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Smart Space Design–A Framework and an IoT Prototype Implementation

Badr Alsamani [1], Samir Chatterjee [2], Ali Anjomshoae [3] and Peter Ractham [4,*]

[1] Department of Information Systems, College of Computer & Information Sciences, Imam Mohammad lbn Saud Islamic University, Riyadh 11564, Saudi Arabia
[2] Center for Information Systems & Technology, Claremont Graduate University, Claremont, CA 91711, USA
[3] Center of International Affairs, Thammasat Business School, Thammasat University, Bangkok 10200, Thailand
[4] Department of Management Information System, Thammasat Business School, Thammasat University, Bangkok 10200, Thailand
* Correspondence: peter@tbs.tu.ac.th

Abstract: In the last decade, the need for smart-space design has been on the rise. Various data collected from Internet-of-Things (IoT) and sensors are used to optimize the operation of smart spaces, which, in urban areas, are evolving into smart cities. How can smart spaces provide value to citizens? There is a need to develop smart services that leverage emerging technologies while taking an inclusive and empowering approach to the inhabitants. To address this need, we present a framework for designing smart spaces and we use a bottom-up (inclusive) approach to instantiate a smart kiosk (SK). The SK prototype provides a practical approach for transforming a traditional building into a smart space utilizing IoT and artificial intelligence technologies. The design science research (DSR) methodology was followed for designing and evaluating the prototype. An iterative process that involves occupant feedback and brainstorming sessions coupled with a literature review was carried out to identify the issues and services related to a smart building. The SK prototype implements three intelligent services that were prioritized by the citizens of the building. The results show that the SK has a high usage and acceptance rate and it can transform a lobby into a highly engaged and smart building space. The prototyping process suggests important factors to ideate and assess smart services and shows that small-scale projects can be successful to enable smart buildings. The framework provides a theoretical contribution while the design and development process assists practitioners in identifying and developing intelligent services based on IoT technology.

Keywords: smart spaces; Internet of Things (IoT); design science research; theoretical framework; smart city

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1. Introduction

According to US Environmental Protection Agency, average Americans spend 93% of their time indoors, including 87% inside buildings and another 6% inside automobiles [1]. The on-going COVID-19 pandemic has set new socioeconomic norms and transformed most of our daily routine tasks to occur inside buildings, such as raising families at home, attending school, and working from home. Thus, improving our quality of life is heavily dependent on providing smart services that meet our individual needs inside the buildings. As a result, over the last few years, city councils, scientific researchers, and technology companies have become increasingly interested in smart city projects and initiatives [2]. The smart city notion incorporates terminology from various fields such as information and communication technologies (ICT), urban study, and public administration [3,4]. In the last decade, the need for smart space design has been on the rise. It is captured in the concept of a smart city, which is a technologically advanced urban area with information and communications technology that collects various data from IOT and sensors to optimize the operation of the city and provide value to citizens [3]. Although cities have diverse ambitions for becoming smart, they share the same overall objective of increasing efficiency and improving citizens' quality of life [5]. Smart buildings and Internet of Things (IoT)-based intelligent infrastructure are the cornerstone of smart spaces and cities [6,7]. The IoT has recently pushed a new wave of smart building services to meet occupants' needs and enrich their experiences while increasing resources efficiency. The IoT allows a network of embedded objects to collect, process, analyze, and exchange data without human intervention.

Over the past decade, a considerable amount of research has been directed toward smart building projects [8–12]. Several applications that have integrated AI with IoT were built for occupancy, urbanization and transportation, and sustainability. Building systems such as HVAC, lighting systems, and plug loads are an important part of smart building services [13,14]. Nonetheless, most of the existing studies have primarily focused on controlling building resources. Existing smart building research tends to focus on automation, which aims to control, monitor, and optimize building services such as heating, ventilation, and air conditioning, lighting, security, and access control.

The Internet-of-Things (IoT) is now entering many different industrial segments, and within the context of smart cities, it spans five key areas: (1) energy, (2) water, (3) mobility, (4) buildings, and (5) government. This study focuses on commercial building environments (in particular academic buildings). In fact, nearly all the applications for smart cities have comparable applicability to building management (e.g., traffic/access control, surveillance, energy management, indoor environmental and air quality (IEAQ)/comfort control, and so on). Most of the recent research on smart buildings is focusing on building management systems with requirements that span energy management (including lighting), video surveillance, access management, and environmental monitoring, including fire detection.

Most recent smart city initiatives have generally followed a top-down approach often controlled by the city government leaders to develop a smart city project. A top-down approach focuses on the provision of predefined sets of services that are chosen by the city's leaders. While a top-down approach was implemented in several cities such as Singapore, Rio de Janeiro, and Oslo, it lacked innovation. Such an approach often does not address citizen needs. It is also controlled by commercial interests and stifles the potential innovation. This has motivated our research to follow a more inclusive approach that treats occupants as active participants rather than passive recipients. However, how does one go about designing such smart spaces? There is a lack of any general theory or framework. Hence, in this project:

- We develop a conceptual framework that guides developers and prospective stakeholders on how to transform any space into a smart space (building).
- In addition to that, we instantiate a smart kiosk (SK) prototype that was deployed inside a building at an academic institution and included three services: (a) air quality monitoring, (b) face recognition, and (c) a newsfeed summary.
- These services were chosen after discussions and brainstorming sessions with users to identify and evaluate possible services. We demonstrate the bottom-up approach to designing smart spaces (academic lobby as an example).

The proposed designed prototype was developed using the design science process and is the result of an inclusive approach by developing smart lobby services that relate to actual community needs. It emphasizes the relevance of occupants as the prime focus in the design process, as opposed to top-down approaches in which certain government officials decide what is needed.

The rest of this paper is organized as follows. Section 2 discusses background related work and highlights the research gap. Section 3 discusses the research design. Section 4 presents the framework and discusses its utility. It also details the SK prototype. In Section 6, we discuss the evaluation and results from the extensive user study of the SK. Section 7, we discuss our research implications including discussions of theoretical contributions and practical insights. Finally, Section 7 concludes the paper and discusses potential future work.

2. Related Work

2.1. The Role of Internet of Things (IoT) in Smart Cities

In 2016, UN estimated that 54% of the world's population lived in urban areas. In 2020, approximately 83% of the people in UK and 87% of people in the USA lived in urban settings (United Nations Population Division, 2018). The trend of human urbanization is predicted to accelerate in the coming years, with two-thirds of the world population estimated to live in urban spaces by 2050, adding 2.5 billion people to urban neighborhoods [15]. The surge in urban population creates several challenges that must be addressed in order to satisfy residents' fundamental requirements. According to IEEE smart cities, the predicted challenges resulting from urban population development include growing levels of pollution, higher crime rates, high living expenses, and so on. The transition into a smart city is seen as one approach toward addressing the expected urbanization challenges. Bringing efficient operations into different aspects of a smart city can curtail the growing challenges of urbanization.

Internet of Things (IoT) plays an instrumental role in the transition from a traditional city and buildings to a smart city [16]. The IoT lays the groundwork for smart cities by deploying a network of electronic devices embedded in ordinary goods, generating a considerable amount of data that may be utilized to enable smart applications. The IoT serves as a foundation for implementing many services for establishing a smart city, such as environmental monitoring, smart transportation, energy conservation, safety and security, education, smart building, and health care. The IoT plays an important role in the development of smart building initiatives, notably, energy-conservation-related platforms. Many studies discussed the potential use of IoT technology to build efficient energy conservation platforms for smart buildings [17].

2.2. Smart Buildings

Population growth is the motivator for the push toward smart cities and buildings. The expected increase in urbanization necessitates cities, buildings, and communities to take responsibility for sustainability, energy management, and improved quality of life [18]. The development of smart cities is inextricably tied with the development of smart buildings. Smart buildings that are interconnected become the foundation for smart cities. The research on smart buildings mainly focused on three areas: innovation and development technologies, performance evaluation, and investment evaluation. According to Wong and Wang [19], the innovation and development technologies research stream mainly focuses on system integration, automation, and controlling buildings resources, such as lighting, fire safety, cooling and heating, security, and communication systems. For example, Singhvi et al. developed an intelligent lighting system and algorithm that trades off between reducing energy and maintaining occupants' comfort using a wireless sensor network. Another study by Agarwal, et al. [20] proposed a framework for an IoT-based system to manage a building's energy based on detailed occupancy information collected from passive infrared sensors. The proposed framework showed potential energy savings from 10% to 15%. To evaluate the level of building intelligence, evaluation studies developed models to assess the building performance in terms of efficiency of controlling and managing building utilities and resources. It also can be used to prioritize opportunities for future improvements. For example, the post-occupancy evaluation process model (POE) is a widely used model to determine the intelligence level of the studied building [21]. Finally, the investment evaluation research stream mainly focuses on the feasibility of investment in smart buildings projects. The investment evaluation studies the return-on-investment benefits, including operating cost, occupancy cost, maintenance cost, and occupant comfort.

2.3. Top-Down versus Bottom-Up (Inclusive) Approach

Smart city initiatives typically follow one of the two most common approaches: top-down or bottom-up. A top-down approach is defined as a city that monitors and integrates its critical infrastructures to better optimize its resources, preventive maintenance, and monitoring security aspects while maximizing services to its citizens [22]. Smart city initiatives that follow a top-down approach are closely related to the idea of a "control room" for the city [23]. Top-down approaches will frequently hand over implementation to technology companies, usually dictated by commercial interests and are criticized for delivering deficient services, preventing innovation [24]. Additionally, too much monitoring and the existence of highly integrated systems and sophisticated analysis tools are seen as a move toward authoritarianism more than freedom [25]. Songdo and Masdar are two examples of smart city projects that were built from scratch and follow a top-down approach. However, both cities were criticized for being over planned, controlled, anonymous, and expensive [26]. The Songdo smart city is seen as a ghost town and is struggling to attract significant business attention while Masdar is not even close to its goal of having a carbon-natural city [27].

On the other hand, a bottom-up approach is motivated by the citizens who use the city. It is defined as a heterogeneous collection of people that collaborate within the city to improve the quality of their lives [28]. A bottom-up approach does not involve any private company with vested interests in the development process of a smart city. This approach is intended to empower local citizens for innovative projects looking to meet local needs rather than controlling the city. A bottom-up smart city initiative enables the citizen to participate in shaping the urban space and making it sustainable. Although bottom-up-approach projects have been criticized for their difficulties in becoming finished, Lindsay believes that with the right program created by individuals who genuinely know the context, we could satisfy and manage the complex needs of an actual city. Lindsay added, "The smartest cities are the ones that embrace openness, randomness and serendipity" [29]. The Amsterdam smart city incentive is one successful example of a bottom-up smart city project. In fact, it was awarded the title of European Capital of Innovation in 2016 for its innovative qualities in science and industry [30]. It basically empowers residents to develop and apply self-invented solutions. A research project investigated and analyzed 40 platforms for the urban bottom-up movement in Amsterdam and concluded that the majority of successful and used platforms were developed after the Amsterdam movement toward the empowerment of the bottom-up approach.

A survey on the existing research on smart building has indicated the focus of smart building studies is on the automation and controlling resources [3]. This is due to following a top-down approach, which inherently enforces control. In this research, a bottom-up approach is followed for designing the SK by identifying potential smart services that address occupants' needs. This paper uses emerging technologies such as IoT and acritical intelligence, as well as a user experience model to develop smart services to transform a traditional academic lounge into an intelligent and informative space.

2.4. Small-Scale Smart Projects

The transformation of cities to smart cities often requires a lot of resources. Hence, it was identified [10] that we need to simulate environments in a small scale and build prototypes that can show the proof-of-concept, which then later can be implemented on a larger scale. Universities have often been chosen to be such a prototype playground with successful implementation of IoT and Big Data projects [10]. In another small-scale project conducted in the city of Rome [31], several fleets of taxi were used as "data mules" to provide LTE connectivity, and the results showed that nearly 80% of the city coverage could be obtained from IoT sensors running in the taxi fleet. In this paper, we take a bottom-up approach and demonstrate a small-scale project that serves as a proof-of-concept towards smart building implementations.

All of the above leads us to ask the main research questions in this paper:

RQ1: How can the bottom-up approach help to create a small-scale smart space that users can benefit from?

RQ2: What framework can act as a theoretical guide for developers who intend to transform any space into a smart space?

3. Research Design

The paper follows the design science research (DSR) methodology to develop and evaluate an IT-enabled artifact [32]. The methodology is useful to solve real-world problems in which the IT-enabled artifact is designed in an iterative design process. DSR typically comprises three interrelated cycles: relevance, rigor, and design, which we now elaborate in the context of this smart building project.

3.1. Relevance Cycle

There are two artifacts we design in this paper: a IoT smart space framework (IoTSS) and a smart kiosk (SK). The IoTSS Framework acts as a theoretical guide while the prototype is an instantiation that can help to transform an academic lobby with intelligent services. The relevance cycle aims to identify the contextual environment and define the requirements and the acceptance criteria for the developed artifact. This cycle bridges the contextual environment of the developed artifact with the design activities [33]. The main goal of SK is to bring life into an academic lobby by following a bottom-up development approach and using new emerging technologies. In this project, three smart services that are offered by SK were identified by representatives of the community groups. Below, we discuss the inclusive process that led to the selection of these services.

Service Ideation and Selection

This section describes the steps that were taken to engage the community and capture their insights into the process of identifying and assessing the most relevant smart services to be developed for SK (bottom-up approach). It comprises three steps: service ideation, service re-engineering, and service assessment. During this phase, we explored the domains relevant to the functional purpose of the college's lobby (health, entertainment, leisure, access, and safety). Then, multiple brainstorming and discussion sessions (Service ideation) were conducted between the researchers and colleagues working in the academic unit. The ideation sessions resulted in identifying a preliminary list of 47 ideas. During the discussion sessions, we reviewed potential new smart ideas to be deployed in the SK. Furthermore, we also discussed opportunities to transform traditional services to smart services using emerging technologies (Service re-engineering).

One week later, a follow-up meeting was conducted, which resulted in refining the list of the proposed ideas down to the nine that seemed to be the most relevant to the space context where the system will be implemented. The proposed nine ideas were presented to the community group. An open discussion and survey distribution followed the presentation. The survey aims to assess the attractiveness and usefulness of the proposed smart services (service assessment). The survey presents each idea with an explanation and case scenarios of its usage and deployment. Participants assess the proposed services in terms of attractiveness and usefulness by answering two questions for each one of the nine ideas using a 7-point Likert scale (ranging from uninteresting/useless to very interesting/useful). The discussion with the colleagues has not only helped to assess the proposed smart services but has also brought attention to other potential ideas that were not initially included in the list, one of which was occupant identification and recognition. Some ideas were dropped either due to cost/financial issues or because their implementation was not feasible within our scope. After careful assessment of the feedback and completed survey, six smart services were selected to be offered by SK. In this paper, we present three services: monitoring indoor air quality, individual identification and recognition based on their occupation profession and ID card generation, and local newsfeed summary. The other three services were developed separately for another project.

3.2. Rigor Cycle

This rigor cycle entails consulting the knowledge base that includes grounding theories, methods, domain experiences, and expertise to inform the design of the developed artifact [33]. The SK presents three different smart services that use various technologies that share the same goal of creating a smart lobby user experience. We used knowledge from the user-experience field to ground the design of the SK. Specifically, we chose two kernel theories that guided our design.

3.2.1. User Experience Model

The model explains how people experience and value the designed product [34]. Specifically, it has four major components: content, user goals, business goals, and interaction. The model presents elements from designer and user perspectives, their functional relations, and instruments to operationalize and measure. Using the model helped us define the characteristics of the SK to be communicated to users to ensure the creation of friendly and easily interpretable user experiences.

3.2.2. Smart Service System Theory

Smart service systems bring a customer's and provider's perspective on value creation with a smart product together [35]. Cyber–physical systems that embed hardware and software systems into physical goods that can connect digitally to other products and information systems are a powerful trend in many industries. Smart products use sensors to obtain contextual data, exchange data with other actors, store and process data locally, make autonomous decisions, and act physically by means of actuators. In this way, previously isolated and passive products join the digitally networked world as actors in their own right. This theory states that co-creation and capture of value in the reciprocal business relationships between service customers and service providers provides "service" that is defined as "the application of specialized competences (operant resources—knowledge and skills), through deeds, processes, and performances for the benefit of another entity or the entity itself" [35].

3.3. Design Cycle

The research design comprised multiple design cycles conducted to test application functionality, improve the design, and achieve the requirements from the knowledge base and the environment. The design cycles are grouped into three cycles (Figure 1). In the first design cycle, we presented a prototype of the SK interface using the JustInMind simulator tool. We conducted a focus-group interview with four occupants to demonstrate the simulation and obtain feedback. The feedback was applied to the design of a functional prototype. We presented the functional prototype to our lab members after improvement from the previous round of feedback. Feedback from the demonstration sessions yielded further interface improvements for the final version of the prototype.

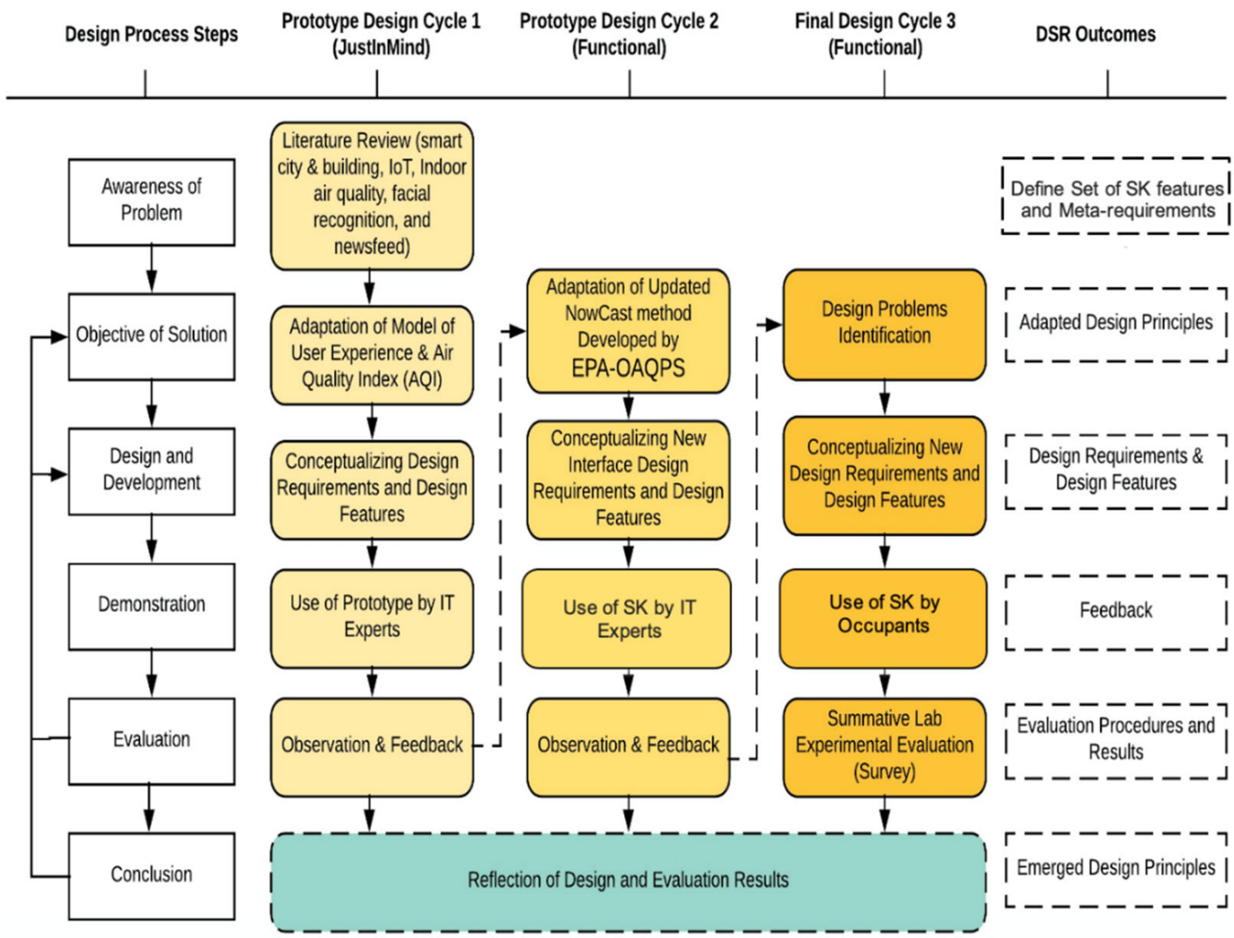

Figure 1. Design Science Research Cycles.

4. The IoT Smart Space Framework (IoTSS)

The IoTSS is a framework for IT developers and engineers who are interested in developing smart building services enabled by IoT. The proposed framework aims to guide the developers throughout the process of developing smart services. It provides a practical sequence of fundamental phases to transform any building (i.e., home, school, commercial building, hospital, etc.) and its targeted space (i.e., bedroom, meeting room lounge, backyard, parking lot, etc.) into a smart building using IoT sensors. The design science research (DSR) approach, presented by Hevner and Chatterjee [32], was adopted to guide the process of developing the framework. During the preliminary development of the framework, the knowledge base was examined through iteration by briefly reviewing the literature review, conducting multiple brainstorming sessions, and by drawing from practical experiences.

To be specific, the literature reviews helped identify the key elements of building features and IoT sensors that needed to be included in the proposed framework. Brainstorming and practical experiences gained from using different IoT-related sensors and boards helped identify new elements that are missing in the literature.

The IoTSS framework consists of five phases: space specification, smart-service initiation and selection, sensor selection, IoT development-board selection, and cloud/fog computing for data management and analytics. The first two phases aim to ideate a smart service that is related to the deployment-environment context. The last three phases aim to guide the process of developing an IoT-related service. Each phase consists of a group of related and necessary steps that need to be considered for successful identification and development of smart service. A bird's eye view and detailed description of the framework are presented at the end of this section (see Figures 2 and 3, respectively).

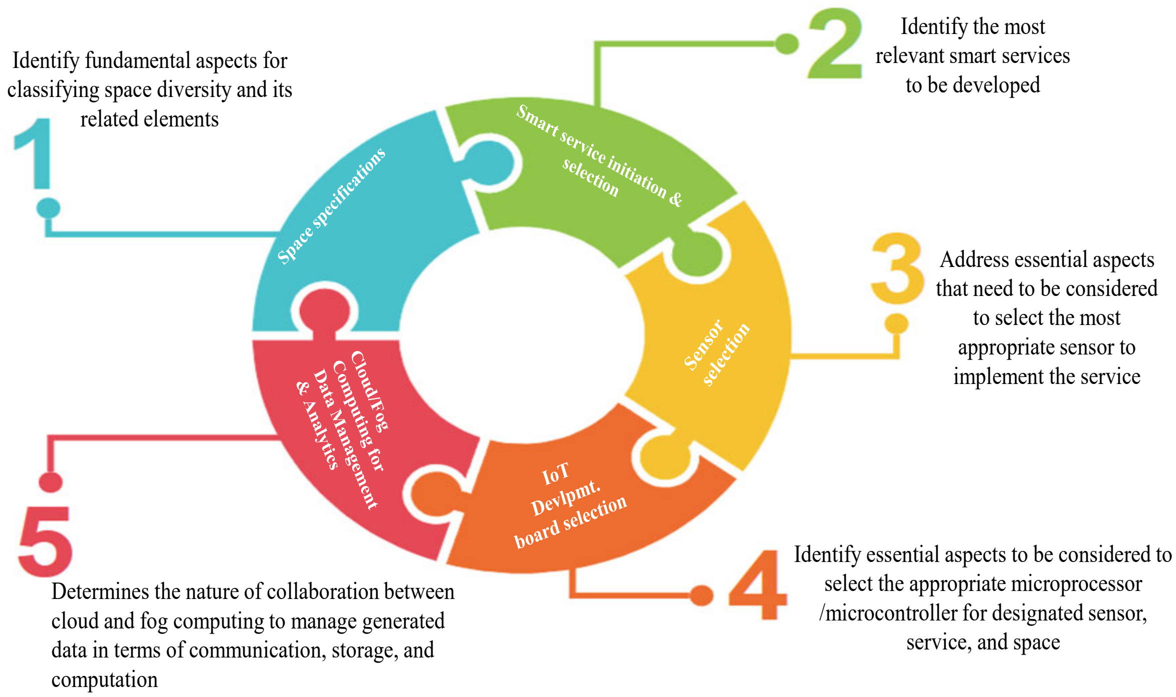

Figure 2. A general framework for developers (bird's-eye view).

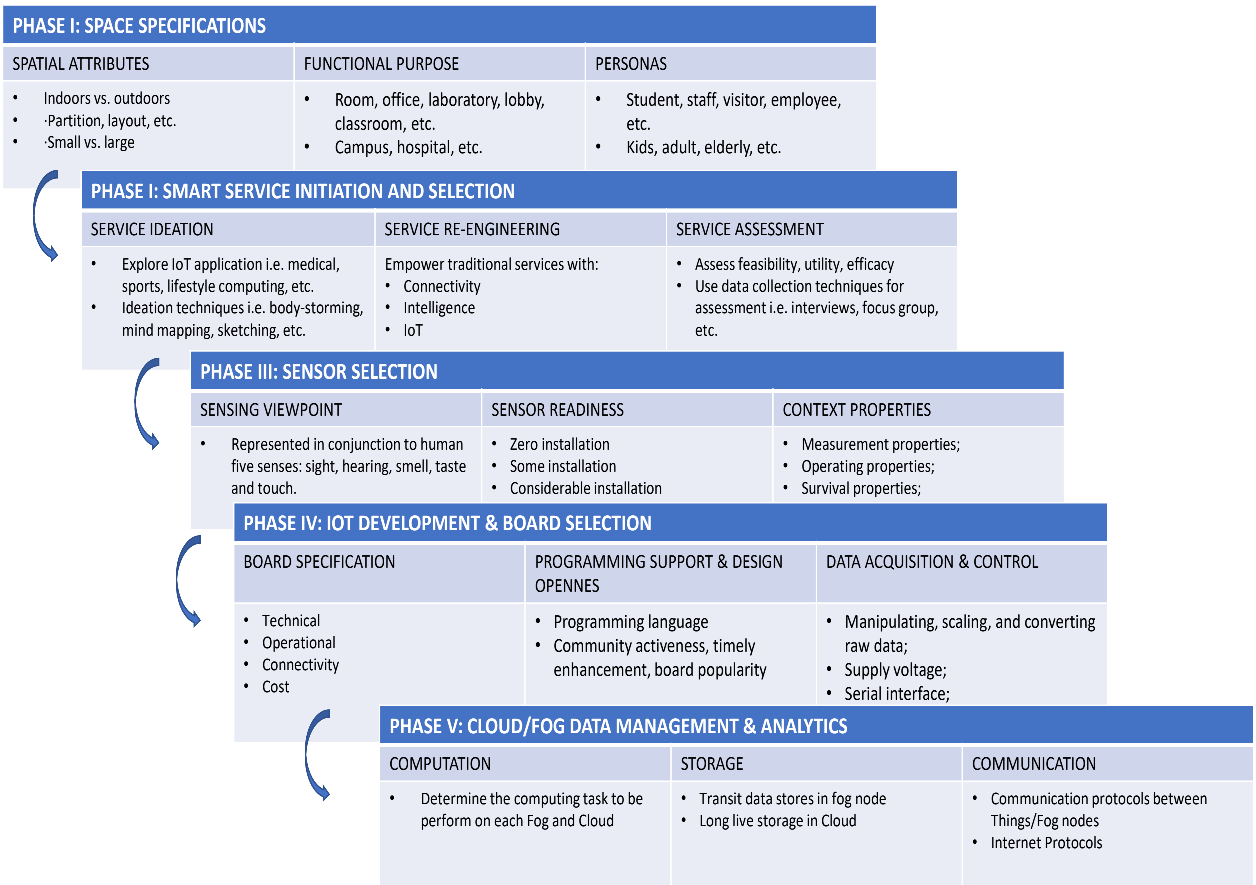

Figure 3. A detailed IoTSS Framework for Developers.

4.1. Phase I: Space Specification

The space-specification phase describes the fundamental aspects for classifying a high number of diverse spaces. The diversity and heterogeneity of spaces are two of the main challenges for developing a system that efficiently serves the space and its users' needs [36]. Thus, space specification should be considered to identify potential and related smart services that can be developed for a particular space. Space can be characterized into three main aspects: spatial attributes, functional purpose, and persona. As Ma and colleagues [36] suggested, it is essential to clarify the space characteristics according to these identified aspects to determine and build smart-space services that efficiently correspond with user activity inside the targeted space.

Spatial attributes help to draw a clear boundary criterion of the intended smart environment. The attributes include space size, structure, and location. Spaces differ from one another according to their spatial attributes such as small versus big, enclosed versus open, partitioned and layout, public versus private, and still versus mobile. According to Kindberg and Fox [37], ubiquitous system developers should have a clear conception of the environmental boundaries that eventually determine the environment-sensed contents. For example, a home is a still, enclosed, and private space, whereas a library is also still and enclosed but a public space. The small differences between home and library in spatial attributes have a substantial impact on forthcoming phases such as service identification. To be more specific, login credentials are essential for smart home services as they address personal information and assets, whereas smart library services should not require such login credentials because the created services are intended for a public audience.

Spaces should be further classified as to their functional purposes to identify related smart services. Spaces generally align with a specific functional purpose. For example, a bedroom is usually used for sleeping, having pleasant and restful purposes, whereas relaxing and socializing are general uses for a living room. Although two different spaces—a bedroom and a living room—have the same spatial attributes (e.g., similar area and structure), they have differing functions and purposes that require different smart services, accordingly. On a much larger scale, a hospital could be similar to a college in spatial attributes, but the former requires services related to providing a healthy environment and managing a patient queue, whereas the latter needs services more focused on delivering an appropriate study environment and experience.

Space persona is the final aspect of the space-specification phase. Personas are fictional characters created for use in scenario-based designs [38]. Personas are a concept widely used in the field of interaction design [39]. The creation of personas is an effective way to define target groups, helping identify the space users to better identify smart services that fit their needs. For example, elderly assisted living is a space that aims to provide health and assistant services for users with limited technology skills and physical capabilities. Thus, the skills and physical abilities of space-related users must be well considered for better smart-service identification, development, and use. To be specific, elderly assisted-living space should focus on smart services that address elderly and caregiver needs for close and continuous monitoring, such as using wearable cardiac and biometric sensors and smart glucometers. Furthermore, developers should classify the elderly in further categories such as a sophisticated younger senior, a senior with chronic physical diseases, and a senior with early-stage dementia [40]. Such classification helps designers carefully identify the appropriate services that fulfill elders' needs. Spaces might have similar functional purposes and spatial attributes but require different smart services, as their stakeholders and their needs differ. For example, two homes that are both still, enclosed, and private spaces (similar spatial attributes) also have identical functional purposes (a place to live comfortably) but may have a completely different set of required smart services, depending on the priorities of household members in the home, such as elders, couples, and families with children.

4.2. Phase II: Smart-Service Initiation and Selection

Smart-service generation and selection is the second phase of the proposed framework. Phase II helps the developer identify the most relevant smart services to be developed. It provides the essential steps to ideate, reengineer, and assess the anticipated smart service. The information elected from Phase I (space specification) along with careful consideration of Phase II aspects should give the developer the opportunity to generate smart services that have the potential to meet users' actual needs. Smart-service generation and selection consists of three main steps: service ideation, service reengineering, and service assessment. These main steps were identified in the prior literature to identify new smart services for smart homes [41]; however, these steps are generic and can be applied to different smart spaces.

Service ideation is an innovative process to identify a new smart service with a strong focus on predefined space specification (Phase I) to ensure service applicability to the targeted space and suitability to the targeted stakeholder. Phase I represents a preparation for the service-ideation step in which a developer has a well-rounded understanding of the problem domain, identified by defining the space specifications and related users to identify their needs and activities in the targeted space. Exploring related IoT applications and services in space-relevant sectors, such as security and safety, medical, wellness, sports and fitness, health care, lifestyle computing, and communication would be beneficial. Various ideation techniques, such as body-storming, mind-mapping, and sketching, are beneficial during this step. In this step, a developer should create a cluster of activities and potential services related to each one of the related users. For instance, a fall accident-detection service using artificial intelligence and image-processing technologies is a new and innovative service that can be used to rescue elders in case of falls. It is a new service that solves a common problem associated with elders who live alone and are highly exposed to accidents that may cause death if not detected promptly.

Service reengineering is a process to identify smart services, transitioning traditional services to smart services using smart technology. Developers should have a list of existing conventional services (a service catalogue) and think of ways to incorporate and empower those services with IoT, intelligence, and connectivity capabilities [41]. For example, traditional door locks have been in use for a long time as a way to secure people's homes. Opening and locking the house door is a routine activity that people do almost every day. With the advancement of technology, particularly IoT, this traditional activity can be reengineered to become a smart lock. Smart locks enable households to open/lock the doors using their phone. Furthermore, door locks might be reengineered to allow the homeowner to assign access privileges to friends and family members wirelessly. This example shows that designers do not actually invent a new activity/service but reinvent the activity by incorporating IoT and connectivity capabilities.

Service assessment and selection is the last step for Phase II, where a developer assesses the feasibility, utility, and efficacy of the generated ideas and chooses the appropriate idea, accordingly. Stakeholders should assess the generated list of ideas using different data-collection techniques such as focus-group meetings, observation, interviews, and surveys. User feedback is essential not only to evaluate and select the proposed ideas but also to generate a new potential idea. In other words, an iteration process between the two earlier steps—services ideation and service reengineering with service assessment and selection—should be sought to generate more relevant ideas.

4.3. Phase III: Sensor Selection

Phase III concerns addressing the essential aspects that need to be considered to select the most appropriate sensor(s) to implement the service, if any. The prior literature emphasized the importance yet difficulty in selecting suitable sensors, especially when a large number of sensors are available [42]. The sensor-selection phase consists of sensing-viewpoint analysis, sensor context properties, and sensor readiness.

Sensing-viewpoint analysis is a simple process that helps designers recognize potential sensing opportunities to be implemented for the selected service [43]. Sensing viewpoint can be represented in conjunction with the human five senses: sight, hearing, taste, smell, and touch. The process of sending sensory information from a sensor to an IoT development board can align with thoughts similar to the way the human five sense organs send data to the brain. Thinking of the sensing viewpoint in this way helps developers be innovative in leveraging potential sensing opportunities to be used for the service, for example, thinking of possible ways to recognize a fall for elders in a natural setting. Falls can be detected either by painful sensations occurring to the elderly person (touch sense), other people watching the fall (sight), or hearing the sound produced by the fall. Similarly, a developer can use sensors to mimic the possible solutions, such as a pressure sensor installed beneath the flooring to simulate the touch sense [44], a camera to capture the fall incident [45], and a microphone to detect the 3-dimensional sound source of the fall [46].

Sensor-context properties define sensors in relation to their functional factors. The prior studies [42] classified sensor-context properties into three categories: measurement properties, operating properties, and survival properties. Sensor-measurement properties include accuracy, response time, precision, and measurement range. Sensor-operating properties include bandwidth, security, operating temperature and humidity cost, and availability. Sensor-survival properties have a lifetime expectancy and power-consumption/battery life. The developers must have a clear understanding of the requirement of the service they developed in the context's properties. Perera et al. [43] presented a model to select and rank sensors when large numbers of sensors with overlapping and sometimes redundant functionality are available. The model allows developers to prioritize context properties based on anticipated service requirements.

Sensor readiness is the last factor to consider in the process of selecting a suitable sensor. Sensor readiness concerns how ready a sensor is to be implemented in the actual environment. It classifies sensors by readiness for installation into three categories: zero-installation, some installation, and considerable installation. In zero-installation, the sensor is embedded with memory that contains configuration information on the sensor. It uses a transducer electronic-data sheet that stores sensor identification, calibration, correction data, and manufacturer-related information [47]. Zero-installation sensors do not need engineering skills such as soldering to connect the sensors to the IoT development board. Second, some-installation is a recalibrated sensor similar to a zero-installation sensor, yet it requires soldering. Finally, considerable installation is a sensor that needs calibration and soldering before implementation.

4.4. Phase IV: IoT Development Board Selection

A large number of IoT board choices make it hard for developers to select the right one to use for their smart services. Phase IV addresses this issue by shedding light onto factors that have the most impact on choosing the right IoT development board, in other words, a microcontroller or microprocessor. This phase consists of three main elements that need to be considered to select the appropriate IoT board: specification, programming language support and design openness, and data acquisition and control.

The specification factor concerns the IoT board's technical, operational, connectivity, and cost specifications. Some technical and operational specifications are memory, processor, input/output (I/O) capability, power consumption, a reliability security feature, and operating and input voltage. It is also important to determine connectivity needs such as Wi-Fi, cellular, Sigfox, or LoRaWAN before the final selection of the IoT board. For example, NodeMCU is a microcontroller embedded with an ESP8266 WiFi Module, whereas Arduino Uno is a microcontroller that does not come with Internet connectivity and the developer needs to attach Wi-Fi or GSM shields to connect the device to the Internet. Finally, the cost is another factor that should be considered prior to sensor selection.

Programming support and design openness is the second factor in Phase IV, uncovering the supported programming languages, community activeness, and richness of the

IoT board. The supported programming language is a critical factor that must be considered when selecting the IoT development board because some boards support only one programming language. According to a survey of developers conducted by the Eclipse Foundation, an IoT Working Group, the top four languages for building IoT solutions are Java, C, JavaScript, and Python; however, they identified 12 programming languages for IoT development [48]. Design openness is concerned with user community activeness, timely enhancements, and IoT board popularity between developers who work toward designing new applications.

Finally, data acquisition and control are the process of manipulating, scaling, and converting sensor readings. Developers should consider this factor to determine whether the IoT development board supports a sensor serial interface and supply voltage. To illustrate, sensors connect to the IoT board through pins using one type of various serial interfaces such as digital or analog general-purpose I/Os, I2C, universal asynchronous receiver–transmitters, and serial peripheral interfaces. Thus, developers must check the compatibility between the sensor and IoT development board regarding serial interface and supply voltage.

4.5. Phase V: Cloud/Fog Computing for Data Management and Analytics

Phase V sheds light on the nature of potential collaboration between cloud and fog computing to manage Things' generated data in communication, computation, and storage. Cloud technology and IoT are two distinct paradigms; however, they closely align in the sense that their characteristics are often complementary [49]. Small devices such as sensors, actuators, and IoT development boards with limited processing and storage capabilities characterize IoT. The cloud, on the other hand, has revolutionized the way people use the Internet in general, mainly in data management (data storage, processing and analysis, and communication). Thus, cloud computing is viewed as the foundation of IoT. Despite the vital role cloud computing plays in revolutionizing the IoT industry, many scholars have pointed out some limitations that are typically associated with using cloud-based solutions for IoT applications [50]. The constraints can be summarized as low latency, mobility, network bandwidth, reliability, geographic distribution, and security and privacy challenges [50]. Bonomi and colleagues introduced a new platform called fog computing that can interplay with cloud computing to overcome the previously mentioned limitations.

The main idea of fog computing is to use an edge device to carry out data computation, storage, analysis, and communication locally. Then, it can be routed to the cloud [43]. A fog node can be any device with storage, computing, and connectivity capabilities such as Raspberry Pi, routers, and switches. It is important to think of the role of fog computing as complementary to cloud computing in developing IoT applications rather than a replacement for cloud computing. The nature of the role and type of collaboration between fog and cloud computing differs from one IoT application to another. In other words, the developer needs to determine the amount and type of data that must be computed, stored, and analyzed in fog computing and what has to be left for cloud computing.

Fog nodes typically obtain streamed data from sensors using a variety of possible communication protocols such as USP, Wi-Fi, Bluetooth, and ZigBee (communication). Fog nodes should perform computation and analysis for time critical IoT applications that require millisecond response time (computation) (Bonomi, et al., 2014). Furthermore, fog computing generally uses transit storage (1–2 h) and aggregates data generated from different Things (storage) [51].

In contrast, cloud service might be used for large-scale and long-lived storage. According to Rao et. al., the cloud is the most convenient and cost-effective solution to handle the tremendous amount of data produced by IoT devices (storage) [52]. Although the fog node has some processing capabilities, it is limited in processing and energy resources that do not allow for complete onsite processing (computation). Finally, developers should also determine the Internet protocol to be used between the fog node/sensor and the cloud, including the transmission control protocol, user datagram protocol, hypertext transfer protocol (HTTP), and file-transfer protocol (communication).

4.6. The Smart Kiosk (SK)–Designed IT-Artifact

The SK is made up of three separate services that are all connected to achieving SK goals. SK involves two main goals. The initial objective was to make the lobby attractive and informative using emerging technologies such as IoT and artificial intelligence. The second goal was to provide smart services tailored to the needs of the occupants.

The frontend of the SK is an Android tablet-based application. It is presented to the users via a touchscreen app with three separate applications: indoor air quality, automatic ID creation, and a current local newsfeed using different information and communication technologies, as shown in Figure 4. The core functionalities of the SK services are carried out in the backend using Digital Ocean, a cloud infrastructure provider.

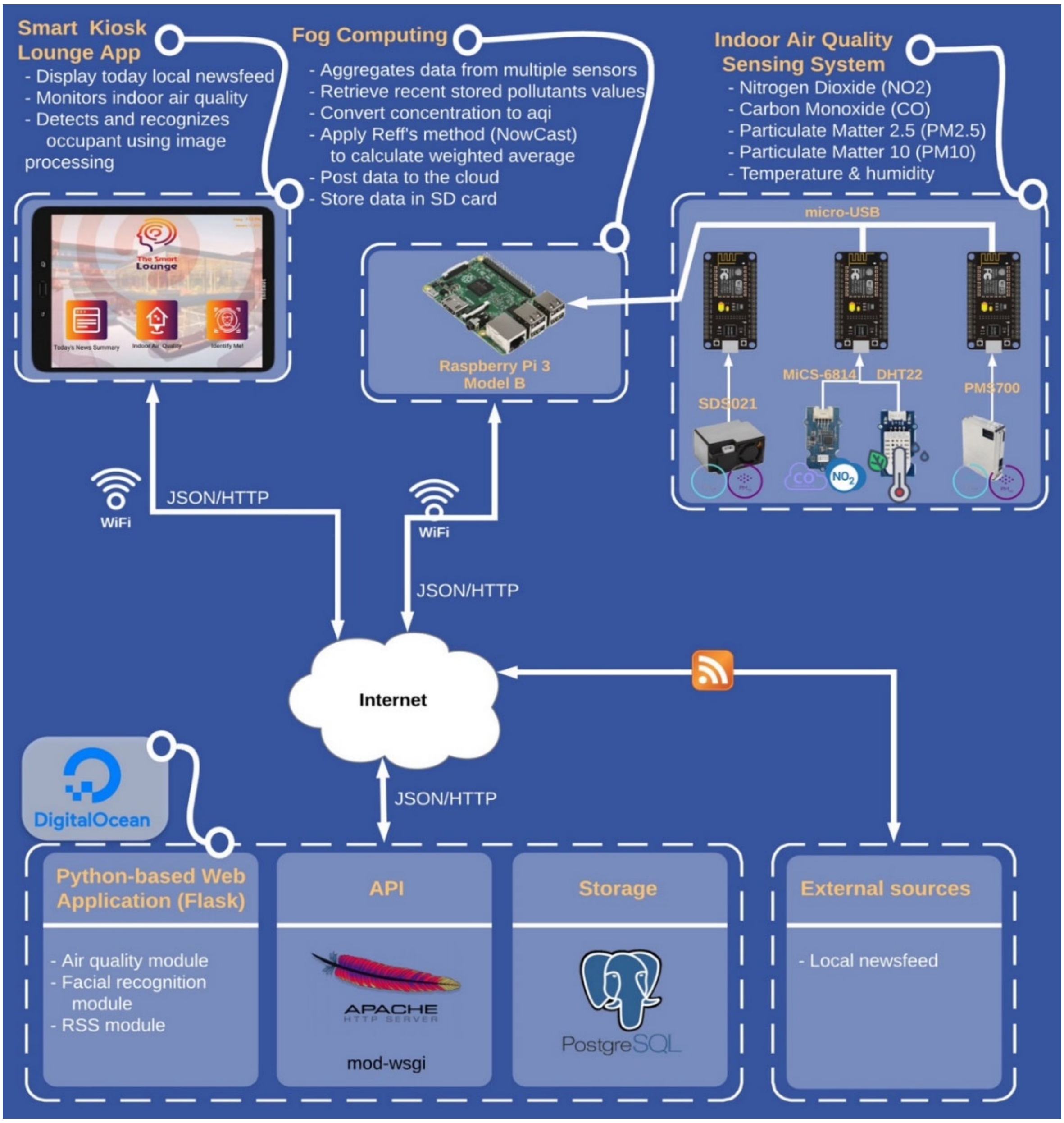

Figure 4. SK System Architecture.

Users interact with the Android tablet interface, which runs the three separate applications. We wrote the web application and fog computing code in the Python programming language. The tablet application communicates with Digital Ocean using JavaScript Object Notion (JSON) messages over a representational state transfer (RESTful) API. In addition, a Raspberry Pi (Rpi3) is used as the fog computing platform to which air quality sensor microcontrollers communicate. The microcontrollers connect to the Rpi3 through Micro USP. The Rpi3 also communicates with Digital Ocean over RESTful API. PostgreSQL is a database used for SK data storage. PostgreSQL is an open-source object-relational database-management system.

4.7. Indoor Air Quality Service

One of the three services provided by the SK is indoor air quality. The first goal of this service was to monitor and display indoor air quality, temperature, and humidity in real-time using sensors. The second goal is to demonstrate the risks associated with indoor toxic-gas concentrations and recommend minimizing occupants' exposure to such risks. We briefly highlight below the technology development to design and build this service.

4.7.1. Infrastructure and Technology Development

Sensors and fog computing devices are the IoT components that are part of the indoor-air-quality service. As illustrated in Figure 4, the air-quality system comprises four sensors (SDS021and PMS700 for PM2.5 and PM10; MiCS-6814 for CO, NO2; and DHT22 for temperature and humidity) that interfaced with NodeMCU and Seeeduino (based on the ATmga328P microcontroller) microcontrollers. The microcontrollers are programmable IoT boards that read signals from sensors and convert them to have more useful value. We set sensors to monitor pollutants (particle matters PM2.5 and PM10) and provide readings every 20 s.

The microcontrollers connect to the Rpi3 through Micro USP. The Rpi3 acts a fog-computing device for indoor air quality. The Rpi3 continuously runs a Python-based program to collect, process, store, and upload air-quality data to the cloud.

The AQI is an air-quality index developed by the U.S. EPA to report daily air quality. It converts different pollutant concentrations into a single standard index. Pollutant concentrations received from the microcontroller are converted to AQI at the fog-computing unit and before being uploaded to the cloud. However, pollutant concentrations, AQI, and other data (temperature, humidity, timestamps, etc.) are all uploaded to the cloud.

We wrote the server-side code in the Python programing language. The Flask framework handles HTTP requests received from fog computing and stores the air-quality data in the PostgreSQL database. It also responds to SK requests by sending JSON messages that relate to current air-quality data, historical AQI for monitored pollutants on an hourly, daily, and monthly basis and advice and recommendations based on the current air-quality data, depending on the user's request.

4.7.2. The UI Front-End Design

The tablet-based SK application presents the current indoor air quality collected from sensing and fog computing data that is received from the cloud. The design of the interface background used the idea of AQI color-code categories as representations of the air-quality level. AQI color-code categories provide an easy, simple, and quick interpretation of the air-quality level. As shown in Figure 5, a green-interface background is displayed to represent good air quality. The background color changes to red and purple to represent unhealthy and very unhealthy air-quality levels, respectively (see Figure 5, top right and left). In addition to displaying the current air quality, humidity, and temperature data, the service provides two related features. First, the service demonstrates the risks associated with current air-quality level, if any and gives recommendations to either minimize occupants' exposure to such risks or maintain the good air quality.

Figure 5. Indoor Air Quality Interfaces.

For example, in a good air-quality condition, it displays that there is no risk to elders, sensitive groups, or children (most left) and recommends (right most) maintaining the good air quality (see Figure 5 bottom left). In a very unhealthy air-quality condition as a result of high NO2, it displays risks for elders, sensitive groups, and children and provides recommendations. Finally, the Trends feature allows users to view historical AQI values for the monitored pollutants in hourly, daily, and monthly increments (see Figure 5 bottom right). AQI color coding represents the air-quality level in the chart.

The occupant user can interact with this air-quality application and learn a lot of useful tips and information about how the quality might affect health.

4.8. Identify Me (Automatic ID Pass Creation)

The Automatic ID Pass Creation hereafter referred to as Identify Me, is the second service offered in the SK tablet application. It aims to identify and recognize occupants based on their status and create a temporary ID pass card automatically. This service was nominated by building occupants during our focus group and brainstorming process. It is an artificial intelligence service built using a deep convolutional neural network. It detects occupants' faces and recognizes their identity by comparing the unique features of users' faces to all occupants stored in the database. It uses a pretrained model with 99.38% accuracy on the Labeled Faces in the Wild benchmark.

4.8.1. Server-Side Implementation

The core functionalities of the Identify Me service are implemented in a Python-based web application (Flask microframework) at Digital Ocean. The service is built using an open-source library such as dlib [53], face recognition [54], NumPy, SciPy [55], and other libraries installed in Digital Ocean (a Linux-based operating system). We used pretrained deep convolutional neural network models for this service [47].

As soon as the server receives the image from the SK, the image goes through a series of steps for face detection and recognition. First, the program determines the location of the face in the posted image (face detection) using the dlib pretrained model [50]. Second, it repositions the face in the image to a standard pose to correctly recognize the same person even if their face is turned in a different direction. This step uses a pretrained face-landmark model [51] that either uses 5-point landmarking that locates the corners of the eyes and bottom of the nose, or a 68-point landmark related to the face such as corners of the eyes, mouth, and along eyebrows. The third step is the face encodings, which use the cropped face image to generate 128 measurements (dimensional vector space) [56]. Face encodings use a pretrained dlib ResNet network with 29 convolutional layers [57]. Finally, the program identifies the individual by comparing the closest 128 measurements that were prestored in the PostgreSQL database to the newly generated measurements. The smaller the difference between the two sets of measures, the most likely it belongs to one person.

We used the PostgreSQL database to store the user's face encodings using the cube-data type. The PostgreSQL cube-data type can present N-dimensional vectors and is ideally suited for face encodings. PostgreSQL sets a limit for the number of dimensions of cubes to 100 dimensions, which must change to a bigger dimension size to store face encodings successfully.

4.8.2. Identify Me UI Design

Any person in the building can walk up to the SK screen and choose the Identify Me service. Since we are working within an academic building, the application can recognize and classify the person as one of the following: faculty, student, staff, or visitor. The user provides permission for SK to use the picture and then looks directly into the built-in camera. After the user is appropriately identified, the display (see Figure 6) will show the badge (or pass). The user can print that. However, the display also allows the user to update or rectify if any information shown is incorrect. There are four different colors chosen on the left banner for the four classes of occupants we expect.

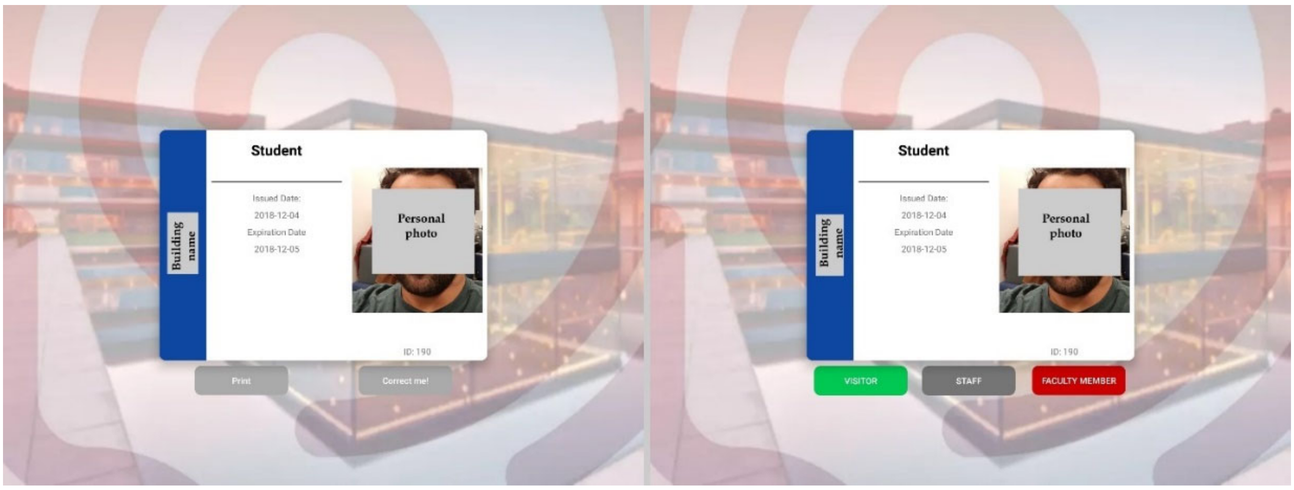

Figure 6. The Identify Me Service UI.

4.9. News Summary Service

The local news summary is the third service offered by the SK. We envision this service to be more suitable for visitors (parents, family members of prospective students etc.) who would learn more about the university or the city. As shown in Figure 7, newsfeeds are categorized based on location areas and cities. The Newsfeed service uses a simple grid view to display news categories in two dimensions. If a building visitor (or occupant) wants to know more about what is currently happening on the college campus or in the city or even in the state, the user can click on the service from the home screen, retrieving news categories and images through HTTP links from the Flask web application (server-side) in a JSON message over the RESTful API. Then, news categories and images are automatically inserted into the layout. The design of the service supports a dynamic layout view that is populated at runtime based on the content received from the cloud. For example, if a user chooses the college's city location as a category, it shows a list of related news articles extracted from different RSS news sources about the neighborhood. However, it displays a web page that is embedded in the SK application if the really simple syndication (RSS) feed sources do not syndicate the full content of their news. Users can adjust the size of the article texts to their liking (see Figure 7)

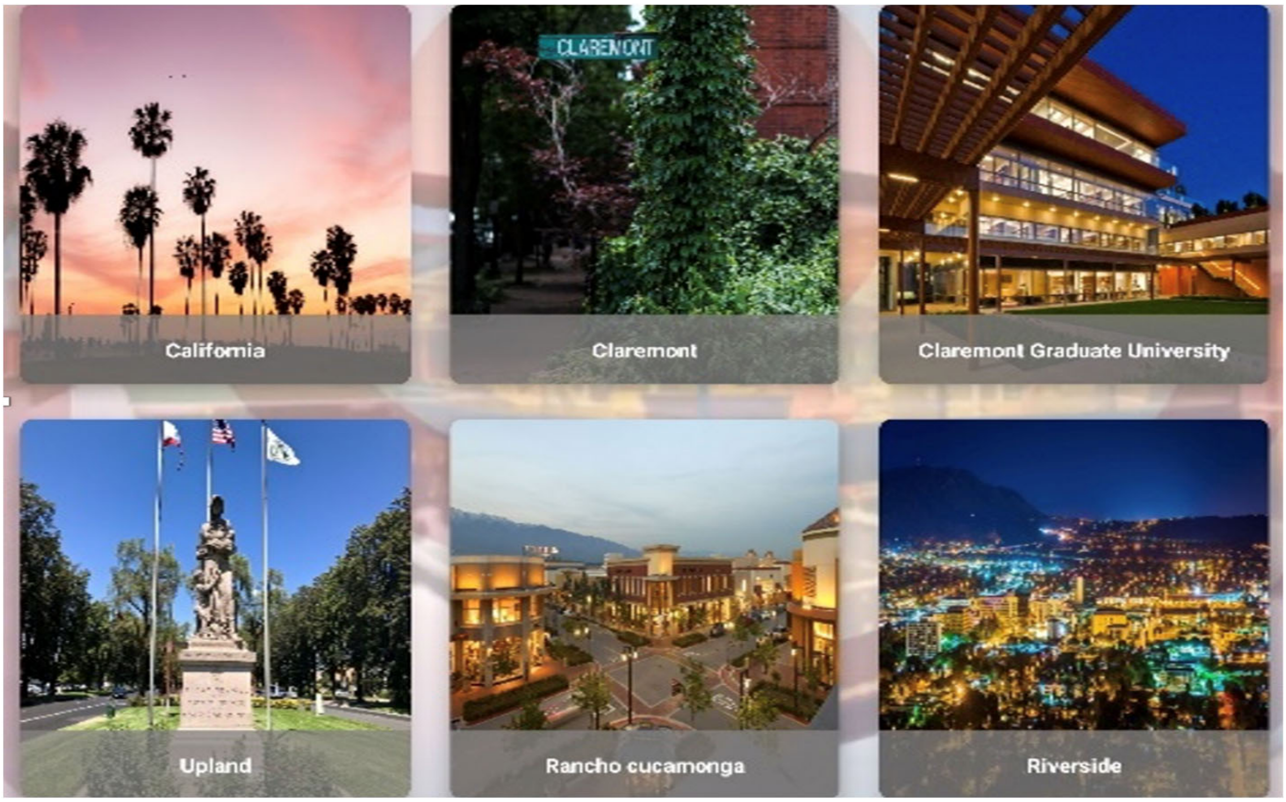

Figure 7. Local Newsfeed Interfaces.

5. Evaluation of SK Prototype

Evaluation is central to DSR to assess the quality, utility, and efficacy of the IT-artifact. The SK will eventually be accessed via a large screen display hung on the wall of the academic lobby. We chose to conduct user tests inside our lab on a large Android tablet to evaluate the SK as a proof-of-concept. The primary focus of the evaluation was to assess the usability of the SK. In addition to evaluating the SK as a whole, each of the three SK services was also evaluated individually based on the services' unique characteristics. To illustrate, we developed a specific questionnaire to assess the utility of a specific feature infused in the design of the indoor-air-quality services to enhance the interpretation of the air quality level. We adopted perceived intelligence [58] and cognitive experience [59] measures to assess the design of the Identify Me service property of an intelligent application. Similarly, we adopted a perceived enjoyment [60] measure to assess the local-newsfeed service. The questionnaires are shown as Appendices A–C in this paper.

5.1. Research Procedure

Upon obtaining IRB approval, we sent an invitation to participate in the user testing to faculty members, staff, students, and visitors by email and text message. Upon receiving their consent to participate, we collected faculty members' and staff members' personal photos from the university website. We asked other participants to either share their photo or had their photo taken to encode their faces for the Identify Me service. Each participant was brought into a controlled laboratory setting and was provided a brief description of the study. We implemented the SK in an Android tablet-based device (9.7-inch) that was given to participants and asked them to navigate through the SK and use its three services. Because the indoor-air-quality service uses AQI color coding to represent different air-quality levels, we instructed participants to navigate through the indoor-air-quality service a few times. The purpose was to test if participants noticed a color change on the interface background of the service after the current air quality was modified to be very unhealthy in the backend. The aim of modifying the air-quality level was to assess the utility of using AQI color coding as a representation of the air-quality level. At the end, we directed participants to complete an electronic survey to evaluate the usability, quality, utility, and efficacy of the SK tablet-based application and its services. We assessed the usability and quality of the SK application using validated instruments (described below). We also developed a questionnaire to evaluate the indoor-air-quality service and reliable measures to evaluate Identify Me and the local-newsfeed services individually.

5.2. Participants

We sent an invitation to participate in our study to faculty members, staff, students, and visitors for the academic unit of the University. In total, we recruited 32 participants (M: 25; F: 7; Students: 20; Visitors: 5; Faculty members: 4; Staff: 3) using a convenience sampling method. We used convenience sampling because it was important to evaluate the smart services by the same community group that initially nominated the services. Participants' ages ranged from 18 to 74 years with an average of 31.9 years. The majority of participants had a master's degree (Master: 19; 59.4%) followed by participants with doctorate degrees (doctorates: 9; 28.1%) and bachelor's degrees (bachelor: 4; 12.5%).

We gave participants the device and asked them to navigate through the SK and use its three services. At the end, we directed participants to complete an electronic survey to evaluate the usability, quality, utility, and efficacy of the SK tablet-based application and its services.

5.3. Metrics & Measures Used in the User Study

Table 1 shows the summery of measures and metrics used for this study.

- Usability

We used the System Usability Scale (SUS) to evaluate the overall usability of the SK prototype [61]. The SUS is a validated and reliable instrument used to evaluate the usability of computer-based systems. It consists of a 10-item questionnaire with five response options (ranging from strongly agree to strongly disagree). According to Bangor et al., [62] the SUS is highly robust and suitable for a small sample size.

- App Quality Ratings

We adopted the Mobile App Rating Scale (MARS) to evaluate the overall SK applications. MARS comprises a multidimensional measure for rating prototype applications. The scale comprises a five-dimension measure: engagement, functionality, aesthetics, information, and overall subjective quality. We adopted MARS constructs, which uses a 5-point scale to measure the user interaction with the SK application.

- SK's Service-Specific measures

The SK consists of three distinct smart services that use different technologies. We adopted measures and developed questionnaires to assess each of the SK services against their design characteristics. We developed a four-item questionnaire to assess the utility and usefulness of the indoor-air-quality service's specific features. The questionnaire aimed to elicit participant feedback on the utility of the service's unique features embedded in the design of the indoor-air-quality service. The first of the four items on the questionnaire aimed to obtain participants' feedback about the utility of using the AQI color code as a background feature to represent the current air-quality level. In the second item, participants responded about the usefulness of the tips-of-the-day feature in reducing possible exposure to indoor pollution. For the third item, we aimed to assess the utility of using charts to present air-pollutant readings hourly, daily, and monthly. The fourth item was to evaluate the utility of using the AQI color codes in the air-pollutant charts as a way to interpret the graphs. The developed items used a 5-point Likert-type scale.

Since the Identify Me service is based on artificial intelligence technology, we looked for measures that captured the intelligence appeal of the service. Perceived intelligence (PI) was used to assess whether participants found the Identify Me service to be intelligent. This was adopted from [57]. Cognitive experience (CE) aimed to elicit users' perceptions and assessments of intelligent services. This measure was adopted from [61].

Enjoyment was identified as the primary character of the local newsfeed service and was considered in the service design. Perceived enjoyment (PE) was utilized to assess if the activity of using the local newsfeed was perceived to be enjoyable. The measure has three items on a 5-point Likert scale.

Table 1. Summary of the measures and metrics.

Evaluation Stage	Techniques	Questionnaire	References
Overall SK Usability testing	Electronic survey	System Usability Scale (SUS)	SUS was used to evaluate the overall usability of all SK and its smart services.
Mobile app quality ratings	Electronic survey	Mobile App Rating Scale (MARS)	MARS was used to evaluate the quality of the SK app.
SK's service-specific measures	Electronic survey	Collection of self-developed and adopted measures	These measures were used to assess each of the SK services against their design characteristics Four measures were developed to assess the features utility of indoor air quality service Two measures were adopted to assess the intelligence and cognitive experience perceived from using the Identify Me service One measure was adopted to assess if the activity of using the local newsfeed is perceived to be enjoyable

5.4. Evaluation Results

We examined the reliability of the used constructs using Cronbach's alpha. Results confirmed the reliability of application-quality constructs (engagement, functionality, aesthetics, and information quality) with scores above 0.7, the recommended threshold. Similarly, perceived intelligence, cognitive experience, and perceived enjoyment constructs used to assess the Identify Me and Newsfeed services were reliable with a score above the threshold.

- Overall Usability

We calculated the overall score on the SUS following the scale-calculation guidelines [61]. The overall score is the mean of users' scores. Based on participants' responses, the SK had an overall SUS score of 90, which is an excellent user experience score and in the 99% percentile, based on SUS benchmarks [56]. This implies that users overall found the smart kiosk to be very usable.

- App Quality Ratings

Table 2 presents participants' application quality assessment for the SK using the MARS rating scale. It shows that the SK had an excellent overall mean objective quality score based on participants responses (mean = 4.52, SD = 0.45). Similarly, results demonstrated that the SK had an excellent overall mean subjective quality score as well (mean = 4.65, SD = 0.54). These statistics confirm that participants perceived the SK apps to be of high quality. The Pearson correlation coefficient showed a significant positive correlation between the overall objective mean score and the overall subjective mean quality score (r = 0.85, p = 0.01). These scores provide evidence that objective quality constructs captured the perceived overall quality. In addition, the results demonstrated very high mean scores on functionality (mean = 4.62, SD = 0.44), engagement (mean = 4.36, SD = 0.62), aesthetics (mean = 4.59, SD = 0.51), and information quality (mean = 4.50, SD = 0.52).

Table 2. MARS constructs (objective) and subjective scores (MARS = Mobile App Rating Scale) [2].

Evaluation Constructs	Mean Score	Median Score	SD
Engagement	4.36	5.0	0.62
Functionality	4.62	5.0	0.44
Aesthetics	4.59	5.0	0.51
Information quality	4.50	5.0	0.52
MARS overall mean objective quality	4.52	5.0	0.45
Overall subjective quality	4.65	5.0	0.54

- SK individual service-specific results

Table 3 presents participants' assessments of individual SK services: Identify Me and newsfeed services. Participants perceived Identify Me as an intelligent service with a mean score of 4.67 and a median score of 5.0. Similarly, participants demonstrated a high cognitive experience with a mean score of 4.58 and a median score of 5.0. Furthermore, the facial recognition algorithm yielded 100% correct recognition for participants' professions and their nicknames, if used, as participants assessed and perceived the Identify Me service. Additionally, participants perceived the local-newsfeed service to be enjoyable, with a mean score of 4.42 and a median score of 5.0.

Table 3. Identify Me and local newsfeed services scores.

Evaluation Constructs	Mean Score	Median Score	SD
Perceived Intelligence (assessing the Identify Me service)	4.67	5.0	0.54
Cognitive Experience (assessing the Identify Me service)	4.58	5.0	0.65
Perceived Enjoyment (assessing the local newsfeed service)	4.42	5.0	0.53

Table 4 presents the results of participants' evaluations for four features provided in the indoor-air-quality service in the utility to enhance the interpretation of the air-quality level and reduce the risk of exposure to pollution. All participants agreed that changing the service background color based on air quality level helped them easily interpret air-quality interpretation (mean = 4.65, median = 5.0, SD = 0.48). For the tips-of-the-day feature, 87.5% of participants thought it helped to reduce possible exposure to indoor pollution with a mean score of 4.37 and median score of 4.5. The results demonstrated that 90.6% of participants believed that presenting air pollutants readings hourly, daily, and monthly helped identify indoor air-pollution trends and sources (mean = 4.53, median = 5.0, SD = 0.67). Finally, 90.6% of participants highlighted that using AQI color codes on air-pollutant charts helped them easily interpret historical air pollution (mean = 4.56, median = 5.0, SD = 0.66).

Table 4. Indoor air quality features score (Note: AQI = air-quality index).

Evaluation Constructs	Mean Score	Median Score	SD
Using AQI color codes as a background color helped in air-quality interpretation	4.65	5.0	0.48
Tips-of-the-day service helped reduce exposure to indoor pollution	4.37	4.5	0.78
Using charts to present air quality by the hour, day, and month helped identify air-quality trends and sources	4.53	5.0	0.67
Using AQI color codes on charts helped users interpret air quality	4.56	5.0	0.66

6. Discussion

In this research study, we tackled the emerging topic of how to design smart spaces (buildings, cities etc.). We had two specific objectives. The first was to provide a theoretical guideline for designers and developers who are interested in building such smart spaces. We propose the IoTSSB framework to assist developers of smart spaces. The second was a small-scale smart-building prototype that offers smart services to address an academic community's needs. Here, we discuss some of the major insights and contributions. First, the deployment of an innovative IT artifact (SK) demonstrated the bottom-up approach to designing smart services. The findings provided empirical evidence on the feasibility of a bottom-up approach to select, assess, and develop smart services according to users' interests. Second, the SK prototype integrated IoT, artificial intelligence, and a variety of technologies to offer something that is of utility and value to the users. Third, a lot of thought went into the design of each application UI for different services. In fact, the quality of the information presented becomes pivotal for a successful smart lobby space project.

The IoTSSB framework will be useful for practitioners looking for guidance on smart space design approaches. Figure 3 shows a simple high-level 5-step process. The detailed framework is shown in Figure 4, which helps designers to transform any space into a smart space.

The IoTSSB framework was evaluated by two facilities planning experts, and they gave positive feedback. Furthermore, the instantiation of the SK prototype followed the IoTSSB framework. The evaluation results indicate that the SK can transform a traditional space into a smart space. The participant perceived the SK as an easy-to-use app with high-usability ratings for functionality, engagement, attractiveness, and information quality. The findings demonstrated the feasibility of following a bottom-up approach that encourages the selection and development of smart services to come with intended users' needs. The results from the user study confirmed that smart services have a high chance of meeting users' interests and expectations in smart services when a community group nominates the services. The experimental results revealed that 80% of participants found the SK as an intelligent application that matches their interests. Furthermore, 96.7% of participants recommend visitors to use the SK. Finally, 93.3 percent of respondents asserted that having the SK in the lounge would make the area more functional.

DSR projects not only build IT artifacts that are useful but also aim to produce some nascent design theory. While full-blown theories are hard, here, we reflected on our approach and the process and from there we have suggestions in the form of simple design principles that led to the success of the project.

DP1: The system must ensure high engagement of its intended user base.

DP2: For public space displays, aesthetics matter.

DP3: The quality of the information presented in the system leads to better adoption of the service.

For future designers interested in smart building projects, DP1 ensures that the services provided have high user engagement. Part of this is likely due to the users themselves being part of the bottom-up approach and community expressing their interests and needs. Since the SK will be displayed in highly visible public spaces, DP2 suggests that designers pay attention to the aesthetics of the content. Look and feel really matters for more engagement. Finally, DP3 suggests that the quality of information presented can lead to better adoption of the services. This was evident from the indoor air-quality service as well as the newsfeed service. Hence, designers of future smart spaces might want to provide high quality information so that users can stay engaged and the same time perceive enjoyment in viewing these applications.

7. Conclusions

This paper presents a small-scale smart space project (e.g., academic lobby) to transform a traditional academic space into an intelligent and informative lobby. The paper identifies the lack of any framework or theoretical guidance on how to design smart spaces and then demonstrates a bottom-up approach for identifying and selecting smart services. To identify smart services for public use in a building lobby, we held several discussions and brainstorming sessions with academic community members. Three services were selected, which include: indoor-air-quality monitoring, face-recognition and ID card creation, and a newsfeed summary. Evaluation results confirmed the usability and utility of the smart kiosk prototype as an intelligent service. This also demonstrates the usefulness of the bottom-up approach in developing the smart space project. The designed artifact—Smart Kiosk—shows a proof-of-concept that was successful in meeting the needs of its intended users. In the process, we also reflected on some basic design principles that can help other researchers also conduct such bottom-up approaches to designing smart space projects.

Evaluation results confirmed the effectiveness of following a bottom-up approach in developing the smart-space project. To be specific, the achievement of the SK's overall goal—smart lounge space—resulted from a careful assessment and selection of services that successfully matched community interests and needs. The results also revealed that each of the SK three services had achieved its goal. This provides empirical evidence of the importance of defining service characteristics at an early stage of the build and design cycle to govern the design requirements for IT products and properly communicate their values.

We acknowledge certain limitations in this paper. To evaluate the prototype, we conducted user studies in a controlled laboratory environment, which limits the generalizability of findings. The next step is to conduct a field experiment. A field experiment would allow us to study natural interactions with the user. We can study how users react to the air-quality readings and perceptions of the AQI color code as a background interface. However, it would be challenging and time-intensive to analyze users' experiences with varying air quality levels and capture their perceptions in the natural environment. In addition, the indoor-air-quality service integrates various expensive IoT objects such as sensitive sensors, microprocessors, and microcontrollers that are susceptible to damage in a field experiment.

In future, we think that other researchers can use our IoTSSB framework to design smart spaces in other commercial settings (such as corporation offices). In terms of new services, we think "wayfinding" would be very useful as many visitors to a new smart building might want to locate someone's office, restrooms, or the conference rooms. They can walk up to a screen on the wall of the smart lobby and find the specific room they are looking for. Another potential service could be to use infra-red sensors and IoT devices that can detect if someone has entered the building carrying any kind of weapon. As soon as that is detected, all office rooms are automatically locked and a text message is sent to all current inhabitants to take precaution. This would be a valuable service for K-12 schools in America where gun violence is a crisis. Future research could deploy the SK on a large screen in the lobby and obtain results from a much larger user community. An interesting research direction would be to explore the use of community crowdsourcing to develop enhanced smart services.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the CGU IRB Committee (protocol code #3248 and date of approval 13 December 2018).

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Survey for smart lounge app

The rating scale assesses app quality on four dimensions. All items are rated on a 5-point scale from "Strongly disagree" to "Strongly Agree". Circle the answer that most accurately represents the quality of the app component you are rating. (The survey is adopted from [56] with modification).

- Engagement
  1. I found the smart lounge app to be highly entertaining (Entertainment)
  2. I felt the smart lounge app matched my interest in smart application (Interest)
  3. I thought the interactivity of the smart lounge app was just about right (Interactivity)
- Functionality
  1. I found the navigation through various features was fairly easy (Navigation)
  2. I found the interactions in the smart lounge app (taps/swipes/scrolls) were consistent and intuitive across all screens (Gestural design)
  3. I found all the three features (air quality, newsfeed, and Identify Me) of the smart lounge app and their components worked accurately and fast (Performance)
- Aesthetics
  1. I found the smart lounge app to be visually appealing (Visual appeal)
  2. I found the arrangement and size of buttons and content on the screen was appropriate (Layout)
  3. I found the quality and resolution of graphics used in the smart lounge app was very high (Graphics)
- Information
  1. I found the information presented in the smart lounge app was accurate (Accuracy)
  2. I found the quality of information in the smart lounge app was very high (Quality)
  3. I found the quantity of information in the smart lounge app was just about right (Quantity)
  4. I found the visual explanation of concepts through charts, graphs, and images was clear and correct (Visual information)
  5. I found the information presented by the smart lounge system was credible (Credibility)

- Overall perception

1. I would recommend other lounge visitors to use the smart lounge app

Appendix B

Survey for Identify Me feature

The rating scale assesses the identify me feature in term of perceived intelligence and cognitive experience. All items are rated on a 5-point scale from “Strongly disagree” to “Strongly Agree”. Circle the answer that most accurately represents the quality of the app component you are rating.

- Perceived intelligence (adapted from [51])

1. I found the Identify Me feature to be competent
2. I found the Identify Me feature to be intelligent
3. I found the Identify Me feature to be sensible

- Cognitive experience (adapted from [52])

1. I found the Identify Me feature to be greatly impressive.
2. I found the Identify Me feature to be interesting.
3. I found the Identify Me feature to be indeed attracted

Appendix C

Survey for local newsfeed

The rating scale assesses the local newsfeed feature in terms of perceived enjoyment and overall usefulness. All items are rated on a 5-point scale from “Strongly disagree” to “Strongly Agree”. Circle the answer that most accurately represents the quality of the app component you are rating.

- Perceived enjoyment (adopted from [53])

1. I found using the local newsfeed to be enjoyable
2. The actual process of using the local newsfeed was pleasant
3. I had fun using the local newsfeed

- Useful

1. I found the local newsfeed feature to be useful

References

1. Becerra, V. Time Spent Inside/Outside-Infogram. 2021. Available online: https://infogram.com/time-spent-insideoutside-1gg4qpz56j3lp1y (accessed on 6 May 2021).
2. Ahad, M.A.; Paiva, S.; Tripathi, G.; Feroz, N. Enabling technologies and sustainable smart cities. *Sustain. Cities Soc.* **2020**, *61*, 102301. [CrossRef]
3. Albino, V.; Berardi, U.; Dangelico, R.M. Smart cities: Definitions, dimensions, performance, and initiatives. *J. Urban Technol.* **2015**, *22*, 3–21. [CrossRef]
4. Giffinger, R.; Fertner, C.; Kramar, H.; Meijers, E. City-ranking of European medium-sized cities. *Cent. Reg. Sci. Vienna UT* **2007**, *9*, 1–12.
5. Ismail, L.; Zhang, L. (Eds.) *Information Innovation Technology in Smart Cities*; Springer: Singapore, 2018.
6. McCraven, M.J. Making the Transition from Smart Buildings to Smart Cities. 2017. Available online: https://blog.se.com/building-management/2017/05/03/making-transition-smart-buildings-smart-cities/ (accessed on 6 May 2021).
7. Minoli, D.; Sohraby, K.; Occhiogrosso, B. IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems. *IEEE Internet Things J.* **2017**, *4*, 269–283. [CrossRef]
8. Intille, S.S. The Goal: Smart People, Not Smart Homes. In Proceedings of the ICOST2006: The International Conference on Smart Homes and Health Telematics, Belfast, UK, 26–28 June 2006; IOS Press: Amsterdam, The Netherlands, 2006; pp. 3–6.
9. Zou, H.; Zhou, Y.; Jiang, H.; Chien, S.C.; Xie, L.; Spanos, C.J. WinLight: A Wi-Fi-based occupancy-driven lighting control system for smart building. *Energy Build.* **2018**, *158*, 924–938. [CrossRef]

10. Tekler, Z.D.; Chong, A. Occupancy prediction using deep learning approaches across multiple space types: A minimum sensing strategy. *Build. Environ.* **2022**, *226*, 109689. [CrossRef]
11. Low, R.; Tekler, Z.D.; Cheah, L. Predicting commercial vehicle parking duration using generative adversarial multiple imputation networks. *Transp. Res. Rec.* **2020**, *2674*, 820–831. [CrossRef]
12. Wang, K.; Tekler, Z.D.; Cheah, L.; Herremans, D.; Blessing, L. Evaluating the Effectiveness of an Augmented Reality Game Promoting Environmental Action. *Sustainability* **2021**, *13*, 13912. [CrossRef]
13. Peng, Y.; Lei, Y.; Tekler, Z.D.; Antanuri, N.; Lau, S.K.; Chong, A. Hybrid system controls of natural ventilation and HVAC in mixed-mode buildings: A comprehensive review. *Energy Build.* **2022**, *2022*, 112509. [CrossRef]
14. Tekler, Z.D.; Low, R.; Yuen, C.; Blessing, L. Plug-Mate: An IoT-based occupancy-driven plug load management system in smart buildings. *Build. Environ.* **2022**, *223*, 109472. [CrossRef]
15. United Nations Population Division. World Urbanization Prospects: 2018 Revision. Available online: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS?locations=US (accessed on 14 September 2021).
16. Kaewkitipong, L. An Introduction to Smart City Research: A review of The Past And The Future. In Proceedings of the ICEB 2019 Proceedings, Newcastle Upon Tyne, UK, 8–12 December 2019; Volume 23, pp. 43–52.
17. Villegas-Ch, W.; Palacios-Pacheco, X.; Luján-Mora, S. Application of a smart city model to a traditional university campus with a big data architecture: A sustainable smart campus. *Sustainability* **2019**, *11*, 2857. [CrossRef]
18. van Winden, W.; van den Buuse, D. Smart city pilot projects: Exploring the dimensions and conditions of scaling up. *J. Urban Technol.* **2017**, *24*, 51–72. [CrossRef]
19. Wong, J.K.; Li, H.; Wang, S.W. Intelligent building research: A review. *Autom. Constr.* **2005**, *14*, 143–159. [CrossRef]
20. Agarwal, Y.; Balaji, B.; Gupta, R.; Lyles, J.; Wei, M.; Weng, T. Occupancy-Driven Energy Management for Smart Building Automation. In Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building, Zurich, Switzerland, 2 November 2010; pp. 1–6. [CrossRef]
21. Preiser, W.F. *Improving Building Performance*; National Council of Architectural Registration Boards: Washington, DC, USA, 2003.
22. Hall, R.E.; Bowerman, B.; Braverman, J.; Taylor, J. The Vision of a Smart City. In Proceedings of the 2nd International Life Extension Technology Workshop, Paris, France, 28 September 2000.
23. Breuer, J.; Walravens, N.; Ballon, P. Beyond defining the smart city. Meeting top-down and bottom-up approaches in the middle. *TeMA-J. Land Use Mobil. Environ.* **2014**, 153–164. [CrossRef]
24. Malik, F.; Shah, M.A. Smart City: A Roadmap Towards Implementation. In Proceedings of the 2017 23rd International Conference on Automation and Computing (ICAC), Huddersfield, UK, 7–8 September 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–6. [CrossRef]
25. Sennett, R. No One Likes a City That's Too Smart. The Guardian. 2012. Available online: https://www.theguardian.com/commentisfree/2012/dec/04/smart-city-rio-songdomasdar (accessed on 12 December 2021).
26. Conway, R. Are Smart Cities Just for Smart Arses? Sensemaking (Blog). 2013. Available online: https://sensemakingblog.wordpress.com/2013/11/25/are-smart-cities-just-forsmart-arses/ (accessed on 25 November 2013).
27. The Economist. Starting from Scratch. The Economist, 2013. Available online: https://www.economist.com/news/briefing/21585003-building-city-future-costly-andhard-starting-scratch (accessed on 7 September 2013).
28. Alverti, M.; Hadjimitsis, D.; Kyriakidis, P.; Serraos, K. Smart City Planning from a Bottom-Up Approach: Local Communities' Intervention for a Smarter Urban Environment. Proceedsing of the Fourth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2016), Paphos, Cyprus, 4–8 April 2016; SPIE: Bellingham, DC, USA, 2016; Volume 9688, pp. 409–420.
29. Lindsay, G. Not-So-Smart Cities. The New York Times, 16-L. 2011. Available online: http://www.nytimes.com/2011/09/25/opinion/sunday/not-so-smartcities.html?_r=0 (accessed on 12 December 2021).
30. Ollongren, K. Smart Amsterdam: It Is like Art, the Context Is More Important than the Product. Smart City Brand: (Blog). 2017. Available online: http://smartcitybrand.com/smartcity/smart-amsterdam-it-is-like-art-the-context-is-more-important-than-theproduct/%20%20 (accessed on 16 January 2017).
31. Bonola, M.; Bracciale, L.; Loreti, P.; Amici, R.; Rabuffi, A.; Bianchi, G. Opportunistic communication in smart city: Experimental insight with small-scale taxi fleets as data carriers. *Ad Hoc Netw.* **2016**, *43*, 43–55. [CrossRef]
32. Hevner, A.; Chatterjee, S. Design science research in information systems. In *Design Research in Information Systems*; Springer: Boston, MA, USA, 2010.
33. Hevner, A.R. A three-cycle view of design science research. *Scand. J. Inf. Syst.* **2007**, *19*, 87–92.
34. Hassenzahl, M. The Thing and I: Understanding the Relationship between User and Product. In *Funology 2*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 301–313.

35. Beverungen, D.; Müller, O.; Matzner, M.; Mendling, J.; Vom Brocke, J. Conceptualizing smart service systems. *Electron. Mark.* **2019**, *29*, 7–18. [CrossRef]
36. Ma, J.; Yang, L.T.; Apduhan, B.O.; Huang, R.; Barolli, L.; Takizawa, M.; Shih, T.K. A walkthrough from smart spaces to smart hyperspaces towards a smart world with ubiquitous intelligence. In Proceedings of the 11th International Conference on Parallel and Distributed Systems (ICPADS'05), Fuduoka, Japan, 20–22 July 2005; IEEE: Piscataway, NJ, USA, 2005; Volume 1, pp. 370–376. [CrossRef]
37. Kindberg, T.; Fox, A. System software for ubiquitous computing. *IEEE Pervasive Comput.* **2002**, *1*, 70–81. [CrossRef]
38. Pruitt, J.; Grudin, J. Personas: Practice and theory. In Proceedings of the 2003 Conference on Designing for User Experiences, San Francisco, CA, USA, 6–7 June 2003; pp. 1–15.
39. Cooper, A.; Reimann, R.; Cronin, D. *About Face 3: The Essentials of Interaction Design*; John Wiley & Sons: Hoboken, NJ, USA, 2007.
40. Nedopil, C.; Schauber, C.; Glende, S. Creating User-Friendly Healing Environments with Adaptable Lighting for Senior Citizens. In *Engineering Psychology and Cognitive Ergonomics. Applications and Services. EPCE 2013*; Lecture Notes in Computer Science; Harris, D., Ed.; Springer: Berlin/Heidelberg, Germany, 2013; Volume 8020, pp. 365–373. [CrossRef]
41. Parchmann, J.; Böhmann, T. Smart Home Service Opportunity Identification. All Sprouts Content. 2013. Available online: https://aisel.aisnet.org/sprouts_all/515 (accessed on 30 January 2019).
42. Perera, C.; Zaslavsky, A.; Christen, P.; Compton, M.; Georgakopoulos, D. Context-aware sensor search, selection and ranking model for internet of things middleware. In Proceedings of the 2013 IEEE 14th international conference on mobile data management, Milan, Italy, 3–6 June 2013; Volume 1, pp. 314–322. [CrossRef]
43. Hirayama, M. Sensor Selection method for IoT systems–focusing on embedded system requirements. In *MATEC Web of Conferences*; EDP Sciences: Les Ulis, France, 2016; Volume 59, p. 01002.
44. Rimminen, H.; Lindström, J.; Linnavuo, M.; Sepponen, R. Detection of falls among the elderly by a floor sensor using the electric near field. *IEEE Trans. Inf. Technol. Biomed.* **2010**, *14*, 1475–1476. [CrossRef]
45. Foroughi, H.; Aski, B.S.; Pourreza, H. Intelligent video surveillance for monitoring fall detection of elderly in home environments. In Proceedings of the 2008 11th International Conference on Computer and Information Technology, Khulna, Bangladesh, 24–27 December 2008; IEEE: Piscataway, NJ, USA, 2008; pp. 219–224.
46. Li, Y.; Zeng, Z.; Popescu, M.; Ho, K.C. Acoustic fall detection using a circular microphone array. In Proceedings of the 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology, Buenos Aires, Argentina, 1–4 September 2010; IEEE: Piscataway, NJ, USA, 2010; pp. 2242–2245. [CrossRef]
47. Geertman, S.; Reinhardt, W.; Toppen, F. (Eds.) *Advancing Geoinformation Science for a Changing World*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2011.
48. Zola, A. 12 Popular Programming Languages for IOT Development | Upwork. Hiring | Upwork. 2017. Available online: https://www.upwork.com/hiring/for-clients/programming-languages-for-iot-development/ (accessed on 19 June 2017).
49. Botta, A.; De Donato, W.; Persico, V.; Pescapé, A. Integration of cloud computing and internet of things: A survey. *Future Gener. Comput. Syst.* **2016**, *56*, 684–700. [CrossRef]
50. Bonomi, F.; Milito, R.; Natarajan, P.; Zhu, J. Fog computing: A platform for internet of things and analytics. In *Big Data and Internet of Things: A Roadmap for Smart Environments*; Springer: Cham, Germany, 2014; pp. 169–186.
51. Atlam, H.F.; Walters, R.J.; Wills, G.B. Fog computing and the internet of things: A review. *Big Data Cogn. Comput.* **2018**, *2*, 10. [CrossRef]
52. Rao, B.P.; Saluia, P.; Sharma, N.; Mittal, A.; Sharma, S.V. Cloud computing for Internet of Things & sensing based applications. In Proceedings of the 2012 Sixth International Conference on Sensing Technology (ICST), Kolkata, India, 18–21 December 2012; pp. 374–380. [CrossRef]
53. King, D.E. Dlib-ml: A machine learning toolkit. *J. Mach. Learn. Res.* **2009**, *10*, 1755–1758.
54. Geitgey, A. Face recognition: Recognize Faces from Python or from the Command Line, Python. 2017. Available online: https://github.com/ageitgey/face_recognition (accessed on 20 December 2020).
55. Jones, E.; Oliphant, T.; Peterson, P. SciPy: Open Source Scientific Tools for Python. Available online: https://www.bibsonomy.org/bibtex/24b71448b262807648d60582c036b8e02/neurokernel (accessed on 20 December 2020).
56. King, D.E. A Toolkit for Making Real World Machine Learning and Data Analysis Applications in C++: Davisking/Dlib, C++. 2017. Available online: https://github.com/davisking/dlib (accessed on 30 December 2021).
57. King, D.E. Trained Model Files for Dlib Example Programs. Contribute to Davisking/Dlib-Models Development by Creating an Account on GitHub. 2017. Available online: https://github.com/davisking/dlib-models (accessed on 30 December 2021).
58. Bartneck, C.; Kulić, D.; Croft, E.; Zoghbi, S. Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots. *Int. J. Soc. Robot.* **2009**, *1*, 71–81. [CrossRef]
59. Dong, X.; Chang, Y.; Wang, Y.; Yan, J. Understanding usage of Internet of Things (IOT) systems in China: Cognitive experience and affect experience as moderator. *Inf. Technol. People* **2017**, *30*, 117–138. [CrossRef]

60. Sun, H.; Zhang, P. Causal relationships between perceived enjoyment and perceived ease of use: An alternative approach. *J. Assoc. Inf. Syst.* **2006**, *7*, 24. [CrossRef]
61. Brooke, J. SUS-A quick and dirty usability scale. *Usability Eval. Ind.* **1996**, *189*, 4–7.
62. Bangor, A.; Kortum, P.T.; Miller, J.T. An empirical evaluation of the system usability scale. *Intl. J. Hum.–Comput. Interact.* **2008**, *24*, 574–594. [CrossRef]