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Developing a Participatory Process for Soil Fertility: A Case Study in an Urban Area of Italy

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Abstract: Approaches that are transdisciplinary and participatory can help to address complex socio-ecological issues by integrating multiple disciplinary perspectives while taking into account the different needs and experiences of community members and other stakeholders. Despite this promise, such approaches are rarely applied within the scientific community, as researchers and public actors often lack the training, practice and reference cases required to handle the working relationships and translations of terminology, ideas and values across multiple bodies of knowledge. A case study described in this manuscript depicts a group of researchers, artists and citizens consciously engaged in the construction of a transdisciplinary process as part of a 40-day 'citizen science' experiment focussed on assessing soil fertility in the urban area of Milan, Italy. The group drew from recognised scientific approaches, applied agronomic methodologies, artistic practices and technological tools, integrating them into a hybrid process of collective and participatory inquiry. As a quantitative outcome of the experiment, a dataset of bio-chemical parameters was generated, which was enriched by agronomic interpretations but also by artistic and reflective materials. Importantly, the process developed transdisciplinary and participatory skills, as it created a potentially replicable procedure of engagement, analysis and presentation for use in other citizen science settings. This article presents the context, the multiple objectives of the research and the applied approach and its timeline. Described in detail are the process of designing and conducting the experiment by involving an extended research community—including both junior and senior researchers—in progressive steps. Quantitative and qualitative results are provided. The findings are meant to contribute case material and methods to inform the advancement of transdisciplinary research approaches within the scientific community as well as examples of ways to transcend the boundaries of science to include artists and community stakeholders. The aspiration is to inform and inspire concrete application of transdisciplinary and participatory methods in concert to address complex socio-environmental challenges.

Keywords: transdisciplinary research; citizen science; urban soil; citizen involvement; local knowledge

1. Introduction

All major challenges facing the current century, whether they are ecological and environmental or socio-cultural and geo-political, are too complex to be adequately tackled by individual disciplines alone [1]. The degradation of ecosystems, the depletion of natural resources, food insecurity, rising energy demands and the increased frequency of severe weather events caused by climate change point to social, economic and ecological issues that are intertwined, often conflicting and contributing to the worsening of social conditions and political tensions. They all require complementary knowledge and diverse perspectives, spanning ecological systems, society and governance, in order to inform and impact decision-making [2,3]. Therefore, a transdisciplinary approach can play a vital role in addressing the phenomena under study [4,5].

Transdisciplinarity can be viewed as both an epistemological and an operational approach that transcends boundaries among disciplines, and fosters connections among different types of knowledge, across scientific and non-scientific communities [6,7]. Transdisciplinarity involves thinking laterally and imaginatively, reassessing the factors that need consideration from various and different perspectives [8]. To this end, the contributions from the arts and humanities are in some circumstances welcomed and integrated to foster deeper awareness of ways of thinking beyond the linear and reductionist approaches that are characteristic of Western modern science and to bring forth modalities of being and knowing that are situated, contextualised, embodied and directed towards the needs of human and more-than-human communities [9].

Furthermore, this emphasis on including different disciplinary perspectives can be extended to encompass practices such as Participatory Research and Citizen Science (CS), which also have high potential for building a deeper integration of knowledge and skills. Albert et al. (2023) [10] suggest that both CS and transdisciplinary research can address not just the analytical and social dimensions but also the ethical dimension by recognising the complex intertwining of disciplines and by developing solidarity among people. Consequently, they help to overcome disciplinary protocols and move goals 'beyond' customary scientific standards. In fact, they claim a constructive encounter among individuals, local communities, policymakers, educators, scientists and experts from different disciplinary fields, possibly with different roles [11,12]. Depending on the level of involvement of different stakeholders, CS may foster communities of both interest and action in which the research questions and the methodologies stem from multifaceted expertise and interests incorporating local knowledge and perspectives [13]. Power dynamics in CS have long been studied; scepticism about policymakers' willingness to consider citizens' perspectives is expressed, and the often-asymmetric relationship between scientists and citizens is emphasised. While scientists decide aims and activities at the outset, citizens are seen as mere executors. More recently, there has been greater recognition of the need for equal engagement and increased citizen participation in decision-making about the methods and objectives of the research [14]. Moreover, CS, increasingly applied by the scientific community and policymakers in the context of environmental and land issues, holds significant epistemological value within the framework of Post-Normal Science (PNS) [15,16]. PNS promotes the creation of 'extended peer-research communities', which include a wider range of stakeholders, each bringing a partial yet legitimate perspective. Both the aim and the challenge of PNS approaches is the idea of open dialogue fostering mutual learning despite different disciplinary backgrounds and the ability to address conflicting interests and value disputes. In this sense, both the PNS and participatory approaches can contribute to generating relevant and responsible knowledge practices [17] and well complement the transdisciplinary approach because of their common ability to tackle complex and 'wicked' problems [8].

This article reports the experience carried out in Milan, northern Italy, within the research project BRIDGES—Building reflexivity and response-ability involving different narratives of knowledge [18]—the goal of which is to develop tools that support responsible and participatory scientific research in the Italian context. This aims to tackle complex socio-ecological problems that hold personal and collective relevance.

Specifically, the BRIDGES project developed transdisciplinary and participatory research, informed by CS and PNS, by involving academic and nonacademic expertise, local knowledge and artistic research practices to face the fundamental concern of urban soil fertility.

Soil fertility represents a complex and contentious matter entwined within the current global socio-ecological health crisis. Soil fertility is a topic of local and global interest; its management and protection imply a series of new relationships and visions between science, society, ecosystems and human and non-human actors. The main causes that are currently leading to the loss of soil fertility are of anthropogenic nature, such as deforestation and the overexploitation of vegetation, the practice of monoculture cultivation, overgrazing and the indiscriminate use of agrochemicals and heavy machinery. Soil fertility impacts various aspects of sustainability including economic, social and environmental dimensions, as reflected in the Sustainable Development Goals. Fertile soil is also important for food production, aligning with the Food and Agriculture Organization (FAO) goal of zero hunger. It provides plants with all the nutrients they need for human health. Furthermore, soil fertility significantly impacts many economic activities, economic growth and efforts towards poverty alleviation. Moreover, good soil fertility management can help reduce pollution in soil, water and air; regulate water availability; support a diverse and active biotic community; increase plant cover; and enable a carbon-neutral footprint [19]. Finally, the fertility of soil has important implications for landscape management, social activities, public health and well-being. Among the many initiatives undertaken to protect soil at the national and supranational level, it is worth mentioning the public consultation on soil fertility launched in 2022 by the European Community [20]. The EU focus has been on maintaining soil health while minimising environmental damage caused by excessive fertilisers. This includes reducing land degradation, conserving and increasing soil organic carbon stocks, reducing soil pollution and preventing soil sealing. To this end, it aimed at involving diverse fields of knowledge and actors from national, regional and local authorities; European, international and multilateral organisations; relevant economic operators such as landowners and users; civil society; research; think tanks; and academic institutions [20,21].

These considerations make soil fertility a paradigmatic and complex problem to be addressed within a transdisciplinary approach and thus motivate the choice of this topic as a case study of the project.

It must be highlighted that the participative experiment—which is the focus of this paper—had both specific goals and broader aims. A first specific objective was to start collating a set base of data and knowledge useful for communities and administrations tasked with taking care of urban soil. As detailed in the following sections, this objective was mostly addressed through participatory CS activities [22]. A second objective was to offer a training opportunity for young researchers and public actors to practise participatory and transdisciplinary research in the context of a concrete case. Thirdly, the study overall was a social experiment aimed at developing a methodological process, supporting transdisciplinary and participative practices. From a broader perspective, the project sought to investigate the possibilities for building a collective and care-oriented understanding of soil fertility, conceived as an encompassing concept incorporating not only its biophysical components but also its socio-economic, ecological and relational dimensions: from its historical evolution to the different economic and administrative purposes it served and the ecological relations that characterise a landscape, including both human and non-human communities. All these aspects are interdependent and inevitably contribute to determining the state of the health and sustainability of urban soils. Enabling local social actors and scientists to act as an extended research community can potentially make for more effective ways to preserve the fertility of urban soils through mutual accountability and shared responsibilities. So, two main research questions guided this study:

To what extent can a transdisciplinary and participative approach be enacted to support a rich set of practices and narrations addressing the complex socio-ecological issue of urban soil fertility?

What procedures and tools are effective in fostering collaboration between scientific disciplines and society on these issues?

The following section illustrates the context of the experiment and the methods applied in its performance. Subsequently, this article describes the original methodological implementation, that is, the process purposely developed for building the research community and the participatory activities, from the iterative design to the field operations. Then, it describes the performance of the experiment by delving into its main activities and synthesising its main achievements. Finally, it provides a critical examination of the process that occurred, the tipping points encountered and reflections on the lessons learned. In response to the described objectives and research questions, the experiment produced both elements of quantitative knowledge on the fertility parameters of the local soils analysed and qualitative insights into the ongoing dynamics between soils and the subjects involved. More than anything else, however, the experience enabled outlining a path for the practical application of a transdisciplinary and participatory approach in a specific local case. This process represents one of the main results of this study. The methods applied here can be revised and adapted for different research topics and in different local contexts, offering both educational and training opportunities as well as operational suggestions to communities and interested experts.

2. Materials and Methods

In this section, the physical and spatial setting of this research (Section 2.1) and the methodological principles adopted in the design of the participatory experiment (Section 2.2) are presented while keeping separate the strategies adopted for building the research community from the scientific and technological components used in the execution of the data collection activities. Next, the methodological steps involved in the implementation of the social experiment (Section 2.3) are detailed, and its evolution and specific component activities are highlighted.

2.1. Study Area

Milan is the largest and most densely populated urban settlement in northern Italy (more than 1.3 M inhabitants in the city area and more than 3.2 M inhabitants in the metropolitan area) and the country's main post-industrial city.

In 2020, the metropolitan area of Milan exceeded 10,500 hectares of artificially covered land, corresponding to 32% of the total area. Of these, 217 hectares fall in protected areas and 695 hectares fall in areas with high hydraulic danger [23]. The intensity of the urban sprawl has brought up environmental and health problems (for example, poor air quality and the consequent high rate of respiratory diseases) but also rising economic inequalities and the loss of historic social ties as a consequence of the displacement of the middle classes towards the peripheral neighbourhoods. Despite the expansion of the urban agglomeration and its myriad socio-environmental challenges, large areas of cultivated land or lawns persist in the city outskirts, some safeguarded by public administrations while others are protected and recovered from industrial settlements, thanks to the efforts of city associations [24]. In fact, Milan has a rich tradition of environmental and voluntary associations, and, in the last decade, numerous small participatory projects have originated from the initiative of active citizens who got together to create social bonds and increase their mutual support networks but also to take care of the neighbourhood.

Starting from the early 2000s, local institutions have promoted policies and initiatives in support of urban agriculture, urban farming and urban food gardening. These practices contribute to restoration and recovery actions, to foster the maintenance of both the agricultural heritage and the historical landscape system, to support the creation of networks among citizens and farmers and to encourage their involvement in the preservation of traditional agricultural techniques [25]. 'Carta of Milan', the city's strategic environmental plan, recognises 'green infrastructure' as the best way to achieve environmental targets, promote social development and improve social welfare. The city of Milan implements different nature-based solutions as part of its architectural and urban renewal strategies [26]. Urban Gardening, for example, plays an important role in the city by involving people in the management of urban green spaces. Green urban areas, in particular public parks, gardens and urban forests, are created for multiple purposes. Green urban areas provide Milan with important ecosystem services, while Green Rays and Green Belts are meant to connect the green areas using pedestrian/cycling green roads. The city of Milan currently includes more than 10.4 km^2 of parks, 909 play areas, 391 areas equipped for recreational use and 354 areas suitable for dogs (data updated to 2021) [27].

Over the past decade, the evolution of these practices in Milan has been analysed from environmental, social and cultural perspectives, and relevant areas have been mapped and investigated [28–30]. The convergence of many socioeconomic and environmental challenges, along with organised citizen groups interested in the potential of these areas, makes Milan an ideal case study for the experiment.

2.2. Methods Used for Building the Research Community and the Participatory Activities

Opting for a transdisciplinary and participative approach to address soil fertility entailed the consideration of specific design features that needed to be incorporated right from the beginning of the study and the selection of a set of methodologies and tools to support participatory research, as described below.

2.2.1. Involvement and Training of Participants

Since its official start in April 2021, BRIDGES could count on the endorsement of diverse active citizenry groups, willing to play their part for a better quality of life and showing interest in the project's research and outcomes. Local associations with environmental, agricultural and social interests had in fact been contacted from the outset since early 2021, in the initial stages of proposal writing. Through a snowball sampling approach, numerous volunteer networks and private citizens approached the project and expressed an interest in joining participatory activities planned for the following months.

In January 2022, the project envisaged the launch of an extended survey—the description of which is beyond the scope of this article—addressed to Italian researchers in the early stages of their careers. The survey reached about 2000 people and was answered by 810. Of these, 78 reported an interest in taking part as volunteers in the next phases of the project. These were then invited to participate in subsequent training events for the purpose of selecting a core group of young researchers to join the original research team to participate in a social experiment of transdisciplinary research (more detail in Section 2.3.1).

The selection of participants for extending the research community aimed to be representative of diverse interests, educational backgrounds, scientific disciplines and personal characteristics (including age, gender and geographical origin). In practice, this objective was balanced by the opportunity to welcome subjects who voluntarily proposed themselves, such as networks of local citizens and associations interested in soil fertility, bringing strong motivations and valuable knowledge.

Motivation to participate was particularly important. While it was necessary that the motivations to participate were strong and rooted, it was equally right and healthy that the motivations were different among the community of participants. Motivations could be linked to personal interests or to the needs of a local community or to study and work reasons. This diversity was beneficial for the project because it shed light on the many facets of soil fertility.

A summary of this information about the participants in the experiment is provided in Figure 1.

	participants	working area	main interest	place of living	gender	age (estimation)		
ORIGINAL RESEARCH TEAM	21	14 scientific res. 2 artistic res. 1 transdisciplinary res. 4 business	4 science communication 3 agronomy 2 artistic research 2 statistics 2 biology 1 transdisciplinary res. 1 science education 1 sociology 1 animal science 1 forest ecology 1 geographical information 1 Citizen Science 1 RRI	5 case study area (Milan) 10 north Italy (not Milan) 4 central Italy 1 south Italy 1 out of Italy	14 f 9 m	12 over 50 8 over 30 1 over 20	EXTENDED RESEARCH TEAM	EXTENDED RESEARCH COMMUNITY
EARLY RESEARCH CAREER VOLUNTEERS	16	16 scientific research	1 landscape architecture 1 philosophy of ecology 1 environmental ecology 1 RRI 1 plastics 1 sewage purification 1 anthropology 1 digital ontologies 1 food philosophy 1 agronomy 1 computational ecolinguistics 1 marine biology 1 spatial data infrastructures 1 urban geography 1 territorial governance 1 marine ecology	4 case study area (Milan) 8 north Italy (not Milan) 2 central Italy 2 south Italy	9 f 6m 1 not binary	7 over 30 9 over 20		
LOCAL VOLUNTEERS	85 (estimation)	6 associations 3 public bodies groups of citizens	2 education (higher, childhood) 2 recovery, renaturalization 2 social promotion and farming 2 sustainable cultivation techniques 1 cultural promotion 1 territorial protection 1 urban horticulture 1 scientific research	case study area (Milan)	balanced (estimation)	16 over 50 17 over 30 11 over 20 41 under 20		

Figure 1. Summary of the characteristics of study participants: spread and number; biographical information; personal interests; and areas of work. Some information is estimated.

The research community's varied backgrounds were also considered during both the design of the procedures and the selection of the tools to ensure satisfactory data quality. The very concept of 'satisfactory quality', which is related to the concepts of 'fitness for use' and of 'fitness for purpose' [31,32], was defined together with the community to respond to the different needs expressed by the group.

The project team established suitable data collection procedures to address the qualitative and quantitative objectives, ensuring their robustness and concurrently fostering a transdisciplinary, knowledge-sharing process.

Specific training was designed to accommodate different community backgrounds and legitimate interests. This was achieved by offering multiple interaction channels (e.g., webinars and face-to-face meetings, theoretical and practical activities, the sharing of relevant literature, digital edutainment proposals, etc.) and diversifying the topics of discussion, according to the requests of the group.

Finally, it was also important to give recognition to the value of voluntary contribution. Very often, when designing CS activities and contributory collections, the project team envisages reward mechanisms for volunteers to foster their motivation [33,34]. This is typical of top–down approaches. In a participatory project instead, when a research community plays an active part in defining research questions and tools, recognition is deserved for both the commitment and time dedicated, as well as the intellectual contribution [35]. Both the analysis of the results and the scientific merit of the work were thus shared with the research community. For the same reasons, the experiment's participants were also the protagonists of co-hosted webinars; they received certificates and had the opportunity to discuss the project topics at conferences and public meetings. Their profiles can be found alongside those of the original research team on the project website. Also, community members have been invited to participate as co-authors in writing research products.

2.2.2. Collection and Management of Quantitative Data

Due to the transdisciplinary nature of the project, the connections between the activities are of great importance. Researchers from different backgrounds purposely designed hybrid activities, combining different approaches, coming from natural sciences, social sciences, geo-information sciences and artistic and educational practice, with multiple objectives. Specifically, in the operational phase of the experiment, two main methodologies were used to gather quantitative information on the presence and viability of the microbial communities in the soils, which are strongly correlated with their fertility: NIR-litterbag analysis and metagenomic analysis.

- The NIR-litterbags analysis consists of the burial, monitoring, extraction and description of litterbags (small net bags with standardised straw content), functioning as biological proxies, which were then subjected to the following laboratory analysis with a near-infrared (NIR) technique. The analysis of litterbags makes it possible to determine the soil microbial fingerprinting and, from this, to extrapolate numerous parameters related to its chemical and microbiological characteristics. From the NIR-litterbags analysis, it is also possible to obtain predictive information on the state of health of a soil and on the estimated rate of productive yield. The participative monitoring of similar biological probes, aimed to measure the decay rate of plant materials, has been carried out in international CS projects such as in the TeaBag project [36], in which volunteers worldwide were called to bury tea bags and report qualitative observations after three months. In BRIDGES, agronomists from the research team proposed to perform the NIR-litterbag analysis with a CS approach, aimed at collecting evidence of microbial activity in different urban and peri-urban soils, as a proxy for their biological activity and diversity.
- A metagenomic analysis is a mass sequencing technique on the total DNA that can be extracted from an environmental soil sample [37]. The statistical analysis of the DNA sequences allows for identifying the presence of taxonomic groups and finally to elaborate biodiversity indices, relating them to soil management methods, environmental conditions and cultivation systems [38]. The activity was proposed by the biologist members of the research team, and the experimental design was completed in conjunction with the agronomists.

Generally, in CS projects, participants are called upon to contribute observations of various natures by the aid of ICT tools, which have the dual function of both providing a user-friendly interface to guide the creation of 'high-quality' observations and uploading the data in a database managed at the server side. This way, data analysts can query the database in real time to monitor the status of the observations and, in the data analysis phase, can perform quality-based filtering and analysis on the collected data.

In the scientific and technical literature, there are several meta-tools that aid technicians to develop web applications, both proprietary and open source. In BRIDGES, it was chosen to use the open-source KoBo Toolbox software toolkit [39] (version 2.022.16) to develop a web application, named Soil_mAPP, dedicated to the collection of field observations relative to the NIR-litterbag experiment and enabling their easy management and sharing.

2.3. Implementation of the Urban Experiment

The following subsections describe how the methodological approaches illustrated above have been implemented in BRIDGES.

2.3.1. The Process

Since its inception, the transdisciplinary research experiment was designed as an iterative process of reflexive adaptation and re-elaboration. It was initially drafted in the proposal by the project research team—mainly composed of scientific researchers, professional agronomists, educationalists, science communicators and artists—and then proceeded hand-in-hand with the expansion of the research community. Part of the research process therefore also included the progressive definition of the research community and an assessment of the strength of its participatory activities. The iteratively designed elements also included training and knowledge exchange activities, defined as a response to the increased awareness of the group's social dynamics and needs. The main steps and iterations are shown in Figure 2.

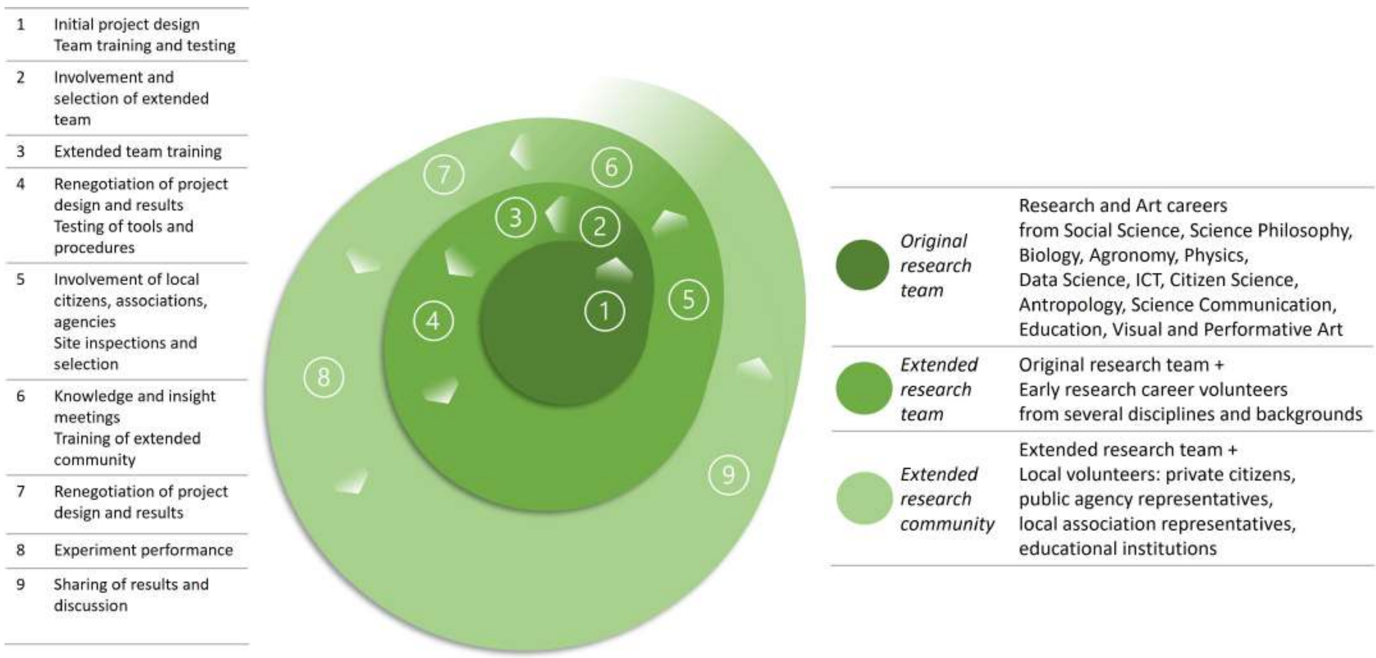

Figure 2. A synthetic diagram of the steps implemented for the building of the community and participatory activities in the BRIDGES project. On the right is the colour legend describing the participant groups.

The diagram shows the progressive enlargement of the research group in different shades of green. In the first turn of the spiral, the original nucleus of researchers and artists, named hereafter the original research team, is joined by a group of volunteer early career researchers from diverse academic backgrounds. As anticipated in Section 2.2.1, a number of early career researchers came into contact with the project for the first time in January 2022 during a large national survey, at the end of which they reported their interest in following and/or being directly involved in the subsequent phases of the project. A selection of them, from May to July 2022, participated in thematic workshops and in a week of training and operational field activities held in the artist residence Pianpicollo Selvatico, together with the original research team. Throughout that week, the project objectives and methods were collectively tested and re-assessed. Subsequently, the extended research team, as it is named hereafter, collaborated in carrying out the following activities, albeit with different roles and based on individual propensity/availability, guided by the project's objective to build a transdisciplinary community.

In the second turn of the spiral, the activities planned as an integral part of the urban CS experiment were presented and proposed to local associations, groups and individual citizens who had shown interest during the previous phases of the project. Some of these include three public bodies, two educational institutions, six associations/communities of citizens and three private groups of citizens. This group, combined with the extended research team, forms what will henceforth be called the extended research community. Most of these subjects had an interest in the recovery of the urban and peri-urban areas of Milan; in urban agriculture, gardening and horticulture; in agricultural production for commercial and self-sustaining purposes; in landscape enhancement; in ecosystem protection; and in environmental monitoring as well as socio-cultural development, education and training in the ecological and agronomic fields (see also Figure 1 for a synthesis).

Figure 2 also summarises, using progressive numbers, the main steps that characterised the planning and development of the urban experiment. They are briefly described below.

1. The original research team discussed methodologies, contents and objectives and sketched the project proposal. From the winter to spring 2022, it carried out self-training courses to enhance the understanding and integration of the different methodologies and approaches of the group members.
2. In the winter 2022, a group of Italian researchers in the early stages of their careers, recruited through a survey, joined—as volunteers—the project and were invited to participate in training events.
3. In the spring and summer 2022, the extended research team took part in two training events: a workshop, focussed on the contribution of transdisciplinarity to knowledge production vis a' vis complex, socio-environmental problems and a one-week research residency focused on exploring artistic research methodologies. The residency included theoretical and practical activities focused on soil fertility issues, addressed in its socio-ecological, artistic and cultural complexity, borrowed from a performative arts approach, and integrating the contributions of the various disciplines and experiences represented, with special guidance by the artists members of the original research team.
4. During this research residency, the project objectives and the methods proposed to achieve them were actively experienced, discussed and re-negotiated by the group. The participatory tools and activities designed by the original research team leading the urban experiment were field-tested and reviewed by the extended team.
5. The organisations and citizens of Milan who had previously expressed interest in the project were contacted in the summer 2022, and the first site inspections and follow-up meetings were held. During the meetings, the mutual interests and objectives gradually became clearer, as well as the capacity of the sites to welcome the scheduled analyses. A dozen urban and peri-urban areas were identified for the field CS activities. They included public parks, association-owned terrains, scholastic institutions' and private citizens' green areas, targeted by preservation or recovering programs, leisure, cultural, gardening, social horticulture and agriculture activities.
6. Numerous individual exchanges and a collective meeting were held in Milan, in which the whole extended research community discussed the theoretical and scientific bases of the urban experiment, as well as their own individual motivations and expectations.
7. The extended community planned the urban experiment: the exact sites of investigation, the working groups, the activity calendar and the operating procedures were agreed to on a participatory basis. Adjustments were made to the activities schedule to better match the needs and interests of the participants.

8. The urban experiment took place according to the agreed timetable in mid-September 2022. It entailed the integrated execution of a set of activities by the extended research community over approximately 40 days.
9. At the end of the 40-day time range, the original project team executed the laboratory elaboration of the parameters from the biological probes and the soil samples collected, interpreting them thanks to the detailed observations reported by the community during the 40-day period. All the results were finally shared in June 2023, discussed and enriched with the extended research community.

2.3.2. The Activities

As anticipated in the previous section, the strictly operational part of the urban experiment took place in a 40-day time range during which the extended community was involved in participative activities. The activities here below are grouped into three main categories, depending on their main objective: (1) data collection, (2) reflection on soil fertility and (3) interaction and communication (Figure 3). Nonetheless, as mentioned earlier, the activities were specially planned to hybridise different methods and approaches from multiple disciplines.

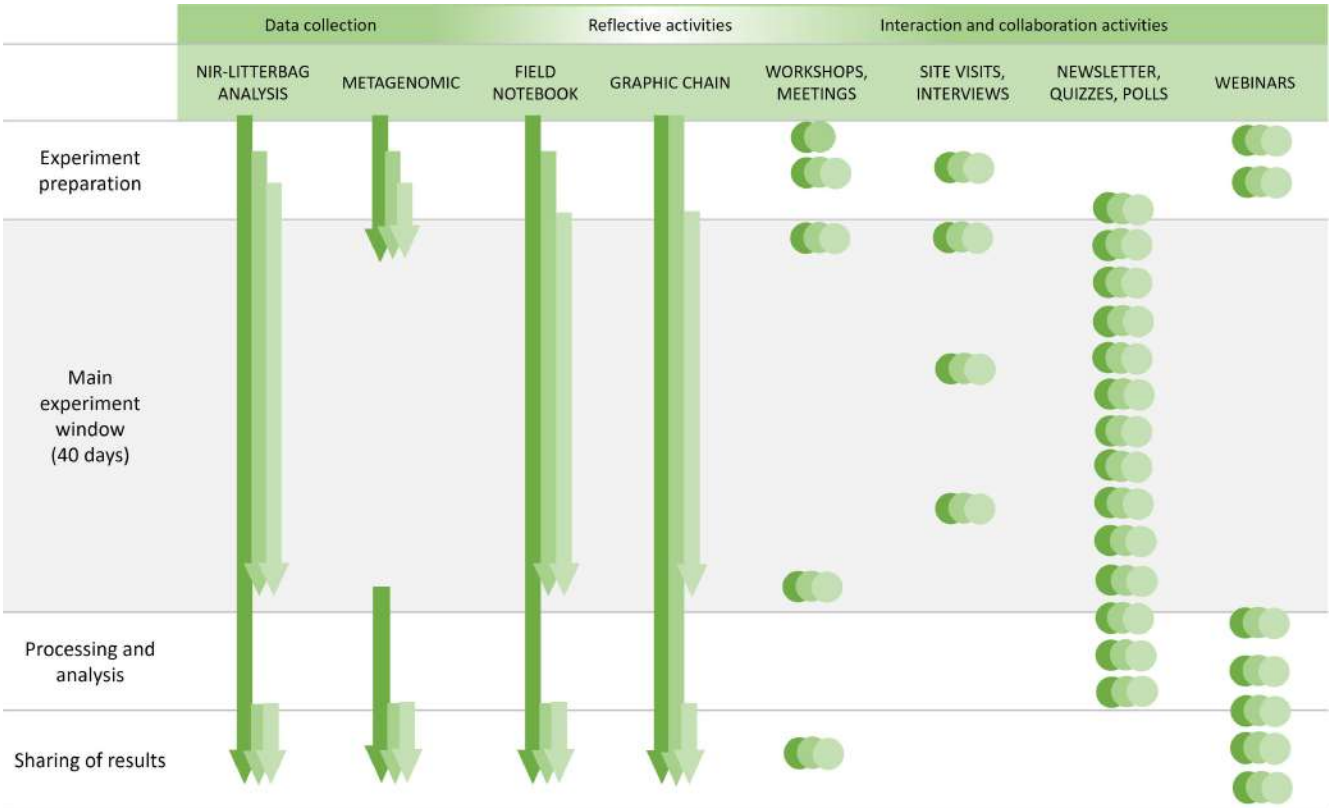

Figure 3. A summary representation of the activities carried out during the urban experiment and their implementation steps. The shades of green (refer to Figure 2 for the legend) indicate which groups in the transdisciplinary team took part in the activities.

The collection of the data from the soils and the observational and reflective activities, for example, were designed to be concurrent by following the same calendar and the same flow of investigation, albeit with different tools. They both involved the community in the production of measurements, those being in the more extended form of textual observations as well as through photographs or with the inclusion of graphical elements. Likewise, the interaction and communication activities were concurrent, aiding the data collection process through periodic updates, both in-person and via online meetings as well as through edutainment formative activities.

Data Collection Activities for Soil Fertility Assessment

- NIR-litterbags analysis: The methodology (Section 2.2.2) was developed as a CS activity and adapted to the study context by the original research team. The web application called Soil_mAPP (Section 2.2.2) was implemented to support the participatory recording of local observations during the burial, incubation and unearthing phases of the litterbags while maintaining the consistency of the dataset. The extended research team, during the research residency in Pianpicollo Selvatico, tested and reviewed both the activity and the web application. The group also provided tutoring to local volunteers in the preparatory and operational phases of the experiment. At the start of the 40-day time range, local volunteers buried a total of 207 litterbags at 69 different sites in the urban and peri-urban areas of Milan, marking them with landmarks. A triplet of litterbags was buried at each single landmark so as to cope with possible losses. The community performed the litterbag monitoring, reporting, digging and drying according to the given schedule (Figure 4). Agronomists from the original research team then executed the NIR laboratory analysis. The results of the analyses were finally presented and discussed with the whole community.

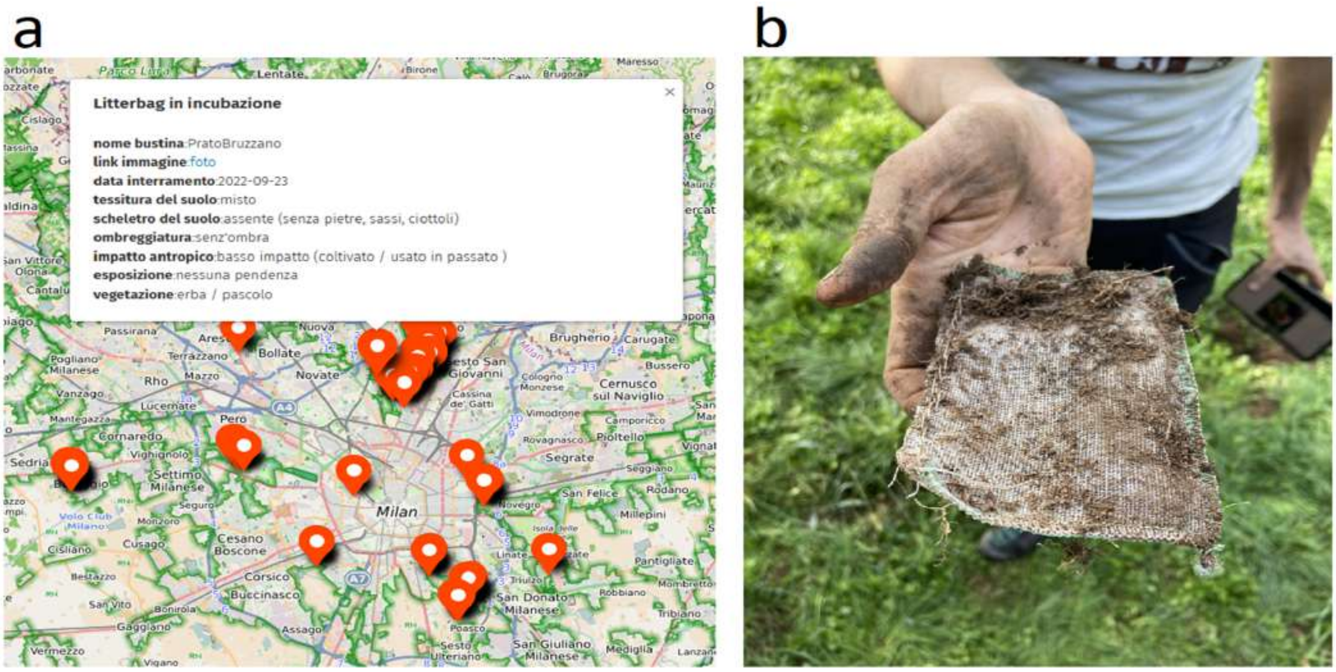

Figure 4. A map of the litterbag burial sites in Milan, as surveyed by the Soil_mAPP, showing an example of the scheduled observations entered by the participants at the time of burial (in Italian language) (**a**), and a litterbag at the time of unearthing (**b**).

- Metagenomic analysis: The extended research team, during the research residency in Pianpicollo Selvatico, performed soil sampling (in a rural area) to learn the methodology and to create a dataset for comparison. The researchers reviewed the experimental design together with the local communities to identify the most suitable sites and to schedule the soil sampling (Figure 5). The specialists from the original research team, together with the local participants, performed the soil sampling on the sites in Milan. The researchers then conducted the laboratory analyses and compared the results with those of the NIR analyses obtained at the same urban sites. The results were finally shared and discussed with the entire extended research community.

Figure 5. Images from the sampling and sample preparation steps for the metagenomic analysis.

Reflective Activities on Soil Fertility

- Field notebook: The visual artists of the original research team proposed to create a personalised field notebook to accompany the 40-day experiment with suggestions for practical activities that stimulated reflection and exchange within the extended community (Figure 6). Members of the extended research team voluntarily contributed to the notebook by proposing textual and visual material and evocative activities. The notebooks were distributed to and used by members of the extended community during the 40 days. A simplified digital copy was made available on the project website for more people to print and use. The activities of artistic research in-action led by the artists further involved the community during dedicated workshops and meetings and deepened the suggestions of the notebook.

Figure 6. Images from the field notebook.

- Graphic chain: An interactive activity was proposed by a member of the extended research team to involve the whole community in the processing and exchange of photographic, graphic and textual material. The activity focussed on the interconnections between the soil fertility, natural aspects and artefacts they observed while recording their observations on the study sites. The contributions exchanged between the participants were tracked and presented to the whole community at the end of the experiment.

Interaction and Communication Activities

- Workshops and meetings: Two main workshops were organised in the preparatory phase by the original project team, dedicated to consolidating the extended research team and the extended community, respectively. During these workshops, the training and redefinition activities of the experiment were carried out. A third meeting was proposed by a member organisation of the extended community at the urban park they manage. The event was designed together by members of the research team and the local community. During the workshop, which officially kicked off the 40-day experiment, the litterbags to be buried were crafted by the participants and some of the activities of the urban experiment were conducted on the host site. This event was attended by the whole extended community together with citizens who were at the site for the local biodiversity festival. The participants were also involved in hands-on activities, designed by artists to stimulate the ability to observe both the materials and the relationship between a living being and soil. At the end of the 40 days, when the litterbag incubation period was over, a meeting was organised to bring together the entire extended research community, to collect and share the contributions produced and to continue to share reflections on soil fertility indices.
- Site visits and interviews: Members of the original research team, together with members of the extended team, made site visits during the experiment and conducted interviews and video-recordings with the local associations and citizens' communities.
- Newsletters, maps, quizzes and polls: During the 40 days of the experiment, periodical emails updated the extended community on the activity progress at the various sites; drew attention to the schedule; shared images and drawings from the participants; and offered short games, polls and interactive material created specifically on the topic of soil fertility. These edutainment contents were designed to provide thematic insights and to strengthen the motivation and cohesion of the community. An interactive map, linked to the Soil_mAPP data collection geospatial web application, was regularly updated during the 40 days to report the observations shared by the community regarding the location and status of the litterbags in a timely manner.
- Webinars: By taking inspiration from the interests and specific expertise on soil management and care of the members of the extended community that emerged during the meetings and interviews, seven public webinars were organised. Here, local associations, representatives of public agencies and experts from several fields of knowledge (including anthropology, microbiology, science and media communication, urban planning, biophysics and ecotoxicology) were invited to discuss soil as a matter of concern and of care in their own experiences. The topics varied from agroecology to global and local food policy; climate change and sustainability in urban areas; citizens' engagement; and collaboration between different areas of expertise within and beyond Academia. All the webinars were moderated by members of the extended research team, with preference towards the younger members, who reinforced their transversal cultural competences (communication, dialogue, transdisciplinarity, etc.), which are considered more and more important in their curricula.

All the data and materials on the soil collected by the extended community were processed in the months following the experiment. The content of the litterbags and the soil samples to be subjected to the metagenomic analysis were analysed and processed by the researchers of the original research team who consulted with the local volunteers for verification and further investigation. During this phase, the extended community was kept up to date with emails, videos and photos from the labs.

The results from the NIR-litterbag analysis and the microbial metagenomic analysis, once achieved, were compared by the specialists to obtain an in-depth bio description of the investigated soils. In a final meeting, open to the entire extended research community, the results were shared and discussed, and the themes for reflection that emerged during the experiment were further explored.

3. Results

As stated at the outset of this article, the broader aims of the social experiment were to create a context in which to (1) train and practise transdisciplinary research in the socio-ecological context; (2) approach the complex issue of soil fertility in a participatory CS perspective, where both the production of quantitative results on local soils' fertility and qualitative insights into the personal and social connections with urban soils were deemed fundamental; and (3) design and test a methodological process that can support transdisciplinary and participatory practice.

With regard to the collection of information on the fertility of city soils, at the conclusion of the incubation phase of the urban experiment, 71.4% of the buried litterbags were successfully found, exhumed and returned to the agronomists for the NIR analysis. The most common reason why some litterbags were lost is that the markers used to identify their location had been removed by animals, people passing by or during agricultural and maintenance operations. The results were statistically processed using the Random Forest algorithm and compared with the observations collected at the burial sites using the Soil_mAPP during the incubation. From the NIR spectra, 23 parameters were extracted. Among these, four parameters were selected as the most significative ones to characterise the microbial activity recorded in the soils:

- The amount of ammonium (NH_4), because microbes decompose organic matter in the soil, releasing nitrogen in the form of ammonium;
- The amount of nitrate (NO_3), because nitrate is the end product of nitrification, a key microbial process in the nitrogen cycle;
- The substrate-induced respiration (SIR), because it specifically assesses the response of the active microbial community to a readily available food source (substrate);
- The microbial R-strategy and K-strategy populations (R_K), which are significant for indicating different aspects of soil microbial activity. R-strategists point towards the opportunistic exploitation of fresh resources, while K-strategists suggest efficient resource utilisation in a stable system.

Analysing all these four parameters together offers a more complete picture of the dynamic microbial community and its functioning in the soil ecosystem. Two interactive charts were created to facilitate a consultation and an aggregated data comparison. They are available on the project website [40], and one of them is shown in Figure 7.

An example of the output of the metagenomic analysis is reported in Figure 8. It shows how the four different agronomic management practices of soil result in different varieties of microorganisms.

The results of the NIR-litterbag and metagenomic analyses were processed, compared for each site, integrated with traditional chemical and physical analyses and with the knowledge provided by local subjects and interpreted together with them.

Each group of volunteers participating in the experiment received a summary sheet showing the numerical results of the analysis on their respective sites. They were particularly eager to know the results of the NIR analysis relative to their site: generally, they asked the agronomists many questions for interpreting the parameter combinations and to know whether their site was characterised by normal or exceptional conditions or whether it would require specific recovery interventions. The community's positive reaction was a clear indication that the delivery of the results served as an excellent reward for them.

As far as the technological support for data collection and visualisation is concerned, the applications used have proved to be adequate, both from the user side and the administrative one. The Soil_mAPP provided users with a custom web form and enabled them to report complex observations on phones, tablets and computers. It automatically detected the user geolocation (corresponding, in the experiment, to the litterbag's burial site) by the GPS receiver, even without internet access, which was perfect for remote locations. A paper questionnaire reporting the same fields was provided to the participants who indicated that they preferred it to the digital version.

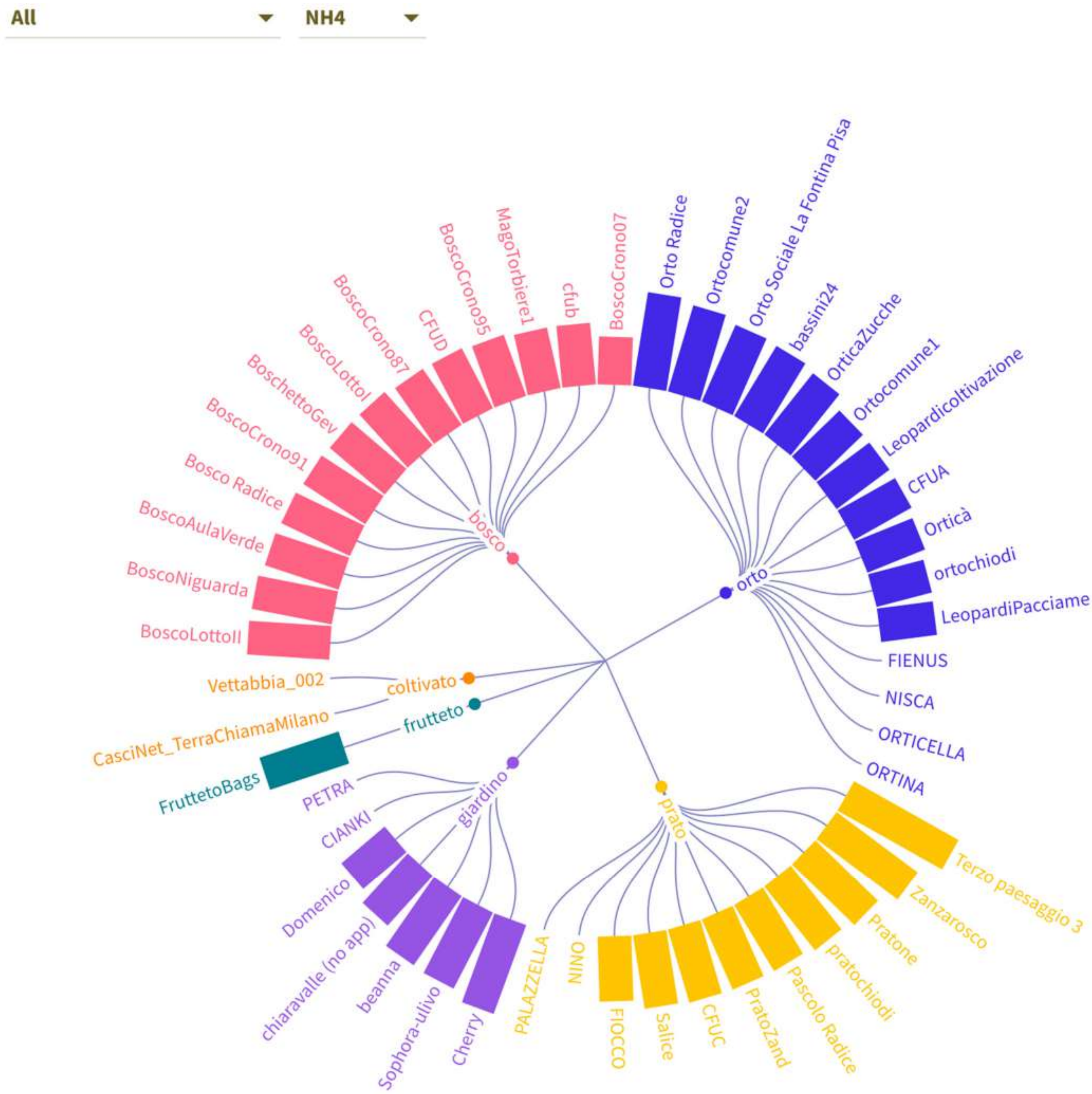

Figure 7. An example of the display of the parameter NH_4 for each litterbag on an interactive graph. From the drop-down menu on the left, users can select the parameter and litterbag group to be displayed. Clicking on the individual litterbag provides context information. The dimension of the bar is proportional to the selected parameter value (in the figure to the quantity of NH_4).

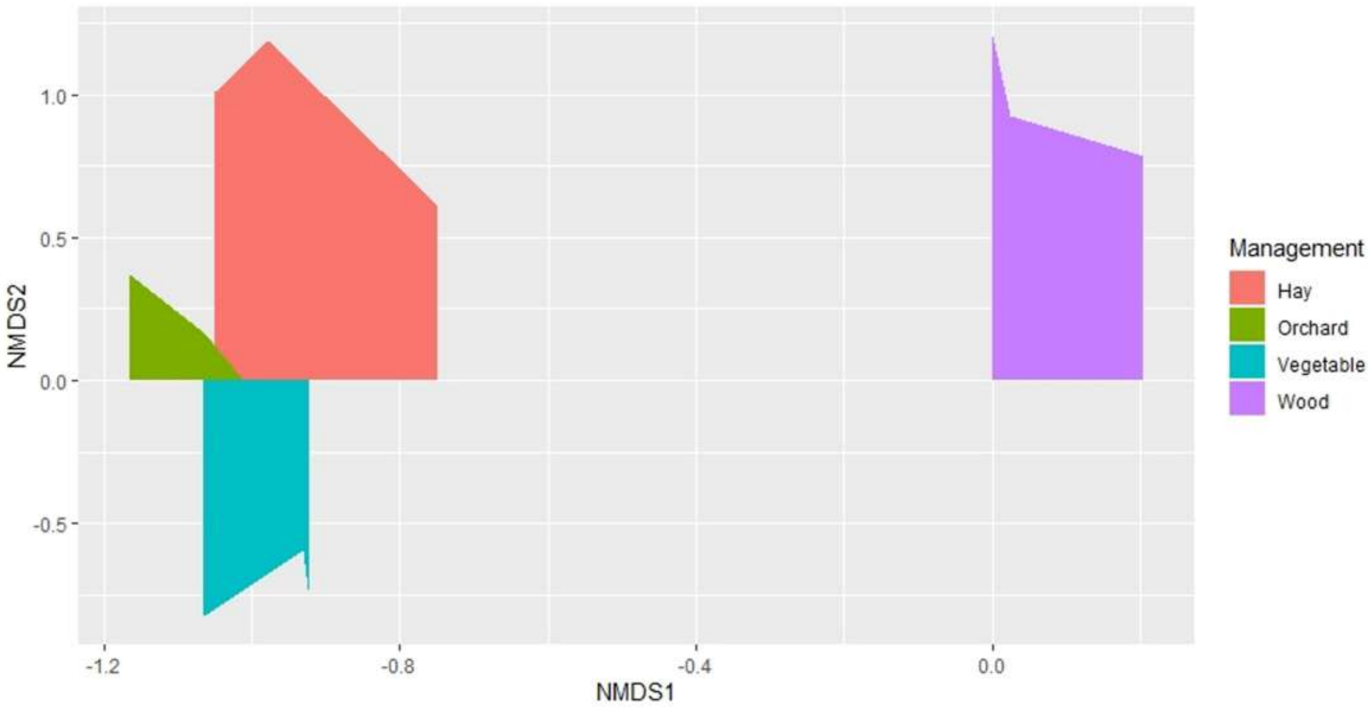

Figure 8. The graph illustrates the variation in the fungal communities' composition (β-diversity) among the soil samples, as resulted from the metagenomic experiment. The sample data are displayed in the nonmetric multidimensional scaling (NMDS) of the Bray–Curtis dissimilarity matrix. Polygons enclose the soil samples from the sites having the same agronomic management. The placement of the polygons shows how the management practices influence the microbial community: the communities characterising wood sites are strongly dissimilar (right side) to the communities characterising the other management types (left side), which are, as well, clearly separated from each other.

The dense observations—345 reports collected by the volunteer participants over the 40 days—documented by means of the Soil_mAPP (or of the equivalent paper version), accompanied by their photographs and descriptions of the experimental sites, provided effective information and created a robust dataset for the laboratory analysis and interpretation.

It is not easy to determine how many people actively participated in the field operations. In fact, some citizens' groups participated with only one or two representatives, while others involved a greater number of people who divided up the operations and took turns over time. It was estimated that the extended research community that actively conducted field and management operations was composed of 21 researchers from the original team, plus 16 researchers in the early stages of their career, plus about 45 adult volunteer citizens and about 40 students from three classes, aged between 5 and 19 (as reported in Figure 1). However, the frequency with which the different local participants contributed to the production of information is not uniform. The top 5 contributors of observations on the Soil_mAPP produced more than half of the total reports. This uneven commitment is in line with the heuristic rule called the Pareto principle, in which effort in CS projects tends to be greatly partitioned with, for example, 20% of participants contributing to yield 80% of observations [41]. Nevertheless, the unevenness is also partly due to the fact that in some cases—as in the case of student classes—the reports were always entered in the Soil_mAPP by the same contributors, although many volunteers were involved together in the field.

The participation of the local communities, both in the preparation period and in the 40 days of field activities, was active and knowledgeable. If the availability of various communication channels (email, newsletter, mobile chat, website and Soil_mAPP with related web pages for data visualisation) created some initial procedural uncertainties, it subsequently turned out to be very useful to allow all the participants to make regular direct comparisons and receive quick answers. All the participants shared effective observations related to the litterbag monitoring, while only a portion of them wanted to share their own personal observations made in the field notebook.

Given the rich skills and areas of interest of the local participants, some of the topics they introduced were developed in dedicated webinars: the citizens' contribution in the regeneration of urban areas, associationism, the conception of the landscape as an active subject and the ecological and social implications of urban green protection. The main impacts recorded in these subjects concern (1) the acquisition of new technical skills and fertility data relating to the soils under their jurisdiction and (2) the strengthening of relationships between associations.

As evidence of the interest aroused locally by the experiment, during the 40-day range, two new city associations contacted the research team and, although they were no longer able to follow the scheduling of activities together with the community, proceeded independently with the burial and monitoring of other litterbags provided and followed the latest project activities.

After completing the field operations and while awaiting the presentation of the analysis results to participants, it should be noted that community interactions tended to become more relaxed, and communication was maintained through webinars and newsletter updates. The extended duration of the project, in contrast with the relatively brief operational 40-day time range, probably contributed to a decrease in participation, as expected. This was also partly motivated by the participants' pre-existing commitments, sometimes related specifically to agricultural activities. It is possible to find some analogies of this behaviour with Tuckman's Stages of Group Development [42]. The initial phases of team structuring (forming stage) and collaborative design (norming stage) saw the initial enthusiasm/concern transform into confidence, constructive criticism and mutual trust. The particular participative nature of the project somehow minimised power conflicts and resistance (storming stage). The most creative and productive phase (performing stage) occurred for the early career researchers ahead of expectations, almost coinciding with the planning phase, culminating in moments of meeting in the presence of the group. The physical distance from the experiment sites (only four early career researchers live in Milan) probably favoured a progressive relaxation of participation in some team members (adjourning stage). Local members of the extended community, on the other hand, had a peak in participation over the 40 days of the experiment (performing stage). Their disengagement (adjourning stage) instead began in the following months, in which the laboratory analyses were carried out and in which they were not asked to perform specific tasks.

As regards the broader aims of the experiment, i.e., building transdisciplinary and participatory capabilities and setting up a devoted process, it turned out that it was beneficial for the entire research community to have specific training and concrete case studies acting as reference points. In particular, the decision to involve early career researchers aimed at filling the gaps in academic training related to transdisciplinarity: the BRIDGES experiment provided them with the opportunity to directly experience it, fostering a lasting impact on their approach to complex socio-ecological problems. Their youth and diverse interests proved valuable for injecting critical thinking into the workings of the group.

Of the early career researchers who volunteered for the project, only a few were familiar with the concepts of transdisciplinary research and CS. The main motivation for participating was related to the possibility of learning less traditional approaches to scientific research. Their initial reaction, after the project presentation and the first training meetings, was sometimes perplexity, sometimes curiosity. Moreover, the level of commitment required to join the extended research team was high, and as a consequence, an initial selection of the group took place spontaneously at this stage. During the project, in the various phases of interaction and re-elaboration, some researchers—especially those with a background in technologies and natural sciences—expressed a certain frustration and shared it with the group. Such a feeling was often due to the lack of familiarity with qualitative or reflective research approaches and with the introduction of the artistic and experiential research component. That said, these approaches also led at times to a light, almost playful atmosphere. This light-heartedness generated positive influences by creating a climate of friendly collaboration between researchers, but there were also moments where such methods were not taken seriously or their validity as research methods was underestimated. Similarly, the need to iteratively rework procedural steps and concepts during the project contributed to a much-appreciated mutual learning environment and, but it also destabilised more pragmatic expectations (i.e., caused delays). Relations within the extended research team also continued informally after the end of the project through online group conversations, in which the sharing of material of interest, experiences and events is still ongoing.

The main outcome of the experience reported in this manuscript, however, is the very construction of a process that facilitates the practical application of the transdisciplinary approach to a complex socio-ecological problem and to include, through successive steps, participants from civil society, bearers of complementary interests and expertise. This process, although defined in the specific case of the study of soil fertility, can easily be adapted to different thematic, geographical and social contexts. Within the process, there is still ample room for training, further quantitative investigation as well as reflection and action-research activities, potentially meeting multiple needs and project purposes.

4. Discussion

Two important objectives of the project, previously stated, were (1) to practise transdisciplinary research within the socio-ecological context and (2) to approach the complex issue of soil fertility in a participative CS perspective. The latter would need to be aware of the overlap among both interests and constraints between the scientific world and the encompassing society. As the findings above, certain difficulties emerged but also impacts of the approach on the researchers involved, as well as emergence of elements that most supported the success of the experiment and controversial reactions of certain public actors.

The transdisciplinary experiment highlighted both strengths and weaknesses that need to be further investigated. Some considerations can be made on how the process was shaped by the transdisciplinary approach and how this impacted on the research team. Involving different backgrounds, interests, languages and research methods towards a common objective inevitably involves accepting initial difficulties and, in order to solve them, many compromises. The compromises concerned both the development times—which may require delays for in-depth discussions, iterations and backtracking—and the research methodologies—which must be agreed upon by several actors and therefore can produce results that are only partially satisfactory for some individual stakeholders. In our context, agronomists and biologists had to adapt their ideal experimental design, converging on the most convenient sites and time range for the local community. Research questions too were not the same for social scientists, natural scientists and land managers. Additionally, project times slowed down, as a longer training period for the researchers themselves became necessary, departing from what had been initially planned. The technological tools initially proposed by the data scientists for monitoring all the activities of the urban experiment have been repeatedly reviewed by the extended community. Specifically, their feedback was very helpful to the ICT members of the community who had to face and cope with both the linguistic gap of a transdisciplinary community (i.e., lack of knowledge of scientific terms and concepts) and the digital-divide problem when designing the web application. With the cooperation of the extended community, more effective solutions were identified by providing explanations of the technical questions asked by the Soil_mAPP with the help of the agronomists. Also used were images and tutorials. There was integration of the Soil_mAPP with paper tools designed in collaboration with artists and young researchers, which proved to be better suited to stimulate reflections and artistic contributions, as well as to facilitate data collection for some citizen groups. This experience confirmed the finding that 'doing-it-together', exploiting transdisciplinary contributions combining frameworks across disciplines, supports out-of-the-box thinking and experimentation [43,44]. Furthermore, the sociological and anthropological investigations, as well as the training activities, have contributed to refinement of the tools designed previously for other objectives: walking conversations during site inspections, open discussions during webinars and workshops, multidisciplinary training cues within the field book and through quizzes and games incorporated in the periodic newsletter and so on. These 'boundary objects', both physical and digital, acted as a bridge between different social groups, helping and facilitating communication, learning and collaboration despite differing backgrounds, knowledge sets and priorities [45].

The strategic planning of hybrid activities not only facilitated introductions and relationship building but also created a platform for knowledge exchange and offered participants opportunities to familiarise themselves with the transdisciplinary approach. As documented in recent studies [46–48], the establishment of 'communication spaces' having fuzzy boundaries, albeit structured interactions, supports the sharing of valuable insights and experiences, leading to collective learning and growth. Investing in well-designed interactions can be seen to have strengthened the community's foundation, unlocking more of its potential.

The linguistic gaps, due to the different semantics of the terms for the distinct scientific disciplines and transdisciplines, may have led to some initial misunderstandings. They were resolved as the experiment progressed, through moments of dedicated discussion and time spent together conducting practical activities. One key feature that was particularly helpful to make people with different disciplinary backgrounds come together and adopt a trusting and collaborative attitude was the implementation of arts-based activities. These activities were proposed to the research community both during the training sessions and during the 40-day experimental window, and they were integrated with hands-on or reflective activities. These arts-based activities provided a common ground for the various disciplines, creating spaces for openness and dialogue among community members, indeed serving as 'boundary objects' that enhanced the capacity to translate across culturally defined boundaries [49–52]. The experience highlighted how sensory and creative activities can create a favourable ground for knowledge exchange across disciplines, backgrounds and generations. They can be a powerful support for the implementation of transdisciplinary approaches. It was also noted how the transdisciplinarity of the approach, besides being a founding value of the experiment, turned out to be a driving force for attracting interest in the project and maintaining engagement.

As the approach to soil fertility from a participatory perspective included both scientific and societal interests, difficulties were encountered in attempts to match the sometimes-conflicting constraints and interests of the community. During the design of urban CS activities, the team experienced different reactions from public administrations, which deserve to be highlighted. An environmental public agency asked to be involved in the project since its first phases. However, the agency did not take action during the course of the project, stopped interacting and did not participate in the field activities. A municipality belonging to the metropolitan area of Milan was the protagonist of an emblematic refusal, when a local environmental association proposed for the experiment a peri-urban green area on which previous surveys were available. The local administration did not give the authorisation to bury the litterbags, nor to take the soil samples. They did not give an official reason but only informally communicated that they did not wish to discover something that could prevent their future plans for the area. If the reasons behind the first cited example can be related to bureaucratic difficulties and an overload of commitments, in the second case the reason for the behaviour of the municipality is to be attributed to an attitude of avoiding scrutiny. In this case, the opportunity for interaction with scientists and citizens in a public area of common interest was perceived by the public administration as dangerous rather than favourable because of potential conflicts with other socio-economic interests. Some would argue that this behaviour is not surprising for managers of private companies, particularly those who choose profitability (e.g., accountability to shareholders) over sustainability whenever they are in conflict are concerned as outlined in Epstein et al.

(2015) [53]. However, this risk aversion also seems to affect public administrators, who can be seen to be driven by concerns about their own forms of accountability.

It has been argued that a conscious participation of public administrations in 'communication spaces' can foster transformative learning and the construction of shared visions for the allocation of local community resources [48]. In contrast to this instance, very constructive collaborations were experienced with other public authorities. A park authority manager of a huge urban public park (about 790 hectares) in the metropolitan area of Milan not only joined the extended research community but also provided maximum support in all phases of the experiment. They provided hospitality for events, proposed activities, and facilitated the participation of several volunteers, school classes and civic groups operating within it. Even the municipality of Milan, which hosted most of the field activities, showed interest and support, taking part in webinars and workshops and facilitating the execution of the activities.

The process described and the approach followed were developed experimentally specifically for this case study and applied for the first time in the Milan area. The experience constitutes a fertile case study to add to the rich literature on transdisciplinarity and societal participation in ecological research.

Benessia et al. [3], in 2017, wondered whether CS could take part in the rescue of the quality and trust in science and argued that this restoration cannot be achieved by 'scientific' means alone. Rather, one needs to complement established science with new forms of practice and exploit avenues external to science's own institutions. The BRIDGES experience offers a contribution to the exploration of these complementary practices to traditional scientific approaches in the field of socio-ecology. It also enriches recent reflections on CS as a transformative ethical practice, enabling researchers to move beyond scientific standards [10,13]. The integration of methods appropriate for artistic and aesthetic research into the participatory experience is an additional step, which builds on didactic and holistic models [9] to foster broader understanding about human–environment relationships. These practices have proven effective in creating 'communication spaces' [47] in which the growth of trust and exchange of knowledge are fostered. They can be seen to contribute to preparing informed citizens capable of facing sustainability challenges [9]. It would be desirable in the future to further investigate the impacts of similar processes–on different research topics–on researchers, administrators and citizens in terms of learning and building mutual trust.

The application of a transdisciplinary and participatory process implies a longer preparation phase for the research team and a greater commitment of time and good will than that required by traditional investigations. However, it was precisely the extension of the preparation times that allowed the extended research team to carry out the (mutual) training process, which was one of the objectives of the project. In this role, it can be argued that patience and flexibility constitute key characteristics to allow for the application of these non-standard practices in the research environment. The inclusion of training courses dedicated to transdisciplinarity and to the participation of civil society in scientific research within academic curricula would be desirable. Such training would enable young researchers to approach scientific activity with greater openness, get off the beaten track and open up new avenues for future research. At the same time, it would be worth further analysing which changes to the system of the production and dissemination of scientific knowledge would favour the application of transdisciplinary processes in scientific research.

The experiment also outlined some limitations and future directions for this research. The possibility of developing the process in a participatory way, and sustaining interaction during the main experimental phases with a co-creation approach, was certainly favoured by the local scale of the activity. Replicating a similar experience on a larger scale—for example, regional or national—would lead to the loss of some of the interactions experienced within the project and it would present difficulty in managing face-to-face activities. On the other hand, a more extensive and denser mapping of the soils would be desirable, both to create a broader dataset that reveals how the history and physiognomy of the territories influences its biological activity and to arrive at a plausible geographical interpolation between sufficient density of data points. In summary, if the local scale facilitated interaction, it probably limited the generalisability of the approach. A future spatial and temporal extension of the methodology and process implemented is desirable but will involve addressing these critical points and the establishment of multi-level and cross-local policies for governing the project.

5. Conclusions

This paper recounted the process followed to build an extended community of research in a transdisciplinary project dealing with the socio-ecological issue of the fertility of soil. This issue is complex and controversial, with its management and preservation requiring a new set of relationships between science and governance, society and ecosystems, including human and non-human actors.

Several reasons motivated the selection of the case study on soil fertility:

- Soil is fundamental for life and biodiversity, but its importance is often underestimated in respect to other planetary emergencies;
- Soil fertility is strongly correlated with the health and prosperity of all living things, human and non-human;
- Diverse knowledge systems (scientific, local, artistic and experiential) and a plurality of methods and multiplicity of scales are crucial for its understanding.

The traditional scientific research can be characterised as featuring a hegemony of theoretical and experimental science guided by disciplinary norms with relative autonomy for scientists and their institutions. This type of scientific research can lack connection with societal needs/interests. Counteracting that calls for diverse modes for knowledge production to be experimented with, subject to multiple accountabilities and reflexivity from a variety of societal actors and interests. For this study, a research community was built that bridges science, governance, society and the environment to perform soil fertility investigations. The proposed approach involved scientists, social scientists, artists and local communities. It combined theoretical, practical and artistic methods across various scales. The experiment aimed at building bridges between different disciplinary approaches—with social sciences and humanities dialoguing with the natural sciences, and academic knowledge interacting with local knowledge. It also sought to build bridges between theory and action, to co-create the conditions for greater participation of citizens in decision-making processes about complex issues related to sustainability arising at the interface between science, society and the environment.

Experimentation allowed the research team to identify and describe key insights: the process of community building and co-designing research was valuable; and combining different knowledge systems fostered a deeper understanding of soil fertility. Another key lesson was relative to the role of arts and emotions. Considering that traditional research often ignores the aesthetic and emotional aspects of environmental issues, the project incorporated artistic experiences to cultivate an 'ecological awareness' and to treat soil as a 'matter of care', in addition to one of interest and concern. Integrating emotional and sensorial connections with soil turned out to be a crucial aspect for responsible actions by participants in this instance, underlining the importance of placing value on the perspectives of a wide array of stakeholders. This shift can be seen as a necessary condition both for the democratisation of science—obviously true for the shared definition of desirable directions of scientific research—but also for the construction of 'socially robust' knowledge, which is responsible, inclusive and relevant.

Collaboration with local bodies and public administration proved to be an important element in the success of the experiment. Local policies can do much to support community involvement in sustainability initiatives and to foster collaboration with researchers, whether in the natural sciences, the humanities and social sciences or even in the arts. A particular challenge for local governments is translating the outcome of participative activities into applied policies that are respectful of the interests of different local stakeholders and forward-looking in their management of collective resources.

The experience described constitutes what can be considered a significant (and potentially the first) application of a participatory and transdisciplinary approach to ecological issues in northern Italy and in the Milan area in particular. It is hoped that it will become a starting point for new and broader joint actions between citizenships, local administrations and the scientific community.

Author Contributions: A.L. coordinates the project from which this case study is extracted. All the authors, who are members of the extended research team, contributed to the design, the performance and the analysis of the experiment described in this paper. L.C. and G.B. guided and moderated the writing of this paper. All authors contributed to the definition of the structure, the writing and the revision. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: The research conducted does not require acceptance of the human ethics committee in Italy. All the research participants have provided explicit consent to participate in the activities and for their data to be used for the research objectives.

Data Availability Statement: The use of the data collected through the Soil_mAPP application is in accordance with the GDPR protocol (https://www.garanteprivacy.it/il-testo-del-regolamento (accessed on 11 March 2024)). The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: Authors Stefano Crosetto and Enrico Ercole were employed by the company SEAcoop STP. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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