Collaborative design of IoT systems for smart cities with and for citizen participation

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Abstract. *Urban populations have grown and consequently cities have turned increasingly to IoT. IoT helps cities to address complex urban challenges and enhance quality of life. This doctoral project investigates how co-design methodologies can be properly applied to effectively implement IoT solutions in smart cities. The research aims to develop a comprehensive framework that provides guidelines, procedures, and artifacts for supporting co-design in the complex smart cities ecosystem. The expected outcomes include a deeper understanding of co-design in smart city contexts and practical insights into stakeholder engagement and technology integration.*

1. Introduction

With the increasing global population, there is a projection that by 2050 approximately 70% of the population will reside in urban areas [Desa et al. 2019]. Countries around the world have prepared to face the challenges that the projected urbanization will pose to existing urban systems [Ahvenniemi et al. 2017]. Simultaneously, cities have prepared to face greater connectivity and automation, with sensors, devices, and intelligent infrastructures that collect and share data in real-time to optimize urban functioning.

In the context of smart cities, Internet of Things (IoT) emerges as a promising solution to the challenges posed by increasing urbanization and the need for greater connectivity and automation. IoT involves the ubiquitous connection of devices to the Internet for data collection and analysis to support decision-making [Syed et al. 2021]. However, the implementation of IoT in smart cities is not trivial, involving complex technical issues such as device interoperability, data security, and the management of large volumes of information [Syed et al. 2021]. It is also crucial to consider ethical aspects, privacy, and social inclusion [Abascal and Nicolle 2005]. Moreover, citizen participation should be included in the process, as citizens are the primary stakeholders. Therefore, the success of IoT in smart cities depends on both the technology and the approach adopted for its development.

Co-design, a collaborative and interdisciplinary approach, arises as a method to ensure that IoT solutions are truly effective, inclusive, and oriented toward the needs of citizens [Wolff et al. 2020]. Co-design allows a wide range of stakeholders, including citizens and designers, to collaborate from the initial stages of the design process through to implementation [Sanders and Stappers 2014].

However, the literature has shown that there are two significant challenges in co-designing solutions for smart cities using IoT solutions. The first challenge is related to how to engage a diverse range of people throughout the process [Boztepe et al. 2023]. The second challenge pertains to the diversity of elements that should be considered in designing IoT solutions [Wolff et al. 2020, Rottleuthner et al. 2019]. There is a need for a representation that makes sense to the population and describes the possible interactions between people, sensors, data, systems, and services to assist during the design process.

This doctoral project aims to explore the follow research problem: how the application of co-design can address technical and citizen participation in the design of IoT software for smart cities. The research objectives are defined as follows: a) investigate the role of co-design in creating IoT solutions for smart cities, focusing on citizen participation, collaboration, and human-centered IoT; b) propose a framework that recommends guidelines, procedures, and artifacts to be applied in the context of smart cities, considering human and technical aspects; c) validate the proposed framework; d) conduct at least one round of co-design using the proposed framework to develop a solution for smart cities.

2. Related Work

In the development of IoT solutions for smart cities, various strategies promote co-design and collaboration among different stakeholders. One strategy involves using interactive and playful methods, utilizing augmented reality and a wearable device to engage communities in creating cultural content [Amaro and Oliveira 2019]. Another strategy incorporates Design Thinking to facilitate discussions among stakeholders and rapid prototyping to develop a service-oriented software platform [Mulvihill et al. 2019]. In [Rottleuthner et al. 2019], the authors created a versatile kit of sensors and reusable media to facilitate the creation of IoT prototypes in real environments that focused on user experience. Additionally, the use of user stories and indoor prototyping with cards and sensors is another approach to involving users in the design process [Berger et al. 2019].

In the studies above, several authors address issues related to engagement, increasing the participation of marginalized and vulnerable groups in co-design, as well as creating and/or listing tools to support co-design. However, co-design should consider a context that involves people with different needs, physical environments with various specific characteristics, and diverse technological elements such as sensors, actuators, and mobile elements generating large volumes of data.

3. Research Method

To address the research problem, this project will utilize an iterative and incremental approach (see Figure 1) in proposing a framework for the co-design of smart cities that considers human aspects and IoT technologies. This approach allows the framework to be developed in successive cycles, enabling a comprehensive understanding of the design process and ensuring the creation of a framework that effectively facilitates the use of co-design in a smart city environment.

The investigation of the State of the Art Research (A) has been completed. The topics explored during the (A) stage were discussed in Section 2. The (A) stage will be updated as this research progresses to subsequent stages.

The systematic review of the literature (SLR) (B) is ongoing and already provided partial results. This SLR aims to identify how technology is considered within the in-

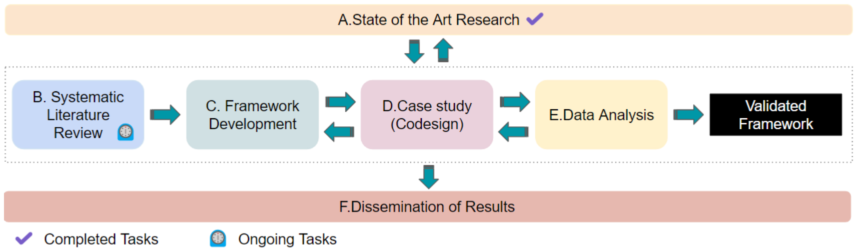

Figure 1. Research Methodology

teraction design process of smart cities. After applying the search string, 2234 articles were found, with 125 duplicates. ChatGPT-4 was adopted as the second researcher for the SLR to apply the inclusion and exclusion criteria [Alshami et al. 2023]. The criteria were applied to a sample of approximately 10% of the total of nonduplicate articles and were carried out manually (by the first author) and automatically (by ChatGPT-4). The literature points out that human error rates in the screening of systematic reviews vary from 5% to 20%, implying that a 100% score is "superior" to humans, while an accuracy score of 80% to 95% for ChatGPT-4 can be considered "on par" with humans [Khraisha et al. 2024]. To calculate ChatGPT's error margin, the percentage of errors relative to the total number of analyzed articles in the sample was determined. After creating and applying different strategies and prompts, an error margin of 2.94% for accepted articles and 3.68% for rejected articles was obtained, which is considered a good result. The sample was also subjected to the Kappa coefficient test, and we achieved an agreement level of 0.87 between the first author and ChatGPT-4, which is classified as almost perfect agreement [Landis and Koch 1977]. The next step of the SLR will be the application of the inclusion and exclusion criteria to the remaining articles using only ChatGPT-4. After this step, the Mixed Methods Appraisal Tool (MMAT) [Hong et al. 2018] will be used to perform the quality assessment of the selected articles.

Based on the findings from the SLR, the stage (C) will focus on the development of the framework first version. The first version of the framework will consist of a set of guidelines outlining the principles and steps for effective co-design in the context of smart cities. These guidelines will help structure the co-design process, facilitating collaboration among stakeholders with different perspectives and knowledge. This approach aims to ensure that the developed solutions are inclusive and technically viable.

The first case study (D) will be conducted in the context of the CONECTA 2030 project [1], allowing for the validation, refinement, and exemplification of the framework's application. The data analysis (E) will involve the collection and interpretation of the data obtained during the case studies. It is also intended to evaluate the use of distributed cognition as a method for analyzing co-design sessions. Distributed cognition views cognition as a systemic process rather than an individual one [Hollan et al. 2000]. It holds that information acquisition and propagation happen through interactions among people, their environment, and artifacts, all of which impact human work.

Regarding ethical aspects during the case studies, the project will adhere to Regulation 510/2016 of the Brazilian National Health Council, which governs non-invasive

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studies involving human subjects. Key procedures include informing participants about the research, explaining data collection, and ensuring data is used solely for scientific purposes. Participant confidentiality and privacy will be maintained, and results will be accessible upon request. The study will be conducted in a suitable setting to minimize fatigue and stress. Participation is voluntary, with the right to withdraw at any time without penalty and without financial compensation. Furthermore, the project will be submitted to the ethics committee for approval.

4. Timeline

The planned activities can be seen in Figure 2.

Activity	2024				2025				2026				2027			
	1st Tri	2nd Tri	3rd Tri	4th Tri	1st Tri	2nd Tri	3rd Tri	4th Tri	1st Tri	2nd Tri	3rd Tri	4th Tri	1st Tri	2nd Tri	3rd Tri	4th Tri
A	✓															
B		⏱	○													
C			○	○				○	○							
D					○	○				○	○					
E							○	○				○	○			
F			○	○				○	○					○	○	○
G	✓	⏱	○	○												

✓ Completed Tasks ⏱ Ongoing Tasks ○ Not Started Tasks

Figure 2. Doctoral project timeline

A01: Research articles to identify the state of the art in the project's subject area.
B01: Define the search string and apply it to the selected databases.
B02: Define the prompt and apply the inclusion and exclusion criteria using ChatGPT for a sample of the articles found.
B03: Apply inclusion and exclusion criteria to the remaining articles using only ChatGPT-4.
B04: Perform quality assessment of the selected articles using the Mixed Methods Appraisal Tool (MMAT).
B05: Extract, synthesize, and analyze data from the selected articles, focusing on relevant contributions to the framework development.
C01: Develop preliminary guidelines for the co-design of smart cities, ensuring inclusion and technical feasibility, based on the findings of the SLR.
C02: Identify existing procedures, methods, and artifacts, recommending them for different situations based on the findings of the SLR.
D01: Conduct co-design sessions using the developed framework, documenting each stage of the process.
D02: Collect feedback from participants during and after the co-design sessions, evaluating the practical application of the guidelines.
E01: Perform qualitative and quantitative analyses of the obtained data, identifying relevant patterns and insights.
E02: Review and refine the framework as necessary, incorporating feedback and data analysis results.
F01: Prepare scientific articles detailing the development, application, and validation of the framework, aiming for publication in relevant journals.
F02: Writing of the qualification of doctoral project and examination.
F03: Thesis writing and defense.
G01: Take courses from the graduate program.

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