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Urban Green Infrastructures as Tools for Urban Interconnection: The Case of San Bartolomeo District in Cagliari, Italy

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Abstract: Contemporary urban areas are often characterized by various forms of enclaves, isolated from their surrounding geographical context. Urban green infrastructures provide an opportunity to open these enclaves, establishing physical and functional connections with the broader city, while also contributing to climate change mitigation and adaptation. This study examines the district of San Bartolomeo in the Italian city of Cagliari as an example of an urban enclave, and employs a participatory planning process to design a project that transforms it into a hub open to the wider city community. The result is a neighborhood shaped by its community, where social, economic, and environmental needs are balanced, fostering constant interaction between residents and the city as a whole.

Keywords: urban enclave; smart city; urban green infrastructure; climate change; citizen science; urban planning

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1. Introduction

Since the second half of the twentieth century, the world has seen a remarkable transformation of urban structure, resulting in urban fragmentation characterized by the proliferation of various forms of urban enclaves. Even though enclaves have been present in cities and in urban settlements since early times, in the last few decades, a new pattern, called by scholars [1–3] "enclave urbanism", has emerged. The proliferation of fortified enclaves has created a new model of spatial segregation and transformed the quality of public life in many cities around the world. Fortified enclaves are privatized, enclosed, and monitored spaces set aside for residence, consumption, leisure, and work. The fear of violence is one of their main justifications. They appeal to those who are abandoning the traditional public sphere of the streets, such as the poor, the "marginal", and the homeless. In cities fragmented by fortified enclaves, it is difficult to maintain the principles of openness and free circulation that have been among the most significant organizing values of modern cities. Consequently, the character of public space and of citizens' participation in public life changes [4]. The condition of contemporary urban areas is often characterized by the presence of entire parts of the city being developed without establishing any connection with the relative geographical context. This phenomenon affects both public real estates, for civil and military use, and private properties, which establish different relationships, material and immaterial, direct and indirect, with the urban context and with local communities. For example, large public complexes, such as barracks and military sites or prisons, were conceived as spaces of exclusion rather than inclusion due to the nature of their original function. Similarly, health centers, schools, and old factories converted into places of culture or other compendia for civil use (sports centers,

cultural and recreational centers) sometimes generate an obstacle to urban permeability due to their fences. Moreover, the logic of the shopping centers which centralize urban functions creates specialized areas isolated from inhabited areas [5]. This trend, coupled with the climate change our planet is facing, is highlighting how adopting urban green solutions is the response most capable of connecting (opening) enclaves to the city while managing to act via a logic of mitigation and adaptation to climate change.

Urban green infrastructure (UGI) has become an essential strategy for addressing the growing challenges faced by cities, such as urbanization, climate change, and social inequities. The definition of green infrastructure we adopt is a "strategically planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings" [6]. In the urban context, this definition includes a diverse array of elements including urban trees, parks, blue and green open spaces, green walls, green roofs, and community gardens, provided they form part of an interconnected network and contribute to the delivery of multiple ecosystem services [7,8]. UGI offers multifaceted benefits that not only enhance environmental sustainability but also improve urban resilience, social equity, and human health. Early conceptualizations of UGI, such as Benedict and McMahon's influential framework, emphasized its role as an interconnected network of green spaces that supports biodiversity and ecological functions, positioning it as a vital element for urban planning [9]. UGI's value goes beyond environmental concerns, as it helps mitigate urban heat islands, manage stormwater, and improve air quality, thereby contributing to the overall resilience of cities to climate change [10]. The integration of UGI into urban planning frameworks is vital for addressing a broad range of urban challenges. Studies have highlighted UGI's capacity to regulate climate, enhance biodiversity, and improve the quality of life for urban residents through the provision of mental and physical health benefits, including stress reduction and opportunities for recreation [11–13]. Furthermore, UGI supports social cohesion and social justice by promoting access to nature in underserved communities, helping to address social disparities while fostering greater community well-being [12,14]. Tzoulas et al. recognized the potential of UGI to mitigate environmental issues, and argued for its integration into cities as a tool for promoting resilience to climate change [10]. In addition, Haase et al. emphasized that UGI is not just about green spaces, but involves a comprehensive approach whereby different green elements collaborate to enhance urban ecosystem services [15]. As cities continue to grow and face the pressures of climate change and urbanization, UGI is increasingly being recognized as a core component of urban sustainability strategies. Elmqvist et al. argued that UGI contributes to the sustainable development of cities by providing crucial ecosystem services, such as water purification, carbon sequestration, and climate regulation, which make urban environments more livable and resilient [16]. Similarly, Díaz et al. and McPhearson et al. have emphasized the importance of UGI in fostering social inclusion, environmental justice, and resilience to external pressures like economic instability and environmental degradation [17,18]. More recent studies, including those by Zhao et al. and Fiorillo et al., have underscored the role of UGI in improving urban biodiversity, managing urban heat islands, and contributing to the health and well-being of urban residents [19,20]. Moreover, UGI plays a crucial role in advancing global sustainability goals. Saito et al. pointed out that urban green spaces contribute to the United Nations Sustainable Development Goals (SDGs) by supporting carbon sequestration, biodiversity conservation, and promoting climate adaptation [21]. The positive impacts of UGI on human health, including improvements in air quality and opportunities for physical activity, have been systematically reviewed by Amin et al., who found significant mental and physical health benefits for urban populations [22]. As climate change intensifies, the need for policies supporting UGI implementation and maintenance becomes ever more critical. Tao et al. further emphasized the need for sustained efforts in integrating UGI into urban planning to tackle environmental challenges like air quality improvement, stormwater management, and heatwave mitigation [23].

In response to the accelerating pressures of urbanization, climate change, and social fragmentation, scientists and policymakers are increasingly calling for integrated solutions that operate "at the intersection of social, cultural, digital, and nature-based innovation" [24]. The effective provision and management of urban green infrastructure (UGI), including urban trees, parks, blue and green open spaces, green walls, and green roofs, has the potential to provide both direct benefits (e.g., ecological connectivity and habitat conservation) and a range of co-benefits to urban societies, thereby realizing the goals of the United Nations 2030 Agenda for Sustainable Development and the new Habitat III urban agenda [25]. Co-benefits include improving air and water quality, advancing technological solutions for stormwater management, fostering social cohesion, and enhancing human health and well-being [26,27].

Due to their multifunctionality and the possibility of being implemented at various scales (building, neighborhood, city, territory), the realization of green areas presents a win–win, economically beneficial, and socially desirable solution, thanks to the numerous ecosystem services they produce over their lifetime. These ecosystem services are the benefits that human society derives from the nature, functions, and life processes of natural systems, even in the increasingly anthropized contexts of our territory. For instance, environmental services such as thermo-regulation, the mitigation of the heat island phenomenon in urban centers, or the reduction in surface water runoff during the increasingly frequent "water bombs" are important benefits that contribute to the perceived quality of life, people's health, and adaptation to climate change. Moreover, the opportunity to move, exercise outdoors, and regenerate from city stress are other valuable benefits offered by the presence and enjoyment of green areas, which provide an essential—but still understudied—contribution to people's mental and physical health and well-being. This is confirmed by the fact that the presence of greenery is considered a determinant of health by the World Health Organization [28]. A recent international study involving six European countries demonstrated how the isolation period during the COVID-19 pandemic changed the value assigned to green spaces, which became essential and of fundamental importance as places of mental regeneration [29].

Other important ecosystem services provided by urban and peri-urban green systems include biodiversity protection, the capture of atmospheric pollutants, carbon storage, noise mitigation, the aesthetic upgrading of urban landscapes, and their property values. They also create environments conducive to healthy lifestyles and promote bicycle and pedestrian mobility, strengthen connections with rural areas, and foster social integration. All of these benefits contribute to making cities and communities more sustainable (Goal 11 of the UN 2030 Agenda for Sustainable Development).

In parallel, the existing literature emphasizes digital infrastructure and the concept of the "smart citizen" [30–35]. Operators are progressively using digital solutions for urban greening to optimize—and in some cases democratize—the provision and implementation of UGI [36,37]. For example, automation supports UGI management in lawn care through autonomous lawn mowers [38], urban forest inventories feature digitally tagged trees that transmit information to smartphone platforms [39], biodiversity assessments are undertaken through gaming [40], citizen nature preferences are monitored through Instagram images and hashtags [41], and urban foraging is supported with community-developed semi-autonomous drones [37]. These technologies are driven by governmental and corporate goals of productivity (and profitability), but also by creativity and innovation, with the promise of "smart" and "real-time" solutions to environmental and social demands and challenges [36,42,43]. Taken together, these examples represent the kind of rapid technological development that suggests a potential upheaval in the field of UGI planning and management.

Looking at the policy level, in many international and European forums (G20 in Rome, COP 26 in Glasgow, Green Deal, Strategy Fit for 55, European Biodiversity Strategy to 2030, and new Forestry Strategy to 2030), the issue of afforestation and reforestation is rightly seen as crucial to the restoration of global ecosystems and achieving carbon

neutrality in Europe by 2050. The European Biodiversity Strategy 2030 [44], for example, sets an ambitious goal of "planting at least 3 billion additional trees by 2030" (p. 10). The same document, along with the new European Forestry Strategy, also emphasizes green infrastructures in urban and peri-urban areas because they "reduce atmospheric, water, and noise pollution, protect against floods, droughts, and heatwaves, and preserve the link between humans and nature" (p. 13). Additionally, the Strategy for Biodiversity to 2030 calls on European cities of at least 20,000 inhabitants to develop ambitious urban greening plans by the end of 2021, including measures to create biodiversity-rich, accessible woodlands, parks, gardens, vegetable gardens, green roofs and walls, as well as tree-lined streets, meadows, and hedges in cities, and to improve connections between green spaces, eliminate pesticide use, and limit the excessive mowing of urban green spaces and other practices harmful to biodiversity (p. 14).

The aim of this study is to explore the potential of UGI in reconnecting urban enclaves with the wider city, thereby promoting both climate resilience and social cohesion, thus filling a crucial gap in the understanding of how UGI can transform fragmented urban landscapes into more sustainable, inclusive, and resilient spaces for all citizens, with a particular focus on the practical application in a real-world enclave setting. To achieve this, the study will pursue three core objectives:

1. Examine the role of UGI in mitigating the spatial fragmentation caused by fortified urban enclaves—investigating how UGI can bridge the gaps between isolated urban spaces and foster greater connectivity within cities, facilitating a more inclusive and sustainable urban environment;
2. Analyze the Italian Regulatory and Policy Framework—a detailed exploration of the national and regional policies shaping urban green infrastructure initiatives in Italy, with a focus on how these policies support the integration of UGI into urban planning. This will include examining specific Italian legislation, EU directives, and local government actions that promote UGI as a strategy for climate resilience and social inclusion;
3. Apply UGI in the San Bartolomeo district of Cagliari, currently configured as an urban enclave—assessing how UGI interventions could be applied in this specific neighborhood to reconnect it to surrounding urban areas, improve environmental quality, and enhance social cohesion.

2. The Italian Regulatory and Policy Framework

In accordance with the new environmental and sustainable development policies promoted at the international and European levels, Italy has given itself Law No. 10/2013 "Norms for the development of urban green spaces", which represents a starting point for revitalizing the fundamental role played by urban green spaces, not only from an environmental point of view, but also from a social and cultural one.

Law No. 10/2013, the first and only nationwide law on urban greenery, has certainly contributed over the years to a greater awareness in the country and among local governments of green issues and their benefits for urban communities.

In the implementation of Article 3(2)(c) of Law No. 10 of 2013, the "National Urban Green Strategy. Resilient and heterogeneous urban forests for the health and well-being of citizens" was drafted in 2018 by the National Committee for the Development of Public Green. It brings together a series of technical contributions and defines basic criteria to guide urban and peri-urban forestry policies in the country, in a new vision of urban greening that places the following strategic objectives at the center of actions: (1) the protection of biodiversity and ecosystem services; (2) resilience to climate change; and (3) improvement of citizens' well-being and quality of life. The Strategy is based on three key objectives, as follows: to move from square meters to hectares, to reduce asphalt surfaces, and to adopt urban forests as a structural and functional urban green reference. The Strategy also calls for the involvement of stakeholders and necessarily multidisciplinary expertise to develop suitable public policies and direct municipal governments to implement plans and projects

based on ecosystem services and the Green Infrastructure network (green infrastructures, nature-based solutions), defined to achieve precise social, environmental, financial and employment objectives.

More recently, The National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza—PNRR) [45] has dedicated a line of intervention (Mission 2, Component 4, Line of Intervention 3) to interventions dedicated to green areas; "Safeguarding air quality and land biodiversity through the protection of green areas, soil and marine areas". This includes Investment 3.1, "Protection and valorization of urban and suburban green areas", which provides for large-scale actions aimed at the 14 Metropolitan Cities, which are increasingly exposed to problems related to air pollution, the impact of climate change, and the loss of biodiversity, to improve the quality of life and well-being of citizens through the creation of urban and peri-urban forests.

Finally, Decree 23 December 2021 approved the 20-year national forestry strategy, which included among its specific actions one related to "Trees and urban and peri-urban forests".

Among the nationwide projects is the "Urban Green Challenge" project, which is the first attempt at a collaborative and digital mapping of urban green. In its first trial, it involved six schools in five different regions. The project comes in two formats—the school trail, aimed at understanding environmental dynamics under the interpretive key of complexity, and the participatory civic crowdsourcing campaign. The goal of the project is to understand the importance of greenery within urban spaces; trees and shrubs are measured by participants using smart device apps in order to assess the benefits that vegetation provides to the ecosystem and all living things, including humans. Measuring these effects allows us to give an economic value, and not only landscape-cultural value, to the greenery present in our cities. This is a crucial lever to promote policies for the care and enhancement of green areas, including through the direct participation of citizens.

Within this framework, some municipalities (see Boxes in Appendix A about Modena, Florence, Bolzano, Mantua, Prato, Messina, Milan cases) have activated specific projects linking digital transformation and enclaves overcoming and implementing green infrastructures, highlighting the importance of the urban green infrastructures to mitigating the effects of climate change, and providing a wide variety of environmental, socio-cultural, economic and clinical–health benefits to cities. These cases, however, highlight two fundamental approaches. The first is a technological approach, based on the implementation of hardware and software, whereby technology represents the "smart" key, which must be more efficient and competitive and based on the neoclassical paradigm of economic growth. The second is a substantially analogical approach, whereby the forestation action is almost completely disconnected from digital transformation actions. In both cases, the logic is substantially top-down, and citizen participation is limited to the phase following the implementation of green solutions.

On the contrary, this research grounds its basis in the circular economy approach and considers technology as a tool to achieve broader goals, rather than as a goal in itself. Adopting a sustainable development perspective, the main targets are to protect biodiversity, to rethink urban development in terms of smart growth (i.e., to abandon urban sprawl and zoning, to adopt solutions that provide for a functional and social mix, to open the urban enclaves), and to systematize skills to achieve common goals.

Within this framework, the paper aims to integrate the smart city paradigm with green infrastructure initiatives, emphasizing the essential role of citizen participation. To develop a comprehensive understanding of the smart city framework that goes beyond more technological implementations, a broader definition of "urban green space" is proposed that incorporates citizen science methodologies into urban planning, emphasizing the significant positive impact of citizen engagement as a critical factor for effective planning outcomes.

In other words, we intend to move from an approach focused on the vision of growth dominated by quantitative indicators, based on the idea that the increase in productivity is infinite (infinite resources and consumerism) with necessary competition (between peoples

and between places), to development focused on qualitative indicators (performance), and to the idea that resources are limited and must therefore be managed to ensure that new generations can benefit from them, with emphasis on cooperation (between different actors and different disciplines).

True innovation (which is not only technological, but also social) can only be achieved through interdisciplinary approaches, and must break away from self-referential localisms. The idea that the urban district can be the "key" for a rethinking of the urban structure cannot and should not be understood as a new enclave, but as a relevant "element". It allows the use of most services, recalling the concept of the 15 min city [46,47] from a pedestrian point of view, while the same time emphasizing interconnection with the rest of the city through smart and sustainable mobility networks.

3. Materials and Methods

3.1. The Study Case: San Bartolomeo District in Cagliari (Sardinia—Italy)

The San Bartolomeo district is located to the east of the historic city of Cagliari, in a marginal area, more precisely in the southern quadrant (Figure 1). It is one of the 31 districts of the city of Cagliari. San Bartolomeo presents characteristics of spatial segmentation, with limited integration in the wider metropolitan context. This district occupies a significant position linking the urban and natural environment, as it is adjacent to the Molentargius-Saline Regional Park. This park represents a protected area of high ecological and cultural value known for its wetland ecosystem and its role as a habitat for migratory bird species such as flamingos, enhancing the environmental importance of the district.

Figure 1. San Bartolomeo district today. Source: Author's elaboration.

The quadrant where San Bartolomeo district lies is historically considered a functional area for defense plans, as a point of observation of dangers from the sea, as evidenced by the Pisan and Aragonese towers and forts present. During the nineteenth century, the San Bartolomeo-Calamosca area housed the facilities of a penal colony, located in the then suburbs of the island's capital. Inmates worked on the construction of facilities in the village of San Bartolomeo and the colony itself and in the nearby salt pans (which currently connect with the Poetto and Quartiere del Sole neighborhoods). In the early twentieth century, this area of strong strategic interest on the slopes of the city's promontory passed from civilian

to military ownership. This process occurred by replacing one enclave (that of the penal colony) with another enclave (that of a military area). The reshaping of the landscape, however, maintained the characterization as an area precluded from the city. From the early 1930s to the 1960s, numerous edifices developed, such as the Ederle barracks, the Mereu and Cascino barracks and the Monfenera barracks, as well as complexes supporting military functions, such as the Navy Logistics Park, the "Pol Nato" fuel depot, the "Campo Rossi" sports complex and firing range, and a series of batteries, depots, and living quarters, which contributed to the structuring of a true military ecosystem that still characterizes the area [48]. Since the early 1960s, the gradual opening of the area to businesses and housing not directly under the control of the Armed Forces has allowed the opening of a number of small private businesses. In 1958, the construction of the Hotel Calamosca began, allowing the rezoning of the land around the beach of the same name, while a cobbler's store and later a grocery store and a small bar opened in Piazza San Bartolomeo, all strongly linked to the economies of the military facilities present. The neighborhood, which for a long time was precluded from the rest of the city, has undergone the slow hybridization of its living spaces, but it has also seen continued control and use by the military due to the slow pace of decommissioning processes that, on the contrary, have seen the consolidation of some historic structures (see Mereu Barracks, Monfenera Barracks and Villassanta Barracks).

Due also to its military origins, the district remains partially isolated from the surrounding urban area, both physically and socially. This condition is reinforced by its peripheral location on the south-eastern edge of the city and its adjacency to natural barriers such as the Molentargius-Saline Regional Park. It is near the Sant'Elia Stadium (the Cagliari Calcio Stadium) and the homonymous social housing district (Sant'Elia District), which separate the neighborhood from the waterfront.

3.2. Methodological Path

The methodology of this paper is based on the citizen science approach. A participatory planning approach is essential to assessing how green spaces and urban green infrastructure are integrated into spatial planning for improved outcomes. Participatory planning empowers stakeholders and decision-makers by fostering a sense of ownership and enabling meaningful involvement in decision-making. It encourages innovative interventions that benefit all social groups, build trust among participants, and provide access to diverse perspectives, helping in addressing grassroots issues and making informed, locally adapted choices. Public participation plays a crucial role in promoting social and environmental equity by bridging the gap between the objectives of planning organizations and the values of local communities and other stakeholders [49]. Actively involving the public has been instrumental in the success of green infrastructure projects in urban areas, fostering more inclusive and sustainable outcomes. By involving diverse stakeholders and citizens, green infrastructure can be more effectively leveraged to address urban challenges and promote sustainable development. In particular, the methodological path is implemented through five succeeding steps (Figure 2).

Data collection. This stage aims to reveal the spatial processes followed to identify and define the potential, aspirations and needs of a definite territory, from a social, economic, and environmental perspective, so as to give value to natural and cultural landscape elements at the urban scale. Data collection is performed through an objective (statistics, plans and programs) and subjective (citizen's opinions and perceptions) approach. We employ a combined approach of in-depth interviews and content analysis of key policy plans and documentation related to green space planning and/or climate change adaptation to evaluate areas of competence in our case study city.

A citizen science approach for adaptive urban green spaces is suggested to integrate citizens' needs and expertise. It includes adaptive strategies derived from climate change adaptation and ecological planning in a structured form to support the best practice to plan and improve green space in planning and practice. In the first phase, citizens were asked for their advice on the best planning approach for the San Bartolomeo neighborhoods in

Cagliari by means of a structured questionnaire. The questions in the questionnaire were formulated as follows. Citizens answered via a Qr code and link, as well as in person. In the second phase, the results were submitted to the citizens to verify the correct interpretation of the needs of the local population.

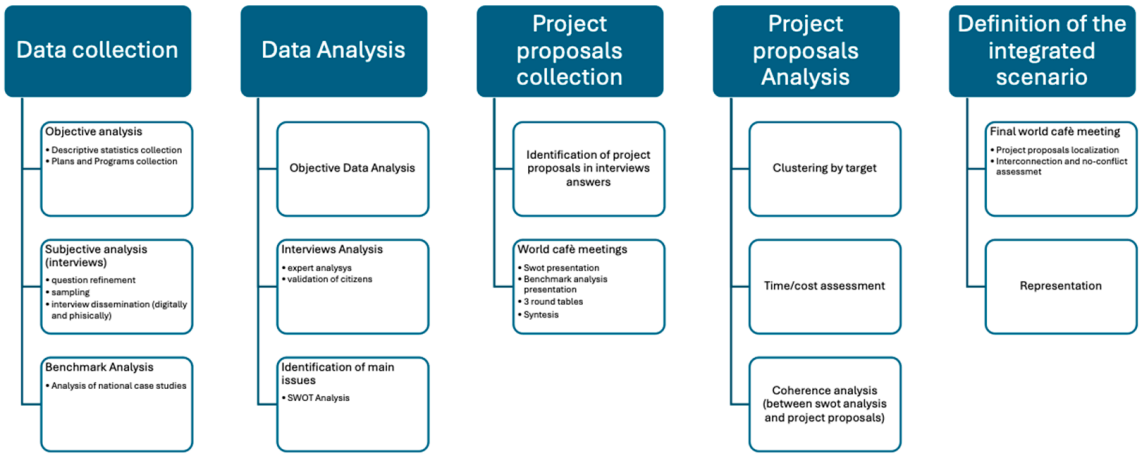


Figure 2. Methodological path. Source: Author's elaboration.

To evaluate the population's needs for greenspace planning in the San Bartolomeo District, a qualitative research study was conducted. Between January and May 2023, an online questionnaire was distributed to the residents of the district. Data collection employed a non-probability snowball sampling method, wherein an initial group of participants was selected, and additional respondents were recruited in a second stage. The questionnaire was disseminated via email and through social media platforms and messaging apps, such as WhatsApp and local Facebook groups, using a QR code and a direct link.

This strategy was designed to reach a diverse audience, particularly in terms of age and socio-cultural background. Online surveys, following a citizen science approach, are increasingly recognized as an effective tool for reaching a broad participant base. They are gaining popularity in academic research, especially for exploring people–environment interactions and preferences [50–53]. The structured questionnaire consisted of 10 questions divided into several sections (see Table 1).

The first section, with 3 questions, gathered demographic information to profile participants. The second section, comprising 5 questions, focused on perceptions of climate change, urban green spaces, and the district's location, aimed at assessing participants' knowledge. Finally, the third section, with 2 questions, explored participants' perceptions of their urban enclave and the role of green spaces in meeting community needs.

The questions were formulated using four different response types, as follows:

- Single-choice questions, where respondents selected only one option;
- Multiple-choice questions, allowing respondents to select more than one option;
- Single-choice items presented on a psychometric Likert scale, requiring respondents to rate their agreement with specific statements (five-point scale: 1—strongly disagree to 5—strongly agree).

Moreover, in this phase, a benchmark analysis of national case studies was performed (Appendix A). In more detail, the strategies of seven Italian cities (Mantua, Bolzan, Milan, Florence, Messina, Prato, Modena) were analyzed for insights into possible solutions to be implemented in the study area.

Data analysis. The collected data were analyzed and represented to make them easily communicable to citizens. In particular, questionnaire responses were analyzed using the methodologies of descriptive statistics (results are reported in paragraph 3). Finally, a SWOT analysis was carried out as a strategic planning tool to identify the strengths, weaknesses, opportunities, and threats of the context.

Table 1. Summary table of questions in the online survey. Source: Authors' elaboration.

Section	Question	Type	Answers
Demographic data	Sex	Single choice	Male; female; non-binary: prefer not to say
	Age	Single choice	Less than 20; between 20 and 39; between 40 and 59; more than 60; prefer not to say
	Education	Single choice	Elementary, middle, high school, university, prefer not to say, other (specify)
Climate change, urban green spaces and location of the district perception	I am concerned about the current climate crisis	Likert scale	1 strongly disagree – 2 disagree – 3 neutral – 4 agree – 5 strongly agree
	Climate change will impact my lifestyle	Likert scale	1 strongly disagree – 2 disagree – 3 neutral – 4 agree – 5 strongly agree
	Is your district well connected with the rest of the city?	Likert scale	1 strongly disagree – 2 disagree – 3 neutral – 4 agree – 5 strongly agree
	Do you think the parts of the district are well connected to each other?	Likert scale	1 strongly disagree – 2 disagree – 3 neutral – 4 agree – 5 strongly agree
	What are the three main negative aspects of your district?		Open
Citizens needs	What changes would you like in your district?	Multiple choice	More green spaces: green spaces for gym, green spaces for children; green spaces for pets; green spaces for co-working, other
	What are the three main positive aspects of the district?		Open

Project proposals collection. The proposals were collected from different sources; from the questionnaires administered to citizens, from the analysis of the territorial context made by experts, and from a participatory process carried out through 3 meetings according to the world café mode.

Project proposals analysis. Proposals were analyzed first by categorizing them according to the objective they are proposed to achieve, and second by evaluating the time and cost of their implementation.

Definition of the integrated scenario. Experts and citizens jointly developed a final proposal (integrated scenario) in a meeting taking into account the contextual constraints and the preferences expressed by the citizens. In the first part of the meeting, the project proposals were presented and discussed to select those that would compose the final scenario. The second part was dedicated to assessing the interrelationships between the chosen proposals, and localizing them. Finally, this step was completed with a communication kit of the final scenario elaborated by the expert, comprising a list of the projects along with their description, a 2D design with the localization of the projects, and a 3D view.

4. Results

4.1. Analysis of the San Bartolomeo District

In the historical Guide of the City of Cagliari, written by Canon Giovanni Spano [54] in 1861, it is documented that the area was already frequented in Roman times. However, the spatial configuration that we can still observe today can be traced back to the construction of the Bagni Penali in the first half of the nineteenth century. The prisoners were employed as a workforce in the activities of salt extraction. The new neighborhood of San Bartolomeo was built between the 1880s and 1890s approximately 500 m from the remains of the old neighborhood. The symbols of the historic district are the square and the San Bartolomeo fountain, which has recently been redeveloped. The new neighborhood is located further north, between the streets of Amerigo Vespucci, Raimondo Carta Raspi, Viale Salvatore

Ferrara and San Bartolomeo. The neighborhood is located south-west of the historic center of the city of Cagliari; it is close to numerous residential neighborhoods (Sant'Elia, Quartiere del Sole, etc.) and numerous territorial and social dominants, such as the Cagliari Calcio stadium, the gulf of Calamosca, the Poetto coast, the Molentargius salt pans, etc. (Figure 1). The new district of San Bartolomeo is mainly reserved for residential use with sporadic exceptions of commercial services, and with a large permeable green area (not equipped). It provides a series of neighborhood facilities, including squares, parking areas, dog areas, green areas, a local market, and a range of commercial activities, especially around the main square of the district (Piazza Francesco Antonio Boi). On the edge of the neighborhood are two areas that will be targeted in the near future by urban transformation projects. The building typology of the neighborhood is that of the residential building, organized in apartment blocks, with a different number of floors (from 3 to 8 floors), some of them with pitched roofs, others with flat roofs. The ground floors of the buildings surrounding the main square are intended for commercial activities. An analysis of the historical evolution of the urban settlement showed the development of the geographical context on which the San Bartolomeo district was built, in an area surrounded by a significant network of road infrastructures (Viale San Bartolomeo, Viale Salvatore Ferrara, Via R. Carta Raspi, Via Amerigo Vespucci). As a matter of fact, the district appears as an enclave within an urban context developed according to a functionalist approach; the urban space is organized by specialized functions of public interest and of different ranks (military, sports, university), each one surrounded by streets. Over time, the routes have been transformed from connecting elements with the city to urban limits for the neighborhood itself. These road routes have contributed to generating a cutting effect between the neighborhood and the remaining urban fabric. The same dynamic emerged relating to the system of military buildings, today totally incorporated into the urban fabric. This structure constitutes a caesura with respect to the surrounding space, a real enclave, because of the high fences equipped with barbed wire at the top that develop for some hundreds of meters. It is important to note that the military complex Attilio Mereu was recognized as of cultural interest in 2015 by the competent authorities, for the clear typological reference it makes to the industrial architecture of the early twentieth century, which still retains the original plant.

Fragmentation caused by heavy mobility systems, unsafe and poorly maintained cycle paths and inadequate road design limit the neighborhood's accessibility. The perimeter streets—Raspi, Vespucci, Ferrara and San Bartolomeo—are characterized by dilapidated fences, unsafe pavements and spontaneous vegetation, which create physical and visual barriers. These conditions add to the urban enclave.

The public transport network in the district of San Bartolomeo in Cagliari reflects a moderately developed infrastructure aimed at connecting the neighborhood with key areas in the city. Public parking facilities are available in two primary locations—between Viale Amerigo Vespucci and Viale San Bartolomeo, as well as near the local supermarket. An additional parking area is located close to the stadium, supporting its role as a hub for events and activities.

The district is served by the CTM public transportation system, which provides connections through several bus lines. The lines 5, 5/11, 6, and IR operate close to Viale San Bartolomeo, facilitating access to the core of the neighborhood. The stadium area is specifically served by line 6, ensuring connectivity for sporting events and other activities held there. Additionally, several bus lines stop near Via Poetto, providing links between the university area and the city center. This proximity enhances the district's accessibility for students and university-related transit.

While the public transport network offers reasonable connectivity, opportunities remain to improve the integration and efficiency of these services, particularly in addressing the challenges posed by the district's current road and pedestrian infrastructure.

From a socio-economic point of view, the data refer to Borgo Sant'Elia district [55], reflecting a close integration between San Bartolomeo and Sant'Elia. The inclusion of San

Bartolomeo within Borgo Sant'Elia highlights shared characteristics and interconnections in terms of population trends, urban development, and social structures, which collectively contribute to a unified community dynamic. This integration allows for a comprehensive understanding of the area as a single entity when analyzing demographic or territorial data.

The population of Borgo Sant'Elia in 2023 [55] stood at 1154 residents (Cagliari counts a total population of 149,726 residents), a decrease of approximately 200 individuals since 2013. This decrease reflects the persistent demographic trends driven by aging, migration, and changes in family structures in Cagliari. The gender distribution is nearly equal, with 575 males and 579 females. Marital status data indicate that 55.30% of males and 44.73% of females are unmarried. Between 2022 and 2023, the population of Borgo Sant'Elia declined from 1168 to 1154 residents.

An analysis of the population distribution by age group reveals that the majority of residents (approximately 60%) are between 30 and 64 years old, followed by individuals aged 65 and older, who constitute around 20% of the neighborhood's population; these values are different from Cagliari's total values, which indicate a population increasingly concentrated in older age groups. Marital status data highlight that 55% of men and 45% of females in the neighborhood are unmarried. Furthermore, the population trend in Borgo Sant'Elia over the decade from 2013 to 2023 has demonstrated a consistent decline.

Persistent challenges include addressing socio-economic inequalities and improving the integration of the district into Cagliari's broader urban framework. The geographical and environmental characteristics of San Bartolomeo, on the other hand, present significant opportunities for innovative urban development and initiatives to improve social cohesion, support local businesses and promote sustainable economic development.

The neighborhood is currently involved in urban regeneration initiatives, though these are still in the stages of approval or planning by the Municipal Administration of Cagliari. One of the key projects includes the development of a sports complex in the northern part of the San Bartolomeo area, near Via A. Vespucci. To the west, as outlined in the guiding project submitted within the framework of the preliminary Municipal Urban Plan (Piano Urbanistico Comunale—PUC), the redevelopment of the Sant'Elia stadium area is also planned.

4.2. Residents' Perceptions

The survey distributed to the residents of San Bartolomeo (Table 1) collected valuable insights into their perspectives on urban green spaces, climate change, and the local community. This information provides a clearer understanding of how greenspaces can be more effectively planned to address the specific needs of the community. The analysis of the questionnaire began by profiling respondents based on demographic data. The research findings were then examined along three key axes: (i) perceptions of climate change at the local level, (ii) governance tools implemented by public and private actors in the development of green spaces, and (iii) potential and targeted actions to mitigate the effects of climate change. A total of 60 online questionnaires were collected. As shown in Figure 3, the questionnaire respondents were predominantly female (68%), with a majority aged 20–59 (86%). Education levels were varied, with 18% holding university degrees, 42% having completed high school, and 40% reporting other qualifications.

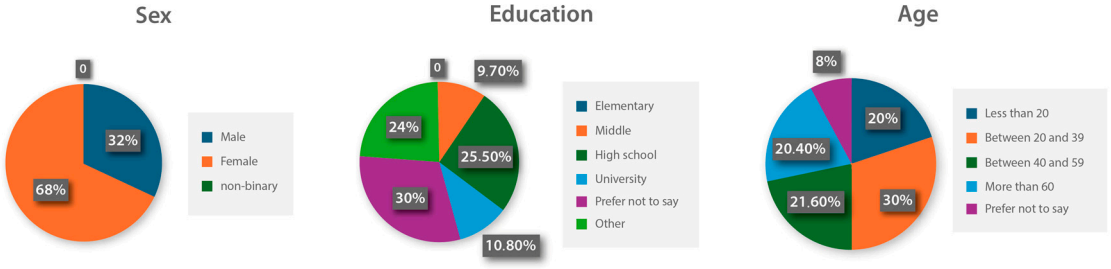


Figure 3. Demographic composition of the respondents. Source: Author's elaboration.

As shown in Figures 4 and 5, a significant majority of respondents (70%) expressed concern about the climate crisis and its potential impact on their lifestyle (65%). While 82% felt their district was not well-connected to the city, 70% perceived poor internal connectivity. When asked about desired changes, respondents overwhelmingly prioritized more green spaces (70%), followed by spaces for children (60%) and pets (30%). Other preferences included gym facilities (35%) and co-working areas (20%). Key negative aspects of the district included poor public transportation, a lack of green spaces, and inadequate infrastructure, while positive aspects included proximity to natural areas and beaches, affordable living costs, and low traffic congestion.

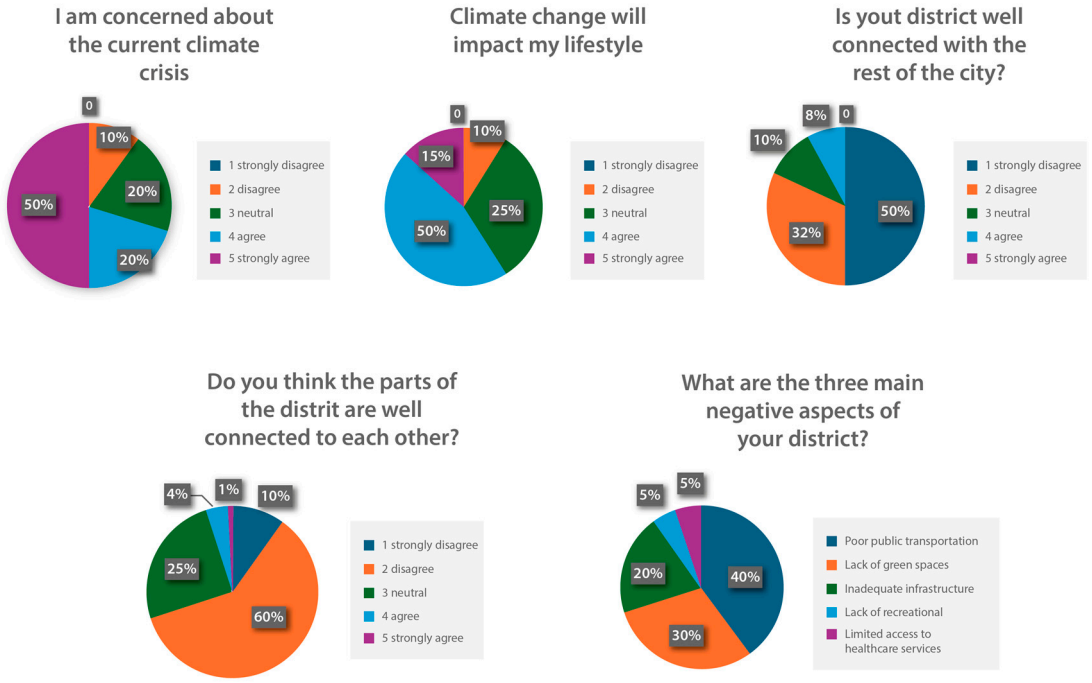


Figure 4. Survey responses from the second section on climate change, urban green spaces and location of the district perception. Source: Author's elaboration.

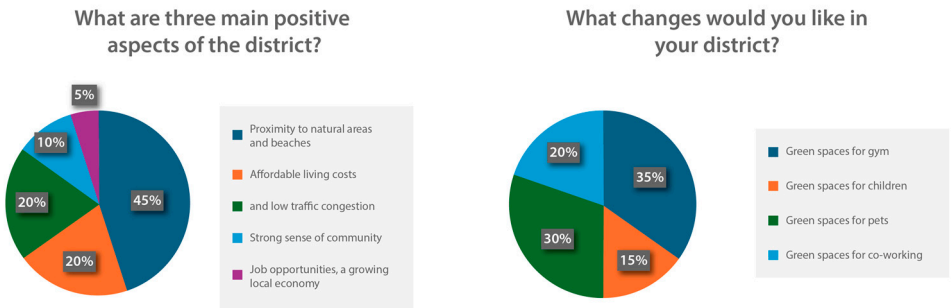


Figure 5. Survey responses from the first section on citizens' needs. Source: Author's elaboration.

When asked about desired changes, respondents overwhelmingly prioritized the addition of more green spaces (70%). Specifically, they expressed a preference for green spaces accommodating gym facilities (35%), pet-friendly areas (30%), and co-working spaces (20%), with spaces for children being the least prioritized (15%).

4.3. Identification of Critical Issues

The SWOT analysis summarizes our previous research findings on the San Bartolomeo neighborhood, and identifies the key strengths, weaknesses, opportunities, and threats that influence its development. The strengths and weaknesses concern internal aspects of

the analyzed system, while the threats and opportunities are the result of external actions (Figure 6).

Figure 6. SWOT analysis. Source: Author's elaboration.

4.4. Definition of Project Actions

According to a participatory planning approach, the district's residents have to date been involved in three meetings to define the possible project actions. These meetings were organized following the "World Cafè" methodology to create a safe, welcoming environment in which to intentionally connect multiple ideas and perspectives by engaging participants in several rounds of small-group conversation. At the start of the first World Cafè, the results of the SWOT analysis were shown and explained to give the participants the same knowledge base. In each World Café meeting, participants (60 people) were divided into three tables and had an hour and a half to discuss possible projects to implement in the area. In each meeting there were three rounds (i.e., three table changes for each participant). Each table had a "host" who remained at the table through the entire exercise. The host's role was to welcome participants to the table, provide an overview of the discussion question, and summarize key ideas shared by previous guests at the table. At the end of the exercise, the host was responsible for sharing a summary of the discussion points from his or her table. From the World Café meetings emerged 24 project hypotheses integrating infrastructure, environmental sustainability, social development and community engagement. These proposals represent a range of strategies aimed at advancing green infrastructure to dissolve urban enclaves and establish both functional and physical connections with the broader urban fabric, and address key aspects of sustainable urban integration, fostering connectivity, ecological balance, and social inclusivity within the cohesive city framework. According to their main goal, these project hypotheses have been classified into four groups (Figure 7): Infrastructure Development, which focuses on building essential facilities and systems; Environmental Sustainability, which emphasizes green solutions and resource efficiency; Community and Economic Development, which promotes empowerment, education and economic vitality; and Urban Design and Aesthetics, which improves the visual appeal and usability of urban spaces.

The project proposals are described more in detail as follows.

1. Spirulina production plant

Spirulina seaweed is a blue-green microalga (it belongs to the blue seaweed group). It is a highly regarded superfood due to its status as a complete nutritional source. This type of algae thrives in freshwater environments such as lakes, rivers, and ponds. Spirulina is

rich in various nutrients, including fat-soluble vitamins (A, E, and K), essential fatty acids (DHA and EPA), beta carotene, and an array of minerals. While it serves as a protein source, it does not contain sufficient levels of some essential amino acids required for optimal bodily function, unless one has a medical condition that necessitates avoiding specific amino acids. Additionally, since spirulina originates from bacteria, specifically "cyanobacteria", it is considered a viable protein option for vegans. We foresee the realization of a production plant (of 300 m^2) using photo bioreactors, or plastic tubular solar collectors, in which pure groundwater circulates and in which the seaweed grows. This plant will allow the least contact of water with air, preventing the contamination of the algae.

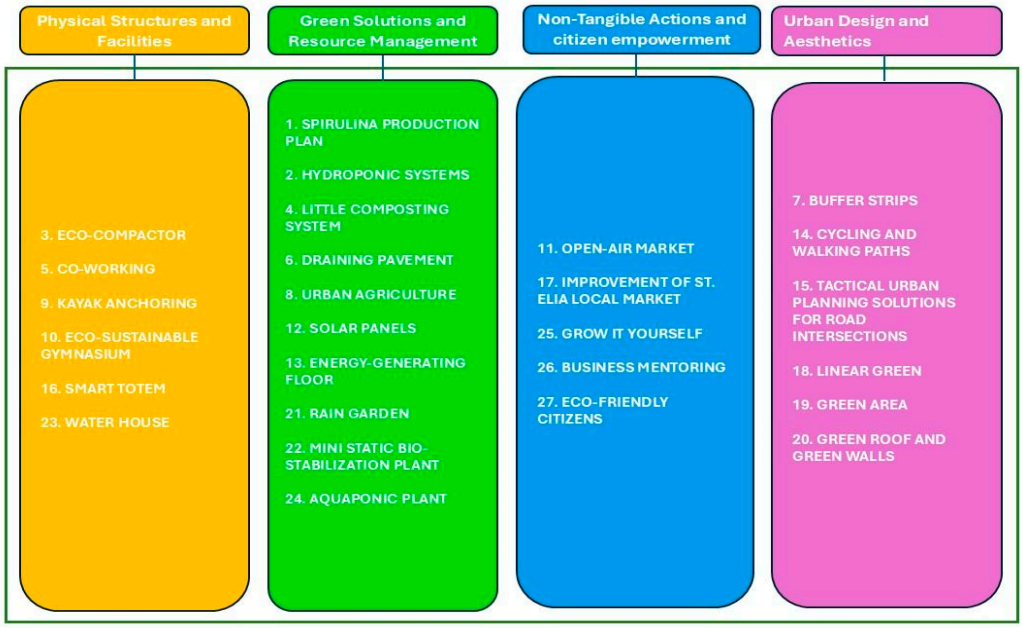


Figure 7. Project proposals based on their purposes and impacts.

2. Hydroponic System

Hydroponics is a cultivation method whereby plants grow without soil. Nutrient-rich water, maintained at the ideal pH, supplies essential elements directly to the plant roots, ensuring efficient absorption. Unused water is recycled for reuse. Plants in hydroponic systems are supported by inert substrates like pumice or coconut fiber, or they are placed in tubular structures with flowing nutrient-rich water. Hydroponics bridges traditional agriculture and aquaculture. These systems feature water-filled basins housing fish. Plants, supported by slabs with holes, absorb nutrients directly from the water. Fish maintain water quality and provide nutrients for the plants. Hydroponic systems utilize inert substrates or tubular structures with flowing nutrient-rich water, eliminating the need for soil. One hydroponic system in an area of 240 sqm is foreseen.

3. Eco-compactor

Eco-compactors are recycling stations strategically placed in public areas. These machines accept various plastic caps, including PET, PS, PE, and HDPE bottles, as well as aluminum cans and PP glasses. Users receive a small monetary reward in the form of discount coupons for their contributions.

Eco-compactors are automated machines that sort and compact waste. Each deposit earns a receipt with a contribution or discount voucher redeemable at participating businesses. This incentive recycling model promotes environmental education. Considering the size of the neighborhood, one eco-compactor in an area of 6 square meters is foreseen.

4. Little Composting System

Composting, also known as controlled decomposition, necessitates a careful balance between "green" organic materials and "brown" organic materials. "Green" materials, such as grass clippings, food scraps, and manure, are rich in nitrogen. In contrast, "brown" materials, including dry leaves, wood chips, and branches, are high in carbon but low in nitrogen. Achieving the ideal nutrient mix often requires experimentation and patience, which is an essential aspect of both the art and science of composting. The size of the particles used in composting plays a crucial role; grinding, chipping, and shredding materials increases the surface area available for microorganisms to feed on. Smaller particles not only create a more uniform compost mixture, but also enhance pile insulation, helping to maintain optimal temperatures during the decomposition process. For the district, a plant with a capacity of 5–10 tons/month in an area of 3 hectares has been planned.

5. Co-Working

Co-working has gained significant traction in the digital knowledge economy, driven by the growing number of independent professionals who often work from home and may lack the social connections needed for feedback, referrals, and support. Shared experiences of working remotely and a mutual understanding of the challenges associated with personalized professional endeavors foster cognitive proximity within home-based coworking environments. Coworkers actively contribute to a productive atmosphere, which is supported by digital platforms, host engagement, and home-based features. For these reasons, a 200-square-meter coworking space was designed within the San Bartolomeo neighborhood.

6. Draining pavement

The impermeable surfaces of public parking lots generate a substantial amount of surface water runoff, necessitating effective channel drainage solutions. For larger commercial parking facilities, drainage systems are optimal for managing surface water, with larger designs offering additional capabilities. Multi-storey car parks and parking decks often face challenges related to limited installation space for drainage solutions. Following Sant'Elia's Masterplan, it was decided to prioritize sustainable environmental practices through the implementation of drainage systems in four parking areas. Given the high volume of traffic brought about by the presence of the stadium, the project involves the use of porous concrete on parking areas (with a total area of 5 ha) that allows the direct drainage of water. This solution requires a well-prepared base and periodic maintenance to avoid blockages.

7. Buffer strips

Buffer strips with trees and mixed vegetation (for a total of 2 ha) are foreseen. The buffer strip is a designated area of land that is permanently covered with vegetation, designed to improve air, soil, and water quality while addressing various environmental issues, particularly in agricultural settings. These buffer strips effectively trap sediment and enhance the filtration of nutrients and pesticides by slowing surface runoff before it reaches local water bodies. The root systems of the vegetation in these strips help bind soil particles, reducing wind erosion and stabilizing stream banks, thus offering protection against severe erosion and landslides. Farmers can also utilize buffer strips to better align existing crop fields, which not only enhances safety for equipment but also promotes more efficient farming practices. Buffer strips can feature a variety of vegetation configurations, ranging from simple grass to combinations of grass, trees, and shrubs. Areas with diverse vegetation provide improved protection against nutrient and pesticide runoff, while simultaneously fostering greater biodiversity among plants and animals.

8. Urban Agriculture

Urban agriculture is transforming city landscapes, with a surge of small-scale operations dedicated to cultivating plants and raising animals at ground level or on rooftops

and terraces. Urban horticulture encompasses the cultivation of vegetables, fruits, aromatic plants, and medicinal herbs, conducted either outdoors or in enclosed spaces on a domestic scale. Urban vegetable gardens minimize the number of intermediaries involved in the food supply chain, leading to reduced transportation, packaging, and storage costs. This not only increases the earnings of horticulturists, but also decreases environmental pollution. Additionally, these initiatives create job opportunities for disadvantaged groups and individuals at risk of exclusion. Urban agriculture plays a vital role in providing fresh food to the population, creating green spaces, recycling municipal waste, and enhancing urban resilience against climate change. Urban vegetable gardens exemplify the principles of a sustainable city. Community gardens have evolved beyond mere vegetable plots to become spaces for leisure, relaxation, environmental education, and therapeutic experiences in natural settings. Many citizens now actively engage in private or community urban vegetable gardens, and municipal authorities increasingly incorporate these initiatives into their sustainable urban planning efforts. Access to the gardens will be free, governed by a service agreement between the Municipality of Cagliari and either local market operators or private citizens. These agreements will also enable residents from diverse cultural backgrounds to grow products not typically available at the local civic market, fostering cultural exchange through food. The project plans to establish multifunctional community gardens on a total area of 1 hectare.

9. Kayak anchoring

A kayak anchoring action plan in the city focuses on creating accessible, sustainable, and eco-friendly facilities that integrate with urban spaces. Strategic locations near parks and public transport hubs encourage easy access, while sustainable materials and designs protect local ecosystems. These facilities link to green spaces, promoting outdoor recreation and healthy lifestyles. Community involvement is encouraged through educational programs on kayaking and water safety, and citizens can participate in environmental monitoring. The plan also supports local businesses by attracting visitors through rentals and tours, boosting the local economy. Additionally, cultural and historical connections can be highlighted along kayaking routes, enhancing the city's appeal. Smart technology and water management systems ensure the facilities are efficient, sustainable, and safe, turning kayak anchoring into a valuable urban asset.

10. Eco-sustainable gymnasium

Advanced outdoor cardio equipment that generates electricity is planned (10 pieces of equipment, covers and interactive systems). This promotes not only physical health and mental well-being, but also community spirit and environmental sustainability. This innovative equipment harnesses human energy and converts it into usable electricity, which can be utilized to charge mobile phones and tablets via a USB port and to illuminate on-site interactive lighting. While it is well established that physical activity enhances both physiological and psychological well-being, more evidence is needed to determine how various environments influence health outcomes. Additionally, exercising in outdoor settings appears to provide unique physiological and mental health benefits. However, people's connection to nature seems to be evolving, which has significant implications for how humans engage with the natural world.

11. District's open-air market

The development of an open-air market within a district plays a crucial role in promoting local commerce, community engagement, and sustainability. Such a market can serve as a vibrant hub where local vendors sell fresh produce and handmade goods, fostering economic activity and cultural exchange. By supporting short food supply chains, the market reduces transportation and packaging, making it eco-friendly. It connects local farmers with residents, promoting trust in food quality and preserving local traditions, while also attracting tourists. Flexible in design, the market can host community events, creating a sense of unity and serving as a social and cultural focal point, aligned with the

city's environmental goals. The market would provide a platform for local farmers and producers to directly connect with residents, enhancing trust in the quality and origin of food. This setup would also help preserve and promote local food traditions, making it a point of interest for tourists seeking authentic experiences. Finally, the open-air market would integrate commerce, culture, and sustainability, enriching both the community and the city's economic vitality. The project foresees 30 designated areas for food vendors, craft stalls, and seasonal pop-up spaces for special events, contributing to the district's identity as a center of sustainable, local living.

12. Solar panels

The project of the new stadium foresees installing solar panels on the roof and most of its external vertical surfaces to harness solar energy during the day. A battery storage system will facilitate the accumulation of this collected energy, transforming the stadium into an "energy supply hub". This setup will also help mitigate the grid impact of numerous electric vehicles charging simultaneously in various locations. As a key outcome, the stadium will achieve 100% energy self-sufficiency, with any surplus energy allocated for several purposes, as follows:

- Illuminating poorly lit areas of the San Bartolomeo district at night, thereby enhancing the livability of public spaces and promoting social activities;
- Charging e-bikes and scooters for residents and visitors to Cagliari who are drawn to the stadium and the surrounding sports facilities.

13. Energy-generating floor

The project foresees an energy-generating floor in some areas near the new stadium to harness energy from citizens walking in the area. These floors convert the kinetic energy generated by pedestrians into usable electricity, which can then be redirected to power nearby facilities, such as lighting for the pitch, surrounding pathways, or public amenities. The system promotes sustainability by encouraging green energy practices within the community while simultaneously enhancing the functionality of the space. By incorporating these energy-harvesting technologies, the city encourages active participation from its residents, linking physical activity to environmental benefits. The initiative also aligns with broader goals of smart city development, where technology and infrastructure work together to create more sustainable, energy-efficient urban environments.

14. Cycling and walking paths

A 4 km cycling and walking path surrounding the Sant'Elia football stadium is planned, which will have direct positive effects on the following:

- Citizens' health by promoting increased engagement in sports activities;
- Reducing air pollution;
- Fostering environmentally sustainable mobility within the district and its neighboring areas.

The path will be built on existing roads by adding horizontal and vertical markings. The construction timeline, including technical, urban planning, and environmental assessments, is estimated to be nine months.

15. Tactical urban planning solutions for road intersections

In district mobilities, project strategies are aimed at the identification of strategic crossing and connection areas according to the main axes of connection identified. Tactical urban planning uses low-cost, temporary solutions to improve road intersections while working toward permanent changes. Common interventions include painted curb extensions to slow traffic and shorten pedestrian crossings, temporary bike lanes for safer cyclist positioning, and pedestrian plazas that reclaim excess road space. Creative crosswalks and pop-up markings increase pedestrian visibility, while enhanced lighting improves safety. This approach allows for real-time experimentation and community feedback, making it easier

to identify what works best in specific contexts. These flexible, quick fixes allow cities to test ideas, prioritize safety, and encourage more sustainable, pedestrian-friendly environments.

16. Smart Totems

The deployment of two multifunctional smart totems is panned along the cycling and walking paths, in order to achieve the following:

- The measuring and monitoring of air quality in the district by increasing the number of monitoring points across the City of Cagliari and expanding the range of detectable pollutants to include not only PM2.5, but also PM10, O_3, NO_2, and SO_2;
- The colleciton of solar energy through vertically integrated solar cells, thereby reducing CO_2 emissions by approximately 300 kg per year for each totem, based on Italy's energy production mix;
- Provide illumination during nighttime;
- Supply power for e-bikes and electric kick-scooters;
- Offer free Wi-Fi connectivity;
- Serve as an information point for mobility issues and daily events in the city and district.

17. Food Hub "Assaggia San Bartolomeo"

The proposed project regards the conversion of Sant'Elia civic market into a food hub as a space for cooking, dining, and tasting. The hub will operate daily, reinforcing social bonds and community collaboration. The hub is designed to foster a sense of belonging and integration, supported by social activities that promote community cohesion. This will involve the use of the hub as a venue for events that address community issues, celebrate different food cultures and combat food waste. Its impact will be further enhanced through partnerships with local schools and universities, which will organize activities that encourage cultural appreciation and social engagement. Finally, the hub will act as a social and culinary gathering point for residents using nearby sports facilities or traveling by bicycle or scooter. Moreover, the hub will take advantage of the establishment of public urban gardens near the local market (project proposal). These gardens will allow market operators, who also sell their produce at the market, to cultivate local fruits and vegetables. This initiative aims to promote a short food supply chain, strengthen the local food system, and build residents' confidence in the quality of their food. Additionally, it seeks to educate younger generations about local traditions and provide tourists with an authentic experience of regional cuisine. This initiative would follow up on the "Comunità del buon gusto (Community of Good Taste)" project launched in the adjacent Sant'Elia's neighborhood, supported by Intesa Sanpaolo and other organizations, which aimed to create spaces for social inclusion and local enhancement through culinary activities and training.

18. Linear green spaces

The proposed solution involves the realization of a total of 5 km of linear green spaces with the aim of enhancing connectivity and integration with the surrounding areas. The linear green spaces have several important objectives aligned with the ecosystem services they provide, including the following:

- Enhancing the visual experience of the area, ensuring a level of visual complexity that increases the enjoyment of green spaces;
- Strengthening ecological corridors to promote territorial and ecosystem continuity;
- Reducing fine dust and pollutants in the atmosphere, as these green surfaces serve as effective physical, chemical, and physiological filters against harmful airborne particulates;
- Establishing a barrier to mitigate noise pollution generated by vehicular traffic.

19. Green Areas

The presence of 5 hectares of uncultivated and vacant spaces surrounding the neighborhood highlights the necessity of transforming these areas into functional spaces through urban forestry initiatives. These green spaces can serve as multifunctional mediation areas, both urban–territorial and social, fostering community engagement among residents and

beyond. Opportunities presented by the development of sports facilities to the north of the neighborhood include the implementation of green roofs on the four football fields, featuring drought- and salinity-resistant macrothermal species. It is noteworthy that this area once hosted salt marshes, making such vegetation particularly suitable. Incorporating microthermal species, known for their resilience against pathogens and foot traffic, would enhance eco-compatibility and cost-effectiveness in maintenance. This type of vegetation cover offers several advantages, including the ability to irrigate with treated wastewater, given its high salinity resistance. A collaborative relationship could be established with nearby residential buildings, whereby the green spaces would provide various ecosystem services, while the residential community could be supplied with adequately purified water for irrigation.

20. Green roof and green wall

The redevelopment of the San Bartolomeo district is intended to provide various ecosystem services. To align with the environmental needs of the community (comprising residents, commuters, and workers), the study is approached at multiple scales, including territorial, neighborhood, and microscale levels. Green roofs and facades are particularly relevant at the microscale. In this context, flat roofs will be transformed into green roofs to enhance building insulation and facilitate outdoor activities related to horticulture, gardening, and the cultivation of pollinator species, such as beekeeping. This approach embodies a perspective that transcends anthropocentrism and promotes the establishment of ecological networks. Moreover, the planned green walls will serve dual purposes, as follows:

- Providing insulation for living spaces and contributing to energy savings, while also mitigating the landscape discontinuities created by the new neighborhood's construction;
- These walls will effectively address the interruption of the skyline formed by the heights of the new buildings, harmonizing the view with the backdrop of Sant'Elia's hill.

A total of 1 hectare of this surface is planned.

21. Rain gardens

Another key design feature involves the implementation of rain gardens on a total area of 2 hectares. These gardens, integrated along the main "slow" road infrastructures such as cycling and pedestrian paths, contribute significantly to achieving essential ecosystem objectives. Rain gardens consist of sunken draining areas populated by plant species that can withstand both drought and temporary root asphyxiation caused by water stagnation during heavy rainfall. These depressions effectively collect and manage water runoff from adjacent impervious surfaces, thereby minimizing disruption to vehicular traffic.

The functions of the rain gardens can be summarized, though not exhaustively, as follows:

- Green barrier—they serve as a green buffer surrounding the cycling and pedestrian paths, providing a clear separation from other road infrastructures. This green component not only delineates the pathway, but also ensures adequate visibility for both pedestrians and cyclists, enhancing safety;
- Phytoremediation—the water collected from impervious surfaces often contains significant pollutants. Therefore, the plant species selected for the rain gardens will also play a crucial role in phytoremediation, either inactivating or retaining these harmful substances within their tissues.

22. Mini static bio stabilization plant

A plant to produce soil conditioner/fertilization obtained through the static bio-stabilization of agricultural residues/by-products and animal manure is planned. The heap does not need to be turned over, and includes a special enzyme (patented) to which earthworms are added. This enzyme has the ability to prevent the proliferation of bad

odors. In the heap just described residues from "agriculture" can be used, but not fish stew; for a heap of fish stew, a special film can be obtained for domestic use.

23. Water houses

The project foresees the implementation of two water houses. These are public dispensers, where people can refill their reusable water bottles with clean, drinkable water. They are equipped with filtration or purification systems to ensure the water dispensed is clean, safe, and drinkable. Filtration may include UV light treatment, activated carbon filters, or reverse osmosis systems. By offering free or low-cost access to drinking water, they encourage proper hydration while reducing the reliance on bottled water and making hydration more affordable and accessible. The widespread availability of water houses contributes to the reduction in plastic pollution, and supports global efforts to combat climate change.

24. Aquaponic plants

These represent a middle ground between hydroponic plants (for vegetable and vegetable production) and aquaculture plants (fish production). They usually consist of tanks of water filled with fish in which polystyrene/plastic plates are placed with holes in them for the roots to draw nutrients directly from the water. The presence of fish serves to purify water, and their feces constitutes nourishment for the plants.

A medium-scale commercial plant is planned with the capacity to produce a significant quantity of fish and vegetables for local sale, including automated systems for monitoring parameters such as pH, temperature, oxygenation and nutrients. The time frame, including detailed design, construction work and the assembly of components, is estimated at 6 months.

Three additional non-tangible actions were identified during the process that will encourage citizen engagement and foster greater citizen participation.

25. Grow It Yourself

Grow It Yourself is an initiative aimed at encouraging the cultivation of products for the table on residents' balconies, terraces, gardens, and urban gardens. A series of digital workshops and monthly "ask the expert" sessions are planned to provide new farmers with the tools and knowledge necessary to succeed in the new activity. In addition, social eating events will be organized once a month, during which it will be possible to share the products of the citizens' own work.

26. Business Mentoring

Business mentoring is a program aimed at supporting local entrepreneurs, promoting sustainable economic development, and creating new job opportunities. It offers a support program for both new and experienced entrepreneurs to start, grow, and renew innovative and environmentally friendly businesses. It provides personalized consulting services to help entrepreneurs achieve their growth objectives.

27. Eco-Friendly Citizens

Eco-Friendly Citizens is a program designed to support local communities in becoming more sustainable by providing them with tips to reduce the waste and consumption of energy and water. Additionally, they will be guided in choosing products that are as environmentally and socially sustainable as possible.

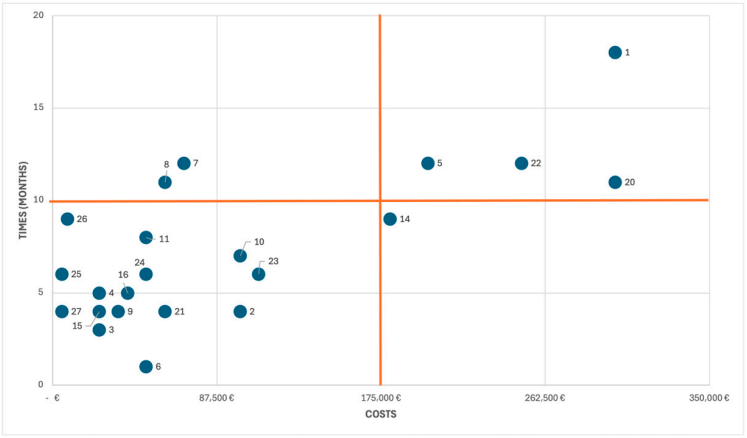
Each of these projects and actions varies significantly in terms of cost and implementation timeline. Following the estimation of these values, it was possible to categorize the projects into two macrogroups—those with an estimated value of less than EUR 1 million (Figure 8A) and those with an estimated value of more than EUR 1 million (Figure 8B). The costs and implementation times for both of these groups were further divided into four classes, thus resulting in eight clusters, as shown in Figure 8A,B. The result of the analysis shows that most of the projects (15 out of 27) are characterized by low implementation

costs and short lead times, while none fall into the opposite group, that is, characterized by high implementation costs and long lead times.

To assess whether the projects address the issues identified in the analysis, the SWOT points—representing a synthesis of the entire analysis—were compared with the projects selected for the final scenario using the matrix presented in Figure 9. It is evident that all aspects of the SWOT analysis have been considered, with projects either enhancing opportunities and strengths or addressing threats and weaknesses.

A

Projects	costs (€)	times (months)
1	300,000 €	18
2	100,000 €	4
3	25,000 €	3
4	25,000 €	5
5	200,000 €	12
6	50,000 €	1
7	70,000 €	12
8	60,000 €	11
9	35,000 €	4
10	100,000 €	7
11	50,000 €	8
14	180,000 €	9
15	25,000 €	4
16	40,000 €	5
20	300,000 €	11
21	60,000 €	4
22	250,000 €	12
23	110,000 €	6
24	50,000 €	6
25	5000 €	6
26	8000 €	9
27	5000 €	4



B

Projects	costs (€)	times (months)
12	3,000,000 €	18
13	3,500,000 €	34
17	6,000,000 €	10
18	4,000,000 €	12
19	1,200,000 €	10

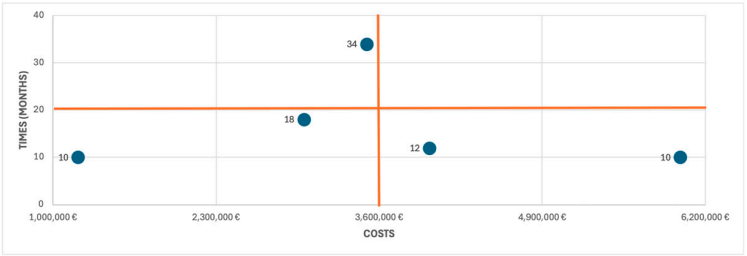


Figure 8. The clusterization of the actions/projects in terms of implementation times and costs. Source: Author's elaboration.

SWOT / Proj	Opportunities				Threats					Strenghts								Weaknesses									
	1	2	3	4	1	2	3	4	5	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10
1							✓	✓			✓																
2							✓	✓			✓																
3							✓	✓			✓																
4							✓	✓			✓																
5							✓	✓			✓		✓	✓	✓	✓	✓					✓					
6										✓																✓	
7										✓																✓	
8	✓	✓					✓				✓			✓													
9	✓	✓					✓	✓	✓		✓	✓	✓														
10	✓						✓					✓	✓		✓	✓											
11							✓	✓			✓		✓	✓	✓	✓										✓	
12																				✓							
13																				✓							
14			✓			✓	✓		✓						✓	✓		✓	✓					✓	✓	✓	
15				✓	✓	✓	✓		✓							✓			✓							✓	
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Figure 9. Relation between projects and SWOT analysis. Source: Author's elaboration.

4.5. Definition of the Integrated Scenario

To define the integrated scenario, a further, and final, meeting was organized, in order to choose which project to use in the final scenario and the localization of the different projects, and to design the new district landscape. This phase was critical to ensuring that planning solutions were effectively integrated, otherwise they risked exacerbating the neighborhood's isolation rather than promoting connectivity.

More specifically, the neighborhood was envisioned as a hub, serving as a "trait d'union" that connects the entire residential area to key territorial infrastructures—currently the very elements that delineate and segregate the neighborhood. After the experts presented the projects (features, implementation time and cost), the assembly decided to include all proposals in the final scenario.

With this vision in mind, the linear green was concretized in a new tree-lined corridor traversing Via F. Alziator, the neighborhood's main street, transforming it into a vibrant green promenade that connects to services associated with the Sant'Elia's guide project and the Cagliari waterfront. This diagonal corridor will intersect with access routes leading to the Sant'Elia promontory and Cala Mosca. To the north of the small neighborhood park, named after the esteemed historian F. Alziator, pathways will branch out towards sports facilities and a designated canoe launch and anchorage. This launch, planned at the entrance of the ancient canal that once fed the salt pans at the base of the Lazzaretto, is situated near the university's biology faculty, which has become somewhat isolated but was historically an integral part of the San Bartolomeo neighborhood. The area between Sant'Elia's Market and where the temporary stadium currently stands (Figure 10) will be the hub of the neighborhood after the new stadium is built.

Figure 10. Analyzed area. Source: Author's elaboration.

There will be a significant influx of people attracted by sports, recreation, commerce and leisure activities. The co-working facility will be built with a multifunctional structure (Figure 11 point 5), comprising the following:

- Co-working hub for digital start-up with spaces and workstations with ample light sources and common areas (to encourage communion between people with different experiences);

- Laboratory for smart cities and urban agriculture—a sort of "Think-Thank" formed by agronomists, engineers, architects, planners, experts in public procurement/partnerships/concessions, researchers, representatives of the productive world and administrators to redefine new parameters and solutions for the arrangement of the city and its relationship with the territory.

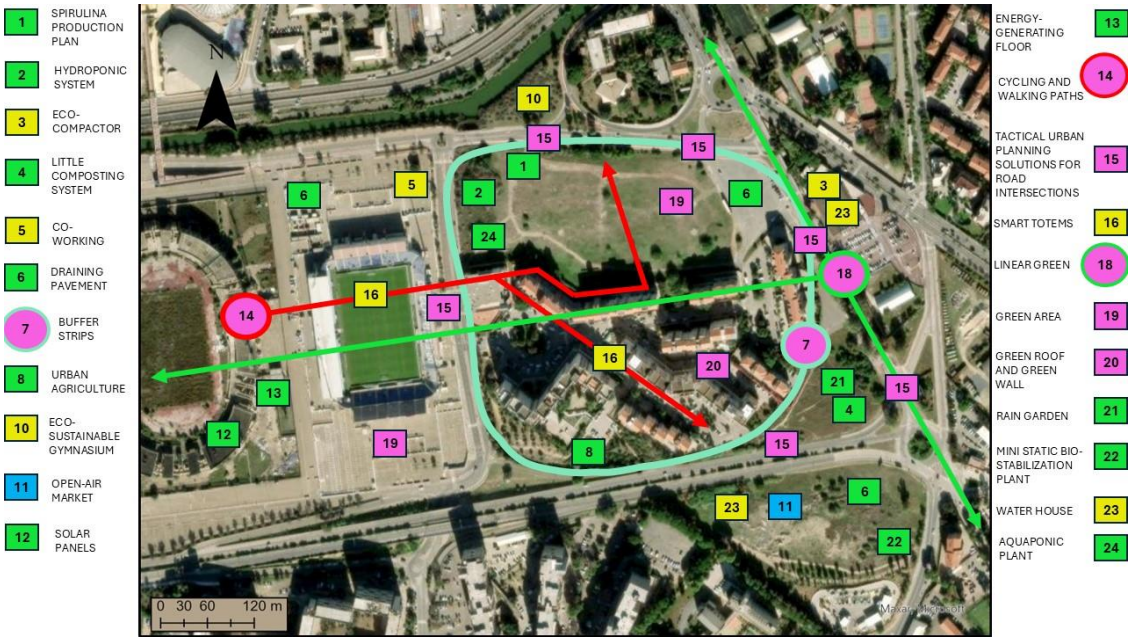

Figure 11. Localization of projects in the San Bartolmeo District. Source: Author's elaboration.

Figure 11 delineates a comprehensive set of sustainable and innovative urban interventions designed for the San Bartolomeo District in Cagliari, with the aim of fostering environmental resilience, enhancing urban ecosystems, and promoting community well-being.

In the northern sector of the district, a spirulina production plant is planned to support microalgae cultivation, offering a sustainable food source and environmental benefits (1). Horizontal photo-blasters will be placed, and the production can be sold on site in the producers' market. Adjacent to this area, a Hydroponic System is proposed to enable efficient, soil-free agricultural practices, enhancing resource optimization in urban farming (2). Central to the district, an eco-compactor is positioned (3) to facilitate advanced recycling and waste management processes. Complementary to this, a little composting system is situated nearby within a green zone (4), aimed at promoting the localized treatment of organic waste and fostering circular waste practices. A co-working space is strategically planned near residential areas (5), enhancing social interaction and supporting remote working opportunities. There will be a significant influx of people attracted by sports, recreation, commerce and leisure activities. A co-working hub for digital start-ups will include spaces and workstations with abundant natural light, as well as shared areas designed to encourage interaction and knowledge exchange among individuals with diverse expertise. The hub will also feature a laboratory focused on smart cities and urban agriculture. This laboratory will function as a "think-tank", bringing together agronomists, engineers, architects, planners, experts in public procurement, partnerships, and concessions, as well as researchers, industry representatives, and administrators. Its aim will be to redefine parameters and develop innovative solutions for urban planning and the relationship between cities and their surrounding territories.

Additionally, draining pavement systems are distributed across the district (6), improving water infiltration to mitigate urban runoff and reduce flood risks. Buffer strips are implemented along key pathways and open spaces (7), serving as transitional ecological

zones to mitigate pollution, enhance soil stability, and promote biodiversity. Toward the southern portion of the district, urban agriculture initiatives capitalize on underutilized land, enabling local food production while strengthening community engagement (8). In the area between Vespucci Street and Fiorelli street (currently unused), an eco-sustainable gymnasium, integrated with renewable energy systems, is also proposed. In this gymnasium, the equipment will be placed outdoors, and this will allow energy to be produced through use by the athletes.

A central open-air market is established as a hub for local trade, fostering economic activity and enhancing social cohesion (11). The open-air market, situated between Salvatore Ferrara Street and Borgo Sant'Elia Street, is proposed as an extension of the existing Sant'Elia physical market. This space will serve as a multifunctional hub for community gatherings and social interaction, offering opportunities to experience locally produced, zero-kilometer products derived from adjacent urban agriculture initiatives and gardens. Visitors will have the chance to enjoy a variety of offerings, including local and seafood dishes, emphasizing the district's focus on sustainable food systems. Due to spatial constraints on the current Sant'Elia market, this new area will host food services specializing in the processing and distribution of products from urban gardens, aquaculture and aquaponic fish farms, as well as nutrient-rich superfoods cultivated from seaweed production facilities. Additionally, the space is envisioned as a hub for food delivery and take-away services, offering prepared dishes made from resources cultivated within the urban area under individual protection schemes. To ensure sustainability, organic waste generated by restaurant, take-away, and food box activities will either be processed on-site in a designated waste management area, or transported directly to the wet waste platform at the district's little composting system.

In locations characterized by high solar exposure, photovoltaic solar panels are installed on the stadium structure (12) to generate renewable energy. This system is designed to meet the energy demands of the stadium itself, while contributing surplus energy to support consumption across the broader district. To harness kinetic energy, an energy-generating floor is integrated at the entrance of the stadium (13). This system is embedded within a cycling and walking path located on the western side of the district (14, 15), contributing to renewable energy production while promoting sustainable mobility. This path extends to connect various green areas (19), supporting active transportation and sustainable mobility solutions. Strategically placed smart totems at intersections (16) provide real-time information and serve as digital communication nodes. Linear green corridors are designed to interlink green spaces, improving ecological connectivity and offering shaded, pedestrian-friendly routes (18). The addition of green roofs and green walls to existing structures enhances thermal insulation and aesthetic value (20), while rain gardens are introduced (21) as bioretention systems to manage stormwater runoff naturally. On the district's southern edge, a mini static bio-stabilization plant is incorporated to enhance waste stabilization processes and optimize waste management (22). A water house is included as a sustainable solution for providing clean and accessible drinking water (23). Finally, at the center of the district, an aquaponic plant (24) merges aquaculture and hydroponic farming systems, exemplifying innovative agricultural practices that integrate fish farming with plant cultivation to maximize resource efficiency.

Figure 12 illustrates targeted interventions primarily located around a waterfront area, with key features situated near a canal, a parking lot, and surrounding green and recreational spaces. The draining pavement (point 6) is situated within the large, paved area in the lower-right quadrant of the map, which functions as a parking lot. This intervention is designed to manage stormwater runoff by allowing water to permeate through the surface, thereby reducing the risk of flooding and minimizing environmental impacts associated with impermeable urban surfaces. The buffer strips (point 7) are located along the canal, extending across a key bridge and forming a lateral green boundary. These strips act as ecological buffers, filtering pollutants from urban runoff before they enter the water and simultaneously providing habitats for plants and wildlife, thus enhancing local biodiversity. The kayak anchoring facility (point 9) is positioned near the canal's

waterfront, close to its entry point. This facility supports recreational activities by offering a designated space for non-motorized watercraft, such as kayaks, to dock. This promotes sustainable water-based recreation and eco-tourism within the district. The food hub (point 17) is in the southern section of the paved area, marked in blue. It serves as a centralized space for food-related activities, including local food production, distribution, and market operations. The hub fosters community engagement and supports the development of a sustainable and resilient local food system.

Figure 12. Localization of Waterfront Projects: Mapping Development and Impact Areas. Source: Author's elaboration.

During the last meeting with the population, an interaction analysis was performed to understand the "system effect" of the final scenario, and whether the various projects reinforce each other (Figure 13).

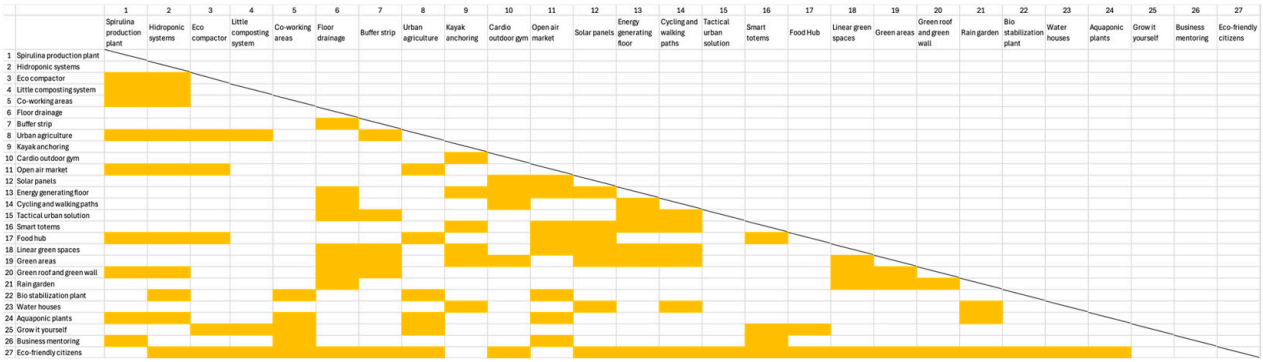

Figure 13. Interaction between project proposals. Source: Author's elaboration.

The result of the participatory planning project was elaborated in a 3D view, as shown in Figure 14, where today's situation (Figure 1) could be compared with the planned one.

Figure 14. The integrated scenario. Source: elaboration by Ferdinando Manconi.

5. Conclusions

The study highlights the critical role of urban green infrastructure (UGI) in addressing the multiple challenges arising from increasing urbanization, urban fragmentation, and climate change. In particular, UGIs provide an innovative framework for reintegrating isolated urban enclaves into their larger city context, fostering greater social cohesion, environmental sustainability, and climate resilience. Indeed, as evidenced in the literature reviewed, UGIs are key elements in defining ecosystem services such as the mitigation of urban heat islands, stormwater management, reductions in soil sealing, outdoor physical activity opportunities, and regeneration from the stress brought about by urban living. These principles and potential goals in urban green space planning are well defined in previous studies that have focused on certain variables such as the quality, quantity, access, systemic contribution, and interconnectivity of open green spaces [56–61]. In contrast to these, the article's contribution is in providing a holistic approach by highlighting how UGIs are able to reconstruct the relationships between landscape, open green spaces and urban functions interrupted by fragmentation (by which it is characterized), thus favoring processes of social inclusion, reducing inequalities and increasing access to green spaces for underserved communities.

The study then highlights the potential of integrating UGI and the solutions offered by new digital technologies. The two types of solutions are, in fact, expressions of two transformations taking place today, the ecological and the digital, which must necessarily act synergistically to achieve the common goal of sustainable development.

To achieve this goal, a citizen science approach was adopted that responded to the needs of citizens by integrating proposals coming from their experience and expertise, with solutions proposed by experts and/or applied in other contexts. The issues addressed in the case study can be used as elements of reference for the redevelopment of urban neighborhoods. The approach proposed in the case study of the San Bartolomeo neighborhood highlights how the needs of residents can be effectively addressed by transforming fragmented urban areas into more inclusive, permeable and sustainable spaces.

From an operational point of view, the adoption of a participatory approach appears more than convincing, in that it has resulted in the breaking down of social fences among residents by succeeding in creating a strong sense of identity and community, making the hypothesized solutions feel like their own. Although real data are obviously not

yet available in this case, such a dynamic has a predictable effect both on the future management of the projects implemented, which will see the community being an active participant in their protection, and on further initiatives that will be proposed, creating a virtuous circle geared toward continuous improvement. However, the process was neither simple nor linear. In fact, it has required quite some time, a lot of patience on the part of the experts, and continuous recalibrations to manage different opinions, to find points of contact, and to heal conflicts and entrenched beliefs. Continuous dialogue, the provision of all information and the support of experts capable of explaining in simple words the characteristics of the various solutions and the consequences of possible choices proved to be the key ingredients for the success of the participatory process.

From a methodological point of view, the main limitation of the participatory planning approach used is that it does not address the priority selection stage. The choice made by the community to include all proposed alternatives does not, in fact, allow the methodology to be generalized to cases where this does not happen. The time–cost ratio is only a first parameter, which must be accompanied by several others based on environmental, financial, and bureaucratic constraints, as well as those defined by social preferences. This could be solved through a multicriteria analysis that will become a decision support tool for both citizens and the administration. Another approach could be to define alternative scenarios by considering project alternatives as tiles of several possible mosaics. Projects could then variously participate in making up different integrated and interacting mosaics. Such mosaics would be composed of the complex actions capable of addressing the different challenges arising in the context.

From a replicability point of view, the set of topics covered includes the strategic objectives that must be considered for greater environmental, social and economic sustainability. The objective is to guarantee all citizens access to green areas, safe and inclusive public spaces, as well as access to basic services through actions capable of supporting and promoting the economic, social and environmental growth of communities. In this framework, the intangible or empowerment-based actions have a fundamental role, which is to accompany the cultural development of the residents by creating an interface between place and community, between anthropic space and nature, capable of fueling the creativity and participation of the residents, with an emphasis on well-being and harmony with the environment.

Finally, the analysis of the solutions adopted by the different Italian cities and of the Italian policy framework underscores the pressing need for enhanced coordination among local, national, and European policies to effectively support UGI implementation, in alignment with the objectives of the 2030 Agenda and European biodiversity strategies.

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Appendix A

Appendix A.1. Box 1—Modena

A platform has been created in Modena to make the city's green areas "smart", which can collect databases and information in real time and offer various features and predictive analysis and simulations, for example, on the variations in pollutants in the atmosphere based on the presence and consistency of green areas. The platform, which finds its regulatory framework in the Digital Plan 2020 of the City of Modena (approved last July by City Council Resolution 29/2020) and in the Three-Year Plan for Information Technology in PA 2020–2022 of the City of Modena (approved by City Council Resolution 803/2020), will support the city's various spatial planning tools (in addition to the Green Plan, the General Urban Plan—PUG, the Sustainable Urban Mobility Plan—PUMS, the PAESC formerly PAES—Sustainable Energy Action Plan), and will be fed by data generated by the public green maintenance service and external maintainers through field census, environmental sensor tools and city smart mobility tools (such as the one for monitoring traffic flows). Several functionalities converge in the platform; citizens can consult open data, map maps, and send reports; at the administrative level, an integrated system of spatial information data, budget data, deeds, contracts with suppliers, and maintenance certificates can be used; through the directional dashboard, decision-makers can consult the tree budget and make forecast analyses. One can dialogue with the platform through different interfaces—from the municipal portal or through dedicated apps, and thanks to a blockchain from the digital signature of the maintainer, plant analysis can be certified. In addition, thanks to the collaboration with ARPAE and the faculty of environmental engineering of the University of Modena and Reggio Emilia, the implementation of a network of sensors is planned, calibrating them for air quality monitoring in green areas.

Appendix A.2. Box 2—Florence

"Florence Green smart city" is a package of initiatives to combine the smart city with the environment. A set of interventions has been implemented thanks to European funds, structural funds, internal human resources in the municipality, technologies for the Internet of Things, and citizen participation.

- The SIVEP—Public Green Information System is a completely open source system that manages the entire process of public green maintenance, allowing us to deal with trees, green areas and their classification, rows, games, plants and hedges. In particular, it is relevant to tree planting, starting from the management of Visual Tree Assessment—VTA in a georeferenced way, and moving towards the production of a computer document for the management of the planting process. The system manages trees, green areas, street furniture, rows, playgrounds, plants, and hedges. Green areas are managed functionally at the sub-area level (sports area, dog area, play area, etc.). For each managed object, it is possible to add data for web publication regarding the equipment present. These data can be updated automatically through geographic reports, since they are themselves geographic archives. It is also possible to add images and movies, giving the citizen better and more up-to-date information.
- The "Donate a tree with dedication" project, included in the environment portal, allows people to donate and dedicate a tree to their loved one with a simple click. The web platform allows users to choose the type of plant to donate from 10 species considered compatible by the Environment Directorate for the chosen location. The plaque on the tree contains the name of the person to whom the plant is dedicated and a Qr Code that links to the dedication. The dedication can also be viewed online if the donor gives consent to view it. A heart appears on the web platform for each donated tree.
- The "A Tree for Every NewBorn" project aims to make it even clearer and more engaging for citizens to comply with the law requiring the planting of a new tree for every newborn. The system automatically and randomly links the new tree planted to

the tax codes of newborns. It is therefore not possible to choose the tree to be associated with the newborn, but it is possible to view the location of the tree associated with your son or daughter on the online map.

- Two "smart irrigation" systems have been activated in the new gardens at the former Galileo Workshops and Porta Leopolda. Dozens of sensors measure temperature, soil moisture and wetting, and through the cloud, they connect to the internet to take in weather forecasts, thus deciding how and when to irrigate. The data are also shared with citizens through information panels located in the two gardens that, via Qr code, will bring the information in real time to the smartphone. This system saves 30% of the water used to water the city's public green spaces, and optimizes environmental workers' inspections, resulting in reduced travel thanks to automatic leak detection, or the sending of alerts for faulty sensors and sprinklers.
- These data arrive in the "smart control room", where they are monitored not only by the city's technical directorates, but also by the utility companies that are involved in their activities on the "smart" gardens. Data on everything to do with city surveillance and management (traffic, garbage collection, street cleaning, public transportation) also converge in this hub, allowing better coordination between different departments, and more effective actions and services.

Appendix A.3. Box 3—Bolzano

The city of Bolzano, in partnership with the city of Lugano, has developed a portal for citizens to inform, in real time, about the status of greenery in the city in order to highlight the value of public greenery and how it contributes to more resilient urban environments, based on the belief that communicating with citizens about the environmental value of their city in a clear and immediate way is of particular importance, especially now, at a time when strategies are needed to cope with increasingly frequent heat waves, droughts, and extreme weather events. To implement the new portal in the two partner cities, the project pursued four specific objectives. Initially, a methodology was identified for collecting and updating urban green data, through which a detailed census of the elements in green areas was conducted. The good management of urban green areas, in fact, cannot disregard a thorough knowledge of the elements found within it. The new census provided detailed information on heritage, which allowed for a greater understanding of the true value of urban green; a snapshot of the heritage that has environmental, cultural, social and, last but not least, economic significance. From there, the GreenSpaces GIS information management platform was updated to implement the new data model and develop the functionality required to quantify the ecosystem services of trees and shrubs. This enabled the realization of the final goal of sharing the results obtained with citizens, and giving them maximum visibility through the creation of the Public Portal. The data are constantly updated on a daily and annual basis, thanks to the daily use of the GreenSpaces platform by the municipality's green care and maintenance technicians. On the portal, citizens can query the various elements that make up the urban green through the use of an interactive map. In addition to the species and ages of trees and shrubs, information is obtained on how plants contribute to mitigating the effects of climate change through CO_2 sequestering, PM absorption, and energy saving.

Appendix A.4. Box 4—Mantua

The Municipality of Mantua has developed a web app (mantovacittàverde) that offers citizens and tourists a timely and detailed view of the city's green areas. Thanks to an interactive map, information on tree heritage, parks, gardens and their accessibility, play areas, drinking fountains, benches, fitness equipment and dog parks is immediately usable. Added to this is an accurate collection of qualified fact sheets on trees and related environmental benefits.

The web app is constantly updated and enriched with information and sections aimed at highlighting the various benefits derived from the environment (ecosystem services),

such as oxygen production, the fixing of carbon dioxide, reducing pollution due to the ability of leaves to block particulate matter and ozone in the atmosphere, the mitigation of the urban heat island, increases in the permeability of city surfaces by limiting the effects of torrential rains on sewer systems, increases in the livability of the city, and the addressing of many needs for recreation, social relations and cultural growth. The platform is capable of providing a dynamic representation of urban greenery, ensuring that it is always better enjoyed and protected through access to timely knowledge of the environmental heritage and the use of innovative mapping and computer tools. The development of an app is planned that will allow visitors to green areas to report problems with equipment, unsafe trees, fallen branches, or other issues.

Appendix A.5. Box 5—Prato

With "Prato Forest City", the second largest city in Tuscany and the third largest in Central Italy by number of residents has developed a road map to promote healthy lifestyles through green infrastructure and the direct participation of citizens and businesses in the reforestation of neighborhoods, encouraging a recovery of sociality and livability even in the most marginal areas. This is also an approach that aims to change the perception of the city by the world, from a center famous throughout the world for its textile industry to an innovative model of urban restyling, capable of placing the ecosystem at the center of a new idea of the city of the future.

The reforestation will be carried out by ensuring that there are at least three trees visible from each home, with at least 30% tree cover in the municipal area and a maximum distance of 300 m from a green area to each home. Citizens can plant trees by making a donation on the pratoforestcity.it portal and obtaining a certification in exchange, with the possibility of monitoring the growth of the plant over time.

From all these initiatives emerges a concept of urban greenery also as a tool for preventive medicine, according to the typical principles of therapeutic gardens and forest therapy. There are already 30 areas designated for forestation, which will be launched on the crowdfunding portal 5 at a time, or 1 for each of the districts into which the city is divided, with the aim of encouraging territorial involvement.

A central role in the project will be played by the "Prato Green Hospital", an initiative designed to provide the hospital with new green areas of a level adequate to the importance and function of the place, with the aim of obtaining a significant increase in both the quality of hospitality and the environmental value of the area.

Another forestation project capable of opening up new spaces for socialization is "Another Declassata", referring to one of the main arteries of Prato's road system, which enacts a gutter function and suffers from traffic problems. In addition to the construction of a tunnel to double the carriageways, three areas surrounding the avenue will be redeveloped with forests and boulevards, with 414 trees and 37 shrubs of more than thirty different species, useful for reducing and absorbing the pollution produced by the 50 thousand vehicles that pass through the area every day.

Appendix A.6. Box 6—Messina

The ForestME project of the City of Messina acts via two types of interventions.

1. By implementing a Green Information System (Sistema Informativo del verde—SIV). This is a simple and user-friendly decision-support tool, consisting of point, linear and real layers, to which the different information useful to and necessary for the proper management of urban green areas can be associated, and which must contain essential information, such as, for example, the types of urban green, as identified by the Green Plan, water points or areas equipped with irrigation systems, the census of urban green, usable and sensitive areas (schools, hospitals, parks, dog areas, etc.), and existing constraints. The SIV also allows for the management of the activities of operators, for planting and for control (maintenance), as well as for the management of work teams.

The aims of the SIV are as follows:

- To increase citizens' knowledge and awareness, and increase and enhance their participation in the care and development of the city's tree heritage;
- To optimize the management of the city green by reorganizing processes from a full-digital perspective and with mobile technologies for public green operators;
- To make city green data and content available with open-data and webGIS interfaces.

2. Extending the monitoring domains of MeSM@RT (the Smart City platform of the City of Messina), implementing a new "vertical", "Smart Green", and thus increasing the tools available to enable the collection of data on the territory, and implementing, in the reference domain, new tools for monitoring the green infrastructure of the city. The Smart Green platform is configured as a new domain of the broader MEsM@RT, through which the administration will be able to do the following: monitor the spatial distribution of heat risk in different areas of the city through assessment tools, so-called heatmaps, capable on the one hand of signaling to the population the "coolest" areas during the hot periods of the year, and on the other hand of facilitating and optimizing planning by the administration for the mitigation of the urban environment; automate the control of water delivery systems in public green areas (e.g., parks and gardens), determining the correct volume of water for each type or tree species. The Smart Green platform makes it possible to deliver both information modules, via the WEBGis3D geoportal and through SIT, that allow the administration to monitor the different "layers" of interest, such as green areas, installed field sensors, heat islands, as well as "smart" components for managing the large amount of big data collected and tools used to implement the necessary dispositive actions.

Appendix A.7. Box 7—Milan

The ForestaMI project was born in 2018, with the idea that nature is a structural part of urban environments. Starting from the census and valorization of existing green systems, the project aimed to lay the scientific foundations for a strategic vision of the role of urban greenery in the Milan metropolitan area. In the first two-year period, 2018–2020, research activities focused mainly on the knowledge of the territory of the Metropolitan City of Milan. First of all, the state of the art of greenery was analyzed and evaluated, to arrive at the estimate of the tree canopy cover, or the percentage of surface occupied by tree canopies for the entire territory, equal to 16%. The study of urban voids led to the identification of the planting potential and to an initial identification of pilot projects. We also proceeded to define indicators useful for evaluating the impact of the project on the environmental system. The reconnaissance work continued in parallel with the consideration of all the active networks, national and international, in relation to the themes of climate change and urban resilience, in order to insert the Forestami project into a broader context and create a network. In the two-year period 2021–2023, research activities focused on four areas, as follows: mapping the development of the project in the metropolitan area, to carry out an assessment of the pre-established targets and the evolution of natural capital; studies on the impact of urban forestry on the health and psychophysical well-being of the population; research on the perceptions of the interventions held by citizens and stakeholders; communication and dissemination activities of the research and the project.

The specific objectives of the ForestMI project are as follows:

- Increase the tree canopy cover by 5% compared to the 16% of existing tree canopy in the Metropolitan City, which will make Milan one of the top cities in Europe and in the world in terms of its focus on tree canopy cover;
- Increase the biodiversity of plant and animal species in urban, peri-urban and agricultural areas;
- Reduce land consumption, thanks to the creation of green barriers;
- Increase green and blue infrastructures and ecological connections between the different parts of the metropolitan area;
- Enhance the existing green infrastructure (GI) heritage, systematizing all the green surfaces, large parks and PLIS of greater Milan through a large urban forestry project.

- Ensure inclusion and social cohesion through community projects for the redevelopment of the suburbs;
- Experiment in pilot areas with new models for the management and design of urban green areas;
- Reduce the average condition of air pollution;
- Promote the creation of shared and community forms of green management, both rural and ornamental;
- Reduce the "heat island" phenomenon, with a local temperature drop from 2 °C to 8 °C within urban areas;
- Increase the number and size of permeable soil surfaces that allow the reabsorption of rainwater (improvement of water run-off) and a reduction in hydrogeological risk;
- Reduce energy consumption dictated by air conditioning, setting the goal of reducing greenhouse gas emissions by 2050 (net-zero emissions 2050, C40 Cities);
- Reduce the average condition of air pollution (30 $\mu g/m^3$ of PM2.5n particles, 3 times the WHO1 safety level).

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