UX evaluation of IoT-based applications for Smart Cities: a rapid systematic review

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Abstract. *The development of systems based on the Internet of Things (IoT) technologies is becoming increasingly popular in the context of Smart Cities. Recent research in Software Engineering (SE) has investigated the characteristics of these systems and the most appropriate approaches to their design and development. IoT-based applications are strongly characterized by the interaction among multiple devices, users, and services. These characteristics make these applications complex and difficult to evaluate, particularly in terms of User Experience (UX) design. In this study, we performed a rapid systematic review to examine the methods and practices commonly employed for evaluating the UX of IoT-based applications for Smart Cities. We analyzed 43 studies covering different types of IoT-based applications, most in the area of Smart Home. Our findings indicate that user testing questionnaire-based (e.g., SUS - System Usability Scale and UEQ - User Experience Questionnaire) and interviews are the most used methods to evaluate IoT applications, while few studies mentioned user testing based on automated measurement or expert-based reviews. This work contributes to SE research by revealing the need to explore UX evaluation methods based on usage data and the combination of methods for continuous UX evaluation in the context of IoT and Smart Cities.*

1. Introduction

Recent research in Software Engineering has increasingly focused on addressing challenges related to the design and development of systems based on the Internet of Things (IoT). IoT plays a key part in the development of Smart Cities platforms by allowing the integration of a wide range of devices and applications [Syed et al. 2021]. Applications based on IoT technologies have been used in the area of Smart Cities to make urban planning and infrastructure maintenance more efficient, monitor air quality, and reduce waste of water, energy, and other natural resources, focusing on boosting the living experience of their residents [Whaiduzzaman et al. 2022]. Regardless of how many aspects and dimensions are involved, IoT-based applications for Smart Cities are closely related to sensor networks, smart devices, real-time data, and information and communications technology integration in all aspects of human life [Cretu 2012].

IoT supplies the technological basis for continuous communication between devices, systems, and people through a combination of three main components: (i) smart devices (hardware) equipped with components to provide communication (sensors, chips, antennas, etc.); (ii) IoT applications (middleware) using computing technologies such as ML and AI for on-demand storage and analysis of data received from various devices; and

(iii) graphical user interfaces (mobile or web application) for management and control of smart devices and data visualization [Gubbi et al. 2013].

IoT-based applications offer novel ways for human-thing and thing-thing interactions. However, such interactions in smart environments involving multiple devices, users, and services make the IoT scenarios complex and difficult to evaluate software quality attributes such as User Experience (UX) [Andrade et al. 2017]. The concept of UX was introduced in the 90s by Donald Norman to describe all aspects of the end user's interaction with the company, its services, and its products [Norman and Nielsen 2020]. Over the years, a variety of definitions have been suggested to better understand the meaning of UX from different perspectives. From an industry perspective, ISO 9241-210 defines UX as "*the user perceptions and responses that result from the use and/or anticipated use of a system, product or service*" [ISO9241-210 2019]. From the perspective of evaluating experience, for Hassenzahl and Tractinsky [Hassenzahl and Tractinsky 2006], the idea of UX goes beyond providing an intuitive and functional *design* about software, emphasizing that experience is a phenomenon that emerges from the integration of action, perception, motivation, and emotion, which occur within a given space of time and place.

Due to the dynamic and temporal aspect of UX, experience information can be collected at different points in the product development cycle to include different experience episodes [Hassenzahl and Tractinsky 2006]. However, IoT-based applications for Smart Cities pose additional challenges for evaluating UX due to the nature of the interaction, which can change from explicit to implicit, encompass different interaction methods, and scale from one to many interactions [Stephanidis et al. 2019]. Furthermore, recent studies have highlighted the lack of generic and systematic approaches to evaluating UX in the IoT scenarios [Stephanidis et al. 2019] [Almeida et al. 2018].

In this study, we present a rapid review (RR) [Tricco et al. 2015] conducted to investigate UX evaluation methods commonly used in the context of IoT and Smart Cities to address a problem identified in practice. RR is a variant of the Systematic Literature Review (SLR) which simplifies some steps of the review procedures intended providing actionable insights for practice at a low cost and in less time [Cartaxo et al. 2018]. The question we are trying to answer with this research is: *Which methods are commonly applied for evaluating the UX of IoT-based applications?* By answering this question, this literature review contributes to an overview of UX evaluation in IoT for Smart Cities, highlighting some research gaps such as the lack of studies on evaluation methods based on usage data, automated measurements, and the combination of methods for continuous UX evaluation in this area.

The remainder of this paper is structured as follows: we present the background on IoT-based applications for Smart Cities and the existing literature on UX evaluation in this area, in Section 2. Section 3 presents the research method describing the RR context, planning, and execution. Section 4 shows the RR results on IoT layers, things and users involved, and UX methods applied in the Smart City context. We discuss our findings in Section 5 and conclude the paper in Section 6.

2. Background

This section provides the concepts covered in our study through an overview of studies on IoT-based applications for Smart Cities and UX evaluation in IoT applications.

2.1. IoT-based applications for Smart Cities

Considering the recent emerging technological trends for smart environments, several studies have pointed out challenges referring to IoT system design and structure [Whaiduzzaman et al. 2022], the management and analysis of large amounts of data collected from different sources [Reinfurt et al. 2017], users working with a set of heterogeneous devices and machines [Syed et al. 2021], and concerns on human aspects to understand context of use, users need, and business interests [Motta et al. 2023]. IoT research is recognized as a multidisciplinary domain that covers a range of topics from socio-technical to business. Motta et al. [Motta et al. 2018] identified seven facets to be taken into account in IoT software systems design by characterizing this multidisciplinary. Interactivity is one of the identified facets that refers to the involvement of humans, non-humans, and things in exchanging information and the degree to which this happens through connectivity and interoperability.

In the Smart City context, IoT systems involve the collection of data from sensors about the city's state to a central cloud, and the performing of data analytics operations to extract information to support policymakers and citizens [Syed et al. 2021]. IoT-based applications have been developed in Smart Cities for many purposes, including monitoring energy consumption, traffic control, pollution reduction, and solid waste management [Abdulsattar et al. 2022] [Ismail et al. 2019]. The eight components of a Smart City are: Smart Energy, Smart Homes, Smart Industry, Smart Infrastructure, Smart Agriculture, Smart Transportation, Smart Health, and Smart City Services [Syed et al. 2021]. A typical IoT architecture for Smart Cities consists of five layers: 1) *sensing layer* (i.e., sensors, actuators, mobile elements), 2) *network layer* (i.e., network technologies and topologies), 3) *middleware layer* (i.e., APIS, databases, security), 4) *applications layer* (i.e., applications, systems, and platforms), and 5) *business layer* (i.e. analytics, machine learning, optimization, deep learning) [Syed et al. 2021].

2.2. UX evaluation of IoT-based applications

The literature has investigated more effective methods for evaluating the UX of IoT applications. Shin [Shin 2017] theoretically conceptualized the notion of quality in the IoT, established a relationship between technical quality and users' perceived assessments, and proposed an approach to evaluating the quality of experience for IoT applications focused on content, hedonicity, coolness, affordance, system, and utility. Almeida et al. [Almeida et al. 2018] conducted an RSL on methods for evaluating UX in the IoT scenario and identified a predominance of the use of empirical methods, such as observation of user behavior and interviews. As challenges in conducting UX evaluation, they found that evaluation in the controlled environment may differ from the user's actual use environment, as well as in an environment with many IoT applications. In an exploratory study, Hacid et al. [Hacid et al. 2023] examined where IoT and UX meet for the benefit of users by associating conventional interaction design principles (i.e., Nielsen's usability heuristics [Nielsen 1994]) to challenges that IoT wider acceptance faces according to existing literature. The authors found that programmability and context sensitivity were the most evaluated aspects of IoT.

Mendoza et al. [Mendoza et al. 2023] conducted an SLR on evaluation in ubiquitous and pervasive technology scenarios of interactive installations (e.g., art installation, multimodal installation, and museum exhibition). They found that most studies adopted classical evaluation methods, such as interviews, video recordings, questionnaires, observation, system logs, and physiological measurements. Moreover, they identified three main groups of objects of evaluation addressed in selected studies: (1) people involved directly in their experience, behavior, learning, engagement, affective states, and social relations; (2) system-focused in its usefulness and design; and (3) an "in-between" human-technology relation, encompassing interaction, usability, usage, and overall scenario. Angeloni et al. [Angeloni et al. 2023] carried out a rapid review (RR) on assessments for quality in the use (QinU) of applications in smart environments. QinU refers to the overall quality of the system in its operational environment used by specific users (e.g., elderly or people with disabilities) for the execution of specific tasks (e.g., to help keep elderly people safe at home). Effectiveness, efficiency, freedom from risk, and satisfaction are the main QinU constructs. Commonly, QinU evaluations can be performed by observing the user's interaction with the application. However, this study revealed that the evaluation of applications in smart environments that consider the end user is often done by questionnaires after the use of the software system.

More recently, Ntoa et al. [Ntoa et al. 2021] proposed a conceptual and methodological framework named UXIE for the evaluation of UX in intelligent environments. Taking into account the various characteristics of intelligent environments, the UXIE framework provides concepts and concrete metrics from seven fundamental quality attributes, namely intuitiveness, unobtrusiveness, adaptability and adaptivity, usability, appeal and emotions, safety, and privacy, as well as technology acceptance and adoption. As a methodological tool, UXIE also provides recommendations on the methods to be used to acquire the specified metrics. In this framework, the evaluation methods were categorized into six categories: (1) user testing task-based, or think-aloud, (2) user testing questionnaire-based, (3) user testing through interviews, (4) field study or in-situ evaluation, (5) expert-based reviews; and (6) user testing using automated measurement. It is worth noting that the categorization of UX metrics and attributes is not part of the scope of this article.

Despite the relevance of the previously mentioned studies, to the best of our knowledge, no study has investigated UX evaluation from the perspective of IoT architecture layers and Smart Cities components. In this study, we adopted the classification provided in [Syed et al. 2021] to categorize studies according to five IoT architecture layers and eight Smart City components (see Section 2.1). The identification of UX methods considering the IoT architecture is useful to indicate the layers commonly evaluated, allowing us to identify more suitable methods for each of them or identify deficiencies in evaluation studies in one layer or another. Additionally, we categorized the UX evaluation methods applied in primary studies based on the categories proposed in the UXIE framework [Ntoa et al. 2021], as it is focused on intelligent environments.

3. Research Method

A Rapid Review (RR) study was performed to investigate how UX evaluation has been applied in the area of IoT and Smart Cities. This RR was motivated by an issue raised in an interaction of the researchers with software practitioners, aiming at investigating the challenges faced by software companies to improve product quality through UX design practices [Choma et al. 2022]. In one of the studied companies, practitioners mentioned a challenge regarding evaluating the UX of an IoT platform to support decision-making in the area of water and gas loss management developed for public and private companies. This IoT platform included three main components: 1) a device for remote noise collection (sensing layer), 2) a database and algorithms involving signal processing using artificial intelligence to capture different formats of data coming from different devices (middleware layer), and 3) a web application for data visualization (application layer). Given the researchers' and practitioners' interest in evaluating the UX of IoT platforms in the Smart City context, the following research question arose: *Which UX methods are commonly applied for evaluating the UX of IoT-based applications?* By answering this question, practitioners will be able to select the most appropriate methods to evaluate their applications and identify UX issues that need to be fixed and/or improved.

RR planning: RR is a lightweight variant of the systematic literature review widely used in medicine, focused on delivering evidence to practitioners on time [Tricco et al. 2015]. Cartaxo et al. introduced RRs into evidence-based software engineering, explaining that some steps of the review procedure are omitted or simplified to reduce costs and completion time [Cartaxo et al. 2018]. As a strategy, RRs can limit the literature search by sources or data, employ just one person to screen studies, eliminate the quality assessment step, and/or present the results succinctly and directly. According to them, RRs can be commissioned by professionals, policymakers, or researchers as long as they offer useful knowledge to support decision-making for a practical problem [Cartaxo et al. 2018]. In our RR, we developed a research protocol that can be seen in Table 1. As shown in this table, we performed a quality assessment on the selected primary studies by checking four criteria (i.e., C1 to C4), where each of them was assigned a value based on the response of "Yes" (weight= 1), "Partially" (weight= 0.5), or "No" (weight=0). In addition, we prepared an extraction form to retrieve the following information from the selected studies: research type, contribution type, study objective, things to be evaluated, target users/ stakeholders, IoT layers [Syed et al. 2021], Smart city areas [Syed et al. 2021], and UX evaluation methods to be categorized from concepts presented in UXIE framework [Ntoa et al. 2021] (see in Section 2).

RR execution: By following the guidelines suggested by [Cartaxo et al. 2018], we opted to limit the number of data sources and search period to reduce cost and completion time. We searched for studies in the three databases, in March 2023. We set a limit of the last five years for searches across all databases (i.e., from 2018 to 2022). Nevertheless, we considered selecting secondary studies in our sample to cover periods before 2018. The search string applied to the databases returned 666 studies. Figure 2 shows the number of studies retrieved per database. The Parsifal tool [1] was used to support the search, selection, and analysis activities. In the selection phase, the duplicate studies were eliminated (n=23). Secondly, the researcher analyzed the studies´ titles and abstracts excluding those that did not meet the selection criteria (n=439), resulting in 204 studies. Finally, the researcher analyzed the entire content of the remaining papers and eliminated 161 additional studies that did not meet the acceptance criteria, resulting in 43 articles for extracting and analyzing data. The searching, selection, data extraction, and analysis took around thirty days. Table 2 presents the selected papers. The selection procedure and data extraction are available at `http://tinyurl.com/cfz74xbt`.

[1] https://parsif.al/

Table 1. Rapid review protocol on UX evaluation of IoT-based applications

Objective	This review aims to investigate commonly used methods for evaluating the UX of IoT applications in the context of Smart Cities.
Search string	("user experience" OR "ux") AND("assessment" OR "evaluation" OR "measurement" OR "monitoring") AND ("IoT" OR "internet of things" OR "smart" OR "smart city")
Sources	ACM Digital Library (http://portal.acm.org) IEEE Digital Library (http://ieeexplore.ieee.org) Scopus (http://www.scopus.com)
Inclusion Criteria	(I1) Primary and secondary studies (I2) Studies addressing UX evaluation of IoT-based applications in Smart City.
Exclusion Criteria	(E1) Duplicated papers (E2) Not articles (title page and preface) (E3) Not fully accessible (E4) Not related to IoT or Smart City areas (e.g., medicine, health) (E5) Not related to UX research (E6) Not written in English (E7) Short papers (4-page long or less)
Quality Assessment Checklist	(C1) Is the research aim/objective clearly defined? (C2) Is the context of research well addressed? (C3) Are the findings clearly stated? (C4) Based on the findings, how valuable is the research to this study?

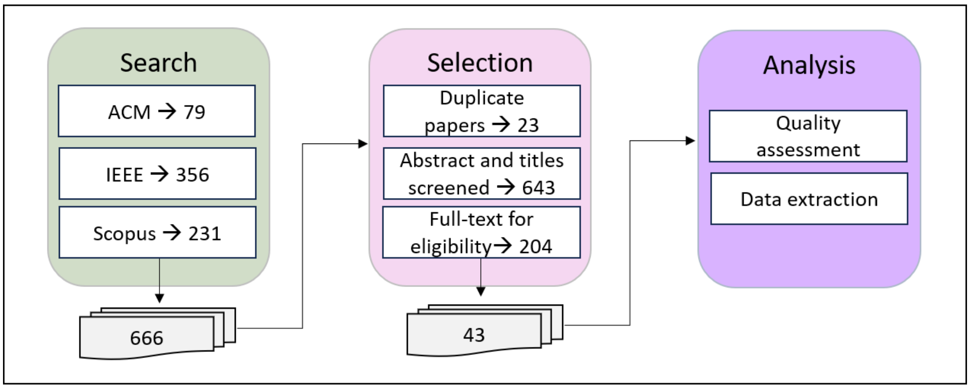


Figure 1. Selected papers process

4. Results

This section presents the results from the analysis of the 43 primary and secondary studies based on the research protocol (see Table 1). Section 4.1 presents an overview of the selected studies. IoT layers, target things, and target users addressed in the primary studies are presented in Section 4.2. Section 4.3 presents the UX evaluation methods commonly applied in IoT applications for Smart Cities. Section 4.4 describes the secondary studies. Finally, Section 4.5 discusses the threats to the validity of this study.

4.1. Overview

As shown in Figure 2-a, 65% of the selected studies (28 out of 43) were from journals, mostly long and complete manuscripts. About 35% of the studies presented proposals of models, frameworks, sensors, platforms, architecture, and guidelines, to name the most frequent ones. We found four studies about IoT and Smart City platforms for intelligent traffic control (S8), urban planning (S23), flood risk, the vulnerability of private properties (S26), and digital urban interfaces (S24). Regarding UX proposals, we found six primary studies proposing UX evaluation guidelines and checklist (S15 and S38), UX evaluation methodology (S24 and S41), and UX metrics (S29). Surveys and interviews were the other two most frequent research methods applied in the studies (Figure 2-b). Figure 2-c

Table 2. List of selected papers

ID	Title
S1	A Context-Aware Concept Evaluation Approach Based on User Experiences for Smart Product-Service Systems Design
S2	A continuous, semi-automated workflow: From 3d city models with geometric optimization and cfd simulations to visualization of wind in an urban environment
S3	A Critical Review of Smart Residential Environments for Older Adults With a Focus on Pleasurable Experience
S4	A generic user interface for energy management in smart homes
S5	A Novel Internet of Things-Based Plug-And-Play Multigas Sensor for Environmental Monitoring
S6	A QoE Model for Mulsemedia TV in a Smart Home Environment
S7	A Study of Smart Home User Personas Based on Context Theory
S8	Adaptive Interface Ecosystems in Smart Cities Control Systems
S9	Address and Command: Two-Handed Mid-Air Interactions with Multiple Home Devices
S10	Adoption of Environmental Information Chatbot Services Based on the Internet of Educational Things in Smart Schools
S11	Ambient intelligence in the living room
S12	An exploratory study on how Internet of Things developing companies handle user experience requirements
S13	An intrusion detection framework for non-expert users
S14	Autonomous parking system user interface – assessment of visual behavior
S15	CHASE: Checklist to Assess User Experience in IoT Environments
S16	Comparing Heuristic Evaluation and MALTU Model in Interaction Evaluation of Ubiquitous Systems
S17	Detecting Anomalies in Daily Activity Routines of Older Persons in Single Resident Smart Homes
S18	End-user Development for Smart Spaces: A Comparison of Block and Data-flow Programming
S19	Environment monitoring system of dairy cattle farming based on multi-parameter fusion
S20	Evaluating a workflow tool for simplifying scenario planning with the online whatif? Planning support system
S21	Evaluating Smart Home Services and Items: A Living Lab User Experience Study
S22	EVLibSim: A tool for the simulation of electric vehicles' charging stations using the EVLib library
S23	Experimental towards User Experience and User Interface in Smart Land Use Informatic Platform
S24	Having a smarter city through digital urban interfaces: An evaluation method
S25	I am not a number: Towards participatory IoT monitoring in the workplace
S26	Less is more? Evaluating technical aspects and user experiences of smart flood risk assessment tools
S27	Longitudinal User Experience Studies in the IoT Domain: A Brief Panorama and Challenges to Overcome
S28	Low-cost IoT remote sensor mesh for large-scale orchard monitorization
S29	Measuring User Experience Quality of Voice Assistants
S30	Mid-air gesture control of multiple home devices in spatial augmented reality prototype
S31	MorSocket: An Expandable IoT-Based Smart Socket System
S32	Multimodal Interface for Human–Robot Collaboration
S33	On User Experience in The Internet of Things
S34	ParlAmI: A Multimodal Approach for Programming Intelligent Environments
S35	QFD-Based Research on Sustainable User Experience Optimization Design of Smart Home Products for the Elderly
S36	Quality Provisioning in the Internet of Things Era: Current State and Future Directions
S37	Reshaping the Smart Home Research and Development in the Pandemic Era: Considerations around Scalable and Easy-to-Install Design
S38	Smart Co-housing for People With Disabilities: A Preliminary Assessment of Caregivers' Interaction With the DOMHO
S39	Ubiquitous Machinery Monitoring – A Field Study on Manufacturing Workers' User Experience of Mobile and Wearable
S40	User experience evaluation for a bus tracking apps in smart campus initiative
S41	User Experience Evaluation in Intelligent Environments: A Comprehensive Framework
S42	User Interface for the Creation of Smart Home Automation Rules
S43	UX Evaluation with Standardized Questionnaires in Ubiquitous Computing and Ambient Intelligence

shows the distribution of studies per year. When evaluating the quality of the articles, we obtained a score of 3.56 on average, which means a high degree of quality regarding rigor and relevance. We found only one article with a score below the cutoff line we established (i.e., <= 1.0), which was excluded from our analysis (see Figure 2-d).

4.2. IoT layers, target things and users

In general, the articles deal with more than one IoT layer in their proposals. The mapping of studies by IoT layers is presented in Table 3. About 77% of studies address the application layer, which uses the data through various API's and database management services to provide users with services [Syed et al. 2021], bridging the gap between the virtual world and the physical world [Hidalgo et al. 2022]. The sensing layer is the second most addressed layer, mentioned in 44% of studies. This layer is where the data is read and passed onward to the middleware layer using the networking layer through wireless net-

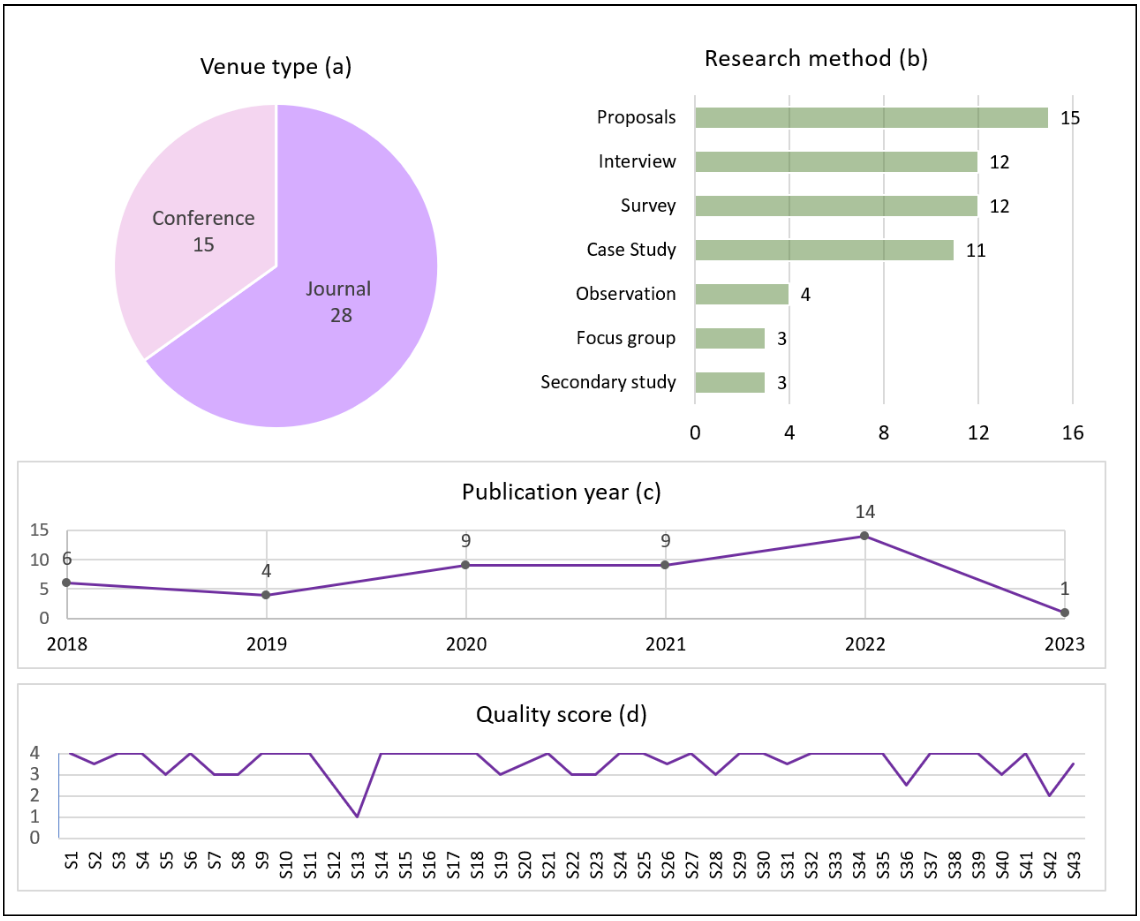


Figure 2. Selected papers overview

work technologies such as Wi-Fi, Bluetooth, etc [Syed et al. 2021]. Few studies mention the business layer in charge of developing strategies and rules that help manage the overall operation of the IoT system, which is attached to the application layer [Syed et al. 2021]. The studies address different types of applications and things, as shown in Figure 3. Regarding target users or stakeholders, smart home residents and UX experts are the focus of most studies (see Figure 3-b).

4.3. UX evaluation methods applied in Smart City

As explained in Section 2, we adopted concepts from UXIE framework [Ntoa et al. 2021] to categorize the UX evaluation methods applied in the studies. In this step, we excluded twelve studies from this analysis either because they did not mention the application of a UX evaluation method or because they were secondary studies. The UX methods identified in the remaining studies were mapped by Smart City areas, as shown in Figure 4. It is worth noting that we identified more than one method in some studies, as we can see in Figure 4. A third of the selected studies applied more than one evaluation method; with two studies applying 3 methods (S30 and S39) and one study applying 4 methods (S38). Also, in some studies, we identified more than one Smart City area covered. The areas most identified in studies are Smart Home and Smart City Services On the other hand, we found few UX evaluation studies in Smart Energy and Smart Agriculture. The most applied method is *user testing based on questionnaire*, which was identified in 57%

Table 3. IoT layers addressed in the studies

IoT Layer	N	Studies
Application layer: applications, systems, platforms	33	S2, S4,S6, S7, S8, S10, S11, S12, S14, S15, S16, S17, S18, S19, S21, S22, S23, S24, S26, S27, S29, S32, S33, S34, S35, S36, S37, S38, S39, S40, S41, S42, S43
Sensing layer: sensors, actuators, mobile elements (e.g., smartphones, cars)	19	S3, S6, S11, S14, S17, S19, S25, S27, S28, S29, S30, S31, S32, S33, S36, S37, S39, S41, S43
Middleware layer: APIs, databases, security	8	S3, S5, S13, S20, S23, S33, S36, S37
Business layer: data analytics, machine learning, optimization, deep learning	4	S1, S2, S9, S36

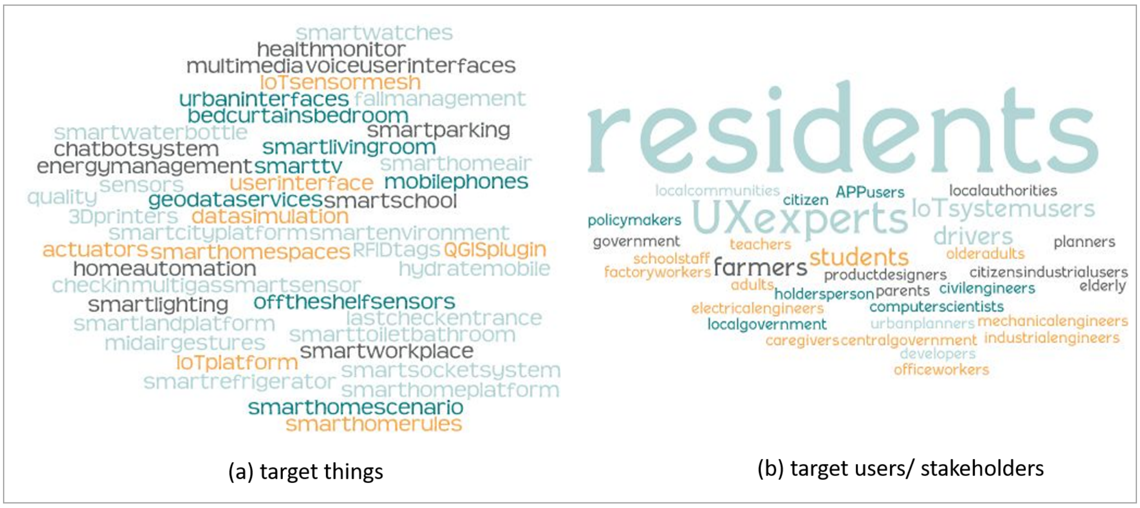
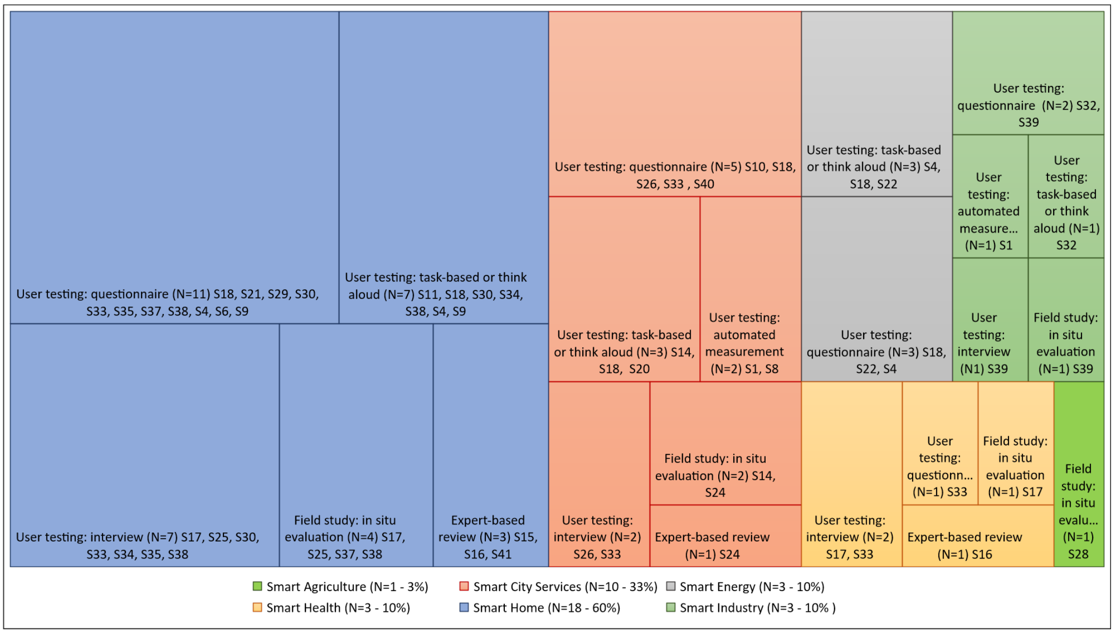


Figure 3. Target things and users/ stakeholders addressed in the studies

of studies (17 of 30). These questionnaires are often applied together with user testing task-based or think-aloud (S4, S9, S30, S32, S38), followed by interviews (S26, S30, S35, S38, S39), or in-field studies (S37, S38, S39). More than half of the studies (9 of 22 - 52%) applied standardized UX questionnaires such as SUS[2] (S4, S9, S30, S32, and S39), UEQ[3] (S9, S18, S29, and S30), meCUE[4] (S40), NASA-TLX[5] (S32), and UTAUT[6] (S10). The remaining eight studies applied non-standardized UX questionnaires (S6, S21, S22, S26, S33, S37, S38, and S35). Only four studies reported expert-based review and the other two reported user testing based on automated measurement. Expert-based reviews were identified in studies related to Smart Home (S15, S16, and S41), Smart City Services (S24), and Smart Health (S16); while user testing based on automated measurement appeared in studies related to Smart Industry (S1) and Smart City Services (S1 and S8).

[2] SUS - System Usability Scale [Brooke 2013]
[3] UEQ - User Experience Questionnaire [Laugwitz et al. 2008]
[4] meCUE - A modular questionnaire for recording the user experience [Minge et al. 2017]
[5] NASA-TLX - Task Load Index [Hart and Staveland 1988]
[6] UTAUT - Unified Theory of Acceptance and Use of Technology [Venkatesh et al. 2003]



* the caption shows the number of studies covering each Smart City area.

Figure 4. Mapping of UX methods by Smart City areas

4.4. Secondary studies

Next, we describe three systematic literature studies that we selected in our RR (S3, S27, and S43). Lee and Kim [Lee and Kim 2020] (S3) conducted a critical review of smart residential environments aimed at supporting positive aging and pleasurable user experience in the architecture domain. From the study findings, the authors provide a framework to evaluate the well-being, independence, acceptance, and design of smart homes. The details covered in their framework are critical factors that should be considered in providing this type of environment, from the beginning stage of understanding the target user to the design and system evaluation stages.

Diáz-Oreiro et al. [Díaz-Oreiro et al. 2021] (S43) performed a systematic literature review to investigate the use of the three most recognized standardized questionnaires for UX evaluation, i.e., AttrakDiff [Hassenzahl et al. 2003], UEQ [Laugwitz et al. 2008], and meCUE [Minge et al. 2017], in studies involving ubiquitous computing, ambient intelligence, and nontraditional interfaces. They analyzed 132 studies evaluated with standardized questionnaires in the areas of ubiquitous computing and ambient intelligence studies, of which 36 studies on in-vehicle information systems, 28 studies on IoT and wearable sensors, and 27 studies on Smart Cities. As a result, the authors found that AttrakDiff has been the predominant questionnaire for studies of Smart Cities, including smart homes and in-vehicle information systems.

Melo et al. [Melo et al. 2022] (S27), firstly, performed the forward snowballing from a set of key studies to investigate UX evaluations in the IoT field, especially focused on long-term evaluation. Secondly, they conducted a systematic mapping to explore how longitudinal evaluations are done in IoT to understand the strategies used by researchers in this domain. Moreover, they also searched for UX theoretical constructs associated with the long-term adoption or rejection of IoT systems, to explore the opportunities, difficulties, and potentialities of conducting UX longitudinal studies in the IoT domain.

Due to privacy concerns about IoT devices, they found that users may tend not to want to participate in longitudinal studies with log collection when the usage information is exposed. Furthermore, they pointed out the difficulties of conducting longitudinal UX evaluations in real scenarios. Due to the cost of execution, many assessments are carried out in simulated environments which do not cover some situations that only occur in real contexts. Lastly, they highlighted the challenge of choosing appropriate UX constructs to evaluate IoT systems over time.

4.5. Threats to validity

As with any other empirical study, Rapid Reviews are also subject to limitations and threats to validity. However, due to lightweight methodology, RRs usually present more threats to validity than other systematic studies [Cartaxo et al. 2018]. To mitigate the threat of obtaining a limited number of primary studies, we applied our search string to three different databases, one of which (i.e., Scopus) indexes and searches several relevant digital libraries on Software Engineering. The search, selection, and data extraction steps were conducted by a solo researcher. To mitigate the selection and interpretation bias of the researcher, these steps were reviewed and discussed by a second researcher. To ensure the reliability of the evidence, we performed a quality assessment of the selected primary studies. Moreover, we adopted a research protocol based on [Cartaxo et al. 2018] to ensure the replicability of the study.

5. Discussion

Previous studies have been concerned with conceptualizing quality in the IoT and extending the conventional UX approach to the IoT context [Shin 2017], as well as developing practical tools to assist UX evaluation in the IoT scenario [Almeida et al. 2018]. Other studies have investigated related areas such as ubiquitous and pervasive technology scenarios of interactive installations [Mendoza et al. 2023] and more general themes such as assessments for quality in the use of applications in smart environments involving specific users [Angeloni et al. 2023]. The secondary studies selected in our review also addressed the UX evaluation of smart environments in a specific domain (i.e., smart homes from an architectural perspective, in-vehicle information systems, and wearable devices [Lee and Kim 2020] [Díaz-Oreiro et al. 2021]) and comprehensively the long-term UX assessment in the IoT domain.

Unlike the studies aforementioned, the primary studies selected in this review cover a broad range of IoT applications from different Smart Cities areas. We found several studies that covered research interests coming from domains outside the SE boundaries (e.g., Urban Planning, Psychology, Buildings, Technologies, and Machines), outlining the multidisciplinary nature of IoT technologies for the Smart Cities context. In SE, this multidisciplinary nature is already recognized, as the IoT paradigm encompasses many knowledge areas (e.g., ubiquitous domains, computing and cloud computing, and data analytics) which are integrated to create autonomous and intelligent software systems [Motta et al. 2018]. Regardless of the UX methods applied, our findings indicate that the UX attributes evaluated may vary depending on the domains and areas of interest. In this sense, we noticed that *the diversity of contexts and purposes in the Smart City area can lead to the combination of UX methods to encompass several constructs to be evaluated (e.g., usability, acceptance, trust, integration, privacy)* (see Section 4.3).

Although studies on the IoT application layer were found more frequently, we found a few studies on UX evaluation in Smart City platforms (see Section 4.1). Smart City platforms usually are based on a continuous workflow embracing data model implementation and analysis of different visualization schemes on urban activities to support different [Deininger et al. 2020]. However, we found a single study that was concerned with defining methodology and tools to evaluate user experience in the domain of digital urban interfaces [Aceves Gutierrez et al. 2019]. In this study, the authors defined a series of specific guidelines for evaluating urban interfaces based on the literature review and other characteristics of urban space such as physical location, use schedule, and citizen profile [Aceves Gutierrez et al. 2019]. Regardless a few studies have applied expert-based user testing methods, our findings indicate the need *to extend conventional guidelines for UX evaluation to encompass details on the characteristics of the context of use, user profile, and technologies involved in the application domain*.

The evidence on the application of non-standardized questionnaires obtained in this RR also reinforces the need *to develop new instruments or expand existing ones (e.g., SUS, UEQ, and meCUE) to cover UX constructs in applications involving IoT technologies and smart environments*. Díaz-Oreiro et al.'s study pointed out that the AttrakDiff [Hassenzahl et al. 2003] questionnaire was predominant for studies in Smart Cities and homes [Díaz-Oreiro et al. 2021]. Curiously, we found a single study mentioning this questionnaire (S15), perhaps due to the time frame set up in our RR (i.e., the last five years). On the other hand, our results can strengthen Díaz-Oreiro et al.'s findings, who had already noticed that UEQ was surpassing AttrakDiff in use since 2017. Thus, we argue that *a comparative analysis between these two instruments (i.e., UEQ and AttrakDiff) can provide insights to understand why the UEQ has gained ground in the evaluation of IoT systems.*

When investigating longitudinal studies in IoT systems, Melo et al. [Melo et al. 2022] reported that most UX evaluations were done in simulated environments. Unlike them, we identified long-term UX studies carried out in real-world environments, mainly field studies involving follow-up of the daily activities of smart home residents through interviews and questionnaires (S17, S25, and S38). Melo et al. argued that an automated collection of UX data in IoT systems could enable longitudinal studies in real contexts by reducing infrastructure and logistics costs. We also found only two studies that involved automated data collection in smart environments (S1, S8). Therefore, we also see the need for *methods and tools to facilitate remote and automated UX data collection that contribute to user engagement with the guarantee of privacy and foster the UX continuous evaluation in IoT and Smart City contexts*.

6. Conclusion and further work

The main contribution of this work is to provide scientific evidence on UX methods commonly applied to evaluate IoT-based applications in the context of Smart Cities to support both researchers and practitioners from the software industry. To respond and transfer scientific knowledge to practitioners at the company that develops an IoT system aimed at identifying water and gas leaks in the Smart City Services area, we are currently working on a report that summarizes the main conclusions and better fits their needs, as recommended by Cartaxo [Cartaxo et al. 2018].

The study contributions also extend to academia by pointing out takeaways that should drive further proposals of UX methods to cover attributes inherent to applications based on IoT technologies for Smart City environments. Further studies are needed to investigate actionable UX metrics and improve UX assessment methods for automated measurement in this area, which could leverage the sensing layer of the IoT structure. Furthermore, a comparative analysis of the use of standardized and non-standardized questionnaires can provide insights to recommend the application of these collection instruments according to IoT scenarios under evaluation. In future work, we will extend this review by mapping the UX attributes, metrics, and constructs that were evaluated in the primary studies, taking into account the methods, context of use, characteristics of applications, things, and users. So, we can deepen our understanding of how IoT layers or target things are linked with UX aspects.

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