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University-Led Citizen Science Projects for Environmental Monitoring and Integrated Urban Development

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Abstract. In the modern world, the issue of integrated urban development is becoming increasingly important, especially in view of modern environmental problems, which require overcoming through new management approaches. One such solution is citizen science, which involves the public in environmental monitoring. Universities around the world are actively implementing citizen science projects, focusing on topics such as climate change, air quality, the impact of the urban environment on human health, etc. This paper examines a case study of a citizen science project on monitoring atmospheric air quality, implemented by the Technical University of Berlin. The paper provides recommendations for universities and citizen science coordinators in the field of environmental monitoring and urban development. The emphasis is placed on the motivational aspects of public participation in citizen science projects and on strategies for effective management of these projects. Furthermore, aspects such as participant training and communication play a significant role in engaging citizens in monitoring projects. A support system that includes the use of digital tools for learning (educational videos, online courses, mobile applications, etc.) and for communication with participants (open platforms for results, feedback via social networks, etc.) is proposed. Gamification is suggested as a method to stimulate participation through game elements (e.g., quests, competitions, interactive tasks). Thus, it is concluded that a comprehensive approach, incorporating digital technologies, gamification, and strategic communication, can significantly increase the effectiveness of citizen science projects, attract a larger number of participants, and contribute to achieving sustainable results.

1. Introduction

In the modern world, the issue of integrated urban development management is gaining increasing importance. This involves the management, planning, and development of cities with consideration for ecological aspects, including climate change mitigation and adaptation, biodiversity conservation, and reducing anthropogenic pollution levels. With ongoing urbanization, urban spaces are becoming central to human habitation, making citizen participation in environmental quality management extremely important, particularly through citizen science projects in the field of environmental monitoring. There is an increasing trend of

citizen participation in urban planning, particularly in decision-making processes, where the opinions and positions of residents are taken into account when addressing issues.

One of the most widespread problems in modern cities is air pollution, and various countries are implementing initiatives to involve citizens in managing air quality. For example, the authors [1] present the results of a study aimed at improving air quality management in Cork, Ireland, through the integration of dispersion model results with large-scale citizen science data collected over four weeks by 642 participants. As part of this project, the main sources of NO_2 air pollution were identified, data on nitrogen dioxide concentration in the city were refined, and the impact of air pollution on the population was assessed. The authors point out that the obtained information is a valuable resource for improving the assessment of NO_2 impact and informing environmental policy.

Another example of involving citizens in addressing urban environmental issues is the use of public pollution monitoring data on plastic waste by municipalities. The study [2] demonstrates the use of mobile phone applications for citizens to collect data on litter in Vancouver, Canada, during 2017-2019. It approves that citizen science data can complement municipal waste audits in the urban environment.

The study [3] shows that citizen science, in addition to being a tool for filling data gaps regarding urban spaces and the environment, is also an approach to improving the reliability of indicators. The data on the Straatvinken project, which measures traffic flow on streets, are presented. This project emerged from a public environmental movement in the Antwerp region, Belgium, and later expanded throughout the Flanders region to monitor the transition to more sustainable modes of transport.

Urban and suburban green spaces are important components of urban areas. The study [4] presents the results of research on citizens' willingness to participate in the management of green spaces. The study covered six Italian cities – Rome, Milan, Naples, Turin, Palermo, and Genoa. The Urban ReLeaf project [5] aims to create data ecosystems based on citizen information to support climate change adaptation, green infrastructure, and urban design planning. Using the citizen science approach, a survey was conducted with 331 residents of Amsterdam, Netherlands, and 22,637 citizen perceptions of the urban space were collected based on various criteria. This data can help in future planning and in selecting the development direction of the city to improve the quality of life in urban areas [6].

One of the most powerful developers of citizen science projects in the field of urban development management is the academic sector. Numerous scientific studies involving citizens are conducted at universities, ranging from biodiversity studies and species identification to environmental quality monitoring and green space management. For example, the University of Helsinki is implementing the Urban Rats project. As urbanization leads to more people living in cities and increasing contact with urban rats, the citizen science approach is used to understand the dynamics of the rat population in Helsinki, Finland, and their impact on urban life in the city [7].

The project "City Layers: Citizen Mapping as a Practice of City-Making" by the Vienna University of Technology, Austria, presents a modern urban mapping framework that focuses on citizens' experiences in urban spaces [8]. As part of the Citizen Science Award 2023, in collaboration with students, citizens, and researchers interested in the democratization and diversification of city formation, the City Layers app was developed. It is used to explore various dimensions of the modern city, such as accessibility, noise, safety, climate resilience, aesthetics,

convenience, and others, through text comments, photographs, suggestions, and citizen voting on improving the urban space.

The first phase of the CLAIRE initiative by the University of Antwerp, Belgium [9], is dedicated to creating a map of the impact of slow traffic roads without cars and with green infrastructure on air pollution, using volunteers. The second phase is focused on studying the relationship between air quality, urban greenery, and the impact of microorganisms.

The joint project "Urban Microclimate Citizen Science Project" by the Royal Melbourne Institute of Technology, Australia, and the University of New South Wales, Australia [10] involves citizens in identifying urban heat islands, studying climate change in specific cities and regions, and collecting data necessary for developing and implementing measures to mitigate and adapt to extreme heat.

Thus, citizen science projects implemented worldwide, particularly by universities, focus on many environmental aspects of modern urban planning and integrated urban development management. These projects address the need for climate change mitigation and adaptation, air quality monitoring, and related spatial planning. In this paper, the focus will be done on a citizen science case study on air quality monitoring, implemented at the Technical University of Berlin (TU Berlin). Additionally, the paper will explore the development of recommendations for higher education institutions regarding managing citizen science projects in the context of integrated urban development and environmental monitoring, particularly considering the results gained from a workshop held at TU Berlin with the case study coordinators.

The aim of the work is to analyse the effectiveness of the implementation of citizen science projects in the field of environmental monitoring and integrated urban development, as well as to develop recommendations for universities and coordinators of citizen science projects, considering the motivational aspects of citizen participation, communication approaches, and the use of digital technologies.

2. Research Methodology

In order to collect information about existing citizen science projects in the field of environmental monitoring and urban development management, primary research methods were used. A desk study was conducted for the analysis of literature sources. The logical-analytical method and the method of scientific cognition were applied during the research.

For the analysis of the practice of using citizen science in air quality monitoring, the case study method was employed – specifically, the analysis of Berlin Air NO_2-Atlas project which was conducted at TU Berlin, and coordinated by the Institute of Environmental Chemistry and Air Research. The main objective of the project was to create a spatial dataset of NO_2 concentrations that would comprehensively cover the entire city of Berlin. Data on the distribution of NO_2 concentrations in Berlin were collected, and a comparison was made between the data obtained through the use of passive air samplers by citizens (a total of 1,268 samples) and the data from the Berlin air pollution monitoring network BLUME [11] . The research was conducted from 2019 to 2020, seasonally, in both summer and winter, using modified Palmes tubes [12]. The samples were taken over a period of 14 days, with an allowable deviation of ±3 days. Chemical analysis was performed based on the Griess–Ilosvay reaction, spectrophotometric analysis, and quantification of concentrations based on Fick's diffusion law [11, 12].

In the context of urban development, it is important to note that citizens had the opportunity to independently choose locations for measurements, which included main streets, side roads, courtyards, open spaces, and so on. For the convenience of participants, several options were

provided for obtaining passive air samplers, either by picking them up at the laboratory, receiving them at a postal office, or through a courier service. Along with the samplers, instructions for conducting the research and a registration form were sent, in which participants later provided information about the start and end times of the sampling period, the exact location of the sampling (address or GPS coordinates), the height of the sampler above the ground, the distance to the road, as well as additional information such as the number of traffic lanes, local speed limits, type of road (main, side, residential), bus traffic, weather conditions, and other location-specific details. After the sampling, the determination of NO_2 concentrations was carried out in laboratory conditions.

The monitoring points in the BLUME network were taken as a reference for the maximum NO_2 concentrations that can be expected in the city's outdoor air, as NO_2 concentrations measured in the monitoring network near traffic-heavy areas are higher than the concentrations to which the majority of Berlin's population is exposed. The results of the research show that the data from citizen monitoring generally correlate with the data from the BLUME monitoring network, with the highest correspondence observed in urban areas. For the traffic and suburban categories, the NO_2 concentrations obtained through citizen monitoring were, in some cases, lower than the readings from the BLUME network. The study within the framework of the citizen science project at TU Berlin confirmed that citizen monitoring data can be used to assess air quality [11]. Moreover, the results of citizen measurements helped refine the impact of meteorological conditions in the city on air quality, as well as the relationship between NO_2 concentrations and sampling locations, indicating that large-scale measurements in citizen science projects can effectively complement air quality measurements in fixed monitoring networks [11].

To develop recommendations for universities aiming to work on projects related to environmental quality monitoring and urban developmant, the Delphi method was used. Expert discussions were held within the framework of a workshop at TU Berlin (November 2024), organized by the author, with the participation of experts (scientific coordinators) of Berlin Air NO_2-Atlas project, A. Held and W. Frenzel, as well as staff and students from the Institute of Environmental Chemistry and Air Research, TU Berlin.

3. Results and Discussion

One of the most important practical results regarding the methodology for conducting citizen science research in the field of environmental monitoring, gained from the Berlin Air NO_2-Atlas project by its research coordinators, is the idea that citizens should have the ability to independently analyze the data they collect. Analyzing a large number of samples in laboratory conditions is a labor-intensive and time-consuming process, and a proper analysis of results should involve corresponding training for citizens. For example, educational videos placed on online platforms, social media, or within mobile apps could be used. There is also significant potential in the use of digital twins, which are successfully employed in other fields – from employee training and assistance in production environments to leisure activities, such as physical exercise or learning dance moves.

Allowing citizens to independently process data could also enhance the quality of the collected data. For example, the implementation of the citizen science project ClimateWatch [13], where more than 1,500 students participated in the research, demonstrated that after independent analisys of the results, the participants became more careful and attentive when collecting data and keeping records. They realized the critical value of metadata quality, which is intended for further use in scientific research.

It is important to highlight the channels for recruiting participants for citizen science projects. For projects conducted at universities, an effective approach is to engage students as well as school teachers. Students can not only participate in citizen science projects themselves but also involve their friends and relatives. Most university departments involved in educational processes collaborate with schools and teachers, which opens up opportunities to encourage schoolchildren and their families to participate, additionally contributing to career guidance efforts and improving the university's image.

Based on the analysis of literature sources, as well as discussions during the workshop on developing proposals and recommendations for academics on citizen science projects, which was held at TU Berlin, the author concludes that the motivation of participants in the project is a crucial factor for the viability and sustainability of citizen science. This insight align with existing studies. Thus, in paper [14], the the results of a survey conducted with citizen scientists from India, Ethiopia, and Honduras are presented. Two main groups of participants were identified: one motivated by the desire to share information (selfish intrinsic motivation), help (altruism), and contribute to scientific research (collectivist motivation); the other motivated by selfish external factors (expectations, interaction with experts, and participation in a community). In the study [15], a motivational model is defined that classifies participants' motivation according to the typologies of citizen science projects. Motivation is divided into three categories for intrinsic motivation: altruism, satisfaction, and entertainment, and for extrinsic motivation: community, self-improvement, and expected future benefits. The authors of the study concluded that motivational factors are directly related to the types of tasks that volunteers perform.

Among the key motivating factors for environmental monitoring projects, the social significance of the project and its impact on the lives of participants and the community as a whole were identified (Fig. 1). This role of citizen science projects is primarily utilized by universities as part of their third mission.

It is important to note that the significance of citizen science projects for society and the environment should be understood by citizens themselves, both as potential participants and as the broader population. This will not only attract a larger number of volunteers to participate in projects but also increase public awareness of citizen science and build stakeholder trust in it.

Another aspect is the identification of citizen science as a way to productively and enjoyably spend leisure time, to avoid staying at home, make new acquaintances, socialize, feel involved and part of a community, and spend time in nature, among other things. These are elements of intrinsic motivation for individuals. In addition to intrinsic motivation, external motivation plays a significant role – in particular, recognition, rewards, winning in competitive contexts, etc., which forms the basis for the third defining factor of motivation to participate in citizen science projects (see Fig. 1).

In addition to the motivation of citizens, other priority factors for their effective participation in citizen science projects in the field of environmental monitoring were identified, including participant training and communication with them. Digitalization and gamification are highlighted as supporting cross-cutting processes.

Table 1 summarizes key recommendations for the implementation of citizen science projects in the sectors of training and communication, which can be carried out using digital technologies and gaming approaches.

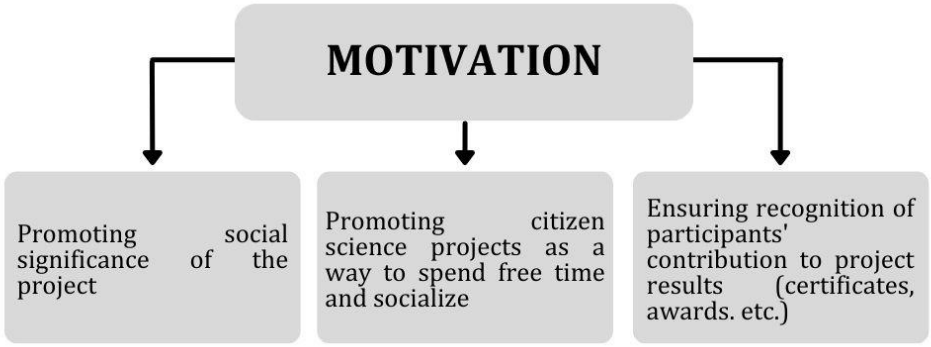

Figure 1. Motivation and strategies for engaging citizens environmental monitoring.

For example, at the training stage, it is advisable to use software, in particular mobile applications, as well as educational videos and video conferences to access training materials. For effective communication with participants, it is advisable to use online platforms, as well as social networks to disseminate information about the project, which allows for wider access to it.

Table 1. Key recommendations for the effective citizen integration in environmental monitoring.

Stage / Process	Training	Communication
Digitalization	Using software products (e.g. digital twins and mobile apps)	Presenting of project results online (open access)
	Using educational videos and video conferencing	Dissemination of information about the project beyond personal links
Gamification	Visual design tools for E-learning	Using interactive platforms, websites, and mobile applications for interaction
	Using gaming technologies (quizzes, quests, competitions)	Using social networks
Digitalization + Gamification	Training games to amplify skills	Teambuilding activities
	Training with storytelling	Providing feedback to participants

Gaming technologies, such as interactive platforms, online competitions and quizzes, can be used at the communication and engagement stages of participants, helping to increase their interest and activity. The use of such instruments allows to create an interactive and interesting atmosphere that stimulates participants to actively participate in the project. The combination of digitalization and gamification at all stages of project implementation helps not only in training participants, but also in building effective communication, feedback, and supporting interaction between participants, which, in turn, increases the quality of data collection and the overall effectiveness of the project.

4. Conclusion

During the study, a few citizen science projects in the field of environmental monitoring were examined. The collected data highlighted the importance of involving citizens in scientific research, especially in the context of monitoring the ecological state and its impact on urban spaces.

Universities play a significant role in the implementation of citizen science projects by providing scientific, technical, and organizational support. Involving citizens in such projects helps foster an understanding of the importance of participating in scientific initiatives aimed at improving environmental quality and living conditions in cities.

It was determined that motivation is a key factor for the successful implementation of citizen science projects. The results show that to engage more participants, it is crucial to develop both internal motivation and provide external incentives. An important aspect of implementing citizen science projects is communication with participants and training them in the process of data collection and analysis. Use of digital technologies (mobile apps, interaction platforms, digital twins) allows for effective training, monitoring, and feedback. This is particularly relevant for projects where participants need to analyze large volumes of data, which requires additional skills and knowledge.

To ensure the high quality of data collected, special attention must be paid to participant training and instructions. To increase the effectiveness of citizen science projects, participants must have the competence to independently analyze the collected data.

Recommendations for universities and coordinators implementing citizen science projects include the use of gaming technologies to engage participants. Gamification makes participation in the project interesting and interactive, encouraging participants to stay active and involved. Gaming technologies increase interest and create additional incentives for joining the project, as well as support sustained participation.

Overall, citizen science has already demonstrated a high level of effectiveness in the context of integrated urban development management and environmental monitoring. Given the rapidly evolving technologies, citizen science projects can become an important part of integrated monitoring systems, contributing to environmental improvement and the creation of more comfortable urban spaces for living. At the same time, given the existing well-known limitations of citizen science, as well as the extremely low level of implementation of citizen science in universities of developing countries, this issue requires detailed study and provision of broader recommendations for the administration of higher education institutions and scientific and academic staff, which determines the prospects for further research.

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