Research on IoT Design Strategies Based On HCD In Smart City Development

Zhuoran Liu[1], Guangliang Sang[2]*

{z5372327@zmail.unsw.edu.au[1], glsang@mail.hongik.ac.kr[2]* }

School of Art, Design & Architecture, University of New South Wales, Cnr Oxford St & Greens Rd Paddington, NSW, 2021, Australia [1]
International Design Trend Center, Hongik University, 101 Dogmak-ro, Mapo-gu, Seoul, 04068, South Korea[2]*

Abstract. In the context of smart city development, the rapid proliferation of Internet of Things (IoT) technologies has drawn attention to user-centered design and overall user experience. This paper presents a comprehensive survey of IoT design strategies, focusing on how to incorporate human-centered design (HCD) principles to address the challenges associated with IoT implementation in smart cities. Insights from these interviews reveal problems in IoT design, including issues related to usability, accessibility, and user satisfaction. This paper proposes strategies to enhance the design process to make it more user-centered and aligned with the unique needs and preferences of smart city residents. By placing human factors at the forefront of the design process, this study aims to improve the overall quality of IoT implementations in smart cities. The results of this study are expected to be useful to designers, city planners and policy makers involved in smart city initiatives, as well as IoT developers looking to create user-friendly, efficient and effective IoT systems. As smart cities continue to evolve, incorporating human-centered design concepts into IoT design strategies is critical to creating technologies that not only meet technical requirements, but also prioritize the experience and well-being of the people living in these urban environments.

Keywords: IoT, design strategy, human centered design, smart city

1 Introduction

Smart cities continue to evolve with advances in information and communication technologies. The purpose of smart cities is to provide a smart environment for people to live smartly through information systems.[1] The application of Internet of Things (IoT) technology as a key technological pillar in information systems is becoming increasingly popular in smart cities, where IoT is ubiquitous from home smart systems to urban transportation systems. [2] However, the growing popularity of smart cities also brings a series of new problems, such as the inability of the public to integrate into smart environments, the deviation of user needs from smart technologies, the loss of public data privacy, and the obstruction of human freedom. This means that in the development of smart cities, how to balance the development of machine intelligence and human needs urgently needs to be paid attention to and solved. Human-centered design (HCD) is a design philosophy that places the ultimate human being at the center of the design process. [3] Human-centered design is based on technologies, and through HCD helps people to communicate, interact and even empathize with these technologies. In this process, people's

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actual needs are often displayed in forms that go beyond their perceptions. [4] This implies that IoT design strategies based on HCD design concepts may be able to help IoT solutions to be more relevant to the needs and expectations of citizens in smart cities.

This article aims to sort out and summarize an IoT design strategy based on the HCD design approach. This article will conduct a satisfaction survey on IoT design and application with designers who have experience in smart city design and the public who have experience in using IoT through the method of dual-group user interviews, so as to identify the problems that need to be solved when public-oriented IoT devices are designed. Based on these issues, HCD design strategies are provided from multiple dimensions of the IoT device design process in conjunction with the HCD design methodology. In addition this paper will critically analyze and evaluate the effectiveness of the strategy through practical case studies. The user requirement research methodology, the design steps of user participation in co-design, and the user experience-centered IoT device iteration guidelines in this strategy may have some guiding value for designers involved in smart city initiatives to explore and satisfy user requirements. The cognitive bias of the dual-user group on data privacy in this study may have some reference value for data security researchers.

2 Key demand analysis of IoT design

2.1 Human Centered Design

According to the International Organization for Standardization [5], Human-centered design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. Smart cities aim to build information infrastructure and services through information systems to provide a better quality of life for the public. The needs of the real public and the effectiveness of the interaction of preferences and digital infrastructure need to be taken into account during the development of smart city construction. [6] The Internet of Things (IoT) consists of a large number of objects connected and regulated through the Internet, connecting data applications to the physical world. The scenarios of human-computer interaction and the efficiency of their interactions are something that inevitably needs to be confronted in the design of IoT before fully entering the era of full automation. [7] Which means that the data sources brought by the IoT are the central pillar of the smart city data interaction system, and the use of HCD-based loT design methodology may help to better specify the public's needs in the smart city, and satisfy the balance between the public and the smart city data automation at the root level.

In-depth user interviews were used as the data collection method in this study to analyze the interaction experience of different groups with IoT in the smart city environment, focusing on the perspective of users in the smart city, and based on this interview data combined with the human-centered design methodology to clarify the needs of the public in the smart city, to assess the interaction experience of the public with IoT technology, and to evaluate the potential problems and aspects that can be improved during the development and application of the IoT technology by using user-centered evaluation methods. The user-centered assessment method is used to evaluate the potential problems and improvements that IoT technology needs to face

in the process of being developed and applied. In this way, it provides a reference basis for the subsequent HCD-based IoT design strategy.

2.2 In-depth interview

In this study, in-depth interviews were conducted to analyze designers with experience in smart city projects as well as citizens who have had interactive experiences with IoT technologies in smart cities. The purpose of these interviews was to understand the feasibility, effectiveness, and user experience satisfaction of the practical application of IoT technologies in smart city development.

The scope of the interviews with designers focused on the design strategy of IoT technology being used in smart cities, the challenges faced during the program development process, and the gap between the project expectations and the actual implementation of the project.

Table 1. Status of IoT designer interviews.

Status of IoT designer interviews.		
Designer experience with the IoT	Quotes from the interview	Research and analysis
User Requirements Mining	"Pain point mining is a necessary process, but user needs are variable."	User needs are not clarified enough.
	"The development of IoT devices will drive system intelligence wherever possible. But it may be overkill for users."	
Iterative process	"We will update the IoT devices based on the cloud data feedback."	User experience feedback is ignored.
	"We focus more on the maintenance of the equipment of the data processor in the cloud."	
Data security and privacy	"Data collection is essential for the effective operation of IoT and smart information systems."	Data collection is necessary, but user privacy needs to be assured.
	"We respect the privacy of our users."	

The results of the designers' interviews shows in Table 1, that the focus of the design and development of IoT devices in the process of smart city development has been centered on the performance of the devices themselves, the sensitivity of receiving and sending data, while the user needs and the user experience have been weakened or ignored in the process, which may result in the public being unable to conform to the development process of the smart city due to their lack of familiarity with not being able to use the IoT smart devices. In the perspective of designers and developers, the data privacy and security aspects of IoT devices are somewhat guaranteed.

The interviews with the users focused on understanding how they interact with, and experience using, IoT technologies in smart cities. In order to better understand the feasibility of IoT technology being practically applied in smart cities and the degree of tolerance for user maneuverability, the citizens interviewed in this study had a wide range of backgrounds and

ages, as well as varying degrees of familiarity with IoT technology, to ensure the diversity of the interview results.

Table 2. Status of IoT user interviews.

Status of IoT user interviews.		
User experience with the IoT	Quotes from the interview	Research and analysis
User awareness of IoT	"I have heard of the concept of smart cities, but this kind of high technology should not be accessible to us ordinary people." "I have a smart IoT system installed in my house, it's smart but not really particularly useful, maybe I'm not very good at it."	Imbalance between product features and user needs.
Human-machine interaction experience	"The operator interface is too small and always mis-touched." "It feels like there are so many special features that I can't understand how to use them."	The ease of use of the machine interaction interface needs to be improved.
Data security and privacy	"They always lead me to open up access to my data, and I have no idea how much of my privacy is compromised under these guides." "Where do we have privacy in the age of data."	The user's right to know what data is being collected needs to be better assured.

The results of the users' interviews shows in Table 2,with the public in the smart city show that the functionality and intelligence of the IoT devices are far beyond the user needs themselves, which may be due to the imbalance of the intelligent environment within the system caused by the lack of unity of the intelligent attributes of the different objects in the system, or it may be due to the low technological needs of the users, which has led to the over-performance of the IoT devices. This means that for the public to better participate in and use IoT technology, a better and more unified smart environment needs to be built to avoid the smart disconnection of different objects in life. In addition, in the development process of IoT devices, user needs always need to be paid attention to, in order to avoid the situation of over-performance of IoT devices. Secondly, the human-computer interaction experience needs to be paid more attention to, which includes the ease of use as well as the recognizable design of the interaction interface of IoT devices, and the fault-tolerant design of IoT devices. Notably, the HCI process should be simplified as much as possible., to minimize the learning cost for users. [8] Finally, in terms of data security and privacy, the results of the public's research and the designers' research appeared to be very different; under the public's perspective, the individual's right to data privacy as well as the right to be informed of the data flow are not respected, which means that the user's sense of data privacy and security is still a direction that the designers and developers need to work on.

3 Case Study & Core Element Research

Scholars can build a complete information system through technologies such as IoT, and it becomes crucial to actively involve and cooperate the public as an autonomous conscious unit level in the smart city in this efficient information system. Guna., Horvat. & Podjed.'s research is to develop a smart waste management system by using the human-centered design approach. Figure1 shows two interface of smart waste management information system. [9] The processing efficiency of the waste recycling and disposal system in a smart city will be greatly improved if the waste generated by each member of the public is collected according to the sorting criteria. The way the system works is that after a user puts waste into the smart waste station, the sensors in the system will intelligently analyze the volume and weight of the waste, and the relevant waste records will be transmitted to the cloud and sent to the waste sorting staff. At the same time, the system provides personalized interaction with the user through RFID identification technology, and the relevant interaction and encouragement information is displayed on the display screen of the smart waste bin, which brings emotional value to the user and enhances the user's experience of waste separation. Based on the human-centered design approach, the smart trash can changes the public's behavioral level from the instinctive 'I want to throw away trash' to 'I want to separate trash for the sake of the environment before I throw away trash.'

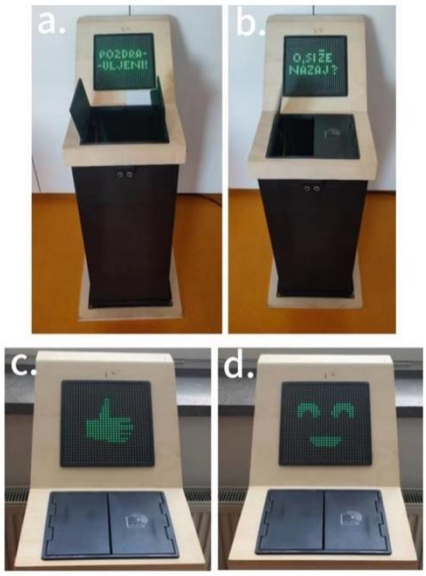

Fig. 1. Two visualizations of smart trash cans a: Specification interactive text interface b: Emotive interactive text interface c: Specification Interactive Graphical Interface d: Emotive interactive Graphical Interface (ibid)

Firstly the researcher identified IoT technology as the key technology support for this smart waste recycling system through literature analysis method in the early stage of the project. Throughout a development process, the user experience, interface and interaction design of the

smart waste management system were likewise explored as key research directions in the study. However, due to the influence of covid-19, the researcher did not conduct any user interviews to determine user needs in the pre-problem identification step. Instead, the focus was placed on user feedback surveys of the prototype experience to determine if and how the solution was accepted by the public.

Public participation and collaboration methods were utilized in this design process. Waste recycling systems in smart cities critically need to consider the effectiveness of recycling behavior, where the key actor is the public. Therefore, this study produced a rapid smart trash can prototype and invited 194 respondents to learn about and use the prototype and invited them to evaluate it. The researcher actively collected opinions and ideas for improvement of the smart trash can from the public. It is worth noting that during this process, some of the respondents, while showing strong negative reactionary emotions towards the design of the smart trash can, raised points that the researchers found very constructive, such as 'The automatic opening time of the smart trash can lid needs to be faster.' As mentioned in the HCD-based IoT design strategy, this means that public participation in co-design can guide and continuously revise the design from different dimensions and needs so that the final design solution is one that meets the real needs of users. The feedback from these prototype evaluations can help make the final design more usable, inclusive, and user-friendly. Without this step, releasing the prototype directly into actual use may result in persistent negative public sentiment about the system, leading to a decrease in the public's cooperation with waste sorting.

The researchers conducted a/b testing of the interaction prototype shows in figure 2. The purpose of this testing is to guarantee the user's interaction experience. Two prototypes with different interaction modes, normative and emotional, were put into prototype evaluation with the same functionality of the smart garbage collection product. Based on the user feedback of the two prototypes, it was concluded that users with different values, mindsets, and habits tend to interact with different interaction modes, and a single interaction mode could not satisfy the needs of different groups of people. This means that the iteration of prototypes helps IoT researchers and designers to better develop IoT devices for the public, which requires developers to focus not only on the technical performance of the IoT devices themselves, but also the human-computer interaction modes and the interaction efficiency need to be taken into account when developing IoT devices for the public.

However, the limitation of the solution development process is that the design process of the smart trash can did not conduct enough user requirements research during the initial user requirements mining phase, so that deeper user requirements were revealed during prototype testing and user satisfaction surveys, which may lead to subsequent prototype iterations of the smart trash can needing to make relatively large changes based on these requirements, resulting in a lengthened design cycle, as well as more development of the smart trash can. cycle time is lengthened and more development funds are lost. The exploration of the use of normative intervention or guidance of HCI on public behavior in this study may be informative for HCI interface development for IoT devices.

Another case is a multi-robot system developed for the elderly. [10] This heterogeneous system is designed to record and analyze the health status of elderly users by collecting their health data and psychological data through IoT devices and uploading them to an information system, in addition to supporting them with robots that assist in socialization. It is worth noting that in the

test phase of the experiment for the collection of emotions from the elderly, in order to ensure that the wearable IoT device can be effectively used by elderly users, the researchers set up a segmented experiment for elderly people with different technological literacy, and for elderly people who have less contact with IoT technology, the first phase of the experiment mainly guided them to learn and adapt to the IoT device. This phase effectively helps elderly users to get used to and accept the information collection system, and effectively avoids problems such as inefficient human-computer interaction caused by users' low technological literacy or poor technological understanding in the subsequent data collection phase. In the second phase of the experiment, IoT devices were used to collect objective physical health data from elderly users, while questionnaires were used to follow up on subjective psychological and emotional data. The results of the study show that compared with the questionnaire survey to collect users' physical data, IoT devices have more continuity and stability in the collection of users' physical data after they are accepted and used to use them, and the stability of the data source is of great significance to the continuous operation of the whole system. This means that during the prototype testing and development of IoT devices, developers need to increase the inclusiveness of IoT devices to make up for the bias in the acceptance of new technologies and devices by users with different technical backgrounds. At the same time, this user unfamiliarity with the technology and the device can also be compensated by a large number of open user practices during the user testing phase.

The third case is an interactive reusable water bottle and smart refilling station system developed through IoT and ICT technologies [11] In this case, during the research phase of the design, in order to conceptualize and develop a smart water bottle that can satisfy the users' needs, the researcher conducted a large number of user surveys in order to clarify the users' needs and perceptions of the smart water bottle. This process users expressed the need for the desired appearance of the smart water bottle in terms of color, whether the structure is easy to clean, and the size. This means that although IoT devices are technology-driven at their core, users will also demand the appearance and size of IoT devices. As designers develop public-facing IoT devices, they will also need to conduct extensive user research to determine how users perceive the problem and what they want and need in the final solution. It is also worth noting that in this study, the developers used the data collected from the user research as input for the smart bottle design.

In the prototype testing stage, the developers observed and recorded the different behaviors of the users at different stages of using the smart bottle, such as the user using the smart bottle to receive water at the smart water station, the user using the smart bottle to drink water, the user cleaning the smart bottle, and the user carrying the smart bottle, etc. By recording and analyzing the users' behaviors, they clarified the aspects of the product that need to be improved. At the same time, users quickly understand and feel the technological experience brought by IoT technology through hands-on practice during the prototype testing stage, and at the same time clarify the performance of the smart water bottle as well as its advantages, which undoubtedly can help the smart product be understood and accepted by users more quickly after its release.

Therefore, the above three cases demonstrate the development methodology of human-oriented IoT devices from the aspects of user requirement research, user feasibility testing, and product iteration.

4 Strategy

Public-facing IoTs should be developed in accordance with HCD design principles, and the public should be continuously involved in the design and application of IoTs, which includes the entire process of IoT conceptualization, design, development, application, and iteration.

4.1 User-Centered Requirements Research

During the initial user needs identification phase, a large number of user needs questionnaires should be administered, and users and program stakeholders should be invited to participate in user interviews, focus groups, and participatory workshops to help designers identify the underlying needs of the users and their expectations of the desired outcomes. Thus, the objectives of the project at all levels are determined from the integration of multiple groups and dimensions, which may help to increase the user-friendliness of the program. However, until the public actually interacts with the IoT, the results of their interviews and expressed expectations of outcomes may be based on personal idealized conceptions and assumptions, which may lead to a deviation of their expressed needs from their actual needs. IoT involves human-machine interaction, so user behavior analysis is crucial. Ethnographic methods may help designers better observe user behavior and think about the logic of user behavior when interacting with machines, which may help designers more rationally identify the user needs generated by verbal interviews, and analyze the root causes of user behavior to dig deeper into the user needs. needs.

4.2 In-depth interview User participation in coordinated design of IoT

Collaborative participatory design requires a shift in the role of the designer to that of a facilitator, while public participation contributes to the power of open design. [12] IoT serves as a key node connecting the real physical and digital worlds. Public participation in the stage of design development and application of IoT may help the final outcome of this technology to be continuously revised closer to the native user needs under the user needs orientation to explore and bridge the gap between the theory and real-world application by producing low-fidelity models, while the role of designers in this process should be to exert their expertise to help the realization of the public needs and the public's ideas in the stage of model development, and at the same time, the designers need to Enhance the user-friendliness of IoT by ensuring the recognizability and ease of use of IoT devices and their related operation interfaces through professional knowledge. In addition, public participation facilitates the interaction logic of IoT technology to be better understood by the public, increases users' recognition and trust of IoT devices, and reduces users' learning costs in the actual interaction phase. However, the collaborative participation of users in IoT design requires a high level of technological literacy, and the vast majority of users may not be able to successfully participate in the process of IoT development. This means that IoT still needs to consider the inclusiveness and accessibility of the final solution for different people from different backgrounds in the design and development phase.

4.3 User-Centered prototype iteration

Prototype iterations of IoT solutions are crucial. According to the results of the preliminary in-depth research, the iterative process of IoT in the past research focuses more on the data

interaction efficiency of the solution itself, however, if the IoT technology only satisfies the interaction efficiency between the object data and the upper information system and ignores the interaction efficiency between the public and the IoT devices, it may ultimately lead to a disconnection between the human and the information system in a smart city environment. This means that, according to the guidance of the HCD design methodology, the development of IoT should incorporate the consideration of user needs and the efficiency of user-human-computer interaction on this basis. The direction of collecting feedback on the usability of prototypes should be expanded to include the efficiency of user interaction behavior, and the survey of user satisfaction with the IoT device during use.

4.4 User data privacy

IoT devices need to collect and transmit a large amount of data to support the effective operation of information systems in smart cities. According to the HCD design principle, user privacy and personal information autonomy should be reflected in the design and development of IoT devices. First of all, in the process of data collection, users should be given full autonomy to decide whether to open personal data and how much personal data to open. Due to the wide coverage of data collection, it is required that IoT devices provide users with a clear and recognizable data collection selection interface at any stage of the user's use, instead of using the traditional simple data collection protocol checkbox pop-up window to give a brief overview of the scope of data collection at the initial stage. in the early stages. This may help to preserve the user's right to information and control over data collection. Second, in IoT systems where large amounts of data are transmitted, designers and developers should monitor the security and privacy of data transmission in real time.

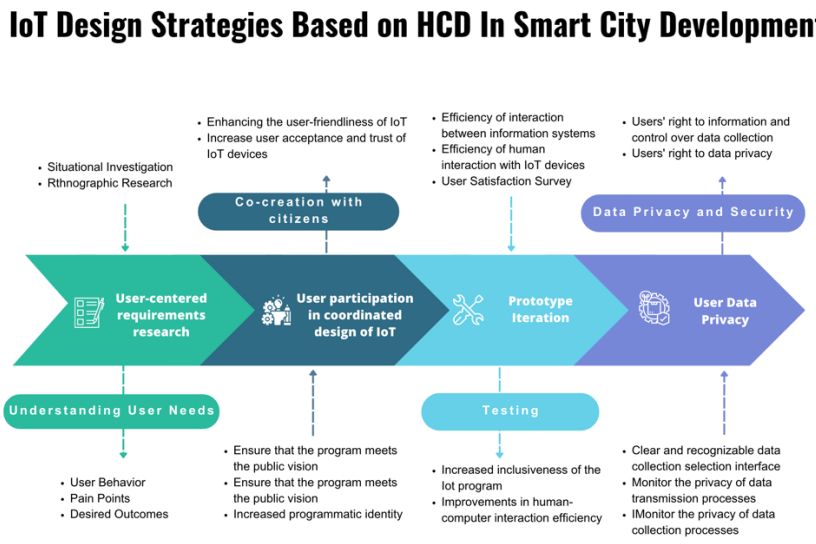

Fig. 2. IoT Design Strategies Based on HCD (self-drown by the authors)

The strategy of the IoT Design Strategies Based on HCD shows in figure 2. Therefore, it is clear that IoT and data are the pillars of information systems, and the essence of information systems

is to bring better services to the public, so the study of HCD-based IoT design strategies in smart city development emphasizes the participation of users throughout the design process, which can help the information system and automation better apply to the public's needs and preferences.

5 Conclusion

This study provides insights into key areas of IoT design in the context of smart city development and highlights the importance of human-centered design (HCD) as a guiding principle. The study first explores the challenges of IoT design from a user experience perspective and utilizes insights gained from in-depth interviews with designers and end users. The findings reveal a range of issues that have far-reaching implications for the realization of user-centered, efficient and effective IoT systems in smart cities. These challenges include issues related to usability, accessibility and overall user satisfaction. By systematically addressing these issues, this research deepens our understanding of the inherent complexity of designing and implementing IoT technologies in urban environments.

In addition, the study proposes a series of design strategies rooted in human-centered design principles that provide a roadmap for bridging the gap between technological innovation and the diverse needs of smart city residents. The adoption of a human-centered design approach in IoT design is expected to improve the quality of smart city technologies by ensuring that they not only meet technical requirements but also closely align with user preferences and well-being. Integrating human-centered design into IoT design strategies is a critical step forward in the evolving smart city. This approach recognizes the central role of individuals in urban environments and places them at the heart of technology development. It is an important step towards realizing smart cities that can truly empower and enrich the lives of their inhabitants. The insights and strategies presented in this study will be invaluable to designers, urban planners, policy makers and IoT developers as smart city initiatives continue to advance. They are the foundation for the harmonious coexistence of technology and urban planning, which will ultimately facilitate the development of smart cities that are inclusive, user-friendly, and truly intelligently designed.

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