenomenon that is not individual, but juridical, as well as the valorisation of the person and his participation on a social level, are highlighted by A. Marra, *Disabilità e diritti umani*, Napoli, 2015, p. 57 ff.; ID., *Diritto e Disability studies. Materiali per una nuova ricerca multidisciplinare*, Reggio Calabria, 2009, p. 57 ff.; ID., *voce Disabilità*, in *Dig. Disc. priv. sez. civ., Aggiornamento, ******, Torino, 2010, p. 555. Among the early advocates of the social model: J. Charlton, *Nothing about us without us. Disability oppression and empowerment*, in *University of California Press*, 1988. Against

At the European level, the general prohibition of discrimination is contained in Article 19 TFEU, which is a fundamental document of the European Union's anti-discrimination framework and empowers the institutions to carry out acts to encourage member states' policies to prevent inequality. The protection of the rights of persons with disabilities against discriminatory acts is then enshrined in the Charter of Fundamental Rights of the European Union, which, in Article 21, prohibits discrimination also based on 'disability' and provides in Article 26 for the 'inclusion' of persons with disabilities in the social and employment fabric, promoting their self-determination.[6] In the broader international framework, the rights of disabled people have acquired a position among the fundamental rights with the proclamation, in the 2006 UN Convention on the Rights of Persons with Disabilities (UNCRPD), of principles of general scope that prohibit discrimination, value diversity, and strengthen the autonomy and self-determination of the person in his or her life choices (art. 1).[7] Article 3 of the UN Convention officially introduces disability into the sphere of human rights, and in acceptance of the 'social model' proposed in the studies dedicated to the protection of the rights of persons with disabilities, it urges States to eliminate obstacles to the enjoyment of fundamental rights with 'reasonable accommodation' to ensure that persons with disabilities enjoy and exercise all human rights and fundamental freedoms, provided they do not impose a disproportionate or excessive burden (Art. 5).[8] To this end, Art. 2 accepts the notion of 'universal design', as a criterion for the production of goods and the planning of programmes and urban areas, suitable for guaranteeing the accessibility of goods and

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attitudes of commiseration: C. Barnes - G. Mercer, *Exploring the Divide: Illness and Disability*, in *Disability Press*, Leeds, 1996, 11 ff.; R. Medeghini - E. Valtellina, *Quale disabilità? Culture, modelli e processi di inclusione*, Milano, 2006, p. 35 ff. For further references see *amplius* V. Di Gregorio, *Principio di non discriminazione e diritti delle persone con disabilità: dal modello sociale alla Web Accessibility Directive*, in F. Imperiale, N. Gianelli (eds.), *Accessibilità web e tecnologia assistiva. Strumenti di inclusione digitale*, Genoa, 2020, p. 19 ff.

6 These principles have been implemented over the years with a series of directives, such as, for example, Directive 2000/78/EC on equal treatment in employment and occupation and Directive 2000/43/EC on equal treatment between persons irrespective of racial or ethnic origin. Directive 2000/78/EC was transposed by Legislative Decree No 216 of 9 July 2003 and Directive 2000/43/EC was transposed by Legislative Decree No 215 of 9 July 2003.

7 These underlying principles, although not explicitly stated, are also covered by the European Convention on Human Rights (Art. 14) and confirmed by the European Court of Human Rights, Judgment 10 September 2020, No. 24888, in Resp. civ. prev., 2020, p. 1969, according to which the conduct of the school that deprives the disabled student of a support administrator violates Art. 14 ECHR.

8 For the doctrine on disability studies and the 'social' model see above, footnote 1. On architectural barriers see A. Marra, *voce Barriere architettoniche*, in *Enc. dir., Annali*, IV, Milano, 2011, p. 196. The definition contained in Article 2 of the UN Convention clarifies the concept of reasonable accommodation, to be understood as "any necessary and appropriate modification and adaptation that does not impose a disproportionate or excessive burden on the enjoyment of human rights and fundamental freedoms on an equal basis with others". On the concept of reasonable accommodation under the Convention see A. Lawson, *Securing rights to reasonable accommodation under the convention on the rights of persons with disabilities: a role for disability studies?* in *Tutela della persona e Disability Studies, Atti del Convegno Catanzaro*, 6.12.2012, Reggio Calabria, 2012, p. 30.

spaces for all, also referred to in the Strategy on the Rights of Persons with Disabilities 2021–2030 (which is based on the previous one of 2010–2020), aimed at improving social inclusion, the realisation of wellbeing, and the recognition of the full exercise of the rights of persons with disabilities, in a perspective also accepted in the recent directives on the accessibility of products, services and websites and by the Court of Justice.[9]

The need for the protection of persons with disabilities against the violation of the principle of non-discrimination is implemented through inclusion and active participation, safeguarding dignity and improving life in terms of autonomy, which are the objectives of the European Parliament Resolution of 30.11.2017–2017/2127 (INI) on the implementation of the European Disability Strategy, whose programme for 2020–2030 aims to ensure that persons with disabilities can exercise their human rights, enjoy equal opportunities, participate in society and the economy on an equal basis, and have the right to move freely within the European Union, while ensuring mitigation and recovery measures to prevent persons with disabilities from being the main victims of the effects of social and health crises, such as the recent coronavirus pandemic. Within this framework, the European Commission is also planning to launch a European resource centre

[9] 5 Thus, most recently, Court of Justice, Judgment 26 January 2021, Case C-16/19 cited above, about wage discrimination against disabled workers and, previously, Court of Justice, Judgment 4 July 2013, Case C-312/11, Commission v. Italy, ECLI:EU:C:2013:446, para. 68 (and in Riv. it. dir. lav., 2013, II, p. 939), which stems from the Commission's action against the Italian Republic for failure to fulfil its obligations due to the incomplete transposition of Article 5 of dir. 2000/78/EC and, therefore, for failing to require all employers to provide, according to the needs of concrete situations, reasonable accommodation applicable to disabled persons. The Court reiterated that the concept of 'disability', although not defined in the directive, must be interpreted in accordance with the Convention and called on the States to provide a definition in conformity with it. Following this decision, legislative decree no. 216/2003 was amended with the introduction of the concept of "reasonable accommodation" in article 3, paragraph 3a. In the case decided by the Court of Justice, Judgment of 18 September 2018, Case C-270/16, Conejero, ECLI:EU:C:2018:17, paragraph 57, concerning disability and sickness (in particular on the indirect discrimination arising from the Spanish provision of Article 52 of the Workers' Statute), the Court instead referred the assessment of the balance between the objective of combating absenteeism and the protection of the disabled worker in the national legislation to the referring court. A similar conclusion, with regard to the referring court's assessment of the question of the 'long-term' nature of the illness, had been reached in the following cases: Court of Justice, Judgment of 1 December 2016, Case C-395/15, Mohamed Daouidi, ECLI:EU:C:2016:917, paragraph 51, concerning a situation of disability due to an accident; Court of Justice, Judgment of 18 December 2014, Case C-354/13, Foa, ECLI:EU:C:2014: 2463, paragraph 64, concerning the disease of obesity; Court of Justice, Judgment of 11 April 2013, Joined Cases C-335/11 and C-337/11, Ring and Skouboe Werge, ECLI: EU:C:2013:222, paragraph 92, on the dismissal due to chronic pain and injury of the worker, in accordance with the precedent of Corte giust., Judgment of 11 July 2006, Case C-13/05, Chacón Navas, ECLI:EU:C:2006:456, paragraphs 56–57. The provisions of the directive also apply when discrimination is perpetrated against the relative of the disabled person who is prevented from providing care (ECJ, judgment of 17 July 2008, Case C-303/06, Coleman, ECLI:EU:C:2008:415, paragraph 75). The European Parliament Resolution 30.11.2017 (2017/2127(INI)) is dedicated to the implementation of the strategy.

called AccessibleEU, intended to create a knowledge base of information and good practices on accessibility in all areas, the creation of an EU disability card to facilitate the recognition of disability status in all Member States, the promotion of participation in the democratic process through the candidacy of persons with disabilities in political elections on an equal basis with others, the publication of a vademecum for the participation of persons with disabilities in the electoral process also through the programme “Citizenship, Equality, Rights and Values” for the period 2021–2027.[10]

The principles expressed at community and international level find correspondence in the normative texts of domestic law: Article 3 of the Constitution, in its second paragraph, requires the State to remove “obstacles of an economic and social nature” that impede the full development of the human person, while law no. 104/1992, inspired by the constitutional principles of dignity and equality, moves from a vision favourable to the integration and reconciliation of liberal rights and constitutionally guaranteed social rights and is aimed at guaranteeing the integration and reconciliation of liberal rights and constitutionally guaranteed social rights. 104/1992, inspired by the constitutional principles of dignity and equality, is based on a vision favourable to the integration and reconciliation of liberal rights and constitutionally guaranteed social rights and is aimed at guaranteeing full respect for human dignity, freedom and autonomy of the so-called disabled person (arts. 1 and 5).[11]

Over the last twenty years, the increase in awareness of the value of human dignity with respect to the phenomenon of disability is attested by the inclusion in the domestic legislation of provisions aimed at protecting persons with disabilities, even outside the work context, with law no. 67 of 1 March 2006 on judicial protection against acts of direct and indirect discrimination and against harassment (in the meaning already accepted in directive 2000/78/EC, arts. 1–2. 1–2), which attributes to the ordinary judge the power to issue injunctive and compensatory measures, in accordance with the requirements addressed by the EU legislator to States on the introduction of adequate remedies through access to administrative and judicial procedures and effective, proportionate and dissuasive sanctions (Art. 9 and 17 Dir. 2000/78/EC).[12]

2.2 Elderly Means Frail?

The Italian legal system does not contemplate a unitary juridical notion of ‘elderly person’, although the system already provides, for various purposes, for marking the transition from an adult age to an elderly age: one thinks, in the labour sphere, of the retirement age and of Article 352 of the Civil Code, which allows the ‘elderly’ adult (i.e. one who has reached the age of sixty-five) to be dispensed from the - burdensome - guardianship office. As part of the policies for the protection of the elderly, Legislative

[10] Available at: https://ec.europa.eu/info/departments/justice-and-consumers/ justice-and-consumers-funding-tenders/funding-programmes/citizens-equality-rights-andvalues-programme_en.

[11] M.R. Marella, *L’integrazione sociale delle persone disabili tra normalità e differenza (in margine all’art.8 della legge-quadro sull’handicap)*, in *Riv. crit. dir. priv.*, 1994, p. 185.

[12] Di Gregorio*, Il principio di non discriminazione nella tutela delle persone con disabilità*, in *Riv. crit. dir. priv.*, 2019, p. 549 ss. spec. p. 574.

Decree no. 29 of 15.3.2024,[13] introduces a formal definition of the registry condition, distinguishing between an 'elderly person' (who has reached the age of sixty-five) and a 'grand elderly person' (who is over eighty), for the sole purpose of the protections provided therein. The legislator has, in fact, avoided introducing a general category of 'elderly person' from which rights or obligations would automatically derive, so as not to risk arbitrary discrimination or exclusion, preferring an approach based on the concrete assessment of individual conditions according to the specific needs of the urban environment.[14]

Legal protection of the elderly is therefore achieved by assessing the individual's personal conditions in relation to the opportunities and services he or she needs. This approach, which is consistent with the constitutional principles of dignity and self-determination, is reflected in the choice of law no. 6 of 9.1.2004, which regulated the support administration without including senility among the prerequisites for its activation, favouring the adoption of customised interventions.

European Union law also guides this interpretation: Article 25 of the EU Charter of Fundamental Rights explicitly recognises the rights of older people,[15] while the European Social Charter enshrines their right to social protection.[16] These provisions emphasise the value of human dignity as a guiding criterion for the protection of the elderly and for the regulation of the impact of new technologies.

Contemporary law, therefore, rejects the idea that ageing is in itself a pathological condition. The current normative approach does not consider old age as an inherent frailty, but as a phase of life that may require, in certain cases, specific protective measures - especially in the everyday context of the city - without compromising autonomy and social inclusion.[17]

[13] Legislative Decree. 29/2024 lays down provisions on policies in favour of the elderly and implements the delegation referred to in Articles 3, 4 and 5 of Law no. 33 of 23 March 2023. The aim of the decree, as expressed in Art. 1, is to promote dignity and autonomy, social inclusion, active ageing and the prevention of frailty in the elderly population. The definitions contained in Art. 2 are rendered for the purposes of the decree itself.

[14] P. Perlingieri, *Diritti della persona anziana, diritto civile e stato sociale*, in *Rass. dir. civ.*, 1990, p. 80 ff., now in Id., *La persona e i suoi diritti*, Esi, 2005, p. 345 ff., p. 351. It does not rule out the possibility of arriving at a 'social notion' of the elderly through elder *law*, which preserves from relativistic drifts.

[15] Bacciardi, *La tutela civile degli anziani alla luce dell'art. 25 della Carta di Nizza*, in NGCC, 2015, II, 293 p. ff.

[16] See Article 23 of the European Social Charter, as revised in 1999. On the significance of this document on the European horizon, Biagi - Salomone, *L'Europa sociale e il diritto al lavoro: il ruolo della "*European Social Charter*"*, in *Lav. nella giur.*, 2000, p. 414 ff. With reference to the text in its first version, Natoli, *La protezione dei diritti dell'uomo e la Carta Sociale Europea*, in *Dem. e dir.*, 1967, 1, p. 56 ff., and in *Rev. dr. contemp.*, 1968, p. 1 ff., now in *Diritti fondamentali e categorie generali. Scritti di Ugo Natoli*, Giuffrè, 1993, 397 ff.

[17] According to S. Corso, *Alla frontiera del diritto privato. Nuove tecnologie e persona anziana*, in *NGCC*, 2025, p. 1256, the new perspective realizes the 'reversal of the adage that *senectus ipsa est morbus*. Old age is not itself a disease'.

3 Smart City Technologies: Amongst Inclusion and Discrimination

In this perspective, the use of new technologies at the service of the smart city, including AI systems,[18] plays a fundamental role in ensuring the inclusion of fragile groups in urban social economic empowerment. They are looked to for solutions to the issues posed by ageing, fostering the wellbeing and autonomy of the elderly (e.g. by optimising access routes to health services through AI) and to promote access to public goods and services on an equal footing with other citizens, adapting goods and services for the city also to people's disability conditions (e.g. robot assistants). More generally, technology plays a decisive role in the service of frail people especially in the field of transport,[19] the Internet of Things, health and personal care services.[20]

At the same time, developments in technology are accompanied by new risks for the individual and his or her rights[21] (e.g. think of the social imbalances that have come to the fore in the course of the pandemic, in the light of the digital differential peculiar to Italian families[22]), making it necessary to devise strategies for compliance with the

[18] In this context, artificial intelligence (AI) plays a key role in the smart city, as it can be used in areas such as public safety, traffic management, urban planning, and transport, enabling the creation of advanced, algorithm-based technological systems. Possible applications include AI-based video surveillance systems, which can automatically detect suspicious behavior or accidents, improving citizens' safety; AI systems can also be used to optimize traffic management, predicting and managing vehicle flows in real time to reduce road congestion. Also in the field of healthcare, AI and robotics can help monitor the vital parameters of citizens/patients in real time and send alerts to healthcare workers in case of emergency. Robotics, in particular, lends itself to multiple uses in the automation of services, with major applications in transport and healthcare, where the use of robots improves both the accessibility of services, by offering proximity services even in the absence of staff, and their effectiveness, by increasing their precision and reducing the risk margins dictated by human operator error. On these topics see V. Di Gregorio, *Intelligenza artificiale e robotica: profili di responsabilità civile in materia di tutela dei soggetti fragili*, in in P. Dameri, M. Bruzzone (eds.), *Smart City. Prospettive di ricerca*, Genoa, 2024, p. 105 ss.

[19] On which see E. Al Mureden - G. Calabresi, *Driverless cars. Intelligenza artificiale e futuro della mobilità, Bologna,* 2021. On a more general level, see G. Sartor, *L'intelligenza artificiale e il diritto*, Torino, 2022. Consider also to refer to M. Turci, *Le nuove tecnologie al servizio del cittadino: Smart city e diritti fondamentali*, in P. Dameri, M. Bruzzone (eds.), *Smart City. Prospettive di ricerca*, cit., p. 143 ff. and, with reference to the protection of the frail person in the context of freedom of movement and access to transport, Id., *I diritti dei passeggeri a mobilità ridotta: tutele attuali e prospettive di riforma tra Italia e UE*, in *Dir. mar.*, 2020, p. 69 p. ff..

[20] On which see V. Di Gregorio, *Principio di non discriminazione e diritti delle persone con disabilità: dal modello sociale alla Web Accessibility Directive*, quot., p. 19 ss. and Id., *Il principio di non discriminazione delle persone con disabilità*, in P. Ivaldi, L. Schiano di Pepe (eds.), *Uguaglianza e giustizia. Itinerario di una ricerca dottorale*, Genoa, 2023, p. 55 ff.

[21] Rodota, *Tecnologie e diritti*, il Mulino, 1995. V. P. Perlingieri, *Note sul «potenziamento cognitivo»*, in Tecnologie e diritto, 2021, fasc. 1, p. 209 ff.; Id., *Sul trattamento algoritmico dei dati*, in *Tecnologie e diritto*, 2020, p. 181 ff. Cfr. C. Perlingieri – Martone (a cura di), *Nuove tecnologie e cultura del diritto civile*, Esi, 2023.

[22] https://www.irpa.eu/lo-smart-working-come-strumento-di-lavoro-primario-per-le-pubbliche-amministrazioni-al-di-la-della-pandemia/

rules in force and the drafting, where necessary, of new rules capable of exploiting the opportunities offered by scientific development, but at the same time capable of limiting the risks generated by the production and marketing of instruments and apparatuses which, while enabling the community to benefit from the advantages in terms of the greater accessibility of the services they provide and public safety, may at the same time represent a danger in terms of safeguarding the rights and interests of the community. In particular, AI can generate discrimination based on the use of information for purposes other than those for which it was provided and can therefore further penalise persons with fragility (e.g. the case of the exploitation of information, issued to obtain services for persons with disabilities, against their interest in other contexts[23]). Digital discrimination is, however, expressed in a twofold dimension: alongside the aforementioned algorithmic discrimination, a further form of unfairness is constituted by unequal access to technologies and services provided in digital form, which affects older people and not "digital natives" more. Failure to guarantee equal access to new technologies can create digital divides between citizens, exacerbating inequalities or generating new ones, both in access to essential services (health, transport, education) and in opportunities for participation. One thinks of the massive 'digitalisation' of registry services, which has had the side effect of initially hindering access to such services for those sections of the citizenry that are not interconnected.

In this scenario, it is up to the law to identify the legal situations to be protected with respect to the possible drifts of technological and digital evolution and its applications, selecting the most suitable regulatory sources to address the issues arising therefrom with the identification of suitable remedies, also in a preventive manner, and promoting the adoption of regulatory interventions to fill any existing gaps, also from a de iure condendo perspective.

4 Protecting Frailties in the Digital Revolution

In particular, digitisation, the driving force behind Smart Cities and a pivotal element in the evolution of contemporary society, has to be measured against fragility. The institutions of the European Union define its strategic objectives, starting with the Communication Shaping Europe's Digital Future 2020,[24] which identified priorities such as technological development at the service of people and the promotion of a fair and sustainable economy, up to the construction of open and democratic cities. The Digital Compass 2030, adopted with the Communication of 9 March 2021,[25] outlines key axes for enhancing digital infrastructure capabilities, improving education and digitising public services, which are essential for the functioning of Smart Cities.

23 As is well known, the concentration in servers and clouds of large amounts of data, including data related to people's fragilities (e.g. health data) exposes them to disclosure of confidential information through databases. On this point see Thumb; Edwards, *Privacy, Security and Data Protection in Smart Cities*, in *European Data Protection Law Review*, 2 (1), 2016, p. 28 ff. But already in Warren; Brandeis, *The Right to Privacy*, in *Harvard Law Review*, 4, 1890, *passim.*

24 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/shaping-europes-digital-future_it

25 https://digital-strategy.ec.europa.eu/it/library/targeted-consultation-2030-digital-compass-european-way-digital-decade

In a broader perspective, it is the principle of non-discrimination that requires the elimination of material barriers, but also virtual ones.[26] The 2006 UN Convention specifically dedicates Article 9 to the principle of accessibility, which, in proclaiming the right of persons with disabilities to live independently and participate fully in all areas of life, specifies that this right must be recognised with access, inter alia, to information and communication, including information and communication systems and technologies, and to other facilities and services open or offered to the public. In particular, Art. 9(1)(b) provides for accessibility to information and communication services, including electronic and emergency services, requiring States to adopt measures to promote access for persons with disabilities to new technologies and information and communication systems, including the Internet (Art. 9(2)(g)) and the design, development, production and distribution of accessible information and communication technologies and systems at an early stage, so that technologies and systems become accessible at the lowest cost (Art. 9(2)(h)).[27]

In this teleological context are important interventions of the European legislator, In particular, Directive 2016/2102/EU on the accessibility of public bodies' websites and mobile applications (Web Accessibility Directive, WAD), which obliges all public and private bodies in the EU to make their websites and mobile applications accessible, transposed within the Italian legal system by Legislative Decree no. 106/2018 and Directive 2019/882/EU on the requirements of accessibility of products and services in the internal market of the European Union (European Accessibility Act), which was enacted to ensure full web accessibility to the websites of PAs and private companies, so that the content can also be used by people with disabilities, implemented by d. lgs. 27.5.2022, no. 82 and intended to harmonise the internal legislation of the Member States, implement the internal market of products and services also in the field of information and communication technologies, with the removal of barriers created by

[26] The elimination of material and sensory barriers to the material accessibility of places, buildings, services, facilities is in fact one of the objectives of the anti-discrimination legislation, aimed at enabling the person in a situation of vulnerability to realize aspirations and exploit resources with autonomous and conscious choices: the principle of self-determination, which is grounded in art. 13 of the Constitution, as well as in Articles 2, 3 and 32, underlies the European and international legislation on disability and is explicitly recognized in the 2006 UN Convention, in the regulations on independent living, inclusion in the community (Art. 19) and personal mobility (Art. 20). On this point see C. Castronovo, *Autodeterminazione e diritto privato*, in *Eur. e dir. priv.*, 2010, p. 1037.

[27] These principles, even before the Convention was ratified, had been expressed by Law no. 104/1992, which provides for the implementation of the right to independent living of the severely disabled person by means of measures that translate into aid programs and customized plans and with specific budget forecasts, anticipating, the directives of the Convention. Arts. 8–10, 39, 2nd paragraph, lett. l ter, and art. 40 l. no. 104/1992. G. Arconzo, *Il diritto alla vita indipendente delle persone con disabilità*, in A. Morelli, L. Trucco (eds.), *Diritti e autonomie territoriali*, Turin, 2014, p. 270.

divergent legislation with a programme to be implemented in a time frame between 2022 and 2027.[28]

The aim of the WAD directive is to ensure the approximation of national measures at European level with regard to the design of websites so as to favour accessibility (Art. 1), with the limit of the disproportionate burden provided for in Art. 5 that allows public bodies to derogate from the requirements, assessing the size and resources of the body and the cost/benefit ratio for the body in relation to the benefits achieved by the person with disabilities, according to a rule corresponding to the one dictated in Article 5 of Directive 2000/78/EC on non-discrimination in employment that refers to "reasonable accommodation". Recalling the UN Convention (cons. 12), the directive establishes that access to technologies and information and communication systems must also be guaranteed to persons with disabilities, on the basis of guidelines drawn up by the States and how the design of products, structures, programmes must be carried out according to universal design criteria. With regard to services of a technological nature, the WAD introduces new rules on the computer accessibility of websites and mobile applications of public bodies and modifies the content of Law No. 4/2004, which already contained innovative rules to facilitate disabled persons' access to IT tools. In Article 2(a) of Law no. 4/2004, in its most recent version, 'accessibility' is described as the 'ability of information systems, including websites and mobile applications, in the forms and to the extent permitted by technological knowledge, to deliver services and provide information usable, without discrimination, even by those who, due to disability, require assistive technologies or special configurations'. Articles 2(a-bis) and (a-ter) define 'mobile applications' and the website, while Article 2(b) describes 'assistive technologies' as 'the technical tools and solutions, hardware and software, that enable disabled persons (i.e. persons with disabilities), by overcoming or reducing their disadvantages, to access the information and services provided by computer systems'. Article 3 bis of the same law indicates, in paragraph 1, the requirements that websites and mobile applications must possess in order to be considered accessible according to the provisions of the directive in the recital, specified in perceptibility, usability, comprehensibility, robustness. In the second paragraph, with regard to services realised by means of computer systems, including websites and mobile applications, the standard requires that the requirements of accessibility to the content of the service by the user (sub-paragraph a) and usability of the information offered (sub-paragraph b) must be satisfied. The latter element must be characterised by 1) ease and simplicity of use, ensuring that the actions to be performed to obtain services and information are always uniform; 2) efficiency in use, ensuring, the separation between content, presentation and mode of operation of the interfaces, as well as the possibility of making information available through different sensory channels

[28] The Ten-Year European Disability Strategy has as its programmatic pivot the elimination of barriers to the participation of persons with disabilities in social, cultural and economic life and indicates the measures to be taken at the European level to make the UN Convention on the Rights of Persons with Disabilities operational, recalling the objectives of inclusion, equal participation in all areas of daily life, the achievement of higher employment rates for persons with disabilities, more inclusive education, improved medical care and strengthened social protection, but above all accessibility (of public spaces, the built environment, and the digital environment), which must be guaranteed with a universal design approach and a separate budget.

3) effectiveness in use and compliance with user needs, ensuring that the actions to be performed to properly obtain services and information are independent of the device used for access; 4) satisfaction in use, ensuring access to the service and information without undue inconvenience or constraints for the user.

With a special focus on the elderly population, the Italian legislature implemented the principles of digital accessibility with Law No. 33/2023,[29] which establishes the criteria for the promotion of active ageing and social inclusion, including digital literacy interventions for the elderly, which are fundamental for access to the services offered in Smart Cities. Particularly relevant for this purpose is Legislative Decree No. 29/2024 (Provisions on policies in favour of the elderly, implementing the delegation referred to in Articles 3, 4 and 5 of Law No. 33 of 23 March 2023), which has determined an articulated reform, aimed at implementing some of the provisions of Budget Law 2022[30] and, with specific reference to the category of the non-self-sufficient elderly, at achieving one of the objectives of the PNRR. This measure consists of 2 Titles and 43 articles and contains provisions aimed at promoting dignity and autonomy, social inclusion, active ageing and the prevention of the frailty of the elderly, including through access to preventive health and telemedicine tools at home and the fight against isolation (also in the digital sense) and relational and affective deprivation. In particular, this decree introduced specific provisions for the training and digital support of the elderly population, providing for the provision of training activities in the digital skills of the elderly and support for them in the use of services provided online by public administrations (Art. 19), as well as interventions to overcome the generational digital divide (Art. 20, which commits the educational institutions to favour the construction of training courses that promote the acquisition of knowledge and skills in the use of digital tools in the elderly, to reduce the generational gap).

Special attention was paid to the digitisation of the health sector, an essential tool to ensure the effectiveness of the right to health and to support the elderly in Smart Cities. The Covid-19 pandemic has accelerated technological innovation in healthcare, with a focus on the accessibility of electronic health records, in line with the objectives of Decision (EU) 2022/2481. On the national side, Article 9 of Legislative Decree No. 29/2024 recognises telemedicine as an essential tool for the care of the elderly, providing for its priority use in cases of non-self-sufficient persons suffering from chronic diseases. The unified multidimensional assessment (Art. 28) and the guidelines for the integration between social and health interventions (Art. 29) represent further tools to ensure integrated and digital care, which is also functional to the management of health services in Smart Cities. Finally, at the planning level, Article 31, Paragraph 7 of Law 29/2024 assigns the Ministry of Health the task of defining national criteria for the accreditation of healthcare facilities, promoting advanced technological solutions such as video-surveillance and telemedicine tools, guaranteeing safety and quality of care, also in urban settings.

[29] Delegations to the Government on policies in favor of the elderly

[30] Law No. 234/2021, Art. 1, c. 159–171

5 AI, Fragility and Algorithmic Discrimination

Artificial intelligence is an integral part of this digital transformation and, as enshrined in Decision (EU) 2022/2481,[31] is promoted for integration into the Union's digital ecosystem, working alongside other technologies such as cloud computing and data management, which are crucial for planning and optimising urban services. In fact, the European Declaration on Digital Rights for the Digital Decade, adopted on 15 December 2022,[32] states that AI must be oriented towards human well-being, a principle that also applies to services offered in Smart Cities, including the protection of the elderly.

The recent Regulation (EU) 1689/2024, known as the AI Act, which regulates the development, commercialisation and use of artificial intelligence in compliance with the values of the Union, in emphasising the need to reconcile European economic development with the protection of fundamental rights, considers vulnerability a condition to which particular attention should be paid, incorporating it in several provisions and providing specific guarantees for fragile individuals. In particular, Article 5 prohibits 'the placing on the market, putting into service or use of an AI system that exploits the vulnerabilities of a natural person.[33] Through this regulatory intervention, the legislator has pursued a twofold objective: to promote the use of technology to improve the quality of life of vulnerable persons and, at the same time, to protect them from the risks that innovation may entail. The result is a vision of the law as a balancing instrument between technological progress and the protection of the individual, in a context of digital and ecological transition that will have to find its concrete application in the coming years.

On the domestic front, the Italian government recently approved a draft enabling act for the regulation of AI,[34] Article 7 of which is expressly dedicated to the use of artificial intelligence in healthcare and for the benefit of disabled people. It states, in particular

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[31] Decision (EU) 2022/2481 of the European Parliament and of the Council of 14 December 2022 establishing the Strategic Program for the Digital Decade 2030

[32] https://www.consilium.europa.eu/it/press/press-releases/2022/12/15/declaration-on-digital-rights-and-principles-eu-values-and-citizens-at-the-centre-of-digital-transformation/

[33] But the recitals of the Regulation also point in the same direction (e.g. cons. no. 29, *'AI systems may also otherwise exploit the vulnerabilities of a person or a specific group of persons due to age, disability within the meaning of Directive (EU) 2019/882 of the European Parliament and of the Council, or a specific social or economic situation that could make such persons more vulnerable to exploitation'*; cons. No. 58 *"Another area where the use of AI systems deserves particular attention is access to certain essential public and private services and benefits necessary for individuals to participate fully in social life or improve their standard of living, and the use of such services. In particular, individuals who apply for or receive essential public assistance benefits and services from public authorities, i.e. health services, social security benefits, social services providing protection in cases such as maternity, sickness, accidents at work, dependency or old age and loss of employment, and social and housing assistance, are usually dependent on such benefits and services and are generally in a vulnerable position vis-à-vis the responsible authorities'*; Cons. No. 60, *'AI systems used in the area of migration, asylum and border control management affect persons who are often in a particularly vulnerable position'*).

[34] Available at: https://www.fiscoetasse.com/files/18248/ddl-intelligenza-artificiale-post-precdm-23-04-2024.pdf

(paragraph 4), that the law 'promotes the development, study and dissemination of artificial intelligence systems that improve the living conditions of persons with disabilities and facilitate their accessibility, autonomy, safety and social inclusion processes.[35]

One sector in which AI finds particular opportunities for application is transport, which has a considerable impact on fragile categories as it can affect the ability to move elderly and disabled people. In this perspective, there is the start of production (the use is for the moment limited, because it is still in the experimental phase) of 'intelligent' vehicles, so-called Smart Cars, both in the self-driving version, which travel with human intervention, and in the driverless version, without a driver or with the driver on board, allowing mere stopping and emergency operations, the use of which by persons with disabilities could allow them, for example, to board the car without accompaniment and without the need to make particular physical movements.[36]

The issue of the safety of autonomous vehicles, the introduction of which is aimed at reducing the number of accidents caused by human driver error and improving traffic, nevertheless requires a balance to be struck between technological development and the suppression of offences that may possibly result from a programmed decision of the machine, given that the choice represented by the comparison between the 'human capital' represented by the driver/transporter and the pedestrian or occupant of another vehicle and the damage caused by the seizure of confidential data by hacking into the car's software systems, in violation of GDPR no. 679/2016.[37] The juxtaposition between the benefits deriving from the introduction of autonomous vehicles on the market and

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[35] This objective must also be reconciled with the provisions of Legislative Decree no. 62 of 3.5.2024 with which the legislature implemented the "disability reform" in implementation of the law delegated to the Government on disability (Law no. 227/2021).

[36] See, again, E. Al Mureden - G. Calabresi*, Driverless cars. Intelligenza artificiale e futuro della mobilità*, quot., *passim.* On a more general level, see G. Alpa (ed.), *Diritto e intelligenza artificiale*, Pisa, 2020; G. D'Acquisto, *Intelligenza artificiale. Elementi*, Torino, 2021; and C. Perlingieri*, L'incidenza dell'utilizzazione della tecnologia robotica nei rapporti civilistici*, in *Rass. dir. civ.,* 2015. With reference to the protections of the frail person in the context of freedom of movement and access to transport, M. Turci, *I diritti dei passeggeri a mobilità ridotta: tutele attuali e prospettive di riforma tra Italia e UE*, quot., p. 69 ss.

[37] The bibliography on the subject is rather extensive: in addition to the well-known study by G. Calabresi*, Costo degli incidenti e responsabilità civile, Analisi economico-giuridico*, Milano, 1975, we would like to point out the recent contribution, also in terms of the economic analysis of law, by E. Al Mureden, G. Calabresi*, Driverless cars. Intelligenza artificiale e futuro della mobilità*, Bologna, 2021; U. Ruffolo, E. Al Mureden, *Autonomous vehicles e responsabilità nel nostro sistema e in quello statunitense*, in *Giur. it*., 2019, p. 1704; for the European experience see M. Losano, *Il progetto di legge tedesco sull'auto a guida automatizzata*, in *Dir. inf*., 2017, p. 1 ss. In Europe, autonomous vehicles are already being tested on the road; in our system, the Ministry of Transport and Infrastructure's decree of 28.2.2018 (the so-called Smart Roads decree), which authorized the testing of driverless cars, was annexed to the 2018 budget law (l. 27 December 2017, no. 2015). In Germany, laws allowing road tests of autonomous driving are accompanied by the introduction of amendments to the Highway Code. As far as the American experience is concerned, the approach in accommodating automated driving systems is in the sense of providing for different levels of automation (precisely six), which can be found on the National Highway Traffic Safety Administration website at https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety and testing is already well advanced.

the provocation of damage resulting from malfunctioning of the system or from its tampering requires the setting up of an apparatus of rules aimed at coping with the risks of personal injury that is currently reconstructed, within the legal system, on the basis of the rules dictated by the Civil Code on the subject of strict liability and, in particular, on Articles 2050, 2051, 2054, and of the regulations on product liability (consumer code, legislative decree no. 206/2005, articles 114–127), especially with regard to damages resulting from defective manufacture, design, and software programming.

The use of Artificial Intelligence systems entails, however, benefits and risks, including the phenomenon of algorithmic discrimination, which can significantly affect vulnerable people in Smart Cities. The principle of non-discrimination, together with the principle of transparency of the decision-making process and non-exclusivity of the automated decision, constitutes a normative foundation for the operation of algorithms, as affirmed by the Council of State in Judgment No. 8472 of 2019, with reference to Regulation (EU) 2016/679 (GDPR), in particular recital 71. In fact, AI, relying on data that are made available on the basis of privacy legislation, risks generating discriminatory effects if the training datasets turn out to be deficient or unrepresentative, with implications also for digital services provided in Smart Cities, in particular in the health sector.

For instance, an AI-powered urban planning tool designed to optimize public transport routes might inadvertently perpetuate spatial discrimination if its training data predominantly reflects the travel patterns of able-bodied individuals, leading to the neglect or inadequate provision of accessible routes for wheelchair users or the elderly. The AI Act, by mandating rigorous quality criteria for training datasets and requiring impact assessments for high-risk systems, directly addresses this by compelling developers to identify and mitigate such biases ex-ante, thereby ensuring that technological solutions genuinely promote universal accessibility rather than creating new barriers

On the other hand, the sharing of data, even non-personal data, can be useful for developing technological solutions within public administrations that implement the levels of services rendered in the context of the development of the European technological market, a context in which regulatory instruments already in force, such as Regulation (EU) 2023/2854 (Data Act) and Regulation (EU) 2022/868 (Data Governance Act), govern the sharing and use of data, promoting a transparent and accessible digital ecosystem also in Smart Cities.

To reduce these risks, the AI Act adopts a risk-based approach, distinguishing low, high and unacceptable risk systems. In particular, for high-risk systems that use data for training, Article 10 requires that datasets must meet strict quality criteria, including the assessment of possible biases that could compromise security, fundamental rights and the principle of non-discrimination. The regulation also complements EU law on non-discrimination by imposing specific requirements for the quality of datasets and the assessment of possible bias. The European legislation on AI also fits into the framework of the European data strategy,[38] which aims to guarantee access to high-quality datasets for training and validation of AI systems, as highlighted in the recitals of the regulation itself.

6 Conclusions

The advent of digital technologies and artificial intelligence is redefining the concept of the smart city, transforming urban spaces into interconnected ecosystems that promise greater efficiency, sustainability and quality of life. However, this digital revolution cannot ignore a critical reflection on its social implications, especially for the most vulnerable groups, such as the elderly and people with disabilities. The law today stands at a fundamental crossroads: on the one hand, it must foster innovation, and on the other, it must ensure that technological progress does not result in new forms of exclusion or discrimination.

The inclusive potential of technology is immense. Tools such as telemedicine, robotic assistance systems, digital accessibility platforms and autonomous mobility solutions can significantly improve the autonomy and social participation of frail people. However, these developments are not without risks. Algorithmic discrimination, for instance, poses a real threat when AI systems are trained on partial or unrepresentative datasets, perpetuating biases that further marginalise certain social groups.[39] The AI Act (EU Reg. 1689/2024) attempts to mitigate these dangers through a risk-based approach by imposing strict requirements for data quality and transparency of algorithms.[40]

Another crucial issue is the generational digital divide, which risks excluding the elderly from the benefits of digitisation. As highlighted by Legislative Decree 29/2024, it is essential to promote digital literacy and to ensure that public services are accessible to all, regardless of technological skills. In this sense, the principle of universal design and the web accessibility directives constitute a model to be extended to all dimensions of the Smart City, from urban planning to digital services.

The law, therefore, must play a dual role: propulsive, in supporting innovation through clear regulations and incentives, and protective, in preventing abuses and distortions.[41] This balance is particularly delicate in areas such as digital health, where the use of

[38] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_itAlso, part of the path outlined by the strategy is the proposed European Health Data Space Regulation, proposed by the European Commission on 3 May 2022, which aims to ensure fair and secure access to data while respecting the EU's high standards of protection. The text of the regulation is available at the link: REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the European health data space and amending Directive 2011/24/EU and Regulation (EU) 2024/2847–2022/0140(COD)

[39] A.G. Grasso, *The Bad Algorithm. Automated Discriminatory Decisions, in the European General Data Protection Regulation*, Esi, 2022.

[40] S. Corso, *On the Frontier of Private Law. New technologies and the elderly person*, quot., p. 1260

[41] P. Perlingieri, *Il diritto civile nella legalita‘ costituzionale secondo il sistema italo-europeo delle fonti*, III, *Situazioni oggettive*, quot., 1 ff. See Giova, *La persona nel contesto digitale: considerazioni conclusive*, in *Tecnologie e diritto*, 2023, p. 326 ff.

medical apps and IoT devices must reconcile efficiency with the protection of privacy and data security.[42]

In conclusion, the challenge of inclusive Smart Cities is not only technological, but first and foremost cultural and legal. Law must rediscover the value of human dignity and the personalist principle, placing the person - not the market or the state - at the centre of the digital transformation.[43] Only in this way will it be possible to build truly smart cities, in which innovation is synonymous with equity, participation and respect for the fragile. The road is mapped out by European regulations and national measures: it is now up to civil society, institutions and legal practitioners to translate these principles into reality, ensuring that no one is left behind in the digital age. The challenge is therefore to reconcile technological efficiency with the protection of fragility, so that the inclusive Smart City does not remain a utopia, but becomes a concrete and sustainable reality.

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[42] C. Irti, *L'uso delle "tecnologie mobili"applicate alla salute: riflessioni al confine tra la forza del progresso e la vulnerabilità del soggetto anziano*, quot., p. 32 ff.

[43] P. Perlingieri, *La personalita' umana nell'ordinamento giuridico*, Esi, 1972.

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Climate Change and Natural Risk Management: The Relationship Between the Precautionary Principle and Artificial Intelligence

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Abstract. One objective of the smart city concept pertains to the broad environmental dimension, including the increasingly relevant management of natural risks due to the significant impacts of climate change. Consequently, the use of new technologies, such as artificial intelligence systems, will undoubtedly play a fundamental role in the evolution of risk administration models, principles, and categories. This research aims to highlight several deeply interconnected evolutionary trends in the relationship between digitalization and environmental risk management: the growing nexus between the precautionary principle and the right to environmental information; the role of new technologies in this context; and the shifting focus of the precautionary principle from administrative action to its "organizing function". To this end, this paper will primarily examine current artificial intelligence-based environmental monitoring and population alert systems.

Keywords: climate change · public administration · precaution · artificial intelligence · risk · monitoring · early warning

1 Introduction: Climate Changes and Natural Risks

There is a strict connection between climate changes and increasing weather and climate extreme events, like storms, floods, landslides and drought. These events have got huge consequences for human lives and security.

For instance, according to the 2023 Synthesis Report on Climate Change of Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for

Notwithstanding the research's unified nature, Sects. 1 and 2 of this contribution are attributed to Piera Maria Vipiana, while Sects. 3, 4, 5 and 6 are attributed to Giovanni Botto. Furthermore, this writing constitutes activity within the RAISE research project (Innovation Ecosystem - Extended Partnership "RAISE - Robotics and AI for Socio-economic Empowerment" funded under the MUR PNRR Program – Mission 4, Component 2, Investment 1.5 – Public Notice for the creation and strengthening of Innovation Ecosystems) and of the SERICS research project (Extended Partnership PE00000014 "SERICS SEcurity and RIghts in the CyberSpace", funded under the MUR PNRR Program – Mission 4, Component 2, Investment 1.3 – Public Notice "Extended Partnerships to universities, research centers, companies for the funding of basic research projects" - Decree No. 341 of March 15, 2022).

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 156–170, 2026.
https://doi.org/10.1007/978-3-032-21842-1_11

assessing the science related to climate change: «Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change. Increasing weather and climate extreme events have exposed millions of people to acute food insecurity. … Between 2010 and 2020, human mortality from floods, droughts and storms was 15 times higher in highly vulnerable regions, compared to regions with very low vulnerability».

Civil protection is an administrative function for preventing and protecting against natural or man-made disasters: this notion of civil protection is statued by article 196 of the Treaty on the functioning of the European Union (TFUE). It is one of the most important administrative functions: it is essential in order to build, to maintain and improve a smart city (Vipiana 2024; Lauri 2021).

In civil protection and in civil protection law it is very important the notion of risk.

The concept of Risk is the product of three terms (Allegretti 2018): hazard, which is the probability of an event in a certain area and during a specific time interval; vulnerability is the level of propensity for damage of a structure or an infrastructure due to the event; exposition is the number of persons or things – also productive activities and historic and cultural heritage – which can suffer the consequences of the event.

2 Civil Protection Function and Natural Risk Management

In Italy, civil protection is a function attributed to an integrated system: the National Civil Protection Service, established in 1992 by Law no. 225 and reformed in 2018 by the Civil Protection Code.

It provides for implementing all activities to protect lives, property, settlements, animals and the environment from disasters and their damaging effects.

The main functions of civil protection are: prediction and forecasting, preparedness, management of emergency, mitigation of risk and recovery. In particular, prevention is one of the civil protection activities according to Law n. 225 of 1992, and now according to the Civil Protection Code of 2018. Prevention consists of all activities aimed at avoiding or reducing possible damage in the event of a disaster. Prevention activities include: the alerting of the National Service, the civil protection planning, and training of service operators; the information to the population, the promotion and organization of exercises at every territorial level.

In the field of civil protection, we must move from the culture of emergency to the culture of risk (Giani et al. 2018): not only deal with emergencies though timely operations and acts; but also, and above all, manage the risks with the plans.

In Risk administrative Law, a central role play: firstly, the Organisation of Civil Protection; secondly the Planning; and thirdly, the artificial intelligence Tools.

From the first point of view, all levels of government are part of the National Civil Protection Service: the State, the Regions, the Autonomous Provinces, and the Local Authorities, and also – very important – the volunteers. Civil protection activities also benefit from the contribution of professional orders and boards as well as private companies, especially those linked to strategic sectors such as communications, transport, and essential services networks.

From the second point of view, the administrative activity of natural risk management consists both of operations and legal acts. Acts can be either specific measures, such as mandatory and urgent orders, or general acts, such as plans. According to the Civil Protection Code each municipality must have a civil protection plan. The plan shall be specific in relation to the characteristics of the territory. The plan shall be updated. In fact, in the field of civil protection it ts necessary, above all, to manage the risks with the plans.

From the third point of view, civil protection requires the use of information technologies and of artificial intelligence in order to fulfill the tasks of planning and implementation of civil protection measures. AI tools are very important, especially with regard to monitoring and information to population and alerting. Integrating AI into Civil Protection is a Challenge and a Must in order to build and to improve a Smart City.

3 The Precautionary Logic and the Environmental Information: An Indissoluble Nexus

The fact that the precautionary principle, due to its general ratio and the modalities of its concrete manifestation, depends decisively on the contribution of scientific and technological knowledge is not a novelty, but rather reflects a characterizing element of the entire European Union environmental law. On this point, it would suffice to recall what is stated in Article 191 TFEU, paragraph 3, which establishes that in preparing its policy on the environment, the Union takes into account, inter alia, «available scientific and technical data».

From this general connotation of environmental policies derives, then, the essentially technical nature of the related legislation, which «is not a law that can be considered the exclusive fruit of the "domain" of political will, but is a law that always needs to be based on "technical-scientific" expertise, that is, on the "domain" of knowledge (certain or uncertain) that is the prerogative of such expertise and from which the public decision-maker is constantly called to draw» (Cecchetti 2022).

This technical-scientific characterization of the principle in question is also reflected in its application in risk administration, as is evident from the essential contents of the 2000 Communication on the precautionary principle, in which the European Commission states that «an assessment of scientific data on risks is a necessary element for resorting to the precautionary principle» and that «this requires reliable scientific data and a rigorously logical reasoning that leads to a conclusion, which expresses the possibility of occurrence and the potential severity of the danger to the environment or the health of a given population, including the extent of possible damage, persistence, reversibility, and delayed effects».

In other words, as emphasized in doctrine, the basic activity for the application of the precautionary principle is risk assessment, which, however, «presents two fundamental profiles, complementary and often closely intertwined but [...] to be kept as distinct as possible, avoiding improper confusions: the scientific assessment of risk and the determination of the level of risk "acceptable" by the society that must bear it» (Cecchetti 2022).

The first activity has an eminently scientific and technical nature; the second, instead, would have a purely political nature, being entrusted to the evaluation and balancing carried out by the competent authorities. On this last element, one could perhaps discuss, given that, as noted in doctrine (Puddu 2015), the application of the precautionary principle is increasingly based on a comparison between risks, rather than between risks and conflicting interests: which tends to give even to the assessment of acceptable risk a technical coloring, which is also accentuated by the ever-greater pervasiveness and advancement of available technological tools.

In all probability, the classic distinction between a "technical" and a "political" phase depends on the traditional application of the precautionary principle as a tool for managing uncertain, but contingent and defined risks, which, moreover, justified the initial inclusion of the topic in the broader context of emergency (Titomanlio 2018).

However, risk management is now a systemic issue (Giani et al. 2018), connected to environmental and health protection within complex systems. While not eliminating political or discretionary aspects, this necessitates a reallocation within the legal system that tends to narrow their scope. This evolution is essential to ensure the precautionary principle's application in modern risk management aligns with the principle of legality.

For present purposes, it is crucial to underscore the precautionary principle's structural reliance on technical-scientific knowledge and the role of environmental information in its proper application. Comprehending the principle's core content necessitates acknowledging not only its dependence on such knowledge but also its nexus with continually updated information concerning the factual risk context. Scientific knowledge forms the essential state of the art for navigating complex realities, utilizing technological and legal tools for grounding even absent initial certainty. Information, such as environmental and territorial data, pertains to the factual dimension and informs precautionary models grounded in consolidated, yet evolving, scientific knowledge.

The aforementioned 2000 Communication on the precautionary principle states that, in risk assessment, «where possible, a report should be drawn up including an assessment of existing knowledge and available information», distinguishing between the two notions. This is, upon closer inspection, an element of no small importance, given that, especially with the advancement of detection tools and related artificial intelligence systems, the state of the art (consisting of the set of statistical data and available scientific knowledge) and the dimension of fact (consisting of the set of continuous modifications of the concrete risk context, translatable into information) will increasingly find themselves in a dimension of continuous communication.

In its most complex form, the precautionary principle integrates technical-scientific demands for the scientific community with informational, participatory, and communicative demands for the public, which the administration must address. These interconnected elements largely correspond to doctrinal models (Garzia 1998) manifesting the evolving subjective legal position termed the "right to environmental information": namely, access to information, public participation in environmental decisions, and communication of environmental risks.

Consequently, a close, perhaps fundamental (Grassi 1990), relationship exists between the precautionary principle and the right to environmental information, potentially broadening the former's scope from administrative action to organizational structure itself (to be further discussed in the conclusions).

Given, in fact, that, due to the link that has been described, it is not possible to imagine an effective precautionary action in the absence of a correct acquisition and management of the necessary information, the words of those who have stated that, «if the essential purpose of the right to environmental information can be usefully pursued only in the event that the administration is able to collect, coordinate, and make available to citizens [...] the requested information, it is evident that the administration itself has the obligation to give itself an organization suitable to be able to pursue this purpose» (Garzia 1998).

The preceding discussion leads directly to the central point: the impact of new technologies on territorial and environmental risk management models and their connection to the public administration's information function. This analysis will first focus on the complex issue of environmental monitoring and subsequently address the related issue of early warning systems.

4 The So-Called "Environmental Monitoring": The Evolution of a Model

Starting with the first theme, artificial intelligence is undeniably a highly valuable tool in monitoring (Botto 2022), owing to its significant capacity to collect, store, and analyze extensive heterogeneous data, as well as its predictive capabilities, rendering it considerably useful even in the planning stage (D'Avanzo 2021).

Previously, concerning territorial information systems and environmental monitoring, the absence of an integrated and unified model of territorial and environmental knowledge – specifically, an institutionally competent entity to develop an integrated system for collecting, processing, disseminating, and sharing such information (Sau 2009) – has been rightly criticized. Such a model would ensure the "(rapid and continuous) availability of certified and updated information to a potentially unlimited range of users, both public and private, while guaranteeing access and security in the management of this public informational asset" (Sau 2009). Furthermore, it was interestingly observed that "the issue appears more organizational than technological" (Sau 2009).

Today, especially in light of the advancements in artificial intelligence systems and distributed ledger technologies, it is increasingly evident that the relationship between technology (particularly digital technology) and the organizational aspects of public administration is inseparable.

From a reconstructive perspective, regarding environmental monitoring, certain significant legal instruments must be considered. These include supranational acts, such as Directive 2007/2/EC (commonly referred to as "INSPIRE" directive), concerning the interoperability of essential territorial and environmental information, and Directive (EU) 1024/2019 on open data and the reuse of public sector information, which impacts the earlier Directive 2003/98/EC, also on the reuse of public sector information.

Additionally, the Italian national legislation is relevant, including legislative Decree No. 112 of March 31, 1998, and, more broadly, the national implementing legislation of the aforementioned European normative acts, such as legislative decree n. 32 of January 27, 2010 (implementing the INSPIRE Directive), the Prime Ministerial Decree of February 20, 2019 (National Plan for the Mitigation of Hydrogeological Risk, Restoration, and Protection of Environmental Resources), Decree-Law No. 120 of September 8, 2021 (containing provisions for combating wildfires and other urgent civil protection measures), and subsequent regulations implementing the National Recovery and Resilience Plan (PNRR), of 2019.

For the sake of clarity, it is appropriate to proceed chronologically, starting with the role of the well-known legislative decree n. 112 of March 31, 1998, concerning the transfer of state administrative functions and responsibilities to the regions and local authorities, in implementation of Chapter I of law n. 59 of March 15, 1997.

This legislation included various provisions relating to what could be defined as the public authorities' informational function, articulated across various sectors and creating a complex system of responsibilities involving numerous entities. Notably, article 51 (found in Title III, which addresses territory, environment, and infrastructure) states that «the transfer also includes organizational functions and related and instrumental activities necessary for the exercise of the transferred functions and responsibilities, including, among others, programming, oversight, access to credit, administrative policing, as well as the adoption of contingent and urgent measures provided by law». Article 54 further clarifies that certain functions remain under the State's authority, including those relating to: «a) observation and monitoring of territorial transformations, particularly with reference to the duties outlined in article 52, illegal construction, and recovery efforts, also based on data provided by municipalities; b) the establishment of criteria for the collection and digitization of all existing official cartographic materials, as well as those under development, to unify different systems for easier data interpretation».

Similarly, article 69, paragraph 3, of the aforementioned decree (Title III, Chapter III) states that «supervision, surveillance, monitoring, and control activities aimed at exercising the functions and duties referred to in paragraph 1 shall also remain under the State's authority», including the preparation of the general report on the state of the environment (paragraph 1, letter c)). From the perspective of the direction of the environmental information function, it is evident that there is strong centralization due to its national significance.

From an operational perspective, the principal entities required by law to collect, process, and produce information concerning the territory of the Italian State are numerous. Pursuant to article 1 of law n. 68 of February 2, 1960, «the cartographic bodies of the State are: the Military Geographical Institute; the Hydrographic Institute of the Navy; the Photocartographic Section of the Air Force General Staff; the Administration of the Cadastre and Technical Revenue Services; and the Geological Service». Furthermore, «the national cartographic production overlaps with the cartographic production of the regions» (Sau, 2009).

In other words, in both cases under consideration, the legislator decided, with respect to the environmental information function, to retain at the state level the «functions of standardization and determination of general criteria», while leaving «operational functions» to the local level.

This general framework, marked by a high degree of fragmentation in the environmental and territorial information function, was addressed by the aforementioned directive 2007/2/EC (so called "INSPIRE").

In particular, the directive identifies the need to establish coordination modules between users and providers of information. This coordination aims to combine the information and knowledge available across various sectors.

Furthermore, according to recital 5 of the directive, the European infrastructure should build on the territorial information infrastructures established by Member States, which should ensure that territorial data are stored, made available, and maintained at the most appropriate level (recital 6). Recital 17 also emphasizes that network services are essential for sharing territorial data among various levels of public administration within the Community.

On this basis, article 1 of the directive sets out the general objective «to establish general rules aimed at creating the Infrastructure for Spatial Information in the European Community for the purposes of Community environmental policies and policies or activities that may impact the environment».

The INSPIRE Directive was implemented at the national level through legislative decree n. 32 of January 27, 2010, aimed at establishing a national infrastructure for spatial information and environmental monitoring. This infrastructure enables Italy to participate in the European Community's spatial information infrastructure for the purposes of environmental policies and other policies or activities that may have environmental impacts. The rules set out in the decree apply specifically to spatial datasets that are available in electronic format, held by (or on behalf of) a public authority, and that «have been produced or received by a public authority or are managed or updated by the same authority and fall within the scope of public service tasks» or by «third parties engaged in activities that may have environmental impacts».

Notably, article 1, paragraph 7 of the decree clarifies that it does not «impose the collection of new spatial data».

Regarding the critical issues previously highlighted concerning the clear discrepancy between the guiding and coordinating functions of environmental monitoring and its operational dimension, the legislative decree introduces several highly significant innovations.

First, article 6, titled "Interoperability of spatial datasets and related services", provides that public authorities shall make spatial datasets available in conformity with the implementing provisions adopted at the Community level. This is achieved through the adaptation of existing spatial datasets or conversion services, thereby establishing an obligation to standardize environmental and spatial information made available.

Second, article 8, titled "National Geoportal", stipulates that the National Cartographic Portal shall be renamed the National Geoportal, which shall replace, for all intents and purposes, the Cooperative Cartographic System – National Cartographic Portal. The National Geoportal also allows public and private stakeholders to access and ascertain the availability of spatial and environmental information and serves as a unified access point for the purposes of environmental monitoring regulations.

By harmonizing the methods for creating and sharing spatial datasets, this provision aims to curb the administrative and operational fragmentation characteristic of the Italian cartographic sector by channeling the information produced by all involved authorities into the National Geoportal.

Third, article 11, titled "Coordination measures", establishes that, for the direct coordination of the contributions of all stakeholders involved in the effective functioning of the national infrastructure for spatial information and environmental monitoring across various levels of administration, the "State-Regions Coordination Table for the National System of Environmental Observation and Information", constituted under Resolution No. 1367 of January 17, 2002, by the Standing Conference for the relations between the State, the Regions, and the Autonomous Provinces of Trento and Bolzano, is transferred to the Ministry of the Environment and assumes the name "National Consultation for Territorial and Environmental Information". This body serves as an institutional liaison between public administrations producing spatial datasets and provides technical guidance to the Ministry of the Environment for the preparation of measures necessary for the functioning of the national infrastructure for spatial information and environmental monitoring.

In essence, the Italian legislator, following the European normative framework, seeks to address the main issues related to the collection and management of environmental information. This approach entails, on one hand, enhancing the uniformity and digital management of data, and on the other hand, establishing forms of coordination at the national level and introducing a dedicated public entity to oversee these efforts.

It is worth reflecting on two general points regarding what has just been outlined.

First, as evident from the aforementioned provisions, the territorial information infrastructure established under the INSPIRE Directive primarily serves to reorganize existing environmental information held by public authorities and other stakeholders. It does not generally require the active creation of new environmental information, unless produced in the course of the entity's public duties. Consequently, it appears to be a system designed to organically reconstruct the national knowledge base regarding the environment and territory, making it accessible to all parties directly or indirectly managing issues affecting specific geographical areas.

Moving to the second reflection, the decision to entrust the coordination of the parties involved in the infrastructure to the National Consultation for Territorial and Environmental Information, rather than, as advocated by some scholars, to a true ministerial agency or even an independent administrative authority, demonstrates the type of approach favored. From this perspective, it is interesting to note that, according to the provisions of the Prime ministerial decree 12 January 2016, n. 72 (concerning the functioning of this body), «the Consultation, pursuant to Article 11, paragraph 4 of Legislative Decree No. 32 of January 27, 2010, is chaired by a representative of the Ministry of the Environment and Protection of Land and Sea appointed by the Minister, and is composed of the following members, chosen among professionals with proven experience: (a) two representatives from the Ministry of the Environment and Protection of Land and Sea, one of whom, appointed by the Minister, serves as the President; (b) one representative for each of the following national cartographic authorities under Article 1 of Law No. 68 of February 2, 1960: 1) Military Geographical Institute; 2) Hydrographic Institute of the Navy; 3) Geotopographic Information Center of the Air Force – CIGA; 4) Revenue Agency – Central Directorate of Land Registry and Cartography; 5) ISPRA – Geological Service; 6) ISTAT – National Institute of Statistics». Essentially, this is a complex body aimed at ensuring mere institutional coordination.

However, one of the key characteristics of modern administrative management concerning environmental risk, and particularly adaptation to climate change, is the need to manage and respond to territorial dynamics adaptively by creating more flexible decision-making processes. This, as expected, requires continuous informational updates for stakeholders in the field and the expansion of co-management capabilities in the short and very short term.

Therefore, environmental and territorial monitoring, playing an extremely important role, must evolve, from a regulatory perspective, in this direction, so that the information derived from it can be used to dynamically manage the territory, quickly and easily coordinating public entities holding the information and decision-makers. Additionally, it should promote practices of disseminating the information itself.

It is no coincidence, as previously mentioned, that the Italian National Recovery and Resilience Plan (PNRR) has addressed this issue, aiming to develop a monitoring system that will allow the identification and forecasting of risks on the territory due to climate change and inadequate territorial planning. The use of advanced technologies will enable remote monitoring of large territorial areas, optimizing resource allocation. The monitoring data will serve as the foundation for developing risk prevention plans, including for existing infrastructures, and for adaptation to climate change.

With ministerial decree n. 398 of September 29, 2021, the Operational Work Plan for the implementation of the investment was approved, with the aim of identifying the necessary actions for the establishment of the monitoring system. Particular attention is given to the initial phase of «preliminary design» carried out by the Ministry for the Environment and Energy Security with the support of the Civil Protection Department and in coordination with other Ministries.

Clearly, the approach to environmental monitoring is markedly different from the original model that we briefly described, as it evolves from the mere collection of data and territorial information for medium- and long-term management purposes to a fundamental tool for the continuous management of ecosystems and territories, promoting forms of adaptive governance.

What has been stated above demonstrates how environmental risk management, in all its components, increasingly relies on the evolution of the organizational aspects of the public administrations involved.

From this perspective, the evolution of the discipline concerning environmental monitoring, as briefly outlined, provides some points for reflection.

First, a clear environmental and territorial information function, based on the use of technology and new technologies, emerges, which is intrinsically connected to environmental protection and risk management.

Second, despite the measures adopted to implement the INSPIRE Directive, this function is significantly weakened by the fragmentation of the administrative structure responsible for it. From this point of view, the innovations introduced and to be introduced as part of the PNRR appear to focus on the implementation of the technological infrastructure, without clearly defining a project for the administration of environmental information suited to modern needs.

In other words, while the legislator's intention to shift from an essentially static environmental monitoring model to a dynamic one can certainly be positively evaluated, the clear tendency to invest on the technological factor must also be noted, without, however, an in-depth reflection on the administrative integration models necessary for the information collected to be used profitably by decision-makers.

5 The Problem of Risk Communication: The Early Warning Systems

Having addressed environmental monitoring, we now turn to the second issue: risk communication, specifically "early warning systems". This topic lies at the intersection of various themes within this study. While seemingly technical/operational, it raises significant legal issues, particularly in administrative law. It exemplifies the close relationship between science, technology, and law, driven by advanced tools and methodologies that significantly alter public decision-makers' capacity to manage extreme events. These events are increasingly viewed not as unpredictable occurrences but as subjects of study and monitoring for forecasting and prevention. Consequently, scientific and technical advancements require the legal system to assume responsibility for forecasting and prevention, deploying resources to mitigate potential negative consequences. While the system's foundation is necessarily technical, this knowledge base is activated and utilized by the legal system through legally enacted instruments. Thus, the integration of technology and law is paramount and, as will be seen, potentially challenges traditional legal categories.

Moreover, the issue of early warning systems – although certainly not widely discussed by legal scholars, at least compared to other topics within environmental law and particularly its specific branch concerning the regulation and management of natural disasters – is not new to the legal world, which has addressed it both at the international level (Samuel, Cornforth 2019) as well as at the supranational and national levels. The reason for this interest by institutions and legal scholars, who structure their functioning, is clearly rooted in the awareness, well-established within the international community, of the link between the practical effectiveness of early warning tools, now very advanced and reliable from a technological standpoint, and the "legal" framework within which they are placed.

The so-called definitional issue concerning early warning systems represents a useful perspective from which to address the evolution of this concept at the European and national levels. From this standpoint, the (admittedly limited, at least at the national level) doctrine that, some time ago, addressed these topics defined early warning systems, in broad terms, as «a method that allows for anticipatory actions, a common-sense rule that prompts countermeasures if danger is presumed» (Lieto 2007), whose legal framework «can only be related to the general regulatory framework provided by each State, particularly with regard to the civil protection service» (Lieto 2007).

The issue is that, at the time when this study was conducted, there was no formal legal definition of early warning, nor was there any specific regulation outlined, forcing interpreters into a certainly exhausting hermeneutical operation (Kelman, Glantz 2014).

Indeed, at the Italian level, law n. 225/1992, which established the National Civil Protection Service, made no reference to early warning systems. It merely identified, in Article 3, the activities and tasks of the newly established service, which included «those aimed at forecasting and preventing various risk scenarios, assisting affected populations, and any other necessary and urgent activity aimed at overcoming the emergency».

At the supranational level, instead, Decision 2001/792/EC had already established the Community mechanism to facilitate cooperation between the European Community and Member States in civil protection rescue operations, limiting, with regard to the issue of alerts, itself to stating that, for achieving the goals outlined in the Decision, the Commission «promotes and encourages the introduction and use, within the context of the mechanism, of new technologies, including notification and alert systems, information exchange, the use of satellite technology, and decision-making support in emergency management».

The aforementioned act was later supplemented by Decision 2007/779/EC, which – reaffirming that «prevention plays a key role in protecting against natural, technological, and environmental disasters, and in this context, further actions should be considered» – made the reference to the alert tool more frequent and relevant.

Article 2 of the Decision, for instance, includes the development of rapid detection and alert systems for disasters that may affect Member States' territories as part of the actions within the "mechanism", in order to enable rapid responses by Member States and the Community.

Furthermore, article 3 introduces an embryonic definition of "early warning", understood as «the timely and effective provision of information that enables action to avoid or reduce risks and to prepare an effective response».

However, it is only with Decision 1313/2013/EU – adopted, as expected, following the Lisbon Treaty, which entered into force on December 1, 2009, and which provided a new and solid legal foundation for the European Union's humanitarian aid and civil protection policies – that the EU's civil protection mechanism was effectively established to strengthen cooperation between the Union and Member States and to facilitate coordination in the civil protection sector.

In this context, primarily characterized by a clearer distinction between preparation actions and prevention actions, the Emergency Response Coordination Centre (ERCC) is established, ensuring operational capability 24 h a day, seven days a week. A series of preparation actions under the responsibility of the Commission are introduced, including the «development and better integration of transnational detection, rapid alert, and alarm systems of European interest to enable a rapid response, as well as to promote the interconnection between national rapid alert and alarm systems».

It is interesting to note how, for the first time, the distinction between alert and alarm emerges more clearly here. In a certain sense, they represent two coexisting, complementary but not identical dimensions of the system generically defined as early warning.

The EU civil protection mechanism has been further integrated and strengthened, most recently through Decision 2019/420/EU, which, among other things, established the European Civil Protection Pool and the action tool known as rescEU, and finally, with the adoption of Regulation 2021/836/EU. This regulation, in the wake of the tragic experience related to the COVID-19 pandemic, emphasized the importance of strengthening collaboration and solidarity among States to ensure the fastest and most effective response to modern risks, especially those arising from the current and future impacts of climate change.

Specifically, with regard to the theme of alert and alarm tools, the aforementioned 2019 Decision amended Article 5, paragraph 1, letter i), dedicated to prevention actions, establishing, as an addition to the previous formulation, that the Commission «supports the efforts of the Member States to inform the public about alert systems by providing guidance on such systems, including at the transboundary level».

This is a significant aspect, as it demonstrates greater awareness of the relationship between risk communication, understood as education and raising public awareness – which is part of prevention measures – and risk communication in the management of imminent or ongoing hazards, which occurs through alert and alarm tools, more properly falling under preparation actions. Regarding the latter aspect, however, no notable novelties are observed.

Regulation 2021/836/EU, for its part, confirms the above and, in article 8, dedicated to preparation measures, makes extensive reference to the importance of alert systems. It reiterates that the Commission collaborates with Member States «to develop transnational rapid detection and alert systems of interest to the Union in order to mitigate the immediate effects of disasters; to better integrate existing transnational rapid detection and alert systems based on a multi-risk approach, to reduce the time needed to react to disasters; […] to establish, maintain, and develop European scientific partnerships in the field of natural or anthropogenic risks, which in turn should promote the connection between national rapid alert and alarm systems and their connection with the ERCC and CECIS; to assist, with scientific knowledge, innovative technologies, and expertise, the efforts of Member States and authorized international organizations when Member States and such organizations further strengthen their rapid alert systems, including through the Union's civil protection knowledge network».

Turning to the Italian context, the revision of the civil protection service legislation required waiting for the new Civil Protection Code of 2018, which dedicates a specific article (article 17) to the issue of alerting, where it is stated that «the alerting of the National Civil Protection Service is structured in a national and regional system consisting of the tools, methods, and procedures established to develop and acquire knowledge, information, and real-time assessments, where possible, concerning probabilistic forecasting, monitoring, and real-time surveillance of events and the subsequent evolution of risk scenarios to activate the National Civil Protection Service at various territorial levels».

According to paragraph 2-bis of the aforementioned provision, «alerting by the National Civil Protection Service also occurs by utilizing the public alarm system», reiterating the distinction already referenced and, in effect, assigning the public alarm system an integrative and complementary role to the alerting system.

Finally, as established by paragraph 3 of the provision, the organization and implementation of the alerting activity, including those referred to in paragraph 2-bis, are regulated by a directive from the President of the Council of Ministers, in order to ensure a coordinated framework throughout the national territory and specifically «a) standardizing, on a national basis, the terminology and conventional codes used to manage the various stages of activation and the response of the National Service; b) regulating aspects related to risk communication, including the drafting of civil protection plans referred to in Article 18, and informing the population about the measures contained therein; c) defining organizational models that ensure the necessary continuity in carrying out the different phases of activity».

Today, early warning has a more robust legal basis at both European and national levels, underscoring its key features: its connection to climate change adaptation policies, its reliance on ICT-based information systems and monitoring by competent authorities, its preventive or, more accurately, precautionary nature requiring early action in risk scenarios, the central role of communication (both preventive and preparatory, in European terms), and the complementarity of alerting and public alarm systems.

6 Concluding Remarks: The Precautionary Principle and the So-Called "Organizing Function" of Public Administration

In conclusion to the reflections that have been developed, it seems interesting to add a further and conclusive consideration.

Typically, in the context of the discussions concerning risk administration and the precautionary principle, the organizational aspect is not particularly valued, often being entirely absent. The attention, normally, is instead entirely concentrated on administrative action, discretion, and it's possible judicial review; in other words, the discussion concerning risk administration and the related precautionary principle would seem to be dominated by the functional aspect, rather than the organizational one.

The tendential recessiveness of the organizational element compared to the functional one should not be understood as a lesser importance of the former compared to the latter, but as the dependence of administrative organization on the needs of managing the individual risk, its scope and its extension. The doctrine, in fact, also believed that «the question of whether the organization in the risk society favors a centralized or decentralized type of administration appears, therefore, poorly posed: organizational models must be designed from time to time in relation to the needs that must be satisfied, in any case rejecting the logic of a Cartesianly (and abstractly) ordered system» (De Leonardis 2018).

From this point of view, one can only continue, even today, to agree with the aforementioned reflections and, in particular, with the existence of a relationship of dependence between the needs of risk management and the organizational structure responsible for carrying out this function.

Similarly, one can only agree with the statement that, by reason of what has been exposed, «the cardinal principle of the organization of the risk society thus becomes that principle of adequacy which, although in force in administrative action, is increasingly often recalled at the level of ordinary legislation […] and which postulates the necessary interaction between the models used and the underlying factual reality» (De Leonardis 2018).

However, in light of the evolutionary path that has been described, it is now possible to identify a substantial difference: if, in the past, the organizational and active function levels were connected, in the sense of a relationship of dependence of the former on the latter, but still well separated; today, instead, there is a progressive convergence of the two levels, in a path of their gradual tangency. In other words, today, it seems increasingly difficult to distinguish the organizational moment of risk administration from that of its active management.

What has been stated, in all probability, depends essentially on that process of retrogression and exhaustion of administrative discretion that sees in precaution itself a criterion for programming and planning risk management, as well as a principle increasingly dependent on the technical tools available to the administration.

In other words – while, in the past, the total centrality of the contingent decision-making moment and the related, broad, administrative discretion contributed to keeping the two levels clearly separated – today the eminently technical characterization (with increasing relevance of informational aspects and their constant updating) and the relocation in the planning phase (with consequent predetermination of the different degrees of intervention depending on the variation of the risk situation, detected by technical tools) of the modern risk management function, broadly understood, mean that the active and “organizing” functions often coincide or, at least, interpenetrate.

Consequently, one could say, the precautionary principle, which governs risk administration, is evolving from a principle that shapes the administrative action of risk management to a principle that shapes the organizing function of risk, moving from the sole dimension of “time” to also extend to the “spatial” one (Cafagno 2007), that is, that of “who” (of competences and attributions) and “through what” (of tools).

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Managing the Circular Transition in Cities. The Case of Genoa and the Food Supply Chain

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Abstract. This paper explores the transition of cities toward circular economy models introducing the case study of Genoa, Italy. The research explains the C-City strategic framework, designed to guide urban systems from a linear to a circular paradigm by integrating four pillars: Processes, Actors, Supply Chains, and Territory. The framework emphasizes the transformation of cities, embedding circularity across all stages of the value chain, moving beyond the most common milestone of waste management. To validate the applicability of the framework, the research implemented the model starting from the food supply chain, a sector with significant environmental and socio-economic impact. The study outlines a process-based approach—Design, Long Use, and Reuse—combined with stakeholder engagement and multi-scale governance. Findings highlight the importance of participatory strategies, adaptive planning, and cross-sectoral synergies for effective circular transition. The Genoa case demonstrates that cities can serve as experimental platforms for circular innovation, despite challenges related to governance tools and economic sustainability. The research contributes a scalable and adaptable model for other urban contexts, fostering resilience and inclusivity in long-term sustainability agendas.

Keywords: Circular economy· Circularity · City · Food · Supply chain · Sustainability

1 Introduction

In recent decades, the sustainability of cities and regions has become a strategic priority, underpinning the long-term city development and the resilience of urban communities [1–3]. The concept of circular city and the city transition to the circular economy are considered as effective approaches for integrating urban development goals with environmental improvement [4]. Within the European policy context, the shift towards the circular model is a central aspect of urban and regional agendas, promoting systemic sustainability, cohesion, and equity [5].

This economic transition takes place within a multilevel governance structure that includes both national and regional entities, positioning cities as key agents of transformative change [6]. As the smallest administrative territorial entities, cities are well-placed to test the effectiveness of economic transformation and assess its short and medium-term social and environmental impacts.

R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, pp. 171–186, 2026.
https://doi.org/10.1007/978-3-032-21842-1_12

The traditional urban economic model, characterized by intensive consumption of primary resources and resulting in significant waste generation and environmental pollution, is no longer viable. Cities must adopt more sustainable resource management practices that integrate economic efficiency with social and environmental resilience [7–9]. The limitations of the linear economic model, driven by consumerism and exacerbated by population growth and urban expansion, have catalysed the emergence of the circular economy as a viable alternative.

However, no consolidated frameworks have been developed until now to guide cities in adopting a circular economy agenda and the conceptualisation for circular city is also inadequate to support urban transformation toward a circular approach [10]. Mapping circular cities, reveals that a circular city strategy is a complex mix of socio-economic factors, nature-based approaches, and technical solutions, involving multiple stakeholders [11]. It requires both standard frameworks to be implemented and a tailored adaptation to each city.

The present paper uses the case study methodology to analyse how to develop an urban agenda for shifting towards a circular city and then generalise some best practices to be further applied to other cities. The case study regards the city of Genoa, in Italy, a medium-size city adopting a sustainable urban development approach aiming at being carbon-neutral in 2050. The circular economy is one of the pillars of this transition. The paper designs a circular city strategic framework and demonstrate how to put it in place in the food supply chain. The discussion and conclusions of the research provide a foundation for adopting the strategic framework also in other cities and supply chains.

The paper continues as follows: Sect. 2 analyses the essential scientific literature and the background of the topic; Sect. 3 introduces the case study; Sect. 4 describes the C-City framework and Sect. 5 defines its implementation to the Food supply chain; Sect. 7 presents the study's conclusions, discusses its limitations, and outlines directions for future works.

2 Literature and Background

In academic literature, the concept of the circular city is closely linked to urban sustainability, as it promotes a regenerative model of production and consumption [1]. Prendeville et al. [8] define the circular city as follows: "A city that practices circular economy principles to close resource loops, in partnership with the city's stakeholders (citizens, community, business and knowledge stakeholders), to realize its vision of a future-proof city". This vision is realised through strategies such as narrowing resource loops, extending product lifespans, closing material cycles through reuse, and regenerating resources via renewable inputs [5, 9]. These approaches aim to reduce the ecological footprint, improve resource security, and mitigate greenhouse gas emissions, while ensuring that circular processes remain economically sustainable for all stakeholders involved [8, 12]. The role of stakeholders is crucial and fundamental for the success of the strategy.

Many international organizations and foundations underscore the imperative to reduce resource consumption, minimize waste, and regenerate natural systems. To this scope, they have developed guidelines and frameworks to support the implementation of such strategies.

The Ellen MacArthur Foundation's model is widely acknowledged as a global resource for advancing the circular economy in urban and regional contexts [9, 13]. Structured around the dynamic interplay between production, use, and consumption, the model is visually represented with the "butterfly diagram," in which the two "wings" delineates the distinct circular pathways of biological and technical cycles. The framework is grounded in three core principles: eliminating waste and pollution across all stages of the value chain; maintaining the utility of products and materials for as long as possible through strategies such as reuse, repair, and remanufacturing; and regenerating natural systems to enhance resilience of ecosystems. This framework is not only conservative in its aim to reduce negative impacts, but it is also restorative, actively fostering the regeneration of both environmental and economic systems.

The OECD has launched a dedicated programme to support the development and implementation of circular economy policies at local level, focusing on cities and regions [10]. This initiative operates on dual analytical and operational tracks. Firstly, it provides a framework to assess local conditions and identify the most appropriate policy tools and governance mechanisms to facilitate the transition to a circular economy in urban and regional contexts. Secondly, it involves systematically analysing specific experiences from cities and regions that have already implemented, or are in the process of implementing, circular economy strategies. These case studies serve to identify challenges, highlight best practices, and inform the development of scalable, adaptable policy frameworks [14].

The city of Amsterdam is one of the best champions in the adoption and implementation of circular economy frameworks and practices [15]. In recent years, the city has developed a circular economy strategy based on Kate Raworth's Doughnut economy model [16, 17]. This framework conceptualises a good space for human growth, defined by two critical boundaries. The first is the ecological ceiling, representing the environmental limits that must not be exceeded to avoid irreversible planetary degradation. The second is the social foundation, outlining the minimum standards necessary to ensure human well-being. Within this 'doughnut-shaped' space, bounded above by environmental thresholds and below by social needs, a city can design a circular economy strategy that promotes economic prosperity while safeguarding ecological integrity and social equity [18]. By adopting this model, Amsterdam demonstrates its commitment to systemic transformation, aligning urban development with planetary boundaries and inclusive growth.

From the analysis of the state of the art, it emerges that both scientific literature and operational reports provide frameworks that allows for the definition of circular strategies for urban areas. However, globally, few cities have systematically and effectively undertaken a transition path towards circular economy [19]. For this reason, the case of Genoa represents a national and international best practice that deserves to be studied to identify the critical success factors for the transition towards the circular city and define models that can be easily applied to other cities.

3 Case Study: Genoa (Italy)

Genoa, a medium-sized city in northern Italy, has placed economic, social, and environmental well-being at the core of its development agenda for the medium and long terms. With the ambition of becoming a carbon-neutral city by 2050, Genoa envisions clean, liveable neighbourhoods, equipped with inclusive services tailored to societal needs. The municipality of Genoa undertakes an urban transformation process to embed the circular economy principles into its long-term smart and resilience development strategy, fostering sustainability and improving quality of life for the citizens [20]. In pursuit of these goals, the Municipality of Genoa has adopted the "Genoa Lighthouse City" initiative, that is a strategic framework structured around three core domains: the environment, the infrastructures, and the citizens wellbeing. As a part of this broader vision, the Municipality has developed the Genoa 2050 Action Plan, a roadmap that outlines the key transformations required to enhance urban sustainability across economic, social, and environmental dimensions.

Within the Lighthouse framework, one of the flagship initiatives to support the development of Genoa is the C-City project, conceived as a strategic tool for the transition of the city from a linear to a circular economic model [21]. The project aims to design the pathways for implementing a Circular Economy Strategy with a long-term horizon extending to 2050. Launched in 2022 under the PON Metropolitan Cities 2014–2020 funding programme, the initiative was carried out through a multi-stakeholder partnership including: the Municipality of Genoa; the University of Genoa (Department of Economics – DIEC); AMIU, the municipally owned waste management company; and the Job Centre Srl, a municipally-owned company supporting public policy and services for employment, development, and sustainability.

A key component of the strategic framework is its effort to move beyond the narrow interpretation of circularity as waste management. On the contrary, it promotes a systemic approach that includes all stages of the value chain: from initial design to production, to long-term use and, only ultimately, to reuse, regeneration and recycling [22]. This holistic perspective is considered fundamental to the development of a resilient and effective Circular City Strategy.

The University of Genoa plays a central role in the C-City project by formulating the strategic framework guiding the city's transition to a circular economy [23]. This framework articulates Genoa's ambition to move beyond the conventional take-make-dispose economic model, promoting an adaptive and regenerative system grounded in circular economy principles. Given the thirty-year horizon of the strategy, it does not prescribe a detailed set of future actions. Rather, it establishes a set of guiding parameters, including strategic boundaries, long-term objectives, and a shared vision. Moreover, the framework is designed to consolidate and to align fragmented initiatives with circular objectives into a coherent, adaptive, and continually evolving strategy for the city's overall circular development.

The transition of Genoa towards a circular city requires a long-term strategic vision. Rather than adopting a fixed masterplan, the University of Genoa has developed a dynamic and adaptive strategic framework designed for implementation over a 25-year horizon. Given the extended timeframe, it is neither feasible nor appropriate to define all actions in advance. Instead, actions will be progressively designed in response to emerging priorities, resource availability, and evolving technological, economic, and social conditions. To ensure its strategic coherence, the framework is not conceived as a collection of isolated initiatives. It is designed as a system in which actions and policies are interconnected and mutually reinforcing. The objective is to define a unified vision that integrates diverse efforts into a cohesive and synergistic transition pathway.

This vision is operationalised through the C-City Strategic Framework, which provides the structural foundation for aligning policies, initiatives, and investments with Genoa's circular economy objectives. It defines strategic boundaries, sets long-term goals, and establishes criteria for the design of consistent and impactful actions.

4 A Strategic Framework for Urban Circular Transition

The strategic framework called C-City has been conceived as an effective tool with four independent but interconnected pillars — Processes, Actors, Supply chains, and Territory — envisioned as the interlocking 'gears' of a mechanism. These pillars operate as coordinated components of a complex system. While each pillar operates independently, their effectiveness relies on synchronized interaction, ensuring that strategies and actions are coherent and effective in the short, medium, and long-term terms.

Figure 1 represents the pillars of the strategic framework. In the outer circle, there are the Processes, which represent the phases of the value chain, including product and solutions **design**, **long use** of artefacts, and **reuse**. The internal circle represents the Actors of the circular city: the municipality, companies, non-profit organisations, and citizens. Some arrows recall the two further pillars: Supply chains and Territory (Fig. 1). All these pillars are defined in detail in the following sub-sections.

Fig. 1. The graphic representation of the C-City strategic framework (source: the Authors)

4.1 Processes

The first pillar addresses the city's transition from a traditional linear economy, defined by the "take-make-dispose" paradigm, towards a circular economy model. This shift involves a comprehensive reconfiguration of production and consumption systems, including the redesign of processes, the extension of product lifespans through repair, refurbishment, and sharing practices, and the promotion of resource recovery, reuse, and recycling [24].

To operationalize the processes redesign, the C-City framework draws on the widely acknowledged "9Rs" model in circular economy literature, which presents a hierarchy of strategies, from higher-level actions such as refusing unnecessary goods and rethinking consumption habits, to more basic approaches like recycling and recovery [25]. These strategies aim to preserve primary resources and extend the useful life of products. To improve strategy clarity and support effective implementation at the urban scale, the framework summarizes the nine principles of the 9Rs model into three integrated and actionable phases: Design, Long Use, and Reuse. This synthesis creates a regenerative loop that can not only maximize resource efficiency but also embed circularity into the entire life cycle of products and services, thus laying the foundation for a circular urban transformation.

4.2 Actors

The transition to a circular economy is inherently collaborative, requiring the active engagement of a broad spectrum of actors [12]. The second pillar of C-City encompasses all actors involved in shaping design, production, distribution, and consumption patterns, ranging from producers and service providers to end-users. In the city circular transition process, citizens play a pivotal role: without their active engagement, no circularity strategy can be truly effective. While consumer awareness and behavioural change are essential components, systemic transformation also needs the adoption of circular business models by producers. These efforts must be supported by local governments and the non-profit sector, especially those that facilitate reuse, distribution, repair, and recycling initiatives. The coordinated engagement of these actors is crucial for fostering a resilient and inclusive circular economy at the urban level [8].

4.3 Supply Chains

Although the overarching objective of circular economy strategies is to enable the comprehensive transition of urban systems toward a regenerative economic model, the strategic framework must be implemented for each economic sector and supply chain. However, due to the inherent diversity of supply chains, it is not feasible to manage the transition to circularity in all production sectors at the same time [7].

It is therefore essential that each city identify the priority value chains from which to initiate the transition, typically those exerting the greatest environmental impact on the urban system and whose operational dynamics are most embedded to the local context. To begin implementing the C-City model, Genoa assessed the most significant supply chains, taking into account factors such as environmental impact, specific importance for the city, and future development opportunities.

The result is represented in Fig. 2. Some supply chains were selected, distinguishing three different categories: priority supply chains, i.e., those with the greatest environmental impact (food and construction sector); intersectoral supply chains, important because they permeate all other economic sectors (energy and mobility); and identity supply chains, which specifically characterize the city of Genoa (blue economy, tourism, and textile).

Each value chain demands tailored interventions to enable circular practices, with special consideration given to sectors like energy and transport, which are highly dependent on local infrastructure and environmental conditions [26].

Fig. 2. The supply chains selected for the city of Genoa (source: the Authors)

4.4 Territory

The city's territorial dimension encompasses both its physical morphology and the administrative organization of the urban system. Like most urban contexts, Genoa is not conceived as a homogeneous entity but rather as a heterogeneous assemblage of interconnected, yet not interdependent, districts and neighbourhoods, each characterized by distinct spatial configurations, socio-economic profiles, and development opportunities [27].

In recognition of this internal diversity, the framework adopts a multi-scale approach that integrates overarching interventions, implemented at the municipal or metropolitan level, with local actions, specifically adapted to the distinctive characteristics of neighbourhoods. This layered governance model facilitates the emergence of circular ecosystems at the microscale, enabling context-sensitive strategies that respond to the complex and diverse nature of urban systems.

5 The Food Supply Chain

The transition from the strategic framework to the implementation of the action plan for Genoa circular transition required a critical examination on the role of the four foundational pillars. The central research question underpinning this process was: Which pillar provides the most effective entry point for implementing circular economy principles in the urban context?

To address this question, the research combined a critical review of the scientific literature with a structured dialogue involving key stakeholders, particularly representatives of the local public administration [23]. This participatory process highlighted the pivotal role of value chains in operationalizing the circular economy model. A value chain can be defined as the sequence of interconnected stages involved in the creation and delivery of a coherent system of products or services— ranging from design and raw material sourcing, to production, distribution, use, and consumption of goods and services. Each stage may engage different actors (e.g., producers, service providers, consumers) and requires distinct activities and processes. By focusing policies and actions on a specific value chain, it becomes possible to apply circular economy principles to a clearly defined set of stakeholders and activities. This targeted approach enables more effective process, by concentrating efforts in the districts where the selected value chain is most active.

The research identified the most relevant value chains for initiating a circular transition in Genoa. As illustrated in Fig. 2, the food system and the construction sector emerged as the most critical chains, due to their significant environmental and economic impact, an observation consistent with trends in many European cities pursuing circular economy strategies. In addition, Genoa has identified three identity-based value chains—blue economy, tourism, and the textile sector—and two intersectoral chains: energy and mobility.

Drawing on these findings, and in cooperation with the Municipal Department for Economic Development, two strategic sectors were selected for initial implementation. The first is the food system, which is widely acknowledged as one of the most impactful domains in urban circular economy transitions in urban circular transitions [18]. The second is the textile sector, which is emerging as a potential new economic identity for the city.

5.1 The Food System in Genoa

After identifying Genoa's priority value chains, the research selected the food system as the first case study to test the strategic framework. The study then focuses on analysing the urban food supply chain in detail, with the goal of identifying its main critical points within the city [28]. These findings help guide the development of a strategy for transitioning Genoa's food environment toward a circular economy model. The food system is presented as a case study that can be scaled and replicated in other urban contexts. The food value chain was identified as a priority through close collaboration with technical experts from the local public administration, who also established a dedicated working group to address the specific challenges of Genoa's food system.

This choice was driven by the recognition of the food system's significant environmental and socio-economic impact, and by the observation that, in cities—and particularly in Genoa—food is rarely produced, widely consumed, and often wasted in large quantities.

To address these challenges, the research designs a circular transition strategy specifically tailored to the food sector. The goal is to demonstrate how the integration of eco-design, long-use, and reuse practices at key points in the food supply chain can improve the efficiency and sustainability of the urban food environment in the short, medium, and long term. In this context the city is conceptualized as the ideal setting for rethinking the food value chain from a process-oriented perspective, with a focus on three main components:

- Circular food design: the redesign of food products and production processes by companies aiming to adopt circular practices;
- Circular food long use: strategies to extend the shelf life of agri-food products by reducing logistical steps and improving preservation methods;
- Circular food reuse: the redistribution of edible food surpluses and the recovery of organic waste for new uses.

This process-based reconfiguration shifts the city's role from a site of food consumption and waste generation to a strategic platform for the application of circular economy principles within the agri-food system.

5.2 Mapping the Food Value Chain Nodes

The analysis of Genoa's food value chain supports the transition from the C-City strategic framework to the implementation of a circular food system addressed to the city. The primary objectives are to reduce the volume of food resources required to meet urban needs, optimize processes at critical points within the chain, and minimize food losses and waste. Figure 3 illustrates the four primary nodes of the food supply chain: production or procurement, processing, distribution, and consumption. Each node represents both an opportunity to enhance the food environment and a challenge for the city's sustainable development.

The first step is related to food production and procurement. Primary food production within the city is minimal and largely dependent on external sources: local, national, and international. As a result, local authorities have limited direct influence over this node. However, they can shape outcomes by adopting sustainable procurement criteria and supporting the few existing local producers. A key strategic goal is to reduce the overall volume of food entering the city.

The second step of the strategy is related to the food processing and distribution. This node includes both the food processing phases and the distribution to households and collective services (e.g., schools, hospitals). This node is central to the city's circular food strategy, which is guided by three pillars: Design, Long-Use, and Re-Use. These principles aim to reduce food input, as well as food loss and waste by promoting best practices in preservation, logistics, and the redirection of both edible and inedible food waste, with inclusive and equity purposes.

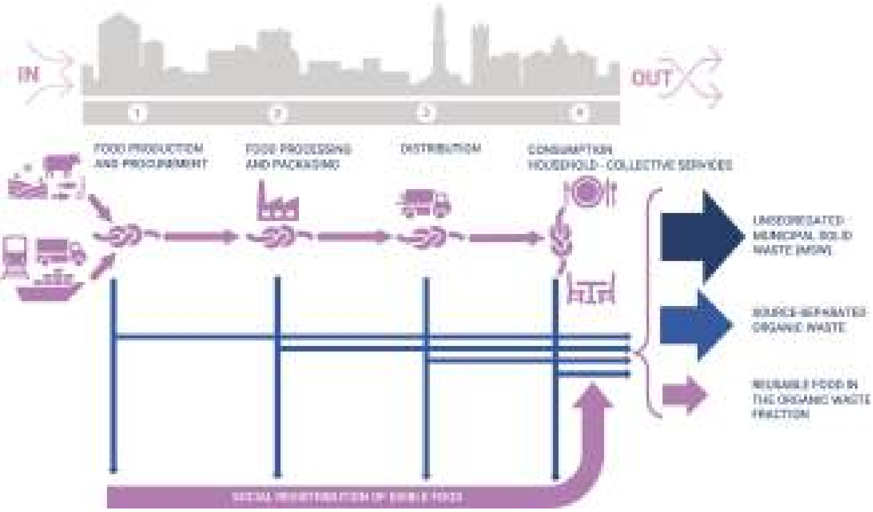

Fig. 3. The main nodes of the food value chain for the city of Genoa (source: the Authors)

The third step of the strategy is related to the food consumption, in the two main sectors of households and collective services (mainly Institutional food services, Canteens, Restaurants, Food delivery services). This stage is critical for influencing demand, reducing waste at the point of use, and encouraging responsible consumption behaviours.

The fourth and final step focuses on the recovery and redistribution of edible food, as well as treatment of food waste. In this context, non-profit organizations emerge as key stakeholders. Their mission may be the recovery of uneaten but perfectly edible food, intervening before spoilage occurs, and the redistribution with the aim of reducing waste and enhancing social equity.

5.3 The Circular Food Strategy

To guide the transition of the urban food environment from a linear to a circular economy, it is essential to adapt the C-City strategic framework specifically to the agri-food sector. This requires a clear articulation of three independent but interconnected core pillars—Processes, Actors, and Territories—emphasizing their contributions from the perspective of the Supply chain (fourth pillar) perspective. The model should aim to proportionally reduce the inflow of food resources by promoting more efficient and rational use, minimizing losses and waste, and generating new value from food residues.

Rather than replacing existing planning tools, the strategy is conceived as a toolkit for gradually integrating circular objectives into current municipal policies and regulatory tools. It aims to embed circular models within the governance structures that already shape both public and private sectors of the city. The effectiveness of this strategy may depend on several key factors. Foremost is the sustained commitment of the local governance, which must make informed political decisions to foster circularity across the food supply chain. The process may begin with the internal adoption of circular principles within the local public administration: the municipality itself, acting both as an institution and as a public enterprise. The process may progress through structured dialogue with the business world —particularly municipally owned companies—by identifying their operational needs and supporting their transition toward circular practices. Equally important is the active engagement of citizens, whose informed participation is critical to transforming everyday behaviours in alignment with circular economy principles. The strategy also acknowledges the pivotal role of third-sector organizations and educational institutions, particularly schools and universities, whose involvement can enhance inclusivity and contribute to closing the loop of the circular system, ultimately contributing to the reduction of food waste and loss.

In this way, the Food strategy works as a catalyst for systemic change, aligning diverse actors and institutional mechanisms around shared circular goals. Its principal strength lies in its adaptability: rather than imposing a rigid structure, it supports the evolution of existing governance tools by incorporating circular principles into their operational logic. This integrative approach ensures that circularity becomes embedded in the everyday functioning of the city, fostering long-term resilience and sustainability across the food system.

5.4 The Circular Food Action Plan

The implementation of the Circular food strategy, conceived for the medium to long term, is articulated through the development of an Action Plan: a coordinated system of policies, interventions, and initiatives designed to operate synergistically toward the intended objectives, with the potential to start in the short term. While defining the Action Plan lies beyond the scope of this study, as it must be developed by the municipal administration in collaboration with relevant stakeholders, this research identifies a set of enabling actions that could be useful to initiating the transition. These actions, which are both cross-cutting and replicable, provide a kind of guidelines for outlining a preliminary roadmap for the circular transition in the food sector.

Again, the Action plan for the transition of the Food Supply chain, is structured around the strategic pillars previously identified—Processes, Actors, and Territories—and aims to support the implementation phase by offering an operational toolkit. The Action Plan should be understood as a flexible framework, subject to refinement and validation through participatory processes. Its purpose is to translate the strategic objectives into specific targets, actionable measures, and pilot projects, to be pursued across the short, medium, and long-term horizons. These actions may be deployed at the most critical and strategically significant nodes of the food value chain.

A key step is the establishment of a coordination entity, i.e. Municipality, with the scope of activating the plan. It must ensure balanced representation of all stakeholders—public and private actors, non-profit organizations, and citizens—across the various stages of the food system, from production and processing to distribution and consumption. It also serves as a platform for fostering synergies with other sectors and supply chains, for instance the sustainable packaging, the logistics, or the tourism.

The proposed actions may be aligned with the three foundational processes of the circular economy: Design, Long Use, and Reuse. For each action, the relevant actors (e.g., municipal authorities, businesses, civil society, and citizens) and the appropriate territorial scale (metropolitan, municipal, district, or neighbourhoods) have been identified. Particular emphasis is placed on local implementation, acknowledging that circular initiatives often achieve their greatest efficacy at smaller, community-based scales. Each strategic goal is associated with a set of temporal milestones and corresponding actions. A dedicated section outlines potential qualitative and quantitative indicators to be used in a monitoring framework, enabling the coordination body to track progress and assess outcomes over time. These indicators are further aligned with international guidelines on regenerative agriculture and circular food design, the Sustainable Development Goals for circular food systems, and relevant certification and measurement standards, such as UNI/TS 11820:2022.

6 Discussion

The pivotal role of the authors of the present paper in designing and implementing the circular economy strategic framework in Genoa are critical factors to discuss the results of the present paper, as their direct involvement permitted to observe the best practices, the strengths, and weaknesses of the solution and to figure threats and opportunities for the future successful implementation of the circular transition [22].

The case study first offered a comparison between the conceptual aspects and the concrete implementation of the circular economy in cities. One of the most important findings is that circular economy is a label that focuses on the environmental transition, but deeply neglects the economic aspects [1, 2, 4]. A viable solution must demonstrate long term sustainability, both environmentally and economically, otherwise it risks remaining a theoretical exercise with limited tangible impact. For this reason, it is essential to both involve companies and use economic levers to push the economic system toward enhanced circularity. Indeed, the C-City framework assigns a great importance to companies in participating to the circular city design. However, their involvement alone is not enough to ensure economic sustainability to the circular processes.

Implementation of the C-City framework also shows that cities represent an attractive platform for implementing the circular transition, as their size is suitable for the direct involvement of all stakeholders [3, 6]. However, local public administrations lack certain policy tools to effectively implement this transition, as it emerged during the definition of the C-City framework [19]. The absence of frameworks and standards for designing the urban circular transition agenda is exacerbated by the lack of fiscal and legal tools, available at the national level but not ever suitable to the urban context.

Despite these weaknesses, cities remain the best place to experiment with circular economy solutions given the opportunity to adopt a participatory approach that actively involves all stakeholders and use methodologies such as living labs to test innovative circular ideas and solutions [27]. The C-City framework (Fig. 1) explicitly includes all the actors, recognising their pivotal role in driving the transition and in implementing effective circular actions.

Some aspects are both a strength and a weakness, depending on how there are addressed. Generally, cities are responsible for waste management, and this could emphasize the final stage of the product life cycle, namely on recycle. However, more effective results can be achieved by intervening in the early stages of the life cycle, namely the circular design of products and services [29]. However, having the Municipal Waste Management Company as partner of the project is a way to better understand how to prevent waste, just by redesigning the supply chain.

These aspects are also important for implementing the framework and applying it to a specific supply chain, such as the food supply chain. The implementation of the circular strategy in the food supply chain in Genoa allowed the researchers to test the framework and its effectiveness, and to understand how to approach its implementation.

With regard to the food system—and more broadly— urban areas typically shows low levels of production and high levels of consumption [28]. This means that local circular policies can focus on the final stages of the life cycle, such as distribution, consumption, and recycling [27]. However, because the amount of food consumed in cities is so high, changing the distribution system or consumer behaviours impacts the entire supply chain, right up to production and packaging. This impact can also be assessed by considering costs along the entire supply chain, comparing the old make-take-waste system with the circular one, including taxation and regulations implemented by local policies. In particular, waste taxation—an instrument of municipal policy—can influence costs across the food supply chain, encouraging producers to adopt more efficient production practices, and incentivising citizens to engage in more sustainable consumption behaviours [29].

Finally, one interesting aspect that emerges from the case study is the role played by innovative start-ups and non-profit organisations in circular food supply chains [18]. Innovative start-ups design new business model that embed circularity, thus natively overcoming the problem of economic sustainability. Non-profit organisations manage the recycling of wasted food, delivering it to individuals in needs, mitigating the problem of food insecurity among disadvantaged citizens and simultaneously reducing waste [30].

A key limitation emerging from these best practices is that both innovative start-ups and non-profit organisations are small and therefore they process only a small amount of the food flow, so their impact on circularity is very low. Nevertheless, these initiatives represent fundamental experiences that should be regarded as pilot projects to test solutions and pursue their greatest impact designing more efficient and effective business models.

7 Conclusions, Limitations, and Further Works

Circular economy is gaining interest as a way to achieve both environmental and economic sustainability. Circular cities are conceived as urban strategies and agendas aiming at implementing the circular economy at the urban level. Several cities, especially in Europe, have begun designing their own circular strategy, albeit lacking best practices, standards, and policy tools to effectively pursue their goals.

Given the heterogeneity of circular practices implemented so far in cities, it is not simple to find a codified process to manage the transition to circular economy, therefore, this research uses a case study to understand how to design a strategic framework for implementing the circular economy in cities, also addressing specific supply chains.

The Genoa case study, which analyses the C-City model and its application to the food supply chain, demonstrates how the topic is still immature and highly complex, as many dimensions interact: stakeholders pursue different objectives, and it is difficult to align the circularity of materials with economic sustainability. Each supply chain has its own specificities, and circular processes must be analysed and modified accordingly. Although cities represent a good platform for launching participatory and experimental best practices for the circular economy, local governments lack sufficient political power and tools to guide this transition. Furthermore, cities are primarily places of consumption, not production, and supply chains transcend city boundaries, undermining urban policies and actions.

Currently, the C-City model is still under development and requires further implementation for thorough validation. Furthermore, given its short term and limited scope of implementation, the C-City project has not yet been evaluated, and no useful data are yet available to assess the strategy's impact. However, a set of indicators has already been defined and is ready for use in the city of Genoa and can easily be extended to other cities.

Some limitations of the work are therefore already known to the authors and further research is already underway, although the long-term goals of the circular economy require time to obtain satisfactory data on the results obtained.

Acknowledgment. The authors have no competing interests to declare that are relevant to the content of this article.

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R. P. Dameri and M. Bruzzone (Eds.): SCIC 2025, LNISO 86, p. 187, 2026.
https://doi.org/10.1007/978-3-032-21842-1