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Designing Context-Aware Urban Citizen Science Systems for Sustained Citizen Engagement: A Pilot Study in Urban Heat Island Detection

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DESIGNING CONTEXT-AWARE URBAN CITIZEN SCIENCE SYSTEMS FOR SUSTAINED CITIZEN ENGAGEMENT: A PILOT STUDY IN URBAN HEAT ISLAND DETECTION

Short Paper

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Abstract

This short paper explores the design of context-aware urban citizen science systems to address the challenge of sustained participant engagement. Building on a pilot study conducted in Zurich involving citizens in urban heat island detection, we investigate engagement barriers and patterns. Grounded in Information Systems (IS) Continuance Theory and leveraging Just-In-Time Adaptive Interventions (JITAIs), we follow a design science research approach and propose initial design requirements and principles for enhancing citizen science systems. These principles include context-aware participation timing, real-time feedback, and adaptive task complexity, aimed at fostering satisfaction, perceived usefulness, and expectation confirmation. Our initial pilot study insights and theoretical analysis indicate that contextual factors may play an important role in moderating user engagement and system interactions. We conclude with insights on system design that align with theoretical models of IS continuance, offering guidance for practical applications and future research in developing context-aware citizen science platforms.

Keywords: Urban Citizen Science Systems, Digital Citizen Engagement, Just-In-Time Adaptive Interventions, Context-Aware Computing, Design Science Research

1 Introduction

Rapid urbanization and climate change present unprecedented challenges for cities worldwide. Over 60% of the global population currently lives in urban areas – a figure projected to reach nearly 68% by 2050 (United Nations Human Settlements Programme, 2024). Simultaneously, weather- and climate-related extremes caused economic losses of assets of over EUR 162 billion (22%) between 2021 and 2023 in Europe alone (European Environment Agency, 2014). While these are global trends, they matter most at the local level. These challenges manifest in various forms, from extreme heat events and flooding to deteriorating infrastructure, air quality issues, and systemic public health risk. Moreover, these impacts disproportionately affect marginalized communities, exacerbating existing inequities (Kempin Reuter, 2019). Understanding and addressing these challenges requires data about local conditions and their impacts on urban life - data that traditional monitoring approaches and municipal resources alone cannot adequately capture (Fritz et al., 2019). In the case of urban heat islands, for instance, dense building structures and limited green spaces in disadvantaged areas create significant temperature variations across neighbourhoods (Hsu et al., 2021). These variations can substantially impact residents' health outcomes, energy consumption, and quality of life.

Citizen science – the active engagement of the general public in scientific research tasks – has emerged as a promising approach to address this data collection challenge by engaging local residents in systematic observation and measurement of their environment (Haklay et al., 2021). Through citizen participation, researchers can access unique local insights and gather spatially distributed data at a scale that would be impractical or cost-prohibitive through traditional methods (Fritz et al., 2019). This approach not only advances scientific understanding but also offers immediate relevance to participants' daily lives and strengthens community well-being through direct involvement in addressing local challenges. Such engagement has enabled advances in environmental monitoring, urban planning, and climate resilience initiatives .

However, a significant challenge threatens the viability of citizen science initiatives: maintaining sustained participant engagement over time (Cappa et al., 2022; Fritz et al., 2019; Sauermann & Franzoni, 2015). Studies have documented substantial participant drop-out rates in citizen science projects, with engagement often declining sharply after initial participation (Fischer et al., 2021). Interestingly, projects that consider participant's personal context (e.g. interest in seabirds, or hands-on field research) report significantly lower drop-out rates in contrast to initiatives that do not (e.g. simple image classification) (Asingizwe et al., 2020). These engagement patterns compromise both data quality and overall project outcomes, underscoring the need for systematic approaches to sustain participant motivation throughout the project lifecycle (Sauermann & Franzoni, 2015).

One promising approach to address this engagement challenge lies in the design of systems that can adapt to participants' changing circumstances and needs. Advances in mobile and sensing technologies enable the development of context-aware systems that can determine appropriate moments for user support based on situational, behavioral, and environmental factors (Nahum-Shani et al., 2017). For example, in the health behavior change domain, so-called Just-In-Time Adaptive Interventions (JITAIs) successfully exemplify this approach, providing personalized, temporally-optimized support to maintain engagement (Hébert et al., 2020). While JITAIs have shown effectiveness in health interventions (Nahum-Shani et al., 2017), their potential for enhancing citizen science engagement remains largely unexplored. We articulate the following research question: *Which design principles should guide the design of context-aware urban citizen science systems to increase citizen engagement?*

Following a design science research approach (Kuechler & Vaishnavi, 2008), we intend to provide a solution for this real-world problem. Our investigation is informed by a pilot study conducted in Zurich in August of 2024, which engaged twenty citizens in urban heat island detection over a three-week period. This pilot informed the problem awareness phase and provided valuable insights into the particular challenges of engaging citizens. We leverage Information Systems (IS) Continuance Theory (Bhattacherjee, 2001) as kernel theory to inform our design. Furthermore, we exploit prescriptive knowledge from the field of context-aware computing, in particular JITAIs. On this basis, we articulate initial design requirements and principles for context-aware citizen science systems that can effectively maintain participant engagement over extended periods.

Through our research, we aim to contribute to both theory and practice by: (1) exploring the extension of IS Continuance Theory with context-aware mechanisms, (2) developing preliminary design principles for urban citizen science systems, and (3) investigating how JITAIs can potentially optimize engagement interventions in citizen science contexts.

2 Conceptual Foundations

2.1 Urban Citizen Science

Urban citizen science engages public participation to address urban challenges (Desouza & Bhagwatwar, 2012). As cities face growing sustainability challenges, citizen science emerges as a crucial tool for gathering data that traditional monitoring approaches cannot easily capture (Fritz et al., 2019). The urban context is particularly suitable for citizen science due to high population density, widespread smartphone adoption, and the immediate relevance of urban challenges to residents' daily lives (Desouza & Bhagwatwar, 2012).

As such, urban citizen science projects span various domains critical to city management and development, including environmental monitoring (e.g., air quality, noise pollution, urban heat islands), infrastructure assessment (e.g., road conditions, accessibility mapping), and public health surveillance

(Fritz et al., 2019). For instance, data collected through such initiatives have led to policy measures that optimize green space allocation, improve public transport planning, and implement targeted heat island mitigation strategies in cities across Europe (Desouza & Bhagwatwar, 2012). However, the urban context also presents distinct challenges for citizen engagement. Urban residents often have competing demands on their time and attention, making sustained participation particularly challenging. Additionally, urban environments are characterized by high mobility patterns and diverse daily routines, which complicate the timing and coordination of data collection activities

2.2 Context-Aware Computing and JITAIs

Context-aware computing enables systems to adapt their behavior based on environmental, temporal, and user-specific factors (Nahum-Shani et al., 2017). In the realm of behavioral interventions, JITAIs provide a structured framework for designing adaptive support systems. A JITAI consists of four key components: (1) decision points - times at which interventions may be delivered; (2) intervention options - the set of possible interventions; (3) tailoring variables - information about the user's current context; and (4) decision rules - logic specifying which intervention should be delivered under what circumstances to accomplish immediate goals (Proximal Outcomes) and long-term objectives (Distal Outcomes) (Nahum-Shani et al., 2017).

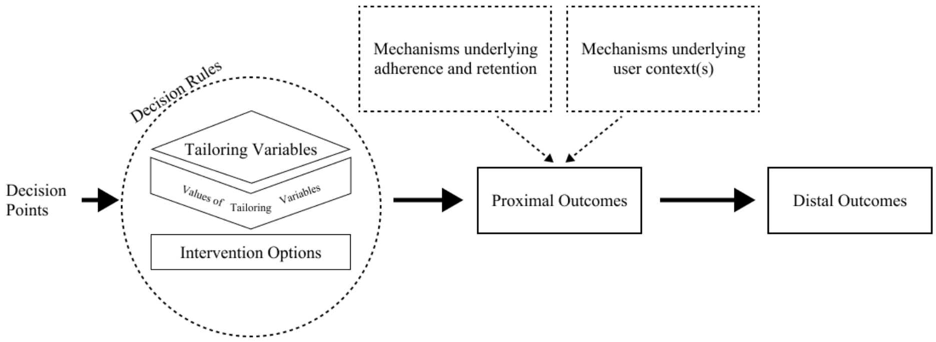

Figure 1. JITAI-Framework (adapted from Nahum-Shani et al., 2017).

3 Design Science Research Methodology

Our research employs a design science research (DSR) methodology following Kuechler and Vaishnavi (2008). In this paper, we report the results of the first cycle through the initial three phases of the DSR process: problem awareness, suggestion, and development.

To inform our understanding of citizen engagement challenges, we performed an exploratory literature review and conducted a pilot study in August 2024 in collaboration with the City of Zurich's Department of Health and Environment. Since Zurich is experiencing periods of extreme heat more frequently, the city approached us to conduct a citizen science project with the objective to detect urban heat islands. The study was carried out in Zuerich's District 4 (Züricher Kreis). Participants (N=20; Age: 65-80) were recruited through an advertisement in a local newspaper and engaged in the project over a three-week period. For this initial exploration, we developed a responsive web application that provided a simple digital form to allow participants to record temperature and humidity measurements as well as contextual observations using their smartphones. The purpose of the application was to simplify the data collection process for project participants while allowing us to track spatial and temporal activity patterns. Through an initial workshop, participants identified measurement locations along frequently visited walking routes and received training on using calibrated temperature and humidity sensors. They also learned to use our application for entering measurements and additional contextual information such as perceived temperature, characteristics of the built environment, weather conditions, and other relevant observations.

Data collection focused primarily on qualitative insights about participation patterns and engagement challenges. We conducted semi-structured post-study interviews with participants to understand their experience, motivations, and barriers to sustained participation. Through informal analysis of participants' responses, we identified several recurring themes regarding how contextual factors like weather conditions, daily routines, and location appeared to influence their participation. To provide a basic form of engagement support, we utilized simple email reminders.

4 Preliminary Results

4.1 Problem Awareness

The results of our exploratory literature review demonstrate that participant engagement in citizen science projects typically decreases after initial enthusiasm (Fischer et al., 2021), primarily due to insufficient feedback, unclear goals, technical difficulties, limited social interaction (Asingizwe et al., 2020; Eveleigh et al., 2014).

Our pilot study confirmed these results and provided additional insights into the issue of continuous engagement in citizen science initiatives. To systematically analyze our findings, we draw on Information Systems (IS) Continuance Theory (Bhattacherjee, 2001), which provides a theoretical foundation for understanding post-adoption behavior in information systems usage. The theory posits that users' intention to continue using an IS is predominantly determined by their satisfaction with prior use and their perception of its continued usefulness. IS Continuance Theory identifies three key constructs that interact to influence continuance intention: satisfaction, perceived usefulness, and confirmation of expectations. Satisfaction, conceptualized as the affective state arising from system use, serves as the primary determinant of continuance intention. This satisfaction is itself influenced by both the confirmation of initial expectations and the perceived usefulness of the system. Users engage in a continuous process of expectation-confirmation, where their initial expectations are either confirmed or disconfirmed through actual usage experience, leading to varying levels of satisfaction and, consequently, different continuance intentions.

In the context of citizen science systems, this theoretical lens suggests that participant retention is fundamentally linked to their satisfaction with the participation experience and their perception of the value of their contributions. Our post-study interviews provided further support for this perspective while revealing specific challenges aligned with the theory's core constructs. Due to field constraints, interviews were documented via detailed note-taking by multiple team members during each session. These notes were cross-validated by the team and analyzed using an inductive thematic approach to derive the key themes, which were then mapped onto IS Continuance Theory constructs. Building on our findings and theoretical foundation, we categorize the identified challenges associated with sustained engagement in citizen science systems by the determinants proposed by IS Continuance Theory in Table 1.

Engagement Challenges	
C1 Satisfaction	C1.1 Lack of immediate feedback on contributions: "After submitting measurements, I often wondered if they were useful or if I should measure somewhere else."
	C1.2 Insufficient recognition of participation efforts: "It would be nice to know how my contributions compare to others and if I'm helping the project progress."
	C1.3 Poor timing of engagement requests: "The email reminders often came at inconvenient times when I was busy with other activities."
C2 Perceived Usefulness	C2.1 Unclear impact of individual contributions: "I wanted to know whether my measurements were actually useful for understanding urban heat patterns."
	C2.2 Difficulty integrating with diverse participant contexts: "I found it easier to take measurements during my morning walk, but the suggested locations weren't always along my usual route."
	C2.3 Limited visibility of collective progress: "It wasn't clear how our combined measurements were helping the city plan for extreme heat."

C3 Expectation Confirmation	C3.1 Unclear participation expectations: "Sometimes I wasn't sure if I should be measuring at different times or locations."
	C3.2 Mismatched task complexity: "The environmental observations felt overwhelming at first - I would have preferred to start with just temperature readings."
	C3.3 Inconsistent value demonstration: "I wish I could see how my measurements fit into the bigger picture of urban heat patterns."

Table 1. Identified Engagement Challenges Clustered by IS Continuance Theory Determinant.

These findings suggest that while IS Continuance Theory provides a valuable framework for understanding engagement challenges, the influence of its core constructs (satisfaction, perceived usefulness, and confirmation) is significantly moderated by contextual factors in citizen science settings. This insight guides our development of context-aware design requirements and principles in the following section.

4.2 Suggestion

Drawing from our understanding of the themes that influence continuous engagement, we map the key challenges to six design requirements and articulate three design principles for urban citizen science systems (Table 2 & Table 3). Based on the derived requirements, we suggest that context-aware citizen science systems should enable sustained engagement by following three core design principles.

First, citizens need to understand when and how they can meaningfully contribute to scientific research. Our pilot study revealed that participation significantly varied based on citizens' daily routines, availability, and environmental conditions (DR1, DR4). Thus, our first design principle is:

DP1: To enhance citizen engagement, design the system with an ability to identify suitable moments of participation through context-aware timing.

The system must identify suitable moments for participation by considering temporal patterns (e.g., time of day, day of week), environmental conditions (e.g., weather), and personal factors (e.g., interests, activity level, location). By learning from participation patterns, the system can deliver intervention requests at moments when citizens are most likely to engage meaningfully, thereby increasing the likelihood of expectation confirmation.

Second, citizens should experience immediate value from their participation while understanding their contribution to the larger scientific endeavour. Our interviews revealed that unclear impact of contributions would lead to declining satisfaction and perceived usefulness (DR2, DR3, DR5). Therefore, we articulate the second design principle:

DP2: To maintain engagement, provide instant feedback and progress visualization that demonstrates the value of contributions.

The system should immediately acknowledge contributions and demonstrate their value through personalized feedback. Additionally, it should visualize how individual contributions support collective project goals, for example by showing the growth of collected data points on urban heat maps and their significance for urban planning. This addresses both the satisfaction and perceived usefulness constructs from IS Continuance Theory.

Finally, to maintain long-term engagement, the system should match participation demands to individual capabilities. Our pilot study showed that participants remained more engaged when tasks aligned with their interests and abilities (DR4, DR6). Thus, the third design principle is:

DP3: To sustain long-term participation, enable flexible engagement through adaptive task complexity that matches user capabilities and interests.

The system should start with basic tasks (e.g., simple temperature measurements) and progressively introduce more complex aspects (e.g., additional environmental observations) based on individual engagement patterns. This adaptation should ensure that participants remain challenged but not overwhelmed, supporting positive expectation confirmation. Table 2 and Table 3 summarize the proposed design requirements and design principles.

Design Requirements		
DR1 The system should optimize engagement timing by considering the user's full context (C1.3, C2.2)	DR2 The system should provide immediate feedback and recognition of contributions (C1.1, C1.2)	DR3 The system should demonstrate both individual impact and collective progress (C2.1, C2.3)
DR4 The system should adapt task complexity to individual interests and capabilities (C3.2)	DR5 The system should provide transparent verification and quality assessment (C1.1, C3.3)	DR6 The system should facilitate social interaction and peer recognition (C1.2, C3.1)

Table 2. Summary of Design Requirements.

Design Principles	
DP1	To enhance citizen engagement, design the system with an ability to identify suitable moments of participation through context-aware timing (DR1, DR4)
DP2	To maintain engagement, provide instant feedback and progress visualization that demonstrates the value of contributions (DR2, DR3, DR5)
DP3	To sustain long-term participation, enable flexible engagement through adaptive task complexity that matches user capabilities and interests (DR4, DR6)

Table 3. Summary of Corresponding Design Principles.

4.3 Development

We operationalized the design principles through a context-aware citizen science system, implementing a mobile application for geotagged data collection and a proposing a JITAI-based framework for sustained engagement. The current mobile application prototype, shown in Figure 2, implements DP2 of providing instant feedback and progress visualization. Upon submission of each data point, the system presents users with a success screen that quantifies their contribution's impact through multiple dimensions: progress toward project objectives, and earned experience points reflecting task complexity. An interactive map interface enables users to explore the spatial distribution of collected data, while a verification pipeline ("submitted," "under review," "verified") provides transparency about data processing.

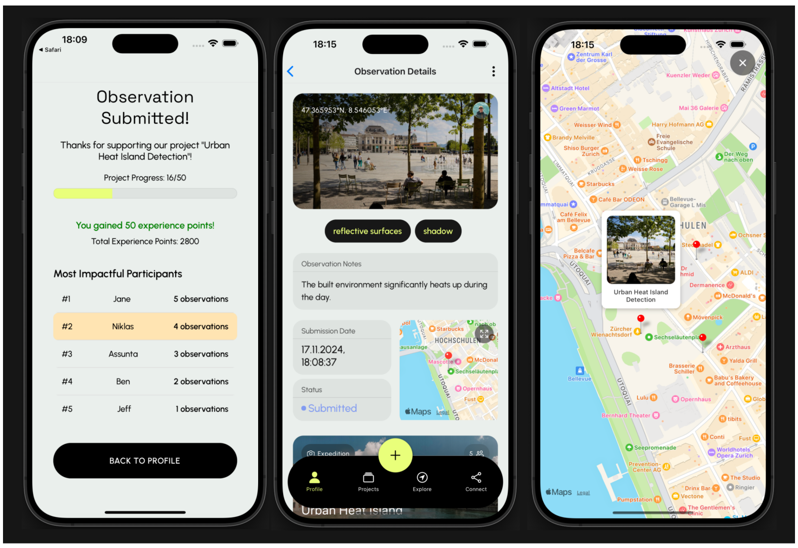

Figure 2. Mobile Application Screenshots showing (a) Instant Observation Feedback, (b) Verification Status, (c) Spatial Distribution of Project Data.

To extend this implementation with context-aware capabilities, we propose an architectural framework that incorporates the four essential components of JITAIs. The framework consists of two primary components: the Context Engine and the Intervention Manager.

The Context Engine implements the decision points and tailoring variables components of our JITAI framework. It processes three critical contextual dimensions: user context (current activity, location, interests, historical engagement patterns), environmental context (weather conditions, time of day), and project context (data collection requirements, coverage needs). This state representation enables the identification of opportune moments for intervention, implementing DP1 of optimizing engagement opportunities through context-aware timing.

The Intervention Manager implements the intervention options and decision rules components. The system maintains a set of interventions that vary in both content and complexity, ranging from basic data collection reminders to structured observation tasks requiring more detailed documentation. This variety supports DP3 by enabling flexible participation through adaptive task complexity.

Our next phase of development will focus on deploying and evaluating these capabilities in real urban settings and perform a large-scale field-based evaluation.

5 Conclusion and Next Steps

This research-in-progress paper presents an approach to addressing sustained engagement in citizen science initiatives. Our work demonstrates how Just-In-Time Adaptive Interventions can inform the design of context-aware citizen science systems. Specifically, we propose that contextual factors moderate the relationship between the core constructs of IS Continuance Theory: while its constructs remain key determinants of continuance intention, their influence is shaped by the user's context at the moment of interaction. This theoretical refinement suggests that the timing and nature of engagement opportunities affect how users evaluate their experience and form continuance intentions.

Our initial implementation of a mobile application enables citizens to contribute geotagged and annotated measurements to various urban development projects. Combined with the proposed framework for context-aware intervention delivery, it provides a foundation for empirically investigating the relationships between context, user satisfaction, and continuance intention. The design principles we developed bridge the gap between theoretical understanding and practical system design, offering guidance for future citizen science initiatives.

Several tasks remain to strengthen this research. First, we will complete the implementation of the Context Engine and Intervention Manager components, integrating them with our existing mobile application. This technical development is necessary for validating our proposed framework and will demonstrate how JITAI components can be operationalized in practice. Second, we will develop an administrative backend system to enable project creation and management, data verification, and intervention configuration. Third, we need to address the ethical implications of context-aware systems, particularly regarding user privacy and data protection. This includes developing guidelines for the collection and use of contextual data, and ensuring transparency about how this information influences intervention decisions. Lastly, we plan to conduct controlled experiments using our enhanced system to test specific hypotheses about how contextual factors moderate the relationships between perceived usefulness, satisfaction, and continuance intention. This validation will help establish the theoretical contribution of our work and provide evidence-based guidance for the design of future context-aware systems.

This work contributes to an understanding how context-aware mechanisms can connect to IS continuance theory while offering a real-world solution to the challenge of sustained engagement in urban citizen science. The framework we propose contributes new design knowledge and provides a foundation for developing citizen science systems that can adapt to users' changing circumstances while maintaining their engagement over time.

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