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# A Framework for and Design of a Smart Academic Building Using Sensors, Citizen Participation, and Volunteered Geographic Information

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# A FRAMEWORK FOR AND DESIGN OF A SMART ACADEMIC BUILDING USING SENSORS, CITIZEN PARTICIPATION, AND VOLUNTEERED GEOGRAPHIC INFORMATION

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## APPROVAL OF THE DISSERTATION COMMITTEE

This dissertation has been duly read, reviewed, and critiqued by the Committee listed below, which hereby approves the manuscript of Neelam Raigangar as fulfilling the scope and quality requirements for meriting the degree of Doctor of Philosophy (Ph.D.) in Information Systems and Technology.

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# Abstract


## A FRAMEWORK FOR AND DESIGN OF A SMART ACADEMIC BUILDING USING SENSORS, CITIZEN PARTICIPATION, AND VOLUNTEERED GEOGRAPHIC INFORMATION

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Claremont Graduate University: 2022

Population growth and migration patterns have shown an influx of residents from rural to urban environments. To deal with the problems caused by unprecedented urban influx, cities should plan to use technology in a smart and distinctive way. Tackling at the city scale is hard. But a set of smart buildings that are interconnected by technology will lead to smarter communities which are then interconnected to create a smart city.

Smart lobby, building, community, or city is distinguished by its application of integrated software, hardware, and network technologies, along with access to real-time data enabling decision-making, facilitating tracing, tracking and real-time monitoring.

For this research project, the unit of study is an academic building that we want to change into a smart building. The goal is to deliver two artifacts. The first artifact is a framework designed to guide developers, while considering stakeholders and technology elements to make a smart

lobby engaging for the users. The second artifact is a mobile based application allowing users to access services on smart devices.

To identity the services, multiple brainstorming and discussion sessions (Service ideation) were conducted between the researcher and colleagues at Claremont Graduate University. Potential new smart ideas to be deployed were discussed as well as opportunities to transform traditional services to smart services using emerging technologies (Service re-engineering). A preliminary list of 47 ideas were identified. The final three services chosen were based on the scoring by the pre-focus group survey participants (Table 2). Services include: restroom availability—making the occupancy in a restroom COVID-19 safe by limiting the number of occupants; conference room availability—displaying available conference room/public space in real time to allow users to reserve a room using their smart device and, allow management to set and verify occupancy limits; incident reporting—enabling people to report and upload pictures of issues in the facility that require attention.

The project's design aims to make a lobby smart and interactive. The key is to start small and start by making buildings, communities, and cities smarter by using ICTs. We learn and grow from there for larger implementations to be successful.

## Dedication

To my parents – Laxman and Mona Raigangar

To my siblings – Kamlesh and Veena Raigangar and their families

To Raigangar family

To my friends and colleagues

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# Chapter 1. Introduction

## 1.1 Motivation/Significance of the Study

Every year the world's population grows by about 83 million people. The United Nations' (UNs') *World Population Prospects: The 2017 Revision, Key Findings and Advance Tables* (2017) working paper estimates that the world's population has reached nearly 7.6 billion people. The world's urban population has grown since 1950 from 746 million to 3.9 billion in 2014, whereas the current rural population is approximately 3.4 billion. That translates to 54% of the world's population being urban dwellers, compared to 30% in 1950. Estimates are that by 2050, 66% of the global population will be urban based, according to the findings reported in the UNs' *World Urbanization Prospects: The 2014 Revision, Highlights* (2014) paper. With continual-growth prospects, the study finds patterns in global migration. People from Asia, Africa, and Latin America and the Caribbean migrate toward high-income and middle-income countries in Europe, Northern America, and Oceania, and settle in urban areas.

This continuous urbanization will pose a challenge to urban life if it is not planned well. Research by Fokaidis (2017, as cited in Apanaviciene et al., 2020, p. 1) finds that: "Cities face major challenges in maintaining a sustainable environment and a healthy lifestyle, considering the growing population, required infrastructure, increasing resources demand, waste management, and the required services that need to be developed." The UNs' *World Urbanization Prospects: The 2014 Revision, Highlights* (2014) paper suggests that governments must implement policies to focus on sharing the benefits of urban growth equitably and sustainably. The report's writers refer to the United Nations Conference on Sustainable Development (Rio+20) — its theme being The Future We Want—which recommended a holistic planning approach, as cities are the conduit that can "lead the way towards economically, socially and environmentally sustainable societies" (p. 17). And for the development of such societies in an urban environment, there is a need to apply integrated approaches to build the institutional capacity and use of ICTs for efficient service delivery.

With continued urbanization in recent years, cities are using ICTs to become smart cities. Zhang et al. (2017) explain that smart cities employ sensing components, heterogeneous networks, and processing units, as well as control and operating elements, and are able to gather and utilize the big data that is obtained from the physical world, transferred through the communication world, and processed in the information world to provide efficient services. The Internet of Things (IoT) comprises at key technology for upgrading current urban areas to smart cities. The IoT consists of distributed agents that enhance the reliability and improve the functionality of smart cities (Amini et al., 2019). This is an important point as now it leads to efforts to make a city smart for its current residents and attractive for talent to want to reside there since there is the promise of new jobs that attract professionals to a better life and living conditions, and this influx helps upgrade the status of the city as there is ongoing urban innovation.

A smart building is the building block for a smart city. To grow a smart city, smart buildings are the ideal starting point since a building is a microcosm of a city (Seiler, 2019). Khanolkar (2021) shares his view that a smart building, being the functional unit of a smart city, is the ideal starting point for the city's growth into a smart city and that: "Connected buildings are the easiest implementation of a digital upgrade and can have a positive impact on all the necessary fundamental elements based on which our societies are organized." (para. 1).

In the article *Can Smart Buildings Lead to Smart Cities?* Wired (2018) magazine says that buildings are critical to the collective and collaborative ecosystem of a smart city and the idea of smart buildings is the hard-wired intelligence in essentially every structure with wireless connectivity, and expanding that idea citywide has potentially world-shaping consequences. Smart technology is being implemented in office buildings, healthcare facilities, and other commercial and institutional buildings to make it more comfortable and engaging for people occupying these spaces such as the residents, staff, visitors, and support personnel.

Research by Apanaviciene et al. (2020), summarizes that: "both smart cities and smart buildings serve people inside the buildings and inside the city, providing them with more rational and personalized solutions, making their lives easier in terms of economic, environmental, social, and cultural aspects" (p. 4). Kanter and Litow (2009) talk about designing a city as an organic whole and infusing intelligence into each city subsystem. "By adding and integrating certified smart buildings, local officials and technology leaders can quickly form smart campuses, smart communities, and scale all the way to smart cities." (Seiler, 2019, para. 18). The multiple subsystems are connected by people who set up and coexist in vibrant residential communities. And for these communities to make connections to one another, technology is used to "enhance the human infrastructure just as it can enhance the physical infrastructure" (Kanter & Litow, 2009, p. 2).

So what does it mean to be smart? In a call for research by the US National Science Foundation (as cited in Alter, 2020, p. 4), the idea of smartness is defined as: "a system capable of learning, dynamic adaptation, and decision making based upon data received, transmitted, and/or processed to improve its response to a future situation. The system does so through self-detection, self-diagnosing, self-correcting, self-monitoring, self-organizing, self-replicating, or self-controlled functions. These capabilities are the result of the incorporation of technologies for sensing, actuation, coordination, communication, control, etc." Nuutinen et al. (2022) defined a smart building as having the following dimensions: "(A) its role as a part of the bigger adaptive, resilient system of a smart city. (B) its capability to provide joy, happiness and good experiences based on its responsiveness and adaptivity to the various occupants' individual needs and preferences. (C) its role as an always ready and always evolving service ecosystem, bringing different actors together to co-create and co-provide new services." (p. 3).

A smart lobby, building, community, or city would be distinguished by its application of integrated software, hardware, and network technologies along with its access to real-time data on smart devices, enabling decision-making that is based on the available visualization and reporting capabilities. It facilitates tracing and tracking and real-time monitoring, enabling users, for example, to design appropriate measures and follow recommendations to minimize personal interactions by leveraging social distancing and controlled space usage. A smart city is basically a collection of smart technologies.

This brings us to this research project. Our unit of study is an academic building that we want to change into a smart building. The project focuses on the lobby of a typical building used by an academic establishment. Tackling at the city scale is hard. But we believe that a set of smart buildings that are interconnected by technology will lead to smarter communities. Those smart communities are then interconnected to create a smart city. The scope of this dissertation is to focus on how to make a building and its lobby smart and offer a framework that developers can follow for a successful implementation.

Therefore, this project starts with a proof of concept to make a lobby smart, which in turn makes the building, the community, and, eventually, an interconnected set of buildings smart. We design a framework for smart lobby implementation and lay down the foundation for delivering next generation citizen services via mobile app to assist users. As a proof of concept, we demonstrate three services: restroom availability, conference room availability and reservations, and incident reporting in the building. These services can be accessed via smart devices.

## 1.2 Problem Statement

McKinsey's (2021) report, (as cited in Hollands, 2015), indicates that by the year 2025, the world's 600 largest cities will compete economically, and each will become a center of high economic growth and account for around 60% of its nation's gross domestic product (GDP). Given the fact that we are seeing urbanization growth at unprecedented rates, cities need to focus their attention on making their communities smart, starting by looking at community connectedness to meet the needs of the residents. There is a need to start with small implementation projects and grow based on learning from them, rather than jumping into efforts that have not proved to be successful and effective.

In recent years, we have seen cities around the world race to become a smart city. The technological advancement of Web 2.0 and the interconnectedness of devices, sensors, and real-time exchange of data have helped make this feasible. But to get to the level of making a city smart at massive scale has its own challenges. There have been lots of promises but the delivery has not seen the light of the day. Once promising endeavors in places such as Song-do in South Korea; Masdar in Abu Dhabi, United Arab Emirates; and CyberJaya, Malaysia are stagnant (Angelidou, 2017). Why is it that we see such huge investments end up in failure? One reason could be that there is "no single 'smart model' for cities" (Ching & Ferreira, 2015, p.163). Cosgrave et al. (2013) ask if there are a multitude of factors that are unknown—is the city so complex with many forces influencing it, or are the concepts not effectively actionable? Or, as per Komninos et al. (2013), is there a digital skills gap, a creativity gap, and/or an entrepreneurship gap? Are these failures due to these having been designed in autocratic countries? There is much speculation, but there are no definite answers as to the failures' cause.

Jacobs (2016) brings the complexity of the city to light and talks about how to understand and design cities. According to Jacobs, the most important part is to understand the process and work inductively—using reasoning that goes from the particular to the general—and to seek "unaverage" clues involving small quantities (resources), which reveal the way larger and "average" quantities are operating (p. 440). These could be resources that are added to something already existing, ". . . whether people, uses, structures, jobs, parks, streets or anything else . . ." (p. 442). These quantities could be economic or social.

In a similar vein, the approach used by Harrison and Donnelly (2011) is to consider a smart city as an organic "system of systems" that looks at products, services, companies, people, and society working together to foster innovation. They also are of the opinion that it should not be a top-down vision rather it should be organic and as such the approach should be bottom-up development which considers citizens who are the generators rather than passive recipients of ideas, services and solutions.

At the same time, the adoption of ICTs can enable cities to study pandemic patterns; prepare timely response to a virus such as COVID-19; curtail transmission of the virus; and have solutions to prevent the disruption of city services, supply chains, and other basic services (Sharifi et al., 2021). As per UN's *Policy Brief: COVID-19 in an Urban World* (2020), estimates are that 90% of COVID-19 cases are in urban areas and the cities have become the pandemic epicenter and the population size and "their high level of global and local interconnectivity make them particularly vulnerable to the spread of the virus" (p. 2).

There is a need to develop a more holistic understanding of what citizens and businesses need as well as to align to the strategy, coordinate with other entities affected by it, build a collaborative platform, and avoid implementing the strategy in silos. Hence, the better approach is to start small—start at the building (and its lobby) level and look at the problem inductively and work toward a general applicability. This will show us the way to larger approaches –city-level and then regional level smartness. For a bottom-up approach, we are able to ask stakeholders what functionalities are important to them and build those functionalities that will improve and enhance their experience thus making them desirous to continue using them.

## 1.3 Objectives and Research Questions

The objectives of the current research are to:

1) Design a framework for a smart lobby:

   This framework will be applicable in an academic setting while considering the various stakeholders and technological aspects. We need a framework for the implementation that is general and applicable while keeping the stakeholders in mind. Since this project is focused on academic building lobby, the stakeholders affected in such a building would be visitors and staff/faculty members. The framework artifact will guide the developers to transform a space into a smart space, taking into consideration the stakeholders affected and the technological factors as well. The practical relevance of the framework as an artifact is also related to supporting the knowledge as well as decision making needs of the designer and implementor of a smart lobby in an academic setting.

2) Provide smart services delivered through the mobile app:

   The problem we are considering is how to change existing lobbies that are typically passive and uninteresting into an exciting, and vibrant ambient environment. What services or applications can provide value and utility in a smart building? How can we design office space in keeping with the next generation's expectations and desires, and use technology to attract and retain talent? How do we make the smart lobby interactive and remove dependency on having a person available 24/7 for the services we need? As per Becker and Steele's (1995) publication *Workplace by Design*, the success of a business organization is directly tied to its physical workplace—so how can we as designers and technologists help businesses succeed and make workplaces more attractive for staff, visitors, and other stakeholders? How can we use technology to facilitate tracking, and use real-time monitoring to be able to design appropriate measures to minimize interactions through social distancing and controlled space usage during a pandemic?

This app can be accessed via a smart mobile device to guide users without needing assistance from another person. These services could also be made available on large screens displayed in the lobby area.

This dissertation study seeks to answer the following research questions:

**Research Question 1:** How can we design a framework for a smart lobby in an academic building that can engage the visitors and occupants?

**Research Question 2:** How can we limit occupancy in a restroom and make it COVID-19 safe?

**Research Question 3:** How can the conference room/public space availability be shared with users to check availability and make reservations?

How can information on occupancy levels of available conference room/public space be made available in real time to building management to ensure space usage compliance?

**Research Question 4:** How can building inhabitants report or notify incidents with respect to safety and other hazards?

The remainder of this dissertation is organized as follows: Chapter 2 covers the background and literature review and theory. The first subsection covers current studies in peer-reviewed journals and the second subsection looks at the theoretical grounding that informed the study.  In Chapter 3, the research approach (Design Science Research) for the framework and smart services artifacts is discussed including how it guided the development of the artifacts. The framework design and build is explained in Chapter 4, and the evaluation and results and discussions are presented in Chapter 5.  Chapter 6 discusses the design and build of the smart services' artifacts, and Chapter 7 discusses the evaluation and results and discussions of these artifacts.  Chapter 8 concludes the study with discussions about the potential limitation and challenges of this study, and the expected research contribution, as well as future research ideas that can be worked on.

# Chapter 2. Background, Literature Review, and Theory

## 2.1 Background and Literature Review

Wired city, digital city, virtual city, information city, knowledge city, learning city, green city, smart city, smart sustainable city—the terms go on and on. Many literature reviews can be found on the different types of smart cities (Ching & Ferreira, 2015; Anthopoulos, 2015; Cocchia, 2014). Likewise, there is literature that is focused on green building certification such as Leadership in Energy and Environmental Design (LEED) (Heidari et al., 2016 ) and the mission to reduce energy consumption; and there is literature that focuses on ENERGY STAR [per https://www.energystar.gov/] compliance; smart security and monitoring; facilities management; materials and construction; energy conservation and sustainability; and water and wastewater engineering using green design. Green design focuses on a smart or intelligent building (Ghaffarianhoseini et al., 2017; Buckman et al., 2014).

A thorough literature search did not include any research that specifically addresses the concept of a smart academic lobby. The basic idea of a smart lobby is to use information technology to provide better services and allow for a differentiated customer experience, using a citizen-centric the design approach.

Based on focus group survey results (see Table 2, see Section 3.2), three functionalities scored high and were shortlisted to be designed for the smart app. These can be accessed via an app on a smart device and a screen in the lobby. Here, I present the literature review for these services that will be available on the app.

- Restroom Availability: Centers for Diseases Control and Prevention (CDC) estimates that annually the influenza virus infections resulted in 9 to 41 million illnesses, 140,000 to 710,000 hospitalizations and 12,000 to 52,000 deaths in the US between the years of 2010 and 2020 (Centers for Disease Control and Prevention (n.d.). While a 2017 global study conducted by CDC and global health partners published in Lancet estimates that annually between 291,000 and 646,000 deaths are due to influenza related illnesses (Iuliano, 2018).

Influenza (flu) is a contagious respiratory illness caused by flu viruses that infects the respiratory system when people are in close contact in a given space. It is spread via droplets containing flu viruses traveling through the air when a sick person coughs or sneezes. A flu pandemic occurs when a new flu virus that is different from seasonal flu viruses emerges and spreads quickly between people, causing illness worldwide (Centers for Disease Control and Prevention, 2017). Given the high numbers of people affected, and since the influenza virus spreads via close contact, it would be prudent to maintain distances in a given space to minimize passing on the germs to others.

A 2006 Nature article published a simulation result and found that if 90% of the cases are isolated, then the infectiousness is reduced from 34% to 27% (Ferguson et al., 2006). Qualls et al. (2017), have shared a CDC recommendation that during times of pandemic, as part of nonpharmaceutical intervention, stopping mass gatherings and practicing social distancing help in reducing the spread of the pandemic virus. For the critical services performed by essential workers, such as hospital and grocery staff, it is not possible to implement home isolation as part of social distancing for a long period of time, and so there has been a surge of interest in the use of digital tools for pandemic containment and preventative measures.

The Occupational Safety and Health Administration (OSHA), in its 2020 article "Guidance on Returning to Work," recommends using the general guideline of maintaining a six-feet distance between all people. According to Senthil et al. (2021), the IoT "has the potential to deal with huge amount [*sic*] of data received from sensors used by [*sic*] number of applications to fight against COVID-19". Hence, being able to monitor common-space usage using sensors and smart devices would help minimize the effect of the pandemic and allow people to follow guidelines and take precautions as suggested by health officials.

- Conference Room Availability: Knowing the number of people in a given area could prove useful during pandemics such as Covid-19. Having a real-time head count can assist with enforcing occupancy limits, allocating resources for events, performing crowd control, or conducting civilian surveillance in case of emergency (Yang et al., 2003). Performing manual head counts is difficult so using sensors to automate the count would eliminate the need for that and make it convenient.

The design firm CallisonTRKL, based in the US, published a technical paper titled "Technology Is the Ultimate Enabler" which states that workplaces should be designed by keeping the future workforce in mind. The newer generation is tech savvy and wants to utilize the conveniences offered by technology to connect and collaborate. The newer generation will be what the firm calls the "1099 generation," composed of workers who will be freelancers, and they will prefer workplaces that allow for collaboration using technology and consequently provide them much more flexibility to collaborate and communicate. Hence, tools such as an app for finding available meeting rooms would be an attractive feature for these workers.

Akkaya et al. (2015), state that technology could also assist with building management systems to reduce energy consumption and take steps to adjust for carbon neutrality. They look at the "variation of occupancy problem" as well as various network and IoT devices along with the classification of approaches into three tiers - Tier-1 relies only on existing Wi-Fi, Tier-2 requires new software on client devices and Tier-3 requires new hardware/software deployment. These tiers allow to assess cost and intrusiveness of the approach. They define and classify occupancy monitoring as Occupancy Detection—answering the question of space occupancy with a binary yes or no; Occupancy Counting—counting people in a zone or building at any given time; Occupancy Tracking—detecting, locating, counting, and tracking occupants; and Occupancy Event/Behavior Recognition—detecting user activity for heating, ventilation, and air conditioning (HVAC) control and looking at sensor- or camera-based monitoring techniques.

- Incident Reporting: Volunteered geographic information (VGI), provided by citizens armed with smart devices and apps, could be a good source of information as per Roche et al. (2012). Outsourcing tasks to residents allows for the completion of tasks much more quickly due to the collaborative nature of VGI (Hancke et al., 2013).

Goodchild (2007) gives examples of the benefit of citizen science for the Project GLOBE, Christmas Bird Count, Wikimapia, and other efforts that have benefited from VGI and "contribute to the growing reversal of the traditional top-down approach to the creation and dissemination of geographic information." The City of Boston's award-winning app BOS:311, formerly known as Citizens Connect [see https://www.boston.gov/civicengagement/bos311-app], enables Bostonians to alert city authorities to issues such as potholes and graffiti, and thus become the eyes and ears of the city (Ballantine, 2013).

With crowdsourcing, messages can be directed to the right department so that appropriate action can be taken. This allows for smarter policing as well (Kanter & Litow, 2009). Also, as per Dustdar et al. (2017), this would manifest the "Cyber-Human Smart City" vision, as employers are expected to employ fewer permanent staff members and instead draw workers from the general population and hire contract workers to make their businesses scalable and dynamic. This is a game changer as firms use technology and the reporting capabilities of mobile devices plus crowdsourced information from the general population to report safety incidents. It takes away the need to hire personnel to walk the grounds or monitor spaces when these collaborative tasks can be performed by the general population.

It is worth noting that VGI efforts are driven by the altruistic nature of humans and depend on people to volunteer their own effort to benefit their community. People are motivated to act voluntarily by the feel-good reward of doing something positive and giving back to the community, as per Stern et al.'s (1999) Value-Belief-Norm aspect of altruism. Since the geographic context is captured, it would be difficult to falsify VGI that is based on the local knowledge and observation. Since there is the possibility of multiple users contributing the same incidents, the reliability of the information grows, recognizing "consensus as the most authoritative account" (as cited in Elwood et al., 2012, p. 584).

## 2.2 Theoretical Grounding

The current study is based on the theories of Task Technology Fit (TTF) and Value-Belief-Norm (VBN) as well as the Knowledge Innovation Matrix (KIM) to categorize the innovative nature of the research in this paper.

**Task Technology Fit—**Goodhue (1995) defines task technology fit (TTF) as "the extent that technology functionality matches task requirements and individual abilities" (p. 1829). Goodhue connects TTF to the cognitive cost-benefit framework, which looks at the impact on an individual's decision-making ability when confronted with different information representations. Goodhue posits that TFF and the cognitive cost-benefit framework have the same proposition, namely that "a) an individual's performance is affected by how well technology options 'fit' his or her task requirements, b) fit operates through its impact on task processes, and c) individuals can evaluate fit and choose technologies on that basis" (p. 1830). He also connects TTF (Fig. 1) to the Organizational Structural Contingency theory and finds similarities between them; while one is at an organizational level and the other at an individual level, the "information technology must 'fit' the task characteristics" (p. 1831).

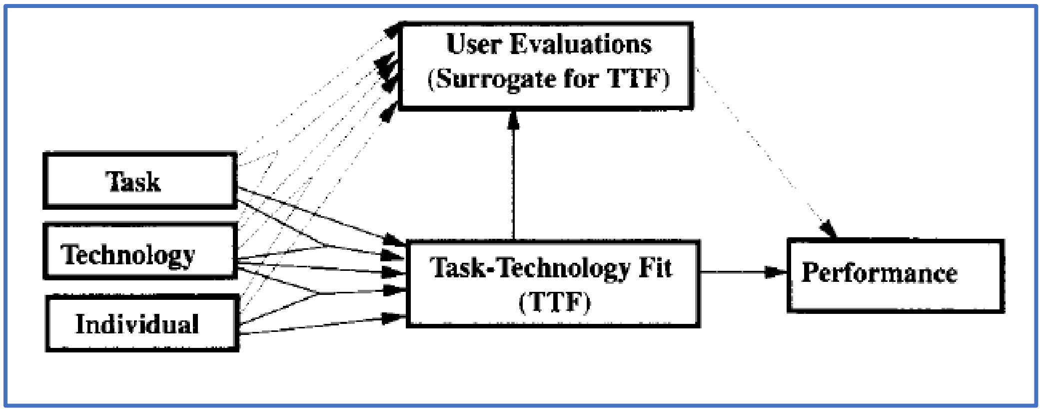



FIGURE 1: TASK TECHNOLOGY FIT MODEL

SOURCE: GOODHUE (1995)

For this research, users will use the app to do a task—namely, to find an available restroom, or a meeting room and reserve it for their upcoming meeting, or to report an incident—and, based on their experience, evaluate the fit of the proposed solution to accomplish the task. They will test the technology based on the system characteristics and their own abilities, and evaluate whether the system meets their task needs. Based on their performance rating, we can get a better understanding of the challenges or acceptance of the app.

**Value-Belief-Norm Theory—**Stern et al. (1999), in their value-belief-norm (VBN) theory (Fig. 2), posit that "norm-based actions flow from three factors: acceptance of particular personal values, beliefs that things important to those values are under threat, and beliefs that actions initiated by the individual can help alleviate the threat and restore the values" (p. 83).

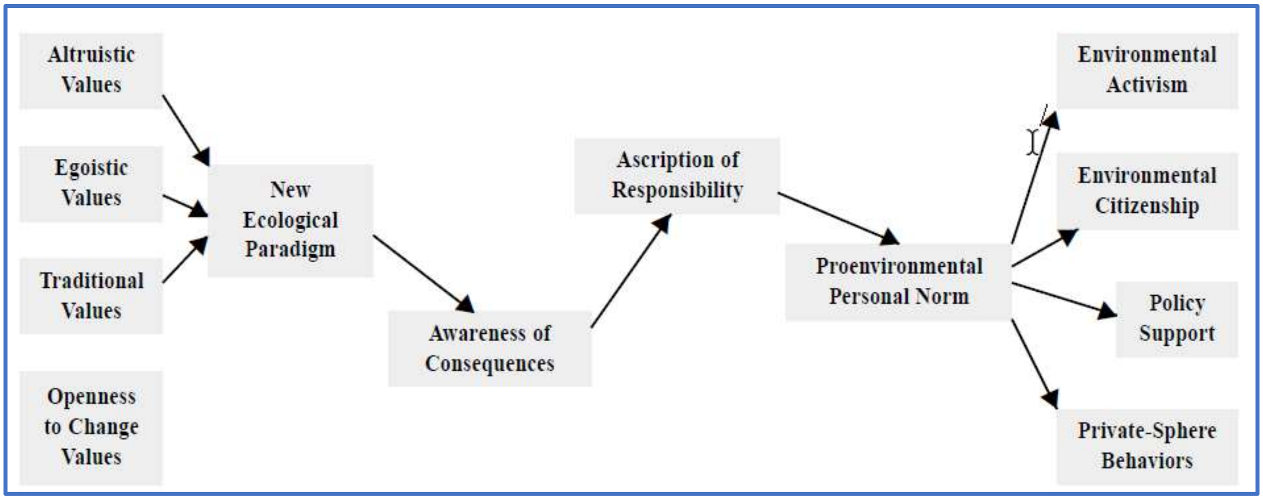



FIGURE 2: VALUE-BELIEF-NORM MODEL

SOURCE: STERN ET AL. (1999)

One aspect of my research involves volunteered geographic information, which encourages users to voluntarily report issues they see in their environment on campus. They can use the app to notify the appropriate authorities so that they can take action. In such volunteer scenarios, consumer behavior/concern about the environment can lead to positive change. The VGI reporters feel involved and seek the collective good based on their personal values and norms and understand the consequences and responsibilities that come with it.

**The Knowledge Innovation Matrix—**The Innovation Matrix (KIM) (Gregor & Hevner, 2014) has been used to categorize the innovative nature of this research to understand how new knowledge can be applied to achieve our goals. KIM (Fig. 3) has four quadrants: Invention, Improvement, Exaptation, and Routine Design. KIM's x-axis indicates the solution/artifact/theory that can contribute to knowledge, and its y-axis indicates the need/opportunity/problem that can be solved by the artifact designed. Chatterjee (2015, p. 10), in his Recipe # 1, states that design principles can also be a contribution to the knowledge base.

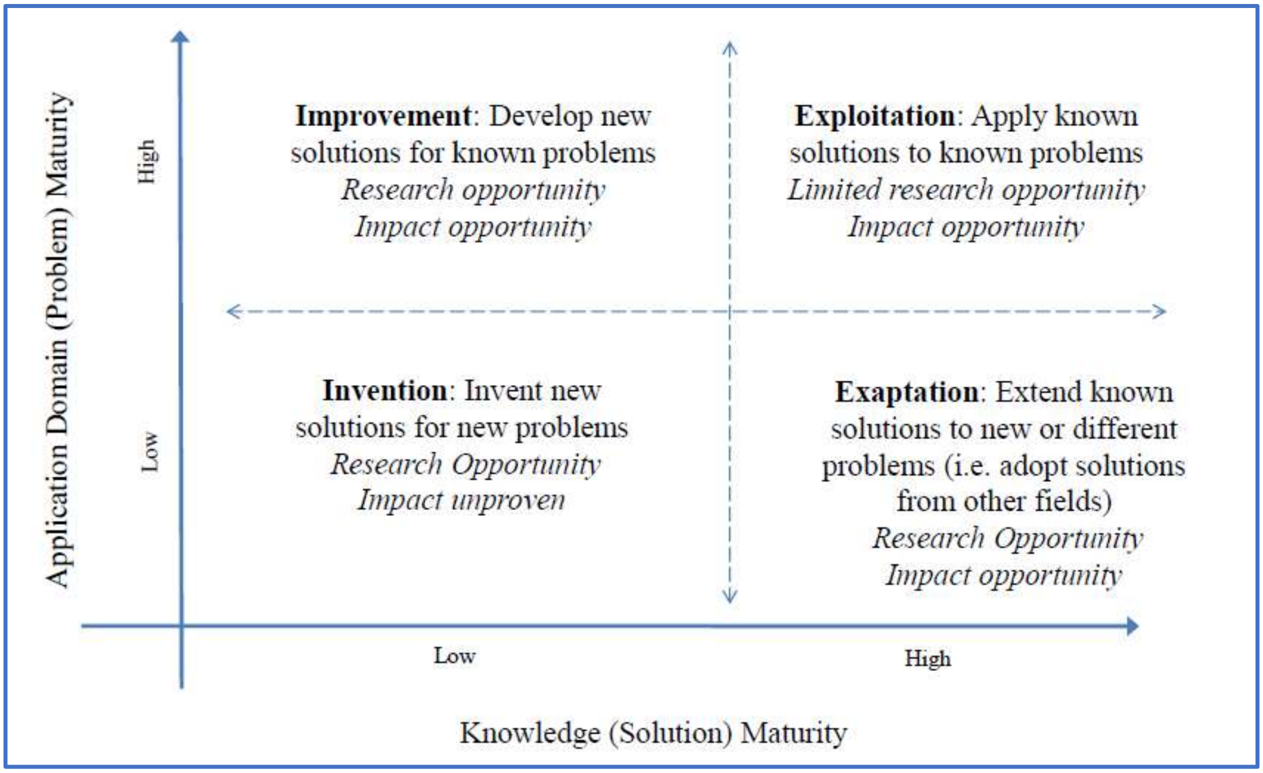



**FIGURE 3: KNOWLEDGE INNOVATION MATRIX**

SOURCE: GREGOR AND HEVNER (2014).

Since there is a lack of known research on a smart lobby, the proposed framework would be part of the Exaptation quadrant since there has not been a framework established to ensure successful deployment for a smart lobby. Additionally, this paper will be leveraging sensors and IoT technology for an innovative design and incorporating it in existing space for an application that has a real-world impact. This is an opportunity to have an impact on taking an existing passive and uninteresting lobby and turning it into a vibrant and ambient environment.

# Chapter 3. Research Approach

Many smart city initiatives have failed. Research has shown that current implementations have not been successfully adopted by the stakeholders. An alternate approach proposed by this research is to start small by implementing smart city concepts at a building level by designing applications and services that would engage stakeholders. This important and as yet unsolved problem can be studied using the design science research (DSR) approach. DSR is a "problem-solving paradigm whose end goal is to produce an artifact which must be built and then evaluated." (Hevner & Chatterjee 2010, p. 5). DSR focuses on developing and evaluating artifacts that solve real-world problems in an iterative fashion, thus the artifact can be made more efficient to solve the problem at hand. The artifact relies on kernel theories that are "applied, tested, modified and extended" (Hevner et al., 2004, p. 1). The output artifact can be a contribution to the IS knowledge base.

## 3.1 Design Science Research

For this research, the DSR (Fig. 4) approach of Hevner and Chatterjee (2010), has been used. This approach is iterative and has three cycles:

**Relevance Cycle:** Environment is a key factor when we design. This cycle shows us the relevance of the research as we look at the people, organizations, and technology that necessitate the need for the research project. There is a problem and an opportunity to find a solution for the problem.

**Rigor Cycle:** The existing knowledge base of foundations, such as theories, frameworks, instruments, constructs, models, methods, and instantiations, as well as methodologies such as data analysis, formalisms, measures, validation criteria, and experience and expertise, are applied to design the process/product in this cycle.

**Design and Evaluate Cycle:** This cycle allows us to build our theories/artifacts and justify and evaluate them using analytics, case studies, experiments, field studies, or simulations. Each evaluation allows us to refine our artifacts.

The final output of the research allows us to add to the knowledge base and apply the design for the benefit of the environment.

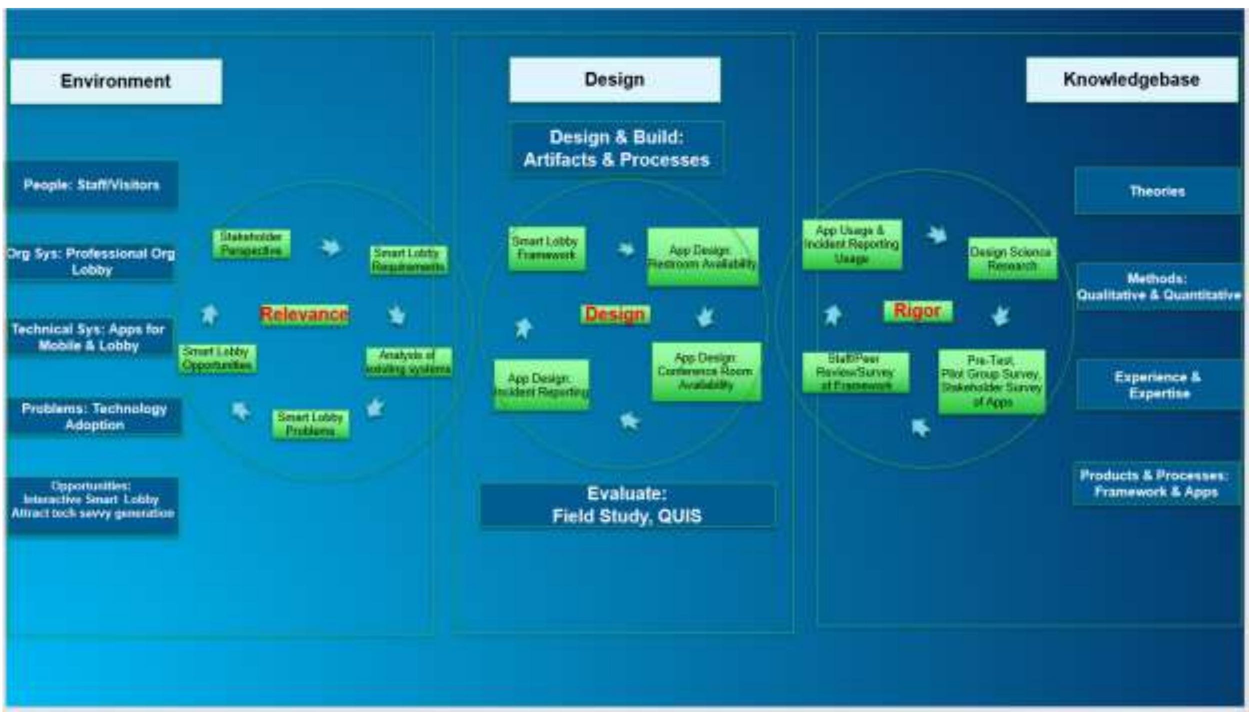



FIGURE 4: DESIGN SCIENCE PRINCIPLES FOR DESIGNING A SMART LOBBY APPLICATION

## 3.2 Research Design

To choose which services can be built in the smart lobby, we utilized a focus group. We describe the service selection process below.

### *Focus Group*

This section describes the steps that were taken to engage members of the community and capture their insights into the process of identifying and assessing the most relevant smart services to be developed. The focus group approach allowed to ask the participants questions and have group discussions. It allowed for interactions amongst members which resulted in healthy discussion on the topic.

During this phase, we explored the domains relevant to the functional purpose of a building lobby (occupancy, entertainment, utility, access, and safety). Then, multiple brainstorming and discussion sessions (service ideation) were conducted between the researchers and colleagues working at the Center for Information Systems & Technology (CISAT) and IDEA Lab at Claremont Graduate University (CGU). During the discussion sessions, we reviewed potential new smart ideas to be deployed. The ideation sessions resulted in identifying a preliminary list of 47 ideas. 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 (Appendix A). 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 helped to assess the proposed smart services and also brought attention to other potential ideas that were not initially included in the list. Some ideas were dropped either due to cost/financial constraints or 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. In this dissertation, we design and build three services: ***restroom availability, conference room availability and occupancy*** and ***incident reporting***. The other three services were developed separately for another project.

Apart from the three services that are addressed in this research, a framework artifact was designed to help guide the developers to transform a space into a smart space, taking into consideration the stakeholders affected and the technological factors. The objective in creating a framework as an artifact in the form of a design tool is to assist the planners of a smart lobby in making decisions about different aspects that are involved in the design and development of a smart lobby initiative to achieve a set of objectives and the desired outcomes. The practical relevance of the framework as an artifact is also related to supporting the knowledge as well as decision making needs of the designer and implementor of a smart lobby in an academic setting. The final design was iteratively developed and included existing research, brainstorming, and personal knowledge and practical experience. To evaluate this artifact, a qualitative survey

(Appendix B) was designed to determine whether the proposed framework encompassed all the necessary elements affecting stakeholders and technological factors.

The smart services artifact/app allows people to use their mobile devices to access functionalities that assist with finding restrooms, an available meeting room and reserve it, and report incidents on campus that need attention. To evaluate this artifact, a qualitative survey was designed for before (pre-test) and after (post-test) the users' experience with and without the smart services (Appendix C). The participants were also given a user interaction satisfaction (QUIS) questionnaire to gauge their overall reaction to each app, the screen display, the terminology and system information, the ease or difficulty of learning to use the app, and the app's capabilities (Appendix D). Another survey was administered to get the participants' feedback on the overall outcome of the project (Appendix E). The surveys were developed using Esri's ArcGIS Survey123 software and were made available online for the participants to respond remotely at their convenience.

# Chapter 4. Design and Build: Framework

Since there is no existing framework for implementing a smart lobby and it is a new concept, it was important to start by understanding the different factors that affect the design of a smart academic lobby. Thus, a framework was designed to understand the relationship between key elements that would guide the developer to set up a smart lobby. An overall framework related to stakeholders and technology was the first step. This framework could be applied to any organizational lobby that was a candidate to turn into a smart organizational lobby. The second step was to dive deeper into the elements individually to understand the various factors that are relevant for an academic setting since the focus of this project is an academic smart lobby.

The framework was evaluated by two participants. One participant is currently the Assistant Vice President of Finance and Administration as well as Technology Services and Information Systems at Claremont Graduate University (CGU), and the other is an enterprise architect currently working at Esri. Both have many years of experience. They were asked to complete an online qualitative survey to provide feedback any additional suggestions/recommendations they may have had.

## Overall Framework: Stakeholder and Technology

Stakeholders and technology are the major entities that affect the design for a smart lobby. According to Hollands (2015), one of the key reasons for failure of current smart city initiatives is that these initiatives predominantly are based in corporations, government agencies, or technology companies so they fail to take the citizen needs into consideration. Those designs are top-down so there is no real citizen involvement or participation by people who live and work where these initiatives have been set up. This is detrimental to the success of any initiative.

In order to earn acceptance, adoption, and continual usage of smart city artifacts, the needs of the community must be considered when designing them for use. The goal is to provide "qualitative and innovative services" to the users (Stratigea et al., 2015, p. 50). This is a critical factor for the success of an initiative, and hence the people/stakeholders are at the heart of this design for a smart lobby. Starting with a lobby and taking smartness from a bottom-up perspective, stakeholders' inputs are necessary for a successful smart city implementation.

The other element that plays a big part in a smart lobby is the technology aspect that has brought about a digital revolution that is evolving at an exponential speed and is disrupting all industries globally. With emerging technological breakthroughs in IoT, artificial intelligence (AI), 3D printing, biotech, quantum computing, and Web 2.0 technologies, the possibilities are unlimited as these products and services help enhance efficiency and contribute to our personal life satisfaction due to the advancement afforded by the technological innovation.

Schwab (2016) writes that we are in the fourth industrial revolution. This is a digital revolution and is characterized by "blurring the lines between the physical, digital, and biological spheres." (para. 2) As per Schwab (2016), there are immense possibilities as billions of people are connected via smart, high-powered, and high-storage mobile devices. Due to the technological advancement and the interconnectedness of devices, sensors, and real-time exchange of data; and access to smart devices, Wi-Fi, and phone service; we see that technology has played a key role in making smart initiatives possible.

Consequently, we posit that people/stakeholders and technology are the major entities that affect the design for a smart lobby. We start by looking at the overall picture for a Stakeholder & Technology Framework for a smart organizational lobby space (Fig. 5) and then dive further into each entity to understand its impact on the design for a smart academic lobby (Fig. 6 and Fig. 7).

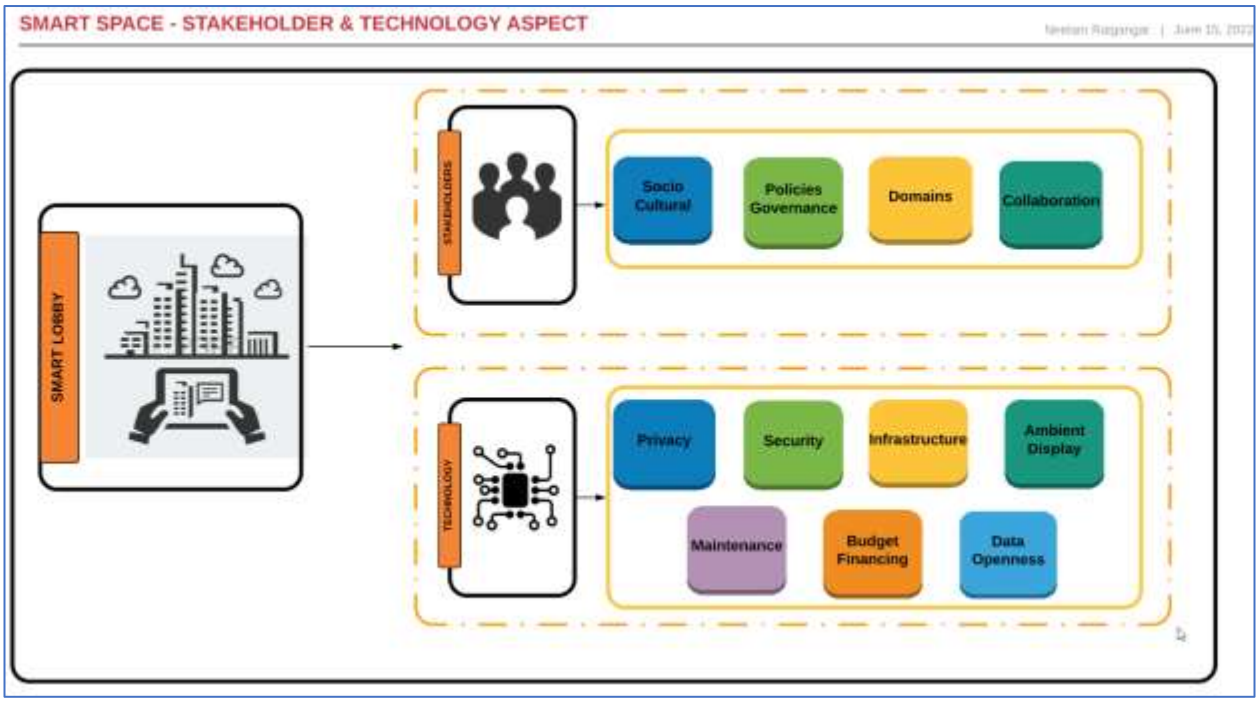



**FIGURE 5: STAKEHOLDER AND TECHNOLOGY FRAMEWORK OVERVIEW**

## Framework: Stakeholder

The goal of a smart lobby design is to benefit people. Figure 6 shows the people/stakeholder component and the various aspects that influence the design of a smart lobby. This framework can be applied to any academic building lobby.

**Sociocultural aspect:** Social and cultural aspects play a big part when designing for a smart lobby. Different approaches are required for designing for an individualist society—in which people look out for only themselves or their immediate family, versus a collective society—in which the emphasis is on benefits for the entire society. As per Kimura and Nakajima (2011), "In order to develop effective persuasive applications, it is important to choose appropriate incentives and to provide users with the incentives in the proper manner as well as to design right user interfaces" (p. 9). From a sociocultural aspect, the following are of considerable importance: anonymization to keep data private, technology acceptance so that there is adoption, and app design to appropriately meet the needs of society.

**Policies/Governance:** When designing it is necessary to consider policy or governance requirements. For example, if we are designing for a hospital, it is necessary to consider patient privacy laws; for another type of organization, it is necessary to consider its internal policies. The Americans with Disabilities Act (ADA), the Health Insurance Portability and Accountability Act (HIPAA), internal organizational policies, standards set by the industry, applicable governance rules, and the trust factor are of great importance.

**Domains:** Different domains have different needs. Since our focus is on a smart lobby for an academic building, our stakeholders are faculty, students, and staff. We would consider what information is relevant to them, and build and design the app/solution to meet their needs based on the feedback we get from them. For instance, they may need to find an available restroom, or look for an available conference room to reserve, or report an incident.

**Collaboration:** For any project to be successful there needs to be collaboration among the various departments responsible for the usage, design, and upkeep of the project. This would allow for "user-driven and user-centric" (Stratigea et al., 2015) design.

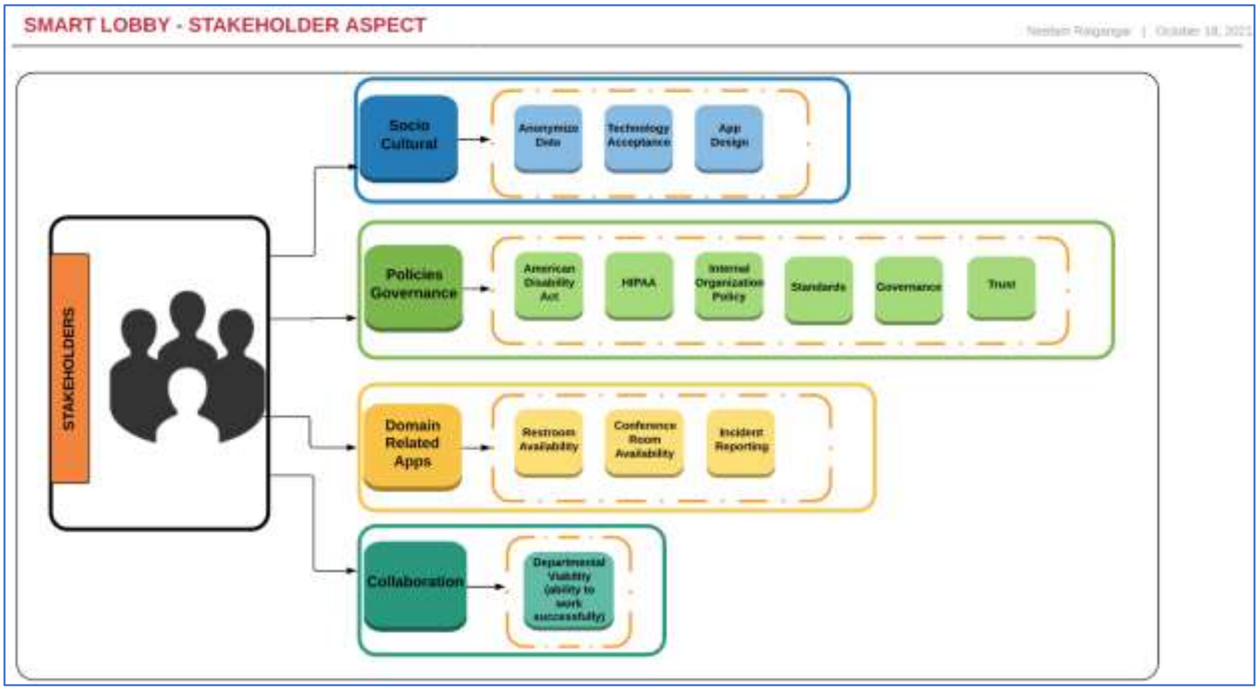



**FIGURE 6: STAKEHOLDER FRAMEWORK**

## Framework: Technology

Next, we look at the Technology aspect (Fig. 7) and consider the various elements that influence the design of a smart lobby. This framework can be applied to any academic lobby.

**Privacy:** Maintaining data privacy is critical. As sensors collect data that is processed and disseminated for user or management consumption, it is vital to ensure that information is kept secure. Logins and two-factor authentication are required. Request for access should be evaluated and permissions should be granted based on the need to know and limited to the level of detail needed to derive knowledge from the data.

**Security:** Set up firewalls and ensure the upkeep of patches and antivirus software. Protected server rooms and device locks are imperative. Access to restricted areas should be granted to personnel with security clearance. Ensuring data availability, maintaining confidentiality, and upholding data reliability and integrity are critical to the security of both the data and the premises.

**Infrastructure:** The design of the architecture to support current needs must be combined with provisions in anticipation of future growth. Ensuring the smart lobby's technology integration with the ecosystem and the space availability for installation, and integrations of systems and applications is important because the IoT and Web 2.0 are pervasive. Sensors, smart devices, apps, software, hardware, servers, and network protocols are key pieces for infrastructure.

**Ambient Display:** Visualization tools are designed for ease of consumption of the user. Evans suggests we should create designs in such a manner that they are "utilizable and understandable by the communities that it is supposed to serve" (Evans, 2002, as cited in Hollands, 2008, p. 310).

**Maintenance:** There needs to be trained and qualified personnel for the maintenance and upkeep of the technology and data to ensure that enhancements and updates to the system are made in a timely manner. This is vital to the smooth running of the systems.

**Budget/Financing:** There are costs associated with hiring and training staff as well as operation and maintenance of the IT systems. Planning for financing to implement, grow, and maintain the system to incorporate future enhancements is key to growth of the organization. Financing is also important for ensuring the longevity of the IT systems to sustain business continuity and growth.

**Data Openness:** Accessibility, quality, availability, and trustworthiness of the data are necessary to stay informed and make educated decisions. Based on organizational policy, data transparency and accountability would be necessary to build trust and utilize the knowledge garnered for the benefit of society.

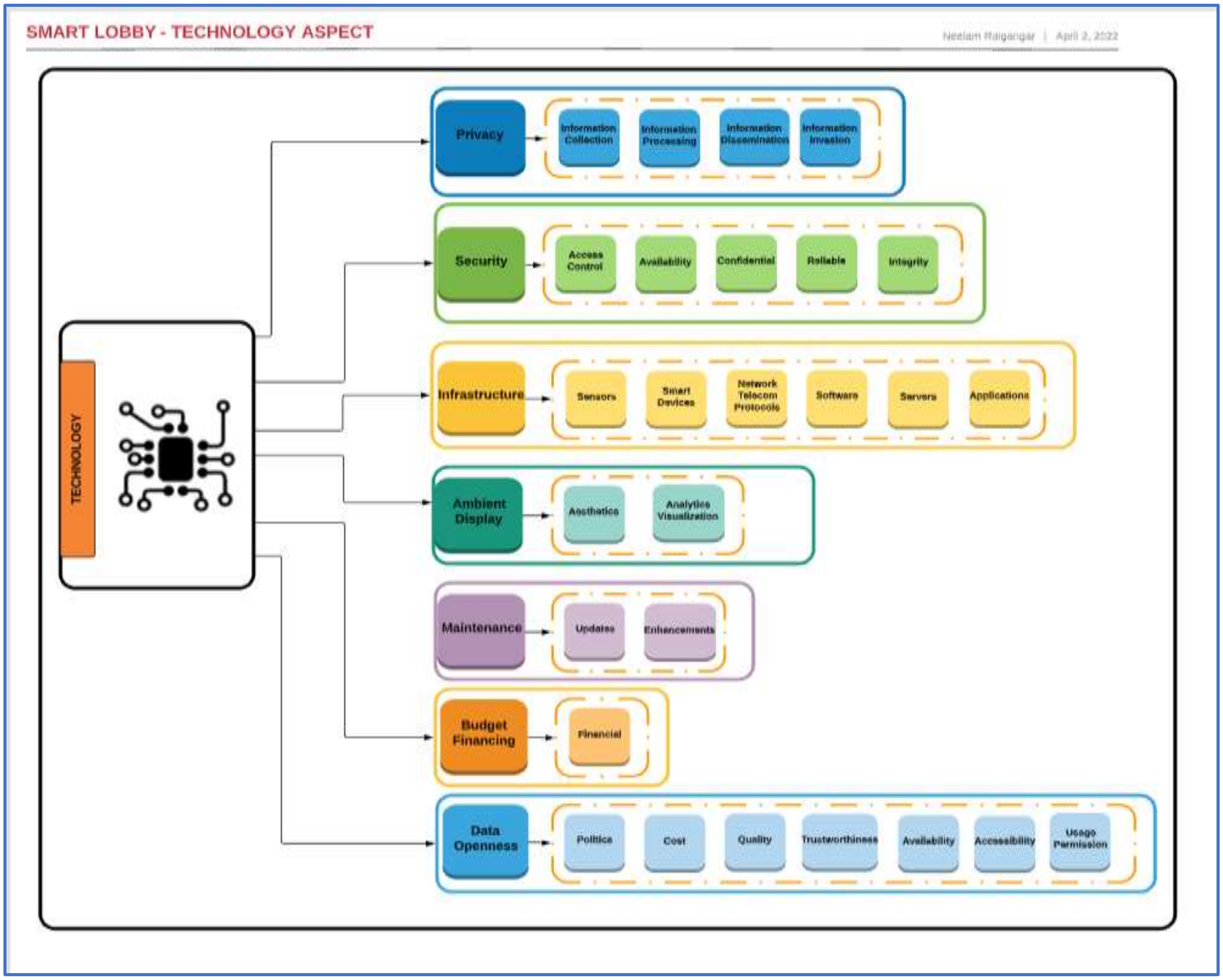



FIGURE 7: TECHNOLOGY FRAMEWORK

## Research Architecture

Figure 8 shows the overall architectural elements. The architecture design accounts for the users and the technology layers. It also considers the multiple considerations that impact the users/stakeholders.

With the app design being citizen-centric, the focus is on the users who will be consuming the products and services. Data is collected via apps and sensors and the information is stored on the servers, which can be hosted on-premises, in the cloud, or in a hybrid environment. The data integration layer allows users to process data from multiple sources such as proprietary databases, enterprise resource planning (ERP) or customer relationship management (CRM) systems. The information can be extracted, transformed, and loaded into the servers. Using various application protocols that allow for communication with other applications on the network, the data can be displayed on the data presentation layer via smartphones, monitors, laptops, desktops, etc. The visualization tools are necessary to make sense of the data and present it in a consumable format without overloading the users with irrelevant information.

The architecture design/layout (Fig. 8) must consider other features such as accessibility; compliance with regulations such as the Americans with Disabilities Act (ADA) or Health Insurance Portability and Accountability Act (HIPAA) especially during a pandemic where the organization has an obligation to notify the community of infected cases without identifying the individual by any personally identifiable information (PII); and the privacy, security, and viability of the application.

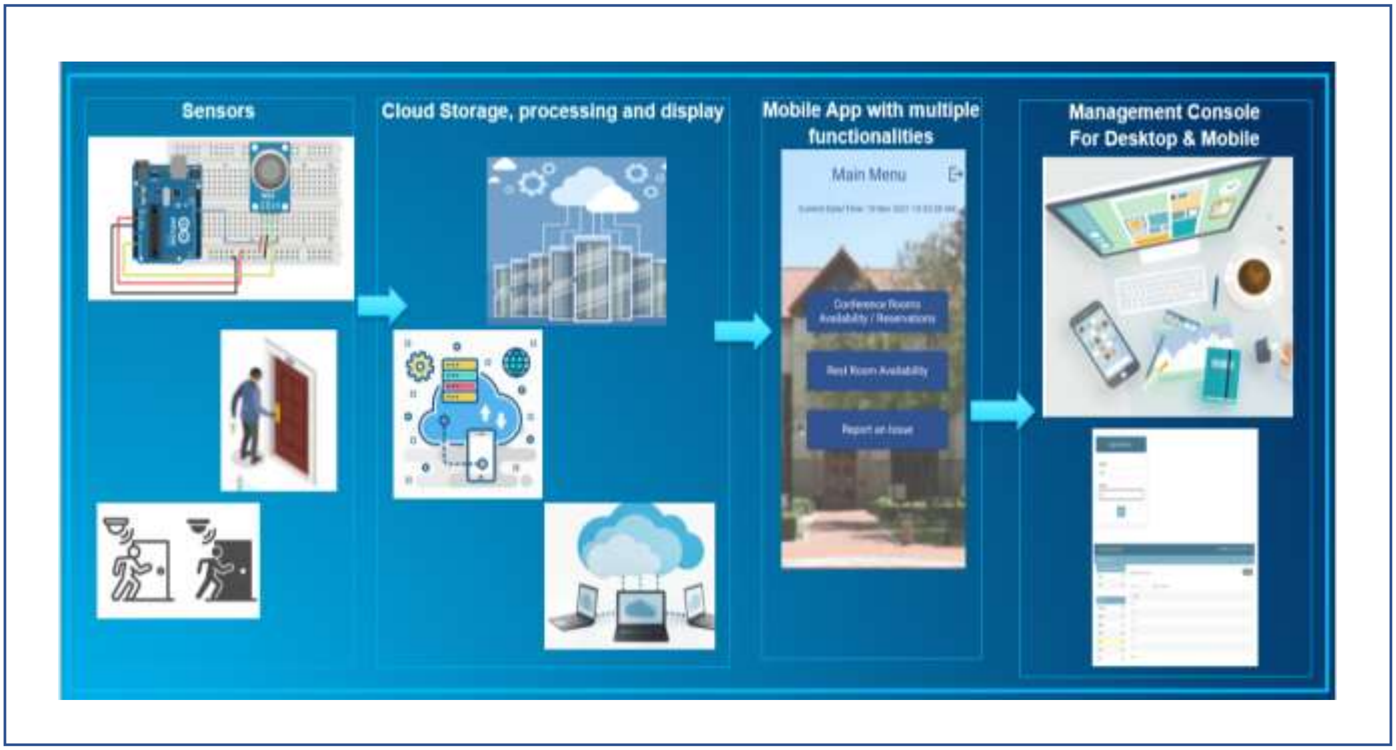



**FIGURE 8: ARCHITECTURE LAYOUT**

# Chapter 5. Framework Evaluation

## *Results*

As explained in Chapter 3, two experts in the field of technology evaluated the Framework. They are both males in the age group of 40-50 years. They were contacted via email followed by a Zoom call to explain the project and share the designed frameworks. They provided feedback on the appropriateness of both the technology and stakeholders frameworks and suggested revisions via a qualitative questionnaire (Appendix B).

The first survey question was on the appropriateness of the framework. Both participant's feedback was that the frameworks were well thought out and appropriate for a smart lobby. One participant mentioned that considering the stakeholder and technology perspectives were the two key relevant design aspects for the project and this framework would be relevant to design/build for any organization. The other participant thought that the framework had more of a technical tilt and focused on feasibility rather than desirability. They found that the domain dimension focused on specific targeted applications versus being open-ended, and that the sociocultural dimension focused on data management and technical adoption.

With regards to the second survey question that asked for their recommendations on changes needed for the framework, one participant suggested to add a dimension of persona development via an assessment of individual needs and the value proposition. The other participant suggested considering adding lessons learnt from the pandemic with respect to smart lobby design. They also asked to consider the purpose the building was designed for to create a differentiated customer experience and suggested to consider including the element of making the lobby environmentally friendly by considering features such as energy conservation, etc. Aesthetics considerations were also mentioned as relevant for a smart lobby. Additionally, having an element for integrative analytics where real time analytics and feedback is possible so that changing needs can be met such as minimizing physical contact, should be part of the framework.

Responding to the last question requesting other comments and suggestions, one participant suggested to do empathy mapping up front for key interaction points. The other participant commented that at a city level, there would be different identifier requirements for stakeholder and technology aspects given the scale and complexity at the city level.

### *Discussion*

Based on the feedback, in some instances, changes were made to the framework and in other instances I explain how it had already been accounted for in the original framework design.

The two main design aspects were already identified namely technology and stakeholders as the key to the design/build of a smart lobby. For both these aspects, most of the elements were already considered in the framework design. There were minor alterations suggested for the frameworks that were later incorporated in the design. Explanations of some of the elements were also fleshed out more to remove any ambiguity and be clear as to the meaning of that element and what it entailed.

For question one, the feedback was to consider desirability for the app, and it was noted that the domains identified were very specific. This project is focused on designing a lobby for an academic building. The stakeholders identified were staff, faculty and students of a university campus. Prior to beginning the project, a pre-focus group survey (Appendix A) had been conducted to solicit feedback from students as well as from a faculty member. Hence the desirability of the app was already considered when the pre-focus group surveys were done. The two framework survey participants were not aware that this had already been done as part of the analysis of the desirability of the app functionalities and hence there was a comment regarding considering not only the feasibility but also the desirability aspect. Since the project is for an academic building, the applications were specific and targeted to meet the needs of the stakeholders based on the feedback provided in the pre-focus survey that was done earlier. As for the sociocultural aspect being focused on anonymizing data and technical acceptance, I think it is relevant since anonymizing data with the student/staff /faculty population is necessary considering the Health Insurance Portability and Accountability Act (HIPAA), Americans with Disabilities Act (ADA), personally Identifiable Information (PII), etc. Since this project does require use of technology there is a need for technology acceptance in the socio/cultural context relevant to the given target population.

Survey question two solicited feedback about any changes that were needed. One suggestion was to do a persona development for the group that the app has been designed for. Since this project is focused on the academic setting and the main personas are the student and faculty, the pre-focus group that was surveyed allowed for a persona value proposition. The students and faculty members who participated in the pre-focus group survey assigned scores to each service for the app which helped to identify and prioritize the app functionalities that were desirable (based on the highest scores). Another suggestion was to document lessons learned from the pandemic.  This is covered by the policies and governance aspects as set out by the university which in turn is based on guidelines and directives given to them by the health and governmental organizations during the pandemic including maintaining "six feet distance".  The other feedback was to consider environmentally friendly aspects such as energy efficiency.  Given the scope of this project, environmentally friendly aspects such as energy efficiency would fall under the building management design side.  For this project, the best that can be done is to use energy efficient devices if available.

One other element of the feedback was about having pleasing aesthetics.  This has been accounted in the ambient display element focused on visualization.  This visualization would consider placement of sensors in an unobtrusive manner and designing the app and management console with appropriate functionality, color and display.  The integrative analytics suggestion is also part of the ambient display since having real-time results on the app and its management console are critical to decision making and are part of this project.  In order to incorporate this feedback, I updated the framework and added two separate functionalities for the element of Ambient Display - Aesthetics and Analytical Visualization.

Survey question three was an open-ended question soliciting further comments and suggestions from the framework survey participants.  One participant commented that at the city level the complexity of the frameworks would be higher since there would be different dynamics at play that require considerations at a grander scale for the stakeholder and the technology aspects.  This is expected since the lobby is at a very small scale versus the much larger scale effort at city level where multiple parties would need to be involved.  Another survey participant suggested doing empathy mapping up front for key interaction points and to understand the persona's behaviors and attitudes. Empathy mapping helps develop an understanding of the user and draws insights for the user's needs (Brown, 2018). This is another way to identify the stakeholders and their needs which we did early on as part of the pre-focus group survey which was conducted to learn about their preferences for the functionalities desired by them. The scores provided by the pre-focus group participants assigned to each item helped to identify and prioritize the functionalities shortlisted for the app.

# Chapter 6. Design and Build: Mobile App and Management Console

The second artifact for this research is a mobile app that has been designed for the users to find an available restroom which has least occupancy and keeping in mind Covid-19 recommendations on maintaining six-feet distance, finding an available conference room and reserving it for the needed date/time, and to report an incident on campus that needs attention.

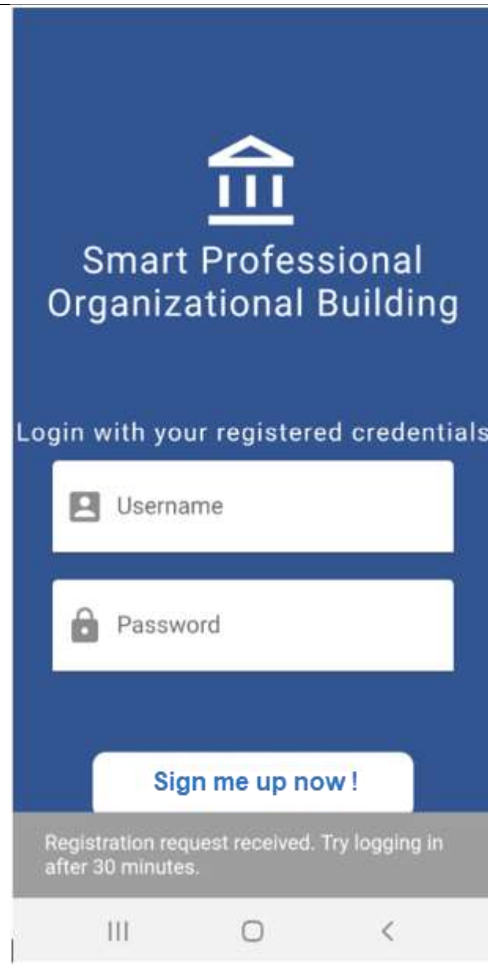
Due to the COVID-19 pandemic, the researcher had to take time off to care for a family member in the United Arab Emirates. Consequently, the prototype was completed and tested in a condo in Sharjah, United Arab Emirates. Staff, faculty, and students at the University of Sharjah tested the app and provided feedback by filling out the online surveys.

## 6.1 Applications

Designing citizen-centric apps allows for a differentiated user experience. The app designed for this research can be accessed via Android mobile devices. The App allows users to maintain a safe distance when using facilities in the building such as restrooms, find and reserve conference rooms, allows management to monitor usage and limit facilities' usage to a set number of people, and improve efficiency by using crowd sourced incident reporting. The app also allows for operational efficiency and reduces the need for full-time staff members to assist and guide users, which can translate into cost savings.

In order to access the app, users can be added up front with their registered credentials and password. For the purpose of this research, an additional option was provided to register new users on an ad hoc basis (Fig .9). After downloading the APK file on their Android device, the user can sign up to register and request access to the app. The app's admin receives the user's request, verifies their setup, and provides the user with access. Further details are provided in the management console (Section 7.1.4) which enables new users to be verified and approved to be given access to the app.


New User Registration




Login Screen

**FIGURE 9: NEW USER SETUP**

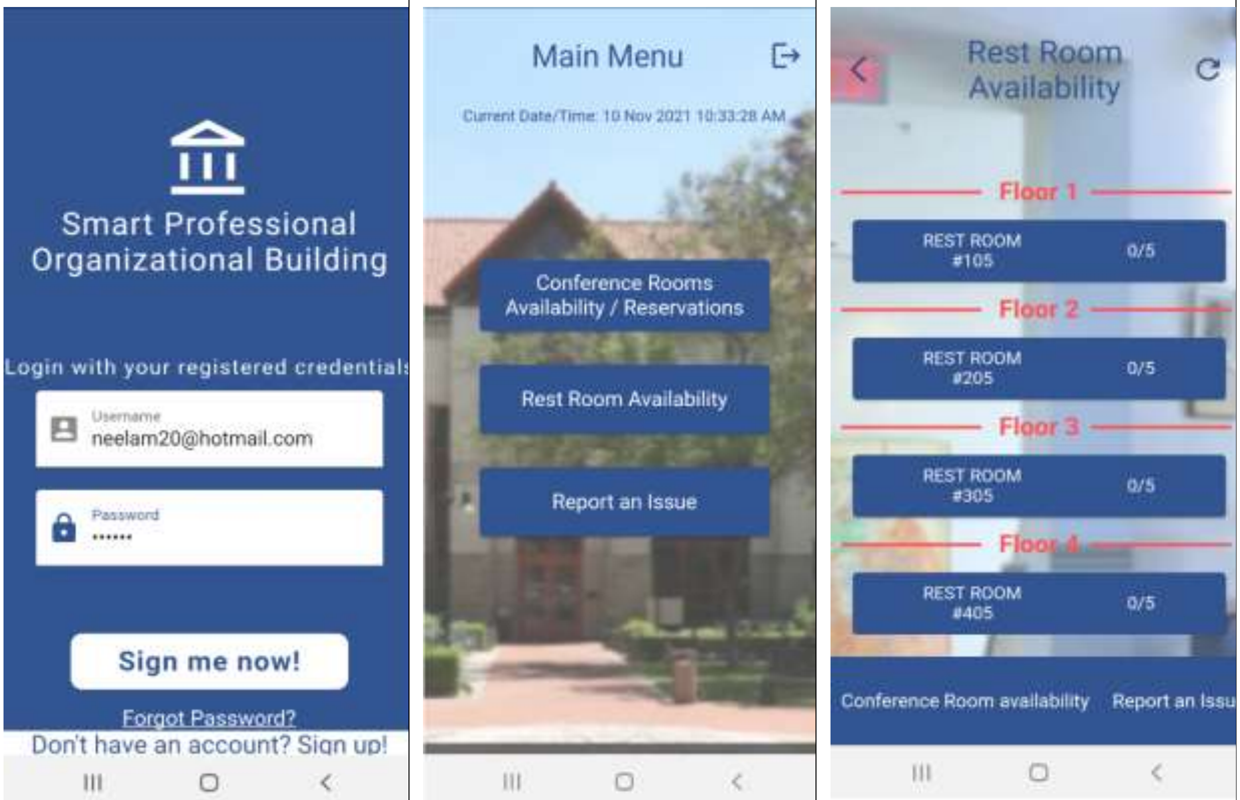
### 6.1.1 Restroom Availability

The goal of this app is to make the restrooms pandemic (e.g., COVID-19) safe. Since the number of people in any given restroom should be restricted to maintain social distancing, the app allows users to see the number of occupants and choose which restroom has the fewest occupants.

To mimic a restroom having multiple stalls in a given organizational building, a sensor was placed on a room entrance doorway in the condo. The actual restroom in the condo could not accommodate more than two people at a time, so the sensor was placed on another room's doorway rather than an actual restroom door.

The restroom availability app displays all the restrooms on all the floors in the building and shows the number of users currently occupying each restroom (note: for the first floor it is the actual count and for all other floors the app shows a simulation for floors and occupancy count). The app also displays the maximum occupancy allowed at any given time, so the user is aware of the limits and current occupancy. This allows users to choose a restroom based on current availability and maximum capacity to ensure that they follow the social distancing guideline for their own and others' safety.

After logging in to the app, the user can check to see restroom availability (Fig. 10). They can navigate either from the main menu or via the link on another screen in the app. If the count is higher than the set limit, the display for that restroom turns red (see Fig. 15 as an example for a visual for the red colored display), providing an additional visual cue.




User Login | User View of Main Menu | Restroom Availability

FIGURE 10: REST ROOM AVAILABILITY

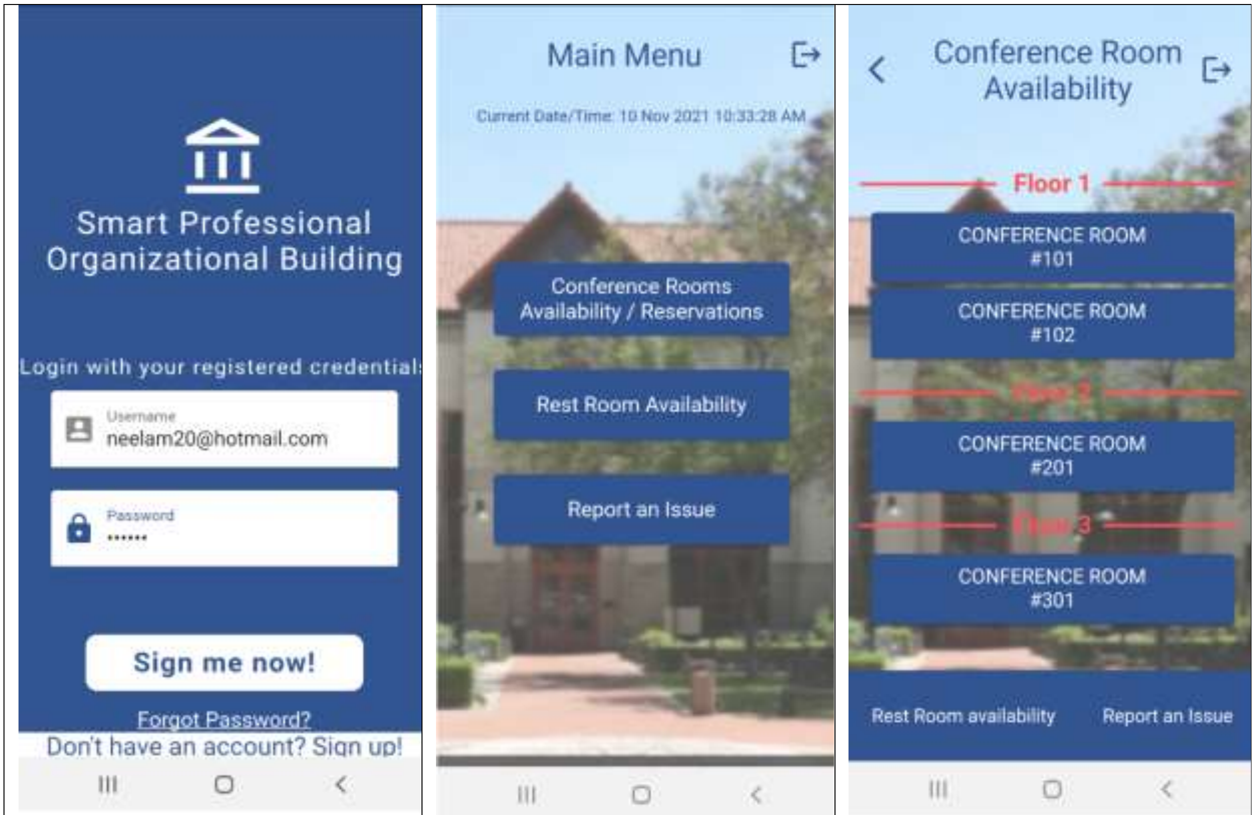
### 6.1.2 Conference Room Availability

The second app functionality allows visualization of the availability of a conference room and allows the user to book a reservation for an available conference room for a selected date/time and send a meeting invitation to invitees. This app takes into consideration that the conference room could have one, two or multiple entry/exit doors. The app tallies the final count of people entering/exiting from each door.

To maintain privacy, the final number of people who went through either door is available only on the management console, it is not displayed to the general user. The general user will be able to see whether a room is reserved or available (Fig. 11). If it is available, they will be able to book the room for their meeting and notify others via an email invitation that shows the meeting room date/time, room number, and the start/end times and purpose of the meeting. If the room is pre-booked and the user tries to reserve it, they will get a notification indicating the unavailability and a suggestion to pick another room or date/time for their meeting as seen in Figures 12 and 13.

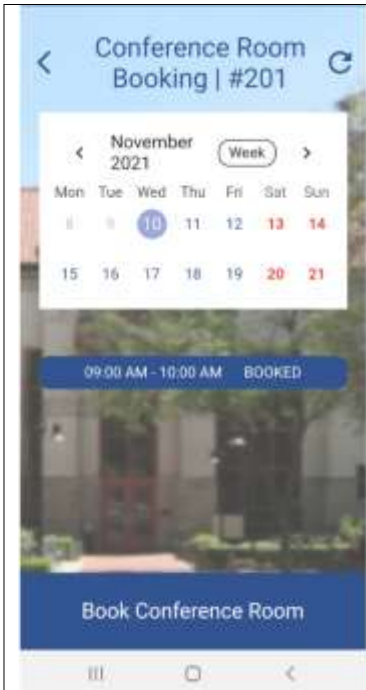
In the condo, the kitchen was used as a proxy since it has two entrances/exits—one adjoining the dining room and the other being the condo's main entryway. This mimicked the two entries/exits to a conference room in an academic building. Sensors were placed on both of these doors to count the number of people entering/exiting from the kitchen (Fig. 24).

The Conference Room Availability app allows the user to know at a glance, which conference room is available. Users could then message their teammates to huddle for a quick meeting in the room that is available. Once the email invitation is sent, it updates the users calendar and at the same time the conference room will not be available to others for the duration that the room is booked. This takes away the need to call an admin to reserve a room and allows ad hoc meetings to happen without wasting time in searching for a meeting spot.

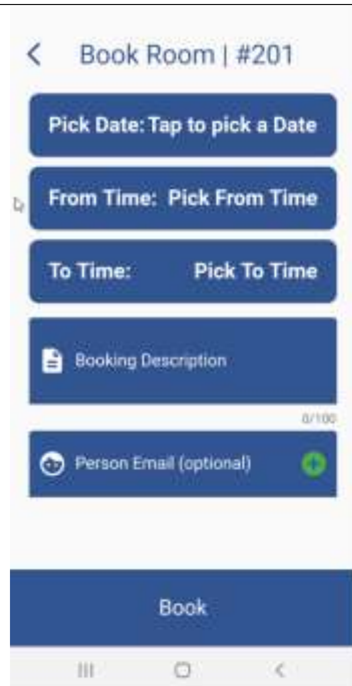



| User Login | Main Menu | Floors/Conference Rooms |
|---|---|---|

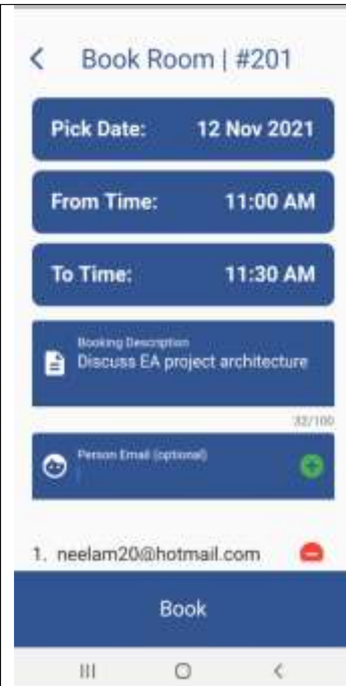
**FIGURE 11: CONFERENCE ROOM AVAILABILITY**



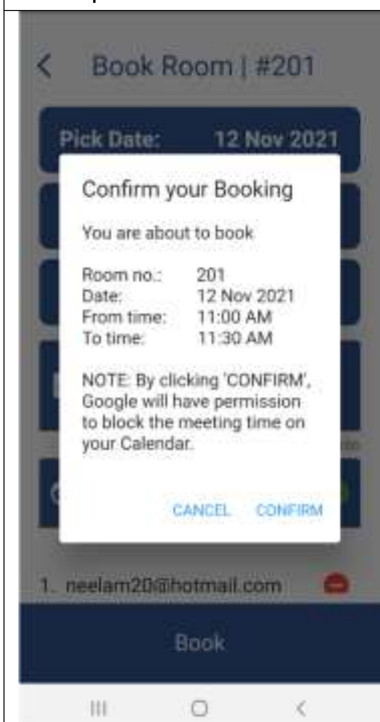

Conference Room Availability and Option to Book a Room



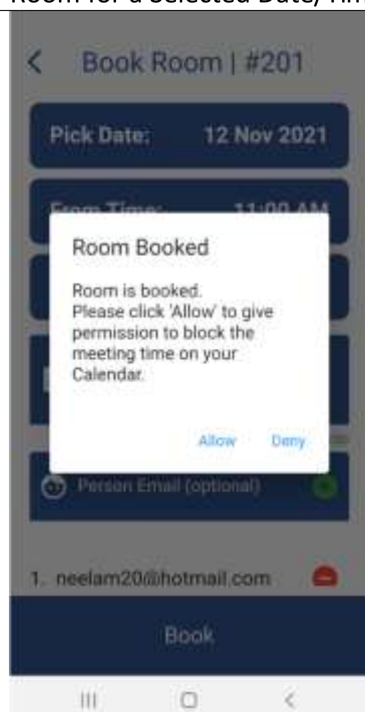

Option to Book a Conference Room for a Selected Date/Time



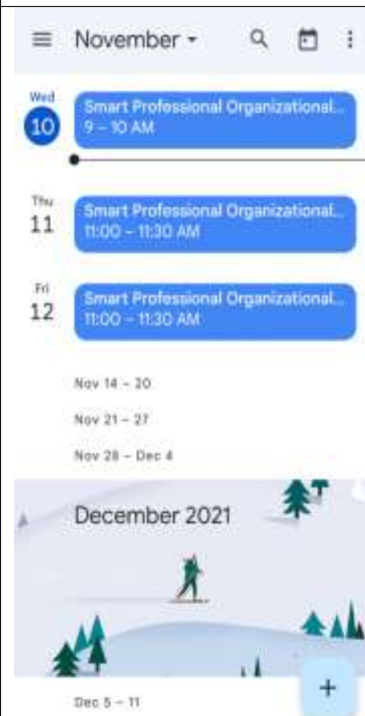

Conference Room Reservation Details




Booked Conference Room Confirmation




Permission to Block Time on Google Calendar




Calendar Showing Booking

**FIGURE 12: CONFERENCE ROOM BOOKING 1**

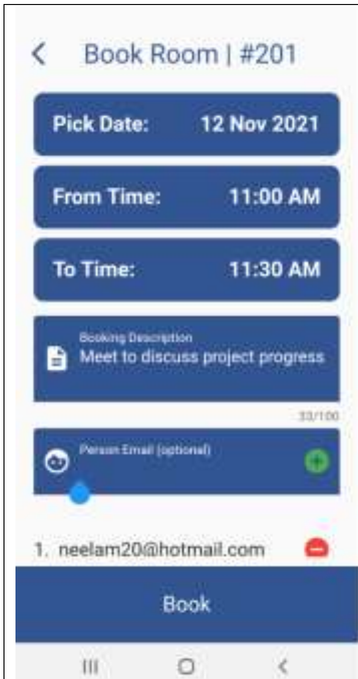
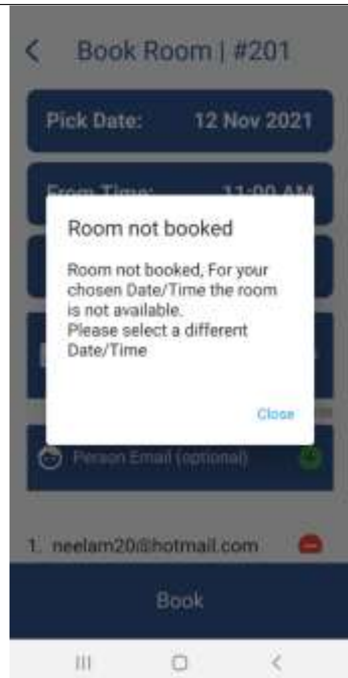
| | |
|---|---|
|   Example of an Attempt to Book a Room Reserved for the Same Date and Time |   Prompt Showing That a Room Is Not Booked |

FIGURE 13: CONFERENCE ROOM BOOKING 2

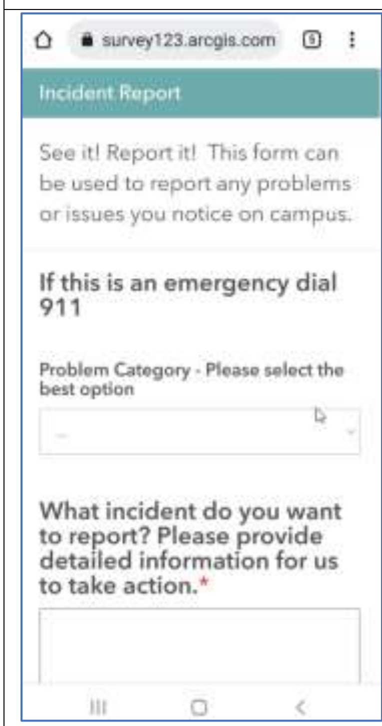
### 6.1.3 Incident Reporting

The third app functionality allows users to report incidents by clicking on a link and filling out an online form (Fig. 14). They have the convenience to include a picture of the issue they report. This data is accessed by university physical plant officials who can send personnel to fix the issue reported. This app makes it convenient for users to report these issues rather than having to call or email the physical plant. This app can be used to report a broken lock, a water leak, a fallen tree, a burglary, property damage, or other problems noticed on campus. The reported incident is then accessed by the physical plant personnel and resources can be assigned by the organization to fix the issue before further damage/harm is experienced.

Over time, analytics could be run to see trends and find patterns, such as recurrence of a problem, by visualizing the hot spots. This provides for an opportunity to design long term solutions rather than just use stopgap solutions. Spatial analysis can enable management to predict and plan for resource allocation to provide better services and greater safety for the campus and the users.


User Login


User View of Main Menu




Incident Reporting Screen (top)


Incident Reporting Screen (bottom)

FIGURE 14: REPORT AN ISSUE

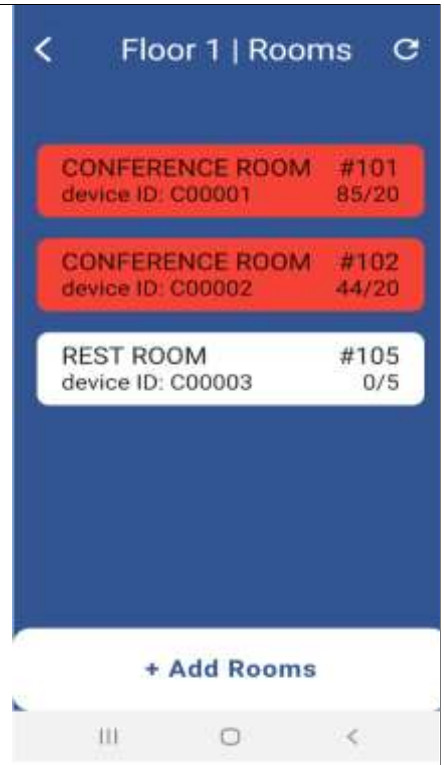
### 6.1.4 Management Console

The management console is open only to the building management staff to allow them to visualize the count in the conference rooms, and to make changes to the maximum number of people who can be in a conference room or restroom.  The occupant count of conference rooms is kept private and open only to building management personnel to ensure that security is maintained and to prevent any potential acts of terrorism intended to cause maximum harm at locations where the greatest number of people are gathered.

Staff can visualize the current count in any of the rooms (Fig. 15) and intervene if the count exceeds the number of people approved to be in that space.  Apart from visualizing the room's current occupancy, the building's management staff can update the number of people permitted in a room as needed based on policies of the organization.  Another benefit of this data is that staff can analyze current and future needs and suggest redesign of the space, if needed.


Admin Login


Admin View of Floors and Pending Users




Admin View of Individual Floors and Occupancy, with Red Indicating Occupancy That Exceeds the Limit

FIGURE 15: ADMIN LOGIN—MANAGEMENT CONSOLE 1

The management console also allows the admin to add new rooms and identify the type and capacity as well as the sensor ID. New users who register to use the app can be added via the management console after the admin does due verification of the requestor (Fig. 16).

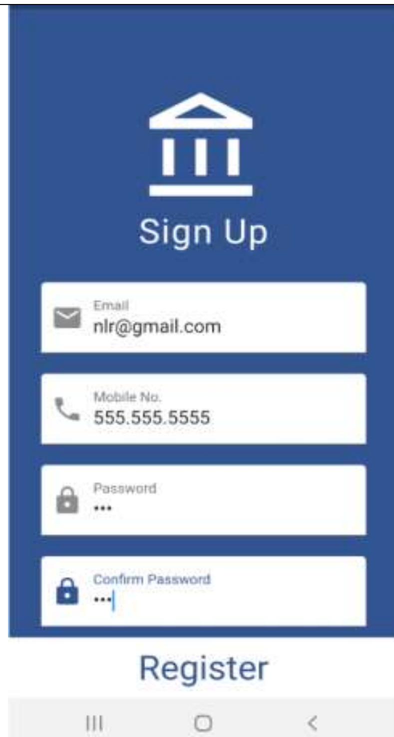
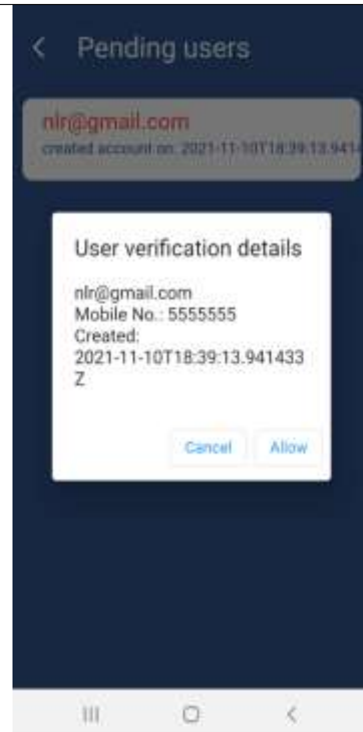
| | | |
|---|---|---|
| <br>Admin View to Add Conference Rooms and Restrooms on Any Floor | <br>New User Registration | <br>Admin View of Pending Users Verification Details |

**FIGURE 16: ADMIN LOGIN—MANAGEMENT CONSOLE 2**

Apart from using the app's management console, the admin can also login to their desktop and access the functionalities to add/remove new buildings, rooms, devices, users etc. (Fig. 17)

Admin View—Desktop Panel

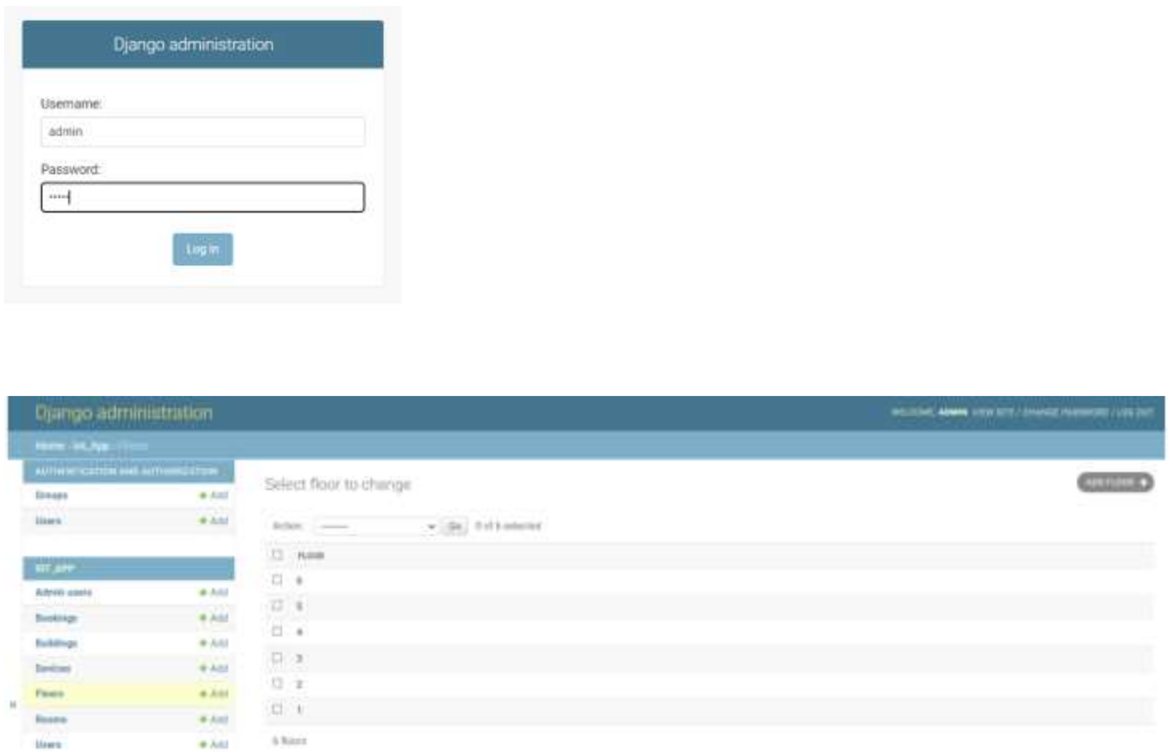



**FIGURE 17: ADMIN LOGIN—MANAGEMENT CONSOLE DESKTOP**

## 6.2 Architectural Diagram and Technologies Used

An architectural diagram (Fig. 18) provides an overall view of the physical deployment of the software system and its evolution road map. It is an important tool as it is a system diagram that allows the user to see and obtain an abstract of the overall outline of the software system and the relationships, constraints, and boundaries between components.

The diagram shows an IoT device (sensor) sends data via the Message Queuing Telemetry Transport (MQTT) message broker to the back end for processing and storage in the SQLite database. The application uses an API (Django) to serve data as needed. The app is packaged in a Docker container and hosted in the cloud (Azure). Each of the technologies is defined in detail in the following sub-sections.

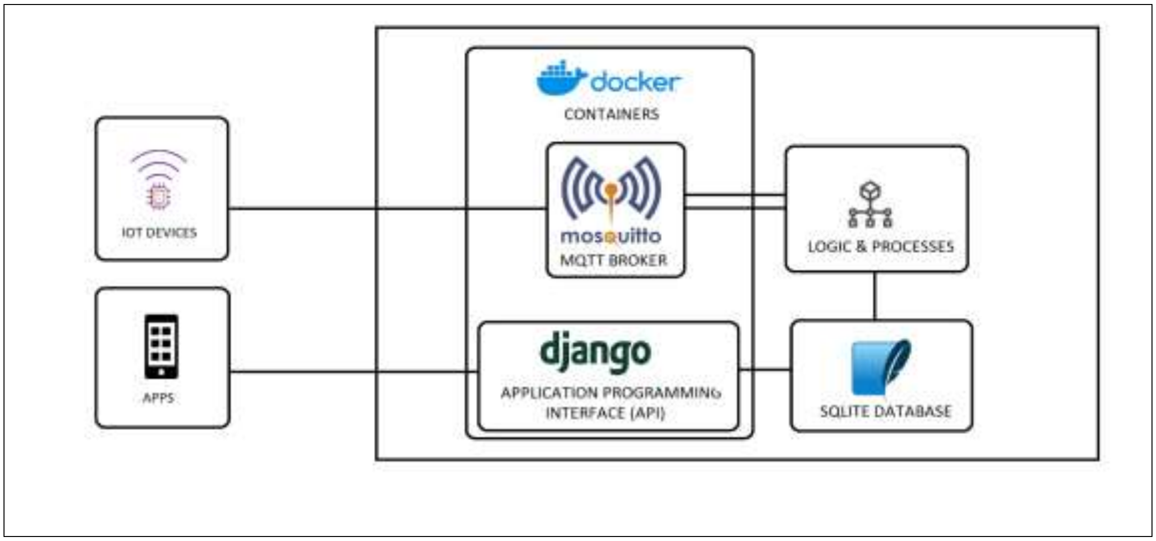



FIGURE 18: IOT ARCHITECTURE

### 6.2.1 Internet of Things Devices—Sensors

IoT devices sense, compute with, and connect to other devices and exchange data over the Internet. IoT features allow users to connect various devices to the IoT platform, analyse the data collected, and use it to gain business intelligence and integrate models to improve the user experience. They allow for fast and real-time processing as well as for running analytics.

For this project, the sensor components and build layout is shown in Figure 19. The sensor is built on an Arduino Uno board, which is a microcontroller board and an open-source prototyping platform. The communication protocol used is Wi-Fi. The ESP8266 Wi-Fi module is connected to the Wi-Fi for accessing the internet to send/receive data to and from the server. The sensor senses the data and sends it to the cloud and feeds it to the message queue for processing. The LCD display screen gets the data from the cloud after processing is completed in real time. The LCD displays the count as it changes when people move in and out of the sensor controlled area.

**Sensor Components and Build Layout**

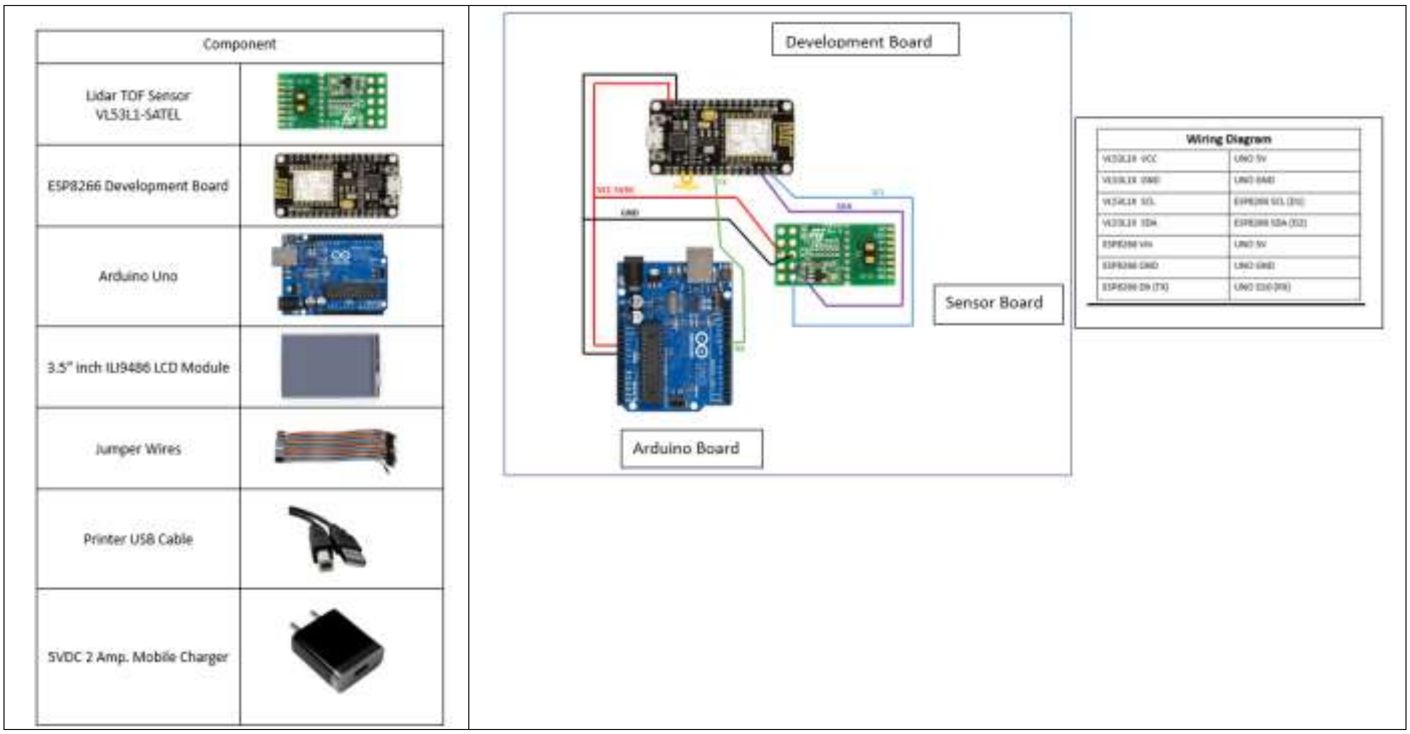



FIGURE 19: SENSOR COMPONENTS AND THE BUILD

The initial build was done using infrared (IR) sensors that emit IR waves and calculate the reflection angle. However, it was a challenge to install the sensor according to the zone, i.e., the field of view for the sensor. The results were not consistent despite attempts to angle the sensor properly, therefore the results were not reliable. Next, a light detection and ranging (lidar) sensor was used. Lidar measures distance by illuminating it with a laser beam. The results of using the lidar sensor were very erratic as it would not recognize the zone area and returned “incorrect path" error messages.  Next, an OEM microcontroller was used to calibrate the device, but the conclusion was drawn that there was an issue with the device. After that, i2c lidar sensors were ordered, and this device produced a successful count.  A comparison of IR and lidar sensors is shown in Figure 20.

| | **IR Sensor (model—E18-D80NK)** | **Lidar Sensor (model—VL53L1X)** |
|---|---|---|
| |  |  |
| Minimum Range | 1 cm | 10 cm |
| Maximum Range | 0.8 m | Up to 4 m |
| Interface | I/O pins | i2c |
| Current | 300 mA | 105–135 mA |
| SPAD Array | No | Yes |
| Zones Defined | No | Yes |
| Gesture Control | No | Yes |
| Mechanical Integration | Complex (large module) | Easy (all in one) |

**FIGURE 20: IR VS. LIDAR SENSOR COMPARISON**

IR had the following challenges:

- Maximum length was 180 centimeters.
- Hanging the sensor from the top of the doorway when occupants' heights vary resulted in miscounts.

- For every zone, Zone A/Zone B—inside door/outside door, separate sensors were needed. It was necessary to mount sensors inside and outside the door. Whenever the door was opened, the door was counted.

Lidar was much better when certain caveats were considered:

- The height between the sensor and the ground should not exceed 7 feet.
- The sensor must be installed at a 90-degree angle.
- There should be no obstruction between the cones of the laser.
- The pathway should be marked so that better results can be obtained.
- Lidar provided 90–95% accuracy.

**Sensor Placement**

Placement of sensors is crucial to achieve accuracy (Fig. 21). With the lidar sensor the accuracy is best when the following caveats are followed:

- The device should be installed on top of and in the center of the door.
- The device should be installed on the opposite side of the direction of door opening.

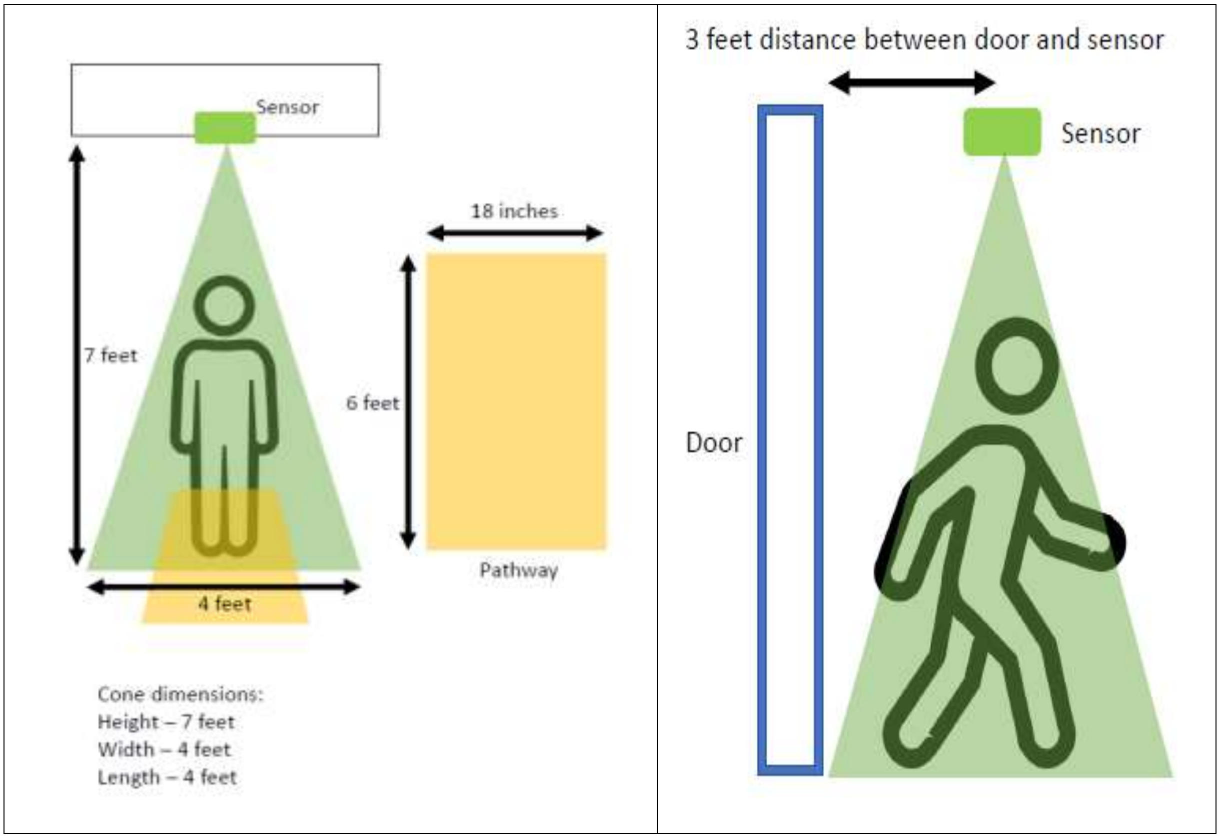



**FIGURE 21: SENSOR PLACEMENT**

Reliability of the algorithm depends on the accuracy of the setup, that detects the distance between the sensor and the floor. The accuracy can be ensured only if nothing (i.e., no obstacle or static object) blocks the front and back field of views. To assess if a setup is reliable, a significant number of distances can be measured with the sensor. This is done by having people with different heights walk under the sensor field of view while staying within the threshold defined. Data collected with this should show same measurement with low variation to conclude that the sensor is reliable and set up correctly.

Counting people with the VL53L1X sensor consists of using the multiple zones of the sensor receiving the single-photon avalanche diode (SPAD) array which are detectors offering imaging capabilities and configuring them with two distinct fields of view to get alternate ranging distances from them and, consequently, recognize the movements of a person.

Using this method, the number of people occupying a meeting room, accessible from a reasonably narrow access, is knowable at all times by detecting the entry and exit of the attendees. By measuring and analyzing the distances of targets within the field of view of the front and back zones, a simple algorithm can detect the direction of a person crossing the area within these two fields of view (Fig. 22). This algorithm takes into account the direction someone is in one of the fields of view provided that the distance measured by the sensor in this field of view is between 0 and a threshold value specified in millimeters.  The threshold value is determined by measuring the distance between the floor and the sensor.  If the distance is 2350mm, and the actual distance measured by the sensor is 2290mm, then the threshold is less than 2290mm (Fig. 23).

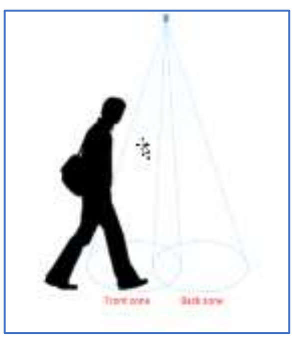


**FIGURE 22: SENSOR FIELD VIEW**

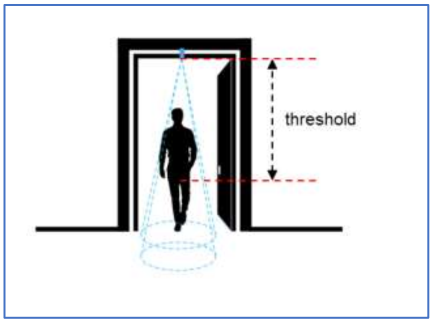



FIGURE 23: THRESHOLD AND RANGE VALUE DETERMINATION

From a timing perspective, the sensor alternately ranges on each of the two zones for a period measured in mere milliseconds. A range is determined by an algorithm that detects the direction a person crosses in the two field of views (FoVs) of the zones in the front and back (see Fig. 23) as well as by measuring and analyzing the distances of the person in the FoVs as being between 0 and the threshold value that has been specified in mm.

It is possible to determine the direction in which a person crosses the area depending on which of the two zones was where this person was first detected. The counting algorithm example relies on a list of states that must occur in a certain order to detect that a person has crossed the specified area and in which direction this area has been crossed. These states are stored in a list and compared to two default lists of states that represent how the area is crossed in two different directions. When no one is seen in either of the two zones, the list of states is reset. If we consider that a person detected in the front zone is assigned a value of 2 and a person detected in the back zone is given a value of 1, the algorithm adds the value of the two states and stores the result as soon as it changes. Eventually, if the consecutive states in the list are 0, 1, 3, 2, 0 or 0, 2, 3, 1, 0 this means that a person has been detected going in one direction or the other (Fig. 24).

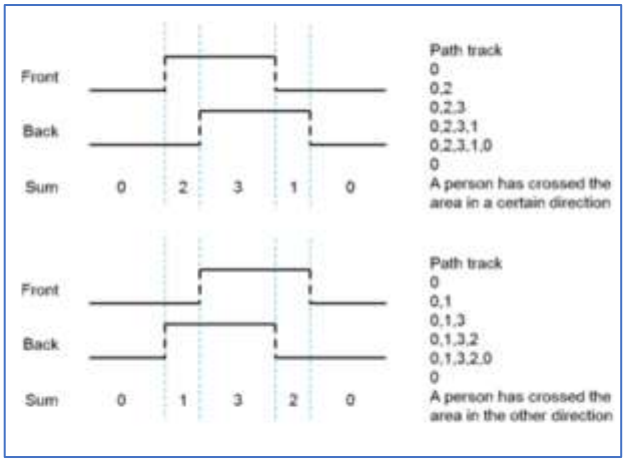



**FIGURE 24: SENSOR ZONE**

Figure 25 shows screenshots displaying the simulated entry for the conference room with door 1 and door 2 of the kitchen representing the two doors of the conference room. The restroom count is simulated by fixing the sensor on the doorway of another room; the screenshots show the update to the count as the researcher moves through the doorway.

**<u>Sensors Application on Conference Rooms and Restroom</u>**

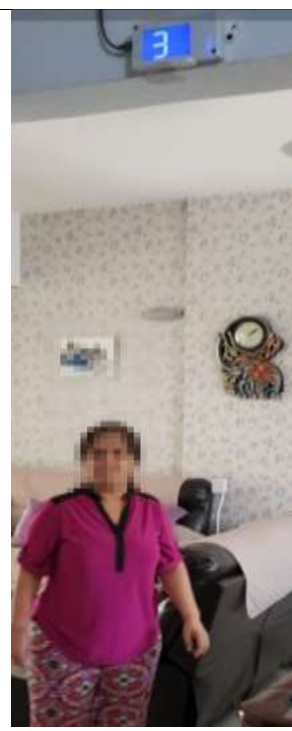
| | |
|---|---|
| <br>Conference Room Door 1 (kitchen entrance door 1) | <br>Conference Room Door 2 (kitchen entrance door 2) |
| <br>Simulated Restroom Entrance | <br>Simulated Restroom Entry Count Update |

FIGURE 25: SENSORS ON DOORS OF CONFERENCE ROOM AND RESTROOM

### 6.2.2 Android App—Flutter

Flutter, created by Google, is an open-source software development kit (SDK) that includes source code and utilities. Cross-platform applications for Android, iOS, and others, can be built from a single code base. Interfaces with flexible designs can be built quickly by using widgets that are customizable. These widgets can be used like LEGO bricks to build the app. To design Android-specific apps, Android Studio provides an Android virtual device manager to create the virtual device Android Emulator, which uses Dart (similar to C#) as the programming language.

### 6.2.3 MQTT Message Broker

Message Queuing Telemetry Transport (MQTT) is a messaging protocol. It is open source and uses the publish/subscribe model between multiple devices, thus making it suitable for IoT messaging with low-power sensors, microcontrollers, mobile devices, etc.

### 6.2.4 Application Programming Interface—Django and Python

An application programming interface (API) allows users to make a request for data retrieval from a remote web server. APIs are useful as data can change quickly which may require a small data subset. The Django REST framework (DRF), along with Django web frameworks, offers a customizable way to build web APIs. The REST framework requires Django and Python. Python is an object-oriented programming language that has a comprehensive standard library. Django is free and open source and has a collection of Python libraries, which allows users to create scalable web applications quickly and efficiently.

### 6.2.5 Database—SQLite

SQLite is a popular database engine. SQLite is used as a storage engine for a database server. Data stored can be in text, numeric, or Boolean form. New tables and columns can be added easily. Data can be queried easily for further analysis.

### 6.2.6 Logic and Processing

Python is used to communicate between the IoT devices and the database (API) via the Mosquitto MQTT message broker, and to maintain the LED count of the IOT device.

The IOT device publishes a message in a specific format. This process (program) is as follows:

1. Gets the message and finds the device ID inside the message.
2. Sends a PUT (updating the database) request on the Django Rooms API.
3. Sends a POST (new entry to the database) request on the Django Logs API.
4. Publishes (sends) back a message to the IoT device to maintain the LED count.

### 6.2.7 Docker (container)

Docker is a platform as a service (PaaS) product and uses operating-system-level virtualization to deliver software in packages called containers. Docker virtualizes application layers and uses an operating system kernel of the host. Containers offer a way to package an application in one environment with all the necessary dependencies and configuration. The package is portable and can be shared with and moved around to different teams. It thus makes development and deployment much more efficient as it takes one command to install the application. As such, setting up the developer environment becomes very easy.

### 6.2.8 Cloud Computing Service—Azure

Azure is a Microsoft cloud computing platform which is used for application management via an online portal. It is usage based—the consumer pays only for the units used. The maintenance, production, and supply of the units are the hosting company's responsibility. Hence, the starting overhead is comparatively low and gives the user has access to basic infrastructure.

### 6.2.9 Entity Relationship Diagram

The entity relationship diagram (ERD) is displayed Figure 26. The ERD shows the entities i.e., tables that hold the attribute information/data. The various links show the relationship i.e., the associations between these entities which could be one or many. In each entity the attribute/data field identified as the Primary Key (PK) is the main identifier for that entity. This PK is listed as the Foreign Key (FK) in another entity. Having this common field between the two entities allows to link the entities together to look at the combined data that are stored in them for a given record.

In this diagram we see that on each floor there could be one or many rooms and each room is on a given floor. The rooms can have one or more bookings that can be done by one or more users. There can be one or more sensor devices for each room. The devices gather the data from the rooms and floors. This data can be accessed via the logs collected for each activity that the device monitors. The admin has the overall access to make changes to add/remove floors, rooms, devices, users and monitor usage.

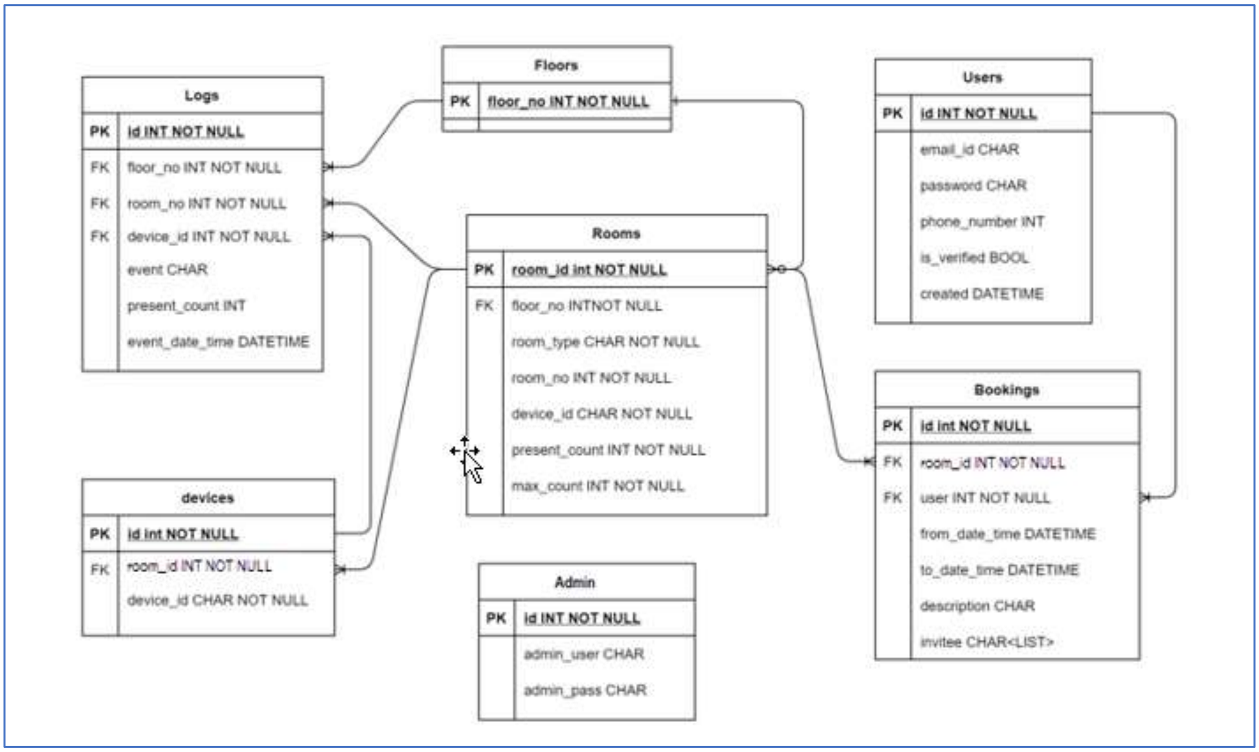



**FIGURE 26: ENTITY RELATIONSHIP DIAGRAM**

# Chapter 7. Mobile App Evaluation

## 7.1 Evaluation Summary

In order to understand the utility and effectiveness of the app, surveys were administered to solicit user feedback which can be incorporated to improve the app. Evaluations are summarized in Table 1.

The first evaluation was with a pre-focus group that was conducted to understand which preliminary research ideas are preferred. This was done with students from Claremont Graduate University's (CGU's) Center of Information Systems and Technology (CISAT) and IDEA Lab. With this group, the domains relevant to a building lobby (occupancy, entertainment, utility, access, and safety) were explored and after multiple brainstorming and discussion sessions (service ideation) were conducted that resulted in identifying a preliminary list of 47 ideas. A follow-up meeting a week later led to refining the list to nine that seemed most relevant to the space context where the system will be implemented. These nine ideas were presented to the community group which led to open discussions and later surveys were administered to the group to assess the attractiveness and usefulness of the proposed smart services (service assessment). Participants provided feedback on 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). After careful assessment of the feedback and completed survey, six smart services were selected to be offered. Three services were designed and built in this dissertation and the other three services were developed for another project separately. Some ideas were dropped either due to cost/financial constraints or their implementation was not feasible within our scope.

The next step was to conduct a pre-test survey to understand users' perceptions of the smartness of their existing lobby. This was done with the faculty, staff and students of University of Sharjah in Sharjah, United Arab Emirates (UAE).

Following that, once the project was implemented, the same group of participants from the University of Sharjah were asked to do a post-test to determine if the users' perceptions about the lobby had changed. This was done to measure the utility and effectiveness of the app.

Finally, an overall survey was administered to the same group of participants from the University of Sharjah to gain an understanding of the users' perceptions of the overall project since they had now used the app for a week.

To assess the user satisfaction with the system, data was collected by using the Questionnaire for User Interaction Satisfaction (QUIS). The questions for all the surveys were computerized so that data collection would eliminate encoding errors and speed up analysis. The same group of participants from the University of Sharjah were administered the survey.

| IT Artifacts | Pre-Focus Test | Pilot Test—Field Experiment | Stakeholder Test |
|---|---|---|---|
| **App: Restroom availability**<br>**Test: Mobile app** | Survey (n = 5) | Survey (n = 5)<br>QUIS | Survey (n = 5)<br>QUIS |
| **App: Display & Reserve Conference Room**<br>**Test: Mobile app** | Survey (n = 5) | Survey (n = 5)<br>QUIS | Survey (n = 5)<br>QUIS |
| **App: Incident Reporting**<br>**Test: Mobile app** | Survey (n = 5) | Survey (n = 5)<br>QUIS<br>ArcGIS Online report | Survey (n = 5)<br>QUIS<br>ArcGIS Online report |
| **Analyze: Framework** | | Survey (n = 2)<br>Qualitative questions | Survey (n = 2)<br>Qualitative questions |
| **Overall Outcome of the Project** | | Survey (n = 5) | Survey (n = 5) |
| **Pre-test and Post-test** | | Survey (n = 5) | Survey (n = 5) |

TABLE 1: EVALUATION SUMMARY

Note: n is the number of respondents.

## 7.2 Evaluation Steps

The evaluation steps were 3-fold. It consisted of pre-focus group, field experiment and evaluation. Detailed explanation follows.

### 7.2.1 Step 1: Pre-focus Group

This step was done with a group of five CISAT students who were given a survey consisting of nine questions listing preliminary research ideas related to a smart lobby (Appendix A). The participants were asked to evaluate the idea using a 7-point Likert scale, answering questions to indicate if they found it to be very interesting/uninteresting and useful/useless. Based on their feedback, the ideas numbered 1, 3, 4, 5 and 6 were short-listed for a smart lobby app (see Table 2 sorted by average score column). As mentioned in Section 3.2 some ideas were dropped due to cost/financial constraints or their implementation was not feasible within our scope. Hence after careful assessment of the feedback and completed survey, six smart services were selected to be offered. In this dissertation, we design and build three services: ***restroom availability, conference room availability and occupancy*** and ***incident reporting***. The other three services were developed separately for another project.

| **Idea Num** | **Description** | **Average Score for Interest & Use** |
|---|---|---|
| Idea 1 | Sensor to count number of people in the building and know their location | 5.9 |
| Idea 6 | Get direction to office, conference rooms, etc. via your cell phone using augmented reality | 5.4 |
| Idea 2 | Sensor to monitor indoor/outdoor pollution and UV level and LED light changes color as per pollution level | 5.3 |
| Idea 3 | Sensor to check conference room availability in real time and send message to group to meet | 5.3 |
| Idea 4 | Map location of water fountains, restrooms, vending machine, library, classroom, medical aid. | 5.2 |
| Idea 8 | Scan people for guns | 4.9 |
| Idea 7 | Report incidences on campus such as water leak, exposed wire, etc. | 4.5 |
| Idea 5 | Sensor to check restroom/classroom vacancy in real time | 4.3 |
| Idea 9 | Scan visitors as they enter the lobby for health-related feedback | 4.3 |

TABLE 2: PRE-FOCUS GROUP RESULTS

### 7.2.2 Step 2: Field Experiment and Testing

Experiment and testing conducted as follows:

1. Five University of Sharjah faculty, staff members, and students were recruited to test the app and provide feedback via a survey (Appendix D). The participants were sourced via an email invitation. Once they showed an interest in participating, options for a phone/Zoom meeting were provided to explain the project and the need for it. Later, instructions were provided via email on how to access the app and the survey. The age group of the participants ranged from 25-55 years. There were two males and three females. One male and one female participant were local Emarati and the remaining were expatriates connected to the university. They tested the app for a week.
2. The pre-test (5 questions) and post-test (7 questions) were administered to understand the differences in participants' perceptions of the lobby's smartness before using the smart app functionality and after using it (Appendix C). The first 5 questions were in the pre-test. The same 5 questions along with questions 6-7 and an open-ended qualitative question were in the post-test.
3. An additional survey was administered to get user feedback on the overall outcome of the project (Appendix E).

### 7.2.3 Step 3: Evaluation

To get user feedback on the app, surveys were designed in Esri's Survey123 tool, which enables creation and sharing of surveys via a URL. This URL can be accessed via the desktop or a mobile device. The tool gathers the feedback from surveys and allows the researcher to export the results to Excel for further statistical analysis. The data gathered was analyzed using descriptive analysis with mean, median and standard deviation.

**7.2.3.1 User Satisfaction:** Questionnaire for User Interaction Satisfaction (QUIS) (Chin et al., 1988)— (Appendix D):

This questionnaire was developed at the University of Maryland and is composed of 27 questions. A subset of these questions were used based on the relevancy to the research project and some words were tweaked to suit the project. Each question's rating is on a 10-point scale with relevant anchors at each end. This questionnaire aims to gauge the users' satisfaction with the app design in terms of visibility, terminology, feedback provided by the system, and ease of learning.

Based on feedback from the participants (Table 3), the overall user satisfaction is high. The average for the individual categories was 8.4 for overall user reaction, 8.4 for the mobile screen, 8.6 for terminology and system information, 8.7 for learning to use the app, and 8.0 for app capabilities.

| Items | Mean | Standard Deviation |
| --- | --- | --- |
| **Category: Overall User Reaction** | | |
| Terrible-Wonderful | 8.4 | 0.89 |
| Frustrating-Satisfying | 8.2 | 0.84 |
| Difficult-Easy | 8.4 | 0.89 |
| Inadequate Functionality-Adequate Functionality | 8.6 | 0.55 |
| Rigid-Flexible | 8.4 | 0.89 |
| **Category: Mobile Screen** | | |
| Characters on the Screen<br>Hard to read-Easy to read | 8.2 | 0.84 |
| Navigation on the Screen<br>Unhelpful-Helpful | 8.4 | 0.55 |
| Organization of Information<br>Confusing-Clear | 8.6 | 0.55 |
| Sequence of features on the app<br>Confusing-Clear | 8.4 | 0.89 |
| **Category: Terminology and System Information** | | |
| Use of terminology throughout the system<br>Inconsistent-Consistent | 8.6 | 0.55 |
| Terminology relates well to the work you are doing<br>Never-Always | 8.4 | 0.55 |
| Position of messages on the screen<br>Inconsistent-Consistent | 8.8 | 0.45 |
| **Category: Learning** | | |
| Learning to use the App<br>Difficult-Easy | 8.8 | 0.45 |
| Performing tasks is straightforward<br>Never-Always | 8.6 | 0.55 |
| **Category: App capabilities** | | |
| App Speed<br>Too slow-Fast enough | 7.8 | 1.79 |
| Correcting your mistakes<br>Difficult-Easy | 7.8 | 1.64 |
| Designed for all level of users<br>Never-Always | 8.4 | 0.89 |

TABLE 3: SURVEY RESULT FOR APP

**7.2.3.2 Utility—Pre-test and Post-test—** Survey - (Appendix C):

To evaluate the app created, pre-test and post-test surveys were administered. This allowed us to gauge user experience; how users felt about the existing lobby and whether their perception of the lobby changed after using the app considering that a large screen on the wall would also display the same screen as the mobile app.

Each question was ranked on a 5-point Likert scale with responses ranging from "Strongly Disagree"(5) to "Strongly Agree"(1). Users evaluated the app and answered questions on the usability of the app pre-test and post-test. The pretest survey consisted of 5 questions while the post-test survey included the same 5 questions along with three additional qualitative questions, one qualitative question requesting for additional feedback and two qualitative questions regarding their productivity and preference for the building after using the app

**7.2.3.2.1** Pre-test survey results

Table 4 summarizes the pre-survey results. Results are summarized as mean, median and standard deviations. The pre-test average score on the 5-point scale is 2.72. As can be seen in Table 4, the median for item 1, users who think the existing lobby is smart, is low. They also were not aware in their existing lobby if a restroom was available (item 2). The standard deviation indicates variance in participants' responses for all five items.

| Items | Mean | Median | Standard Deviation |
|---|---|---|---|
| 1. I think the lobby is smart | 3.0 | 4 | 1.87 |
| 2. I know which restroom is available for use. | 3.8 | 4 | 1.64 |
| 3. I find it difficult to find available meetings rooms | 2.2 | 2 | 1.30 |
| 4. I can report issues to facilities department easily | 2.4 | 3 | 1.34 |
| 5. If I notice a safety issue, I can easily report it | 2.2 | 2 | 1.30 |

TABLE 4: PRE-TEST SURVEY RESULT

**7.2.3.2.2** Post-test survey

The survey results for the post-test are shown in Table 5. With a mean and median of 1, the users think the lobby is smart. They felt that the app allows the users to find an available restroom, and report issues easily. Due to the lobby being smart now, they would prefer this building to others on campus. Average for the post-test is 1.91. The standard deviation is varied when compared to the pre-test since each user has a different experience from using the app. For the additional qualitative question in the post-test posed to garner other feedback, two of the participants mentioned in their survey that they thought it is a nice app. For questions 6 and 7 that were also additional in the post test, almost all participants agree/strongly agree that the app has influenced their preference for the building and has potentially enhanced their productivity.

| Items | Mean | Median | Standard Deviation |
|---|---|---|---|
| 1. I think the lobby is smart | 1.0 | 1 | 0.00 |
| 2. I know which restroom is available for use. | 1.8 | 1 | 1.79 |
| 3. I find it difficult to find available meetings rooms | 3.0 | 4 | 1.64 |
| 4. I can report issues to facilities department easily | 2.2 | 2 | 1.64 |
| 5. If I notice a safety issue, I can easily report it | 1.8 | 1 | 1.79 |
| Additional questions asked in Post-test: | | | |
| 6. I prefer this building to others on campus. | 1.2 | 1 | 0.45 |
| 7. I think the app has made me productive | 2.4 | 2 | 1.52 |
| 8. Qualitative Question for Post-Test: Any other feedback: 1) It's a nice app. 2) Nice app | | | |

TABLE 5: POST-TEST SURVEY RESULTS

**7.2.3.2.3** T-Test for pre- and post-test survey

A two tailed t-Test of paired samples for means with alpha of .05 was done to test if there was a significant difference in the values for pre- and post-test means. Although the t test revealed no significance [two tailed significance ($p<0.05$)], all post-test mean values are lower indicating probable positive impact of using the app.

| | Pretest [Mean (SD)] | Posttest [Mean (SD)] | T | 2 tailed sig (p) |
|---|---|---|---|---|
| The lobby is smart | 3.0 (1.87) | 1.0 (0.0) | 2.39 | 0.08 |
| I know which restroom is available | 3.80 (1.64) | 1.8 (1.79) | 1.91 | 0.13 |
| Difficult to find available meetings rooms | 2.20 (1.30) | 3.80 (1.64) | -1.32 | 0.26 |
| Report issues to facilities department easily | 2.40 (1.34) | 2.20 (1.64) | 0.25 | 0.82 |
| If I notice a safety issue, I can easily report | 2.20 (1.30) | 1.80 (1.79) | 0.49 | 0.65 |

*p<0.05=significant

TABLE 6: T-TEST TO COMPARE PRE-TEST AND POST-TEST

**7.2.3.3 Overall Outcome of the Project—** Survey - (Appendix E)**:**

Participants were asked to describe their overall experience of using the app as well as their knowledge about the app after using the system. The feedback obtained is in Table 6. Overall, the participants are more excited about the lobby after using the app (all 5 participants strongly agreed) and consider it smart.

| **Items** | **Mean** | **Median** | **Standard Deviation** |
|---|---|---|---|
| 1. I am more excited about being in the Lobby now. | 1 | 1 | 0.00 |
| 2. Is the Lobby Smart now? | 1.2 | 1 | 0.45 |
| 3. Before using the app, I was aware of the app for finding available restrooms. | 3.2 | 4 | 2.05 |
| 4. Before using the app, I was aware of the app for Conference Room searching and reserving. | 3.2 | 4 | 2.05 |
| 5. Before using the app, I was aware of the app for Incident reporting. | 3 | 3 | 2.00 |

**TABLE 7: OVERALL OUTCOME OF THE PROJECT RESULT**

In summary, with improvement in post test scores for all questions, the results demonstrate that the app was user friendly and exciting to the participants. Furthermore, the app influenced building preference and would potentially enhance the user's productivity at work.

**7.2.3.4 Utility—Data Collection and Measuring Metrics**

Regarding the incident reporting app, analytics were captured about:

i) How many people accessed the app.

ii) How many incidents were reported.

**Results:**

i) Since we conducted the survey, on average the participants have accessed the app once.

ii) Looking at the incidents report, each of the users reported one incident (Table 7) with one of the users submitting a picture (Fig. 27) of an exposed wire.

| Items | User 1 | User 2 | User 3 | User 4 | User 5 |
|---|---|---|---|---|---|
| Problem Category: Please select the best option from: Water Leak, Fallen Tree, Electric Outage, Crime, Other) | Fallen Tree | Electric Outage | Water Leak | Electric Outage | Other |
| What incident do you want to report? Please provide detailed information for us to take action. | Section | Exposed wire | Water is leaking from a tap | Bulb fused | Exposed hoke and wires |
| On what date did you notice it? | 12/22/2021 | 12/22/2021 | 12/23/2021 | 12/23/2021 | 12/23/2021 |
| At what time did you notice it? | 11:25:00 | 11:31:00 | 11:33:00 | 12:00:00 | 12:18:00 |

TABLE 8: INCIDENT REPORTING DATA COLLECTION RESULT

**Figure 27: Issue Submitted via App**

## 7.3 Results and Discussion: Mobile App

Participants were sourced from the University of Sharjah via an email invitation. They represented the faculty, staff and students of the university. Once they showed an interest in participating, options for a phone/Zoom meeting were provided to explain the project and the need for it. Later, instructions were provided via email on how to access the app and the survey.

Feedback for the app was solicited via online surveys using Esri's Survey123 software. Survey123 enables creation of online surveys. The data is collected in the system and can be exported into Excel or other statistical tool for further analysis. Since the surveys were online, participants had the flexibility to fill out the survey using their mobile devices at their convenience.

When the app was discussed with the survey participants, they were excited to participate and use the app as the Covid-19 pandemic had been affecting most of them and their families, and there was concern especially given the high incident rates of Covid-19 positive cases going on in the country. Unlike the United States, where people have been working from home since the start of the pandemic and continue to work from home due to concerns with the multiple variants and people choosing not to be vaccinated, UAE-based Sharjah University faculty, staff and students were required to go back to campus in 2021 since vaccination for every resident was mandatory. Still with the new variants, for which the current vaccines at that time were not known to be effective, the concerns of being infected were high and the participants were excited to have an app they could use for their safety and security.

Having an app to find an available restroom and being able to see an available conference room and book it via their mobile app for an impromptu meeting versus having to contact an administrative assistant or go back to their offices which may/may not have been sanitized, as well as having an app to report incidents on campus were very exciting to them and they thought it was a novel idea. They could see the applicability and the benefits of using the app.

For the restroom app and the conference room app, they acknowledged the safety and convenience aspects. For the reporting an incident app, they thought it was important to have a way to volunteer information about incidences on campus since due to staff shortage, there were issues such as exposed wires, or faucet leaks that were not being attended to as there were less personnel to do the walk-abouts to notice these issues. Thus, having an easy reporting mechanism would ensure that the wider population would have an easy way to draw attention towards these problems before they cause (possibly severe) harm to the people or the structure of the building.

The results of the survey to gauge the users' satisfaction with the app design in terms of visibility, terminology, feedback provided by the system, and ease of learning, indicated high scores that suggest that the app design supports the purpose of our project. Averages for the individual categories were: 8.4 for overall user reaction and the mobile screen design, 8.6 for terminology and system information, 8.7 for learning to use the app, and 8.0 for app capabilities. For app capabilities, the slightly lower score compared to other categories such as the speed related question in that category, may be due to the wi-fi speed where the participant tested could be slow and spotty. With regards to correcting the mistakes, it is possible that once they submitted the survey, they were not able to make changes to their submission and hence the score.

In their post-test survey, the average score was 1.91. The feedback from the survey participants indicated that they now thought the lobby was smart and would prefer the building where they can see restroom availability and be able to report incidences online. They also indicated that they felt their productivity would increase due to the app functionalities provided to make the lobby smart. Two of the participants provided additional feedback and they mentioned that it was a nice app.

Based on the overall feedback provided by the participants, the scores indicate that the users are excited to use the app as it allows them to use the display/feedback from the app and be smart about the choices they make regarding using the facilities and reporting incidences. The app serves the need to keep users safe during a pandemic, allows them to volunteer reporting incidents by using the app, as well as take advantage of the app to search and book a conference room and invite participants to a meeting, notify them, and update their calendar. The results indicate that all three services offered on their mobile devices, achieved the goal of making a lobby smart and interesting and achieved the goal of this research.

# Chapter 8. Conclusions

## 8.1 Limitations and Challenges

This study took place during the Covid-19 pandemic. Given the challenges and the strict lockdowns enforced at the university, this project was done as a simulation inside a condo. The sensors were placed on the first floor and the app displayed the results for it. For the remaining floors the app simulated the floors and occupancy rate. The app and sensors on the first floor were tested with regards to functionality. Hence this could be considered as a prototype since I did not have access to a multi-storied academic setting to test the app. The other limitations and challenges are listed below.

**Technology Laggards:** There may be users who do not buy into the idea of a smart lobby or support its goals. They may not see value in the collective benefit and may ignore the app or dissuade others from using it. There is an off chance that some users do not have smart devices or are wary of downloading and sharing information.

**Employee Resistance:** There could potentially be resistance from the employees since the need for full-time workers could be reduced. Economists Erik Brynjolfsson and Andrew McAfee have indicated that with the digital revolution, there is the potential to disrupt labor markets (Schwab, 2016). But in the long term as per Schwab (2016, para. 8), “the displacement of workers by technology will, in aggregate, result in a net increase in safe and rewarding jobs”.

**Data Ownership:** As information is crowdsourced, it will need to be determined who owns the data since it is cocreated.

**Privacy, Security, and Hacking:** A smart lobby app must ensure that information is kept private and secure, and that access to information is limited to authorized personnel.

**Information Quality and Overload:** Since information will be captured and reported by multiple people, it will be imperative to ensure that the information is of good quality and be able to determine when multiple people report the same issue so that resources are not assigned redundantly.

## 8.2 Contribution

With the expected growth in urban population, and the necessity of adherence to pandemic-related health guidelines, as well as the desire of cities to be able to sustain themselves and stay competitive by attracting talent and investments, there is a need to make the city smart by using information and communications technology. Researchers have argued that starting small is a relevant method for building a smart city because a bottom-up approach is more likely to involve citizens in the process. As a proof of concept, this dissertation aimed to show how this could be achieved by using a university academic building as an example of the process, namely by creating and evaluating a smart lobby application.

With a smart citizen-centric mobile app designed to enhance the user experience, this research not only provides a proof of concept for a smart lobby, it also contributes a framework to assist developers to make a passive academic lobby into a smart lobby that is interactive and meets the needs of the stakeholders.

The elements identified in the DSR approach is a valuable contribution as well as it serves as a guidepost for a repeatable process.

Another contribution of this research project is the citizen-centric process utilized to identify the functionality to be built to make a lobby smart. We invited a pre-focus group of users to identify what is important to them and to rank ideas that would be advantageous and enhance the smart lobby experience. Rank was based on usefulness and users' interest. This strengthens the hypothesis that stakeholder feedback is relevant, and this contribution can guide future approaches to identifying the need of the stakeholder.

The Knowledge Innovation Matrix is a contribution to the knowledge base, since this framework helps by looking at the x-axis for the solution/artifact/theory and the y-axis for the need/opportunity/problem that we solved by the artifact designed. We use the KIM to categorize the innovative nature of this research as falling under the exaptation quadrant as we have applied new knowledge to achieve our goals. This research leveraged sensors and IoT technology for an innovative design and incorporated it in existing space for an application that has a real-world impact. The research extends the use of sensors, GIS, smart-devices and app functionalities to provide guidance to people to maintain safe distance and to utilize available restrooms and be able to view room count to monitor usage, as well as allow people to remotely report any incidences on campus that required attention. The framework artifact that was designed as a contribution of this research also falls under the Exaptation quadrant to ensure successful deployment for a smart lobby as there is no existing framework to make an academic lobby smart taking into account stakeholder and technology considerations. This research has allowed us to make an impact on taking an existing passive lobby and turning it into an ambient environment.

Starting off with a smart academic building lobby and having a framework to implement it in any lobby will allow for quicker implementation and allow organizations to set up a smart, user-friendly lobby using a citizen-centric app. Once a smart lobby has been implemented and successfully adopted, the next focus can be to look for opportunities to make a building smart. Following that, we can focus on making the community smart and, consequently, a city smart. A smart city is thought to be more competitive, attract investments and talent, and have the potential to absorb an influx of people in the urban environment.

## 8.3 Future Research

The work done for this dissertation can be built upon for future research. In this section I will refer to possible lines of further, related research.

Given the limitations afforded due to Covid-19 lockdown, as part of a future study, the services could be deployed in a real academic setting and a larger sample size could be surveyed to help generalize the findings.

This app was designed for Android since the researcher had access to only Android devices. As part of future growth, this app and future additional services could also be designed for iOS.

Another potential future research would be to crowd source ideas and assess the needs of the larger campus community to further develop other services that could prove useful and be applicable to an academic setting. As part of further expansion, besides the three services this app provides, more services could be added to the app as needs change.

With this research we saw that the top-down design approach could potentially be the reason for low adoption of a smart city and the bottom-up approach showed that the users preferred the smart building to other buildings on campus. It would be interesting to take this research further by looking at smart building approaches wherein the city's policies and building codes require new buildings to have built in smarts, and survey the residents to see if they prefer living in these buildings given the functionalities that are built in as part of city's building codes.

Other possibility is to use this research and combine with another research for Building Management System (BMS). BMS manages building systems such as HVAC, security, fire, etc. and utilizing knowledge gained from this research to monitor and control the energy consumption of the building or directing security and fire systems to the areas needed, would be an application that would be quite beneficial to meet the energy efficiency needs as well as protecting and saving lives in emergency situations.

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# Appendix A—Survey of CISAT Students

**PURPOSE:** The purpose of this study is to evaluate a preliminary research ideas related to smart building, specifically, smart Lobby.

**PARTICIPATION:** We will provide you with a preliminary research ideas related to smart building and ask you to rate the proposed ideas.

We really appreciate your participating in this study! We are now going to present you with a brief smart lobby ideas along with use case to illustrate the use of each proposed idea.

**Scale: 1-7**

I think the idea would be

| Uninteresting | 2 | 3 | 4 | 5 | 6 | Very Interesting |
|---|---|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| Useless | 2 | 3 | 4 | 5 | 6 | Useful |
|---|---|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ | ○ | ○ |

**Ideas:**

**Idea 1:** Sensor to count number of people in the building and know their location.

*Use case: If there is a need to evacuate the building or assist during an emergency.*

**Idea 2:** Sensor to monitor indoor/outdoor pollution, UV level. LED light changes color as per pollution level.

*Use case: You can know if there is a high level of pollen/dust and wait till the count goes down as the wind blows it away. Physical plant can take of indoor issue such as Carbon Monoxide leak.*

**Idea 3:** Sensors to check conference room availability in real time and send message to the group to meet.

*Use case: Students/faculty can find and reserve a room available real time and don't need to reach out to an admin to reserve a room.*

**Idea 4:** Map location of water fountains, restrooms, vending machine, library, classroom, medical aid.

*Use case: Find locations easily without having to ask anyone or look for indicators in/on the building.*

**Idea 5:** Sensors to check restroom/classroom vacancy status in real time.

*Use case: Students/faculty can go directly rather than having to go to each floor and checking manually. Saves time.*

**Idea 6:** Get direction to office, conference rooms, etc. via your cell phone using augmented reality.

*Use case: Useful for emergency personnel or for a new visitor. Also, if there is a leak, anyone can take a picture and report it via text to appropriate personnel.*

**Idea 7:** Incidence Reporting on campus

*Use case: Faucet leak, exposed wire, fallen tree. Inform physical plant*

**Idea 8:** Scan people for guns

*Use case - As there have been lots of campus shootings, gun detection will be helpful to prevent such incidences.*

**Idea 9:** Scan visitors as they enter the lobby for health-related feedback.

*Use case: As a visitor enters the lobby, a picture of the person's eye is taken and within a few seconds a message is sent to the person informing him/her if they have high cholesterol. They are then suggested to seek medical attention. This technology has already been built at Claremont. Biometric sensor that detects/monitors emotion such as stress, restlessness.*

**Results**:

| Participant | Type | Idea 1 | Idea 2 | Idea 3 | Idea 4 | Idea 5 | Idea 6 | Idea 7 | Idea 8 | Idea 9 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Interest | 7 | 3 | 5 | 6 | 1 | 7 | 3 | 0 | 0 | 3.6 |
| 1 | Use | 7 | 6 | 7 | 7 | 4 | 7 | 5 | 0 | 0 | 4.8 |
| 2 | Interest | 5 | 6 | 7 | 7 | 7 | 7 | 5 | 6 | 6 | 6.2 |
| 2 | Use | 6 | 6 | 6 | 7 | 7 | 7 | 5 | 6 | 6 | 6.2 |
| 3 | Interest | 5 | 5 | 3 | 4 | 4 | 4 | 5 | 5 | 5 | 4.4 |
| 3 | Use | 4 | 6 | 3 | 5 | 4 | 4 | 5 | 5 | 5 | 4.6 |
| 4 | Interest | 7 | 7 | 7 | 4 | 4 | 4 | 5 | 7 | 6 | 5.7 |
| 4 | Use | 7 | 7 | 7 | 4 | 5 | 5 | 5 | 7 | 4 | 5.7 |
| 5 | Interest | 5 | 4 | 4 | 3 | 5 | 5 | 5 | 6 | 6 | 4.8 |
| 5 | Use | 6 | 3 | 4 | 5 | 2 | 4 | 2 | 7 | 5 | 4.2 |
| | Average | 5.9 | 5.3 | 5.3 | 5.2 | 4.3 | 5.4 | 4.5 | 4.9 | 4.3 | |

# Appendix B—Qualitative Survey for Framework

1. I find the framework appropriate for a smart lobby

2. I would recommend the following changes to the framework

3. Other Comments

# Appendix C—Pre and Post-Test for a smart lobby

| | Strongly Disagree | | | | Strongly Agree |
|---|---|---|---|---|---|
| 1. I think the lobby is smart | 1 | 2 | 3 | 4 | 5 |
| 2. I know which restroom is available for use. | 1 | 2 | 3 | 4 | 5 |
| 3. I find it difficult to find available meetings rooms | 1 | 2 | 3 | 4 | 5 |
| 4. I can report issues to facilities department easily | 1 | 2 | 3 | 4 | 5 |
| 5. If I notice a safety issue, I can easily report it | 1 | 2 | 3 | 4 | 5 |

6. I prefer this building to others on campus.

| | | | | |
|---|---|---|---|---|
| | | | | |
| 1 | 2 | 3 | 4 | 5 |

7. I think the app has made me productive

| | | | | |
|---|---|---|---|---|
| | | | | |
| 1 | 2 | 3 | 4 | 5 |

| Qualitative Question for Post-Test: Any other feedback: |
|---|
| |

# Appendix D—QUIS for App

## The Questionnaire of User Interaction Satisfaction (QUIS) for app

Please circle the number which most appropriately reflects your impression about using this system

N/A = Not Applicable

**Overall User Reaction:**

| | Terrible | | | | | | | Wonderful | |
|---|---|---|---|---|---|---|---|---|---|
| Overall reaction to the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Frustrating | | | | | | | Satisfying | |
|---|---|---|---|---|---|---|---|---|---|
| Overall reaction to the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Difficult | | | | | | | Easy | |
|---|---|---|---|---|---|---|---|---|---|
| Overall reaction to the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Inadequate Functionality | | | | | | | Adequate functionality | |
|---|---|---|---|---|---|---|---|---|---|
| Overall reaction to the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Rigid | | | | | | | Flexible | |
|---|---|---|---|---|---|---|---|---|---|
| Overall reaction to the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

**Mobile Screen:**

| | Hard to Read | | | | | | | Easy to read | |
|---|---|---|---|---|---|---|---|---|---|
| Characters on the Screen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Unhelpful | | | | | | | Helpful | |
|---|---|---|---|---|---|---|---|---|---|
| Navigation on the Screen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Confusing | | | | | | | Clear | |
|---|---|---|---|---|---|---|---|---|---|
| Organization of Information | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Confusing | | | | | | | Clear | |
|---|---|---|---|---|---|---|---|---|---|
| Sequence of features on the app | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

**Terminology and System Information:**

| | Inconsistent | | | | | | | Consistent | |
|---|---|---|---|---|---|---|---|---|---|
| Use of terminology throughout the system | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Never | | | | | | | Always | |
|---|---|---|---|---|---|---|---|---|---|
| Terminology relates well to the work you are doing | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

| | Inconsistent | | | | | | | Consistent | |
|---|---|---|---|---|---|---|---|---|---|
| Position of messages on the screen | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

**Learning:**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Difficult | | | | | | | | Easy | |
| Learning to use the App | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |
| | Never | | | | | | | | Always | |
| Performing tasks is straightforward | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

**App capabilities:**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Too slow | | | | | | | | Fast Enough | |
| App Speed | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |
| | Difficult | | | | | | | | Easy | |
| Correcting your mistakes | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |
| | Never | | | | | | | | Always | |
| Designed for all level of users | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | N/A |

# Appendix E—Overall Outcome of the Project

| | Strongly Disagree | | | | Strongly Agree |
|---|---|---|---|---|---|
| 1. I am more excited about being in the Lobby now. | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| 2. Is the Lobby Smart now? | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| 3. Before using the app, I was aware of the app for finding available restrooms. | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| 4. Before using the app, I was aware of the app for Conference Room searching and reserving. | | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| 5. Before using the app, I was aware of the app for Incident reporting. | | | | | |

# Appendix F – IRB Exemption

**4097 IRB Review Not Required**

CGU IRB <noreply@axiommentor.com>
Wed 9/29/2021 2:23 PM
To: Neelam Raigangar

Claremont Graduate University
*Institutional Review Board*

09/29/2021

Dear Neelam,

An IRB representative has conducted a preliminary review of protocol **IRB # 4097 Smart Professional Organizational Building.** Pursuant to federal regulations 45 CFR 46.102(e)/(l), your project is not human subjects research, and does not require further IRB review or oversight.

Please note that changes to your protocol may affect this determination. Please contact me directly to discuss any changes you may contemplate.

Respectfully,

James Griffith,
IRB Manager
james.griffith2@cgu.edu

150 East Tenth Street • Claremont, California 91711-6160
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