CONTACTLESS AND CONTEXT-AWARE DECISION MAKING FOR AUTOMATED BUILDING ACCESS SYSTEMS

DJORDJE STOJANOVIC[1] and MILICA VUJOVIC[2]
[1]*University of Melbourne*
[1]*d.s@unimelb.edu.au*
[2]*University Pompeu Fabra*
[2]*milica.vujovic@upf.edu*

Abstract. In the current context of the COVID-19 pandemic, contactless solutions are becoming increasingly important to making buildings more resilient to the spread of infectious diseases in complementing social distancing and disinfection procedures for disease prevention. The presented study focuses on contactless technology and its role beyond automated interaction with the built environment by examining how it expedited space use and could improve compliance with sanitary norms. We introduce a conceptual framework for the intelligent operation of automated doors in an educational facility, enabled by the network of sensory devices and the application of computational techniques. Our research indicates how versatile data gathered by RFID systems, in conjunction with data extracted from occupancy schedules and sanitary protocols, can be used to enable the intelligent and context-aware application of disease prevention measures. In conclusion, we discuss the benefits of the proposed concept and its role beyond the need for social distancing after the pandemic.

Keywords. Human-Building Interaction; Interactive Environments; Responsive Environments; Occupancy Scheduling; Occupational Density.

1. Introduction

Contactless technology is rapidly finding applications in medicine, retail, and travel. In the current context of the COVID-19 pandemic, contactless solutions are also becoming increasingly important to making buildings more resilient to the spread of infectious diseases in complementing social distancing and disinfection procedures for disease prevention. To this end, public touchpoints in workplaces, lobbies, toilets, and elevators are being replaced with touchless interfaces. However, the cumulative impact of contactless solutions such as automatic doors, soap dispensers, taps, and electrical switches on how buildings are used is not fully understood. The potential of nascent technologies, enabling touchless interaction in the built environment is not adequately explored, and its relation to how buildings are designed and used is not fully discussed. Interactions

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between buildings and their occupants through multi-modal Human-Computer Interaction such as interactive speech and gesture recognition can dramatically enhance the way buildings are experienced, managed, and operated (Malkawi and Srinivasan 2005). The presented study focuses on contactless technology's purpose beyond automated interaction with the built environment, and it examines its role in expediting space use to improve compliance with sanitary norms.

We introduce a conceptual framework for the intelligent operation of automated doors that would be used in an educational facility, enabled by the network of sensory devices and the application of Computational Techniques (CTs). While focusing on a school building's needs, the paper shows how data capturing occupancy patterns, health and disease prevention measures, and learning environment requirements are coordinated to inform automatic doors�something operation. The data is used to enable seamless entry to and trespassing across different areas of the school. The proposed framework would assist a 'return to the campus' as a tool for balancing between students' individual needs, social distancing measures, new sanitation protocols, class timetable, and curriculum specific requirements. In response to CAADRIA 2021 'Projections' topic of Interactive Environments, this paper contributes to computational design innovation by grounding a method for the application of CT's to enact evidence-based inquiry into architectural notions of context, access, and the relationship between people and buildings.

This paper outlines the research as follows. In the first section, a brief literature review establishes known technologies supporting contactless access systems and context-aware decision-making techniques relevant to the built environment and applicable to school buildings. The emphasis is placed on the use of Radio-Frequency Identification (RFID) systems. The aim is to create an information-rich decision-making context for automated access systems to the school building to help implement social distancing measures while maintaining efficient use of spaces. And to employ sensing devices to facilitate contactless interaction with the built environment. We propose and describe the use of an algorithmic framework to control the operation of automated doors across the school building, using the Melbourne School of Design building as a setting for our research. In the results section, we present a framework for data collection, processing, and structuring. Our research indicates that versatile data gathered by RFID systems, in conjunction with data extracted from occupancy schedules and sanitary protocols, can be used to enable the intelligent and context-aware application of disease prevention measures. In conclusion, we discuss the benefits of the proposed conceptual framework and its role beyond the need for social distancing after the pandemic.

2. Background Research

The investigation related to touchless interaction systems in the built environment is part of a broader and growing research scope on the use of sensing devices for data gathering and CTs for information processing. Sensing devices most commonly applied in capturing data from the built environment include Passive Infrared (PIR) sensors, Carbon-Dioxide (CO2) detectors, Radio-Frequency

Identification (RFID), Wi-Fi counters, optical and infrared cameras, and a combination of devices to compensate for their individual insufficiencies (Hobson et al. 2019). At the same time, an increasing number of studies into advanced CTs shows how computation is employed to improve accuracy and robustness and reduce the operation cost of sensing devices (Dai et al. 2020).

RFID, as well as PIR based systems, are tried and tested solutions for automated access in buildings. While PIR sensors measuring infrared light radiating from objects in the field of view offer cost-effective and reliable solution for the operation of automated doors, RFID based systems permit wider application and can be used to collect diverse information from the built environment, such as location and identification of goods, animals, and humans (Irani et al. 2009, Oliveira et al. 2016). Advances in RFID technology first introduced in the 1990s are well documented by researchers in 17 190 papers published between 2006 and 2015 (Oliveira et al. 2016). The reduction of cost and the increase of longevity enable even more extensive use of this versatile technology. Systems composed of several readers, a large population of tags with an antenna and a server, are used in conjunction with information processing techniques to enhance their performance and structure data acquired by the system for multiple uses (Chen et al. 2018). For example, in the Architecture, Engineering, Construction, Owner and Operator industry, multi-level encryption is used to enable role-based access to data stored on tags attached to building components (Motamedi et al. 2011). In terms of access to buildings, the use of rules to override the system's binary operation is successfully linked with either PIR of RFID systems to either restrict or grant access at certain times (Aprilananda-Sujatmoko and Sujarwo 2020).

Moreover, the use of roles, i.e., for staff and students, with RFID systems, is developed for selective application of rules according to predetermined privileges (Rahman et al. 2019). Additional benefits to the security features of a door locking system can include a log containing check-in and check-out of each user along with basic information of use (Verma and Tripathi 2010), and can help attendance management by registering and tracking tags (Chiagozie and Nwaji 2012). Therefore, albeit some challenges to the implementation, such as those related to dealing with colliding tag responses and facilitation of the efficient tag identification (Wu et al. 2020) and factors such as attenuation and cross paths of signals or interference between systems (Ting et al. 2011), RFID systems provide a tool for harvesting versatile information from the built environment.

Recent research shows that the information gathered by RFID systems and other sensing devices, when processed and structured, can become valuable to understanding behavioural patterns (Guo et al. 2019) and intelligent management and operation of buildings (Duan and Cao 2020). Wireless sensor networks, groups of sensors linked with wireless media, have found diverse applications in the built environment linked to both optimising the use of resources and occupants' wellbeing (Wu and Noy 2010). Strides in miniaturization, wireless networking, and sensor technologies enable computers to be used in more places and have a greater awareness of the dynamic world they are a part of (Hong and Landay 2001). Recognizing context from the sensor data plays a crucial role in adding value to the raw sensor data, and therefore context-awareness is considered the core feature of ubiquitous and pervasive computing systems (Yang and Cho 2017).

Context is regarded as a key factor of computation, alongside the explicit input and output (Moran and Dourish 2001). Context-aware computing and computational frameworks are employed to automate and integrate context-aware sensing, data aggregation, information extraction and understanding, and qualitative decision-making through intelligent algorithms (Biswas et al. 2016). Recent research involving context-aware systems for home automation proposes the hierarchical model to reason from uncertain facts inferred from real sensor data (Chahuara et al. 2017) and adaptive decision-making systems for learning from data (Brenon et al. 2018).

The primary use of RFID-based automated access to educational buildings is driven by the need to improve the security of occupants and assets (e.g., Farooq et al. 2014, Rahman et al. 2019). However, in the context of the current COVID-19 pandemic, this study examines how the existing automated and RFID supported access systems can be enhanced using CTs to include context-aware decision-making and improve occupants‘ health and well-being while maintaining the efficient use of facilities. The proposed system aims to respond to occupants' needs and balance between efficient space usage and sanitary measures imposed by the current pandemic.

3. Research Aims

An automated access system's default role would be to open or close a door when an occupant approaches and passes through that door. From the disease prevention point of view, this helps minimize exposure to potentially contaminated door handles. The system can be put in operation at certain times of the day, which is also helpful as it can restrict access when there is no need for the use of individual facilities, and therefore, minimize further any unnecessary exposure. Significantly, the system could also facilitate the right of entry to only some users. For example, staff could be allowed to enter individual rooms while students may not be, which could also help minimize unnecessary contact. These features are achieved with well-known and frequently applied RFID systems in educational facilities, initially introduced to improve security in buildings identified in this paper's previous section. In the context of the current pandemic and much-expected return to campuses in Australia, these contactless interfaces have also become valuable as they minimize exposure to public touchpoints. However, the system's ability to selectively give access to some occupants offers itself as an effective disease prevention tool and forms this study's focus.

The aim is to define a decision-making context and develop an information processing framework to facilitate automated access to the school building's rooms to help implement disease prevention measures and disinfecting procedures while enabling efficient use of spaces. The proposed system's role is to open or close doors at certain times for certain users when certain conditions are met. The objective of this study is to help establish what users under what circumstances are permitted to enter individual rooms of the school. The study aims to answer the following research questions. What information is relevant, and how is it processed to create a disease prevention computing context? And what sensing tools and CTs can be employed to facilitate an intelligent access system within such a context?

The study addresses the Melbourne School of Design building's needs to examine the correlation between social distancing measures, disinfection procedures, and activity schedules to inform automated doors' operation. The study aims to provide intelligent and dynamic assistance rather than to apply generic disease prevention measures, insusceptible to human behaviour's unpredictability. Current disease prevention measures related to the use of buildings, namely social distancing rules, are generic and do not address the nature of activities and rooms. Moreover, current measures do not take many human-related aspects into account. Human behaviour varies, and it is difficult to predict, and therefore the application of uniform measures may not be adequate at all times

4. Framework for context-aware automated building access

The proposed algorithmic framework outlines a method for data harvesting to create a decision-making context. The computing context is built from the information gathered by RFID devices and extracted from occupancy scheduling. There are three relevant sets of data. First, the new sanitary protocols impose disinfection procedures in an individual room between occupational shifts, such as when one tutorial group leaves, and the other takes possession. Although cleaning slots are programmed and scheduled, restricting access to a room to students and staff while cleaning is in progress would enhance their safety by reducing unnecessary exposure to potentially contaminated areas or surfaces. Second, an RFID system controlling door operation at the entrance to a room provides the count of people entering and exiting the room. The count is translated into the number of people in a room and checked against social distancing norms, currently requiring 4 [m2] area per user to establish if more users can be allowed to that room. Third, timetabling and class schedules provide valuable sources of information for the operation of doors. For instance, access permission can be given selectively to students registered for a class unfolding in a specific room. In turn, this would also enhance their well-being by further minimisation of contact and the probability of breaching social distancing rules. At this stage, the proposed approach is to extract data from class timetabling and cleaning protocols to inform the system, while occupants count data is to be provided by RFID system monitoring access to individual rooms. We recognize that occupancy scheduling in educational buildings is becoming an increasingly complex field and identify the need to address how data gathered by RFID count could be used to inform timetabling in future studies.

Based on the occupant's alignment with one of the predetermined roles, the decision-making process is outlined in the second part of the proposed algorithmic framework (Figure 1). Such roles would typically be students, teachers, cleaners, maintenance, and security in school buildings. Moreover, within each role, subcategories would be used to further differentiate between occupants' privileges.

For example, students' access to individual rooms would be related to their enrolment in subjects or study programs. The use of roles is a well-developed feature of RFID systems whereby individual users are listed in sets and subsets with different access privileges, initially developed to enhance security and ease people's circulation through buildings. In this study, an RFID system with a role feature is used to exercise access control to individual rooms to improve disease prevention measures while maintaining efficient use of space in educational buildings.

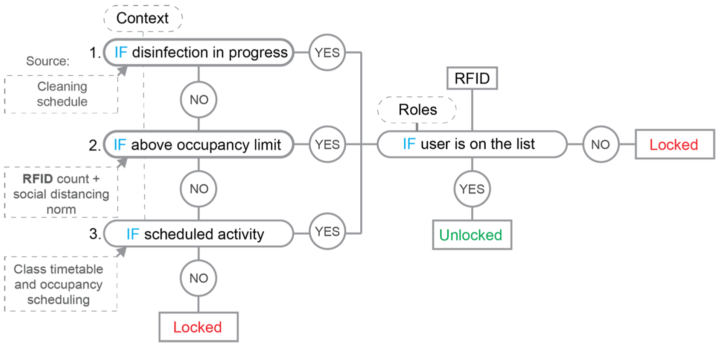

Figure 1. Computational framework for a contactless and context-aware building access system.

The proposed conceptual framework's significance is the ability to collect data across three levels of inquiry and evaluate if it is safe for a particular role to have access to that room, or if the presence of a specific role would compromise other occupants' safety, such as to students and staff during disinfection routine. The proposed concept's main benefits are enabling contactless interaction with the building, enacting intelligent and context-sensitive application of disease prevention measures rather than generic social distancing measures, and the capacity to act preventatively by minimizing overcrowding in buildings

The visible and tangible part of the proposed system, or the actuation, would be through a controlled operation of the automated door system, facilitating the right of entry to individual rooms if specific conditions are met. Four different scenarios are presented to examine the flow of information and demonstrate possible outcomes (Figure 2).

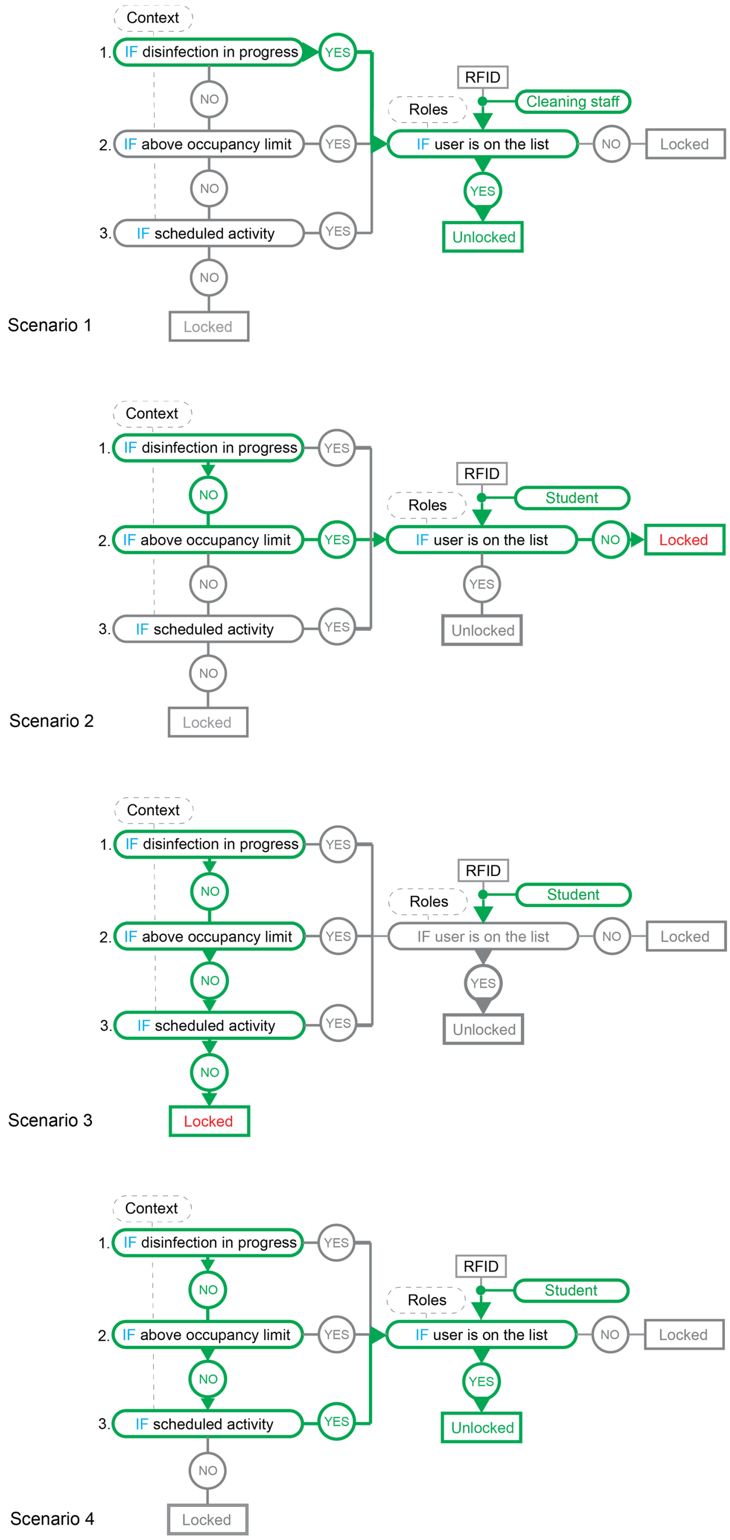

Figure 2. Four scenarios for information processing with outcomes.

Scenario 1 shows that when cleaning is in progress, doors are locked for everyone but specific user IDs, such as cleaners, maintenance, and security. In Scenario 2, it is not a cleaning time, but occupants count is high, and social distancing measures are compromised. The critical threshold or the number of people allowed to any room fluctuates according to prescribed sanitary norms. In the context of the COVID-19 pandemic, currently prescribed norms fluctuate between 2 and 4 [m2] area per user. The number of people allowed in the room is calculated when the room's floor area is divided by 4. If an RFID reader positioned at the room entrance records a critical number of occupants, the access is restricted to students, and everyone but personnel dealing with the emergency is meant to be out of the room. In Scenario 3, an occupant's tag is identified as a student, disinfection is not scheduled at this time, occupants' count is below the critical threshold, but the room is not booked through timetabling, and therefore, access to students is not granted. This inquiry line could be extended to establish if the occupant, student, or teacher is directly involved with scheduled activities. If the student is not enrolled in the study programme scheduled to occur in that room, their access to the room will be denied, giving priority to occupants enrolled in classes unfolding in that room. Scenario 4, all levels of inquiry are satisfied according to the occupant's ID, and doors are automatically unlocked and opened to grant access and avoid the use of public touchpoints such as door handles. The proposed system would facilitate a far greater number of scenarios, and four selected scenarios are to demonstrate the flow of information and possible outcomes.

5. Discussion and Conclusions

The proposed conceptual framework is an innovative use of the existing RFID based technology, enabling an automated and context-aware building access system to improve infection control measures. The primary use of RFID-based automated access to educational buildings is in improving security. However, in the context of the current COVID-19 pandemic, this study examines how the existing automated access systems can be enhanced using CTs to include context-aware decision-making to improve occupants' health and well-being and the efficient use of facilities. The proposed system is designed to maintain efficient use of space while responding to sanitary measures imposed by the current pandemic. The contactless human-building interaction is employed to minimise exposure to potentially contaminated surfaces and public touchpoints. It also expedites the use of space to improve compliance with the sanitary norms by granting access to individual rooms only when it is safe or when occupational density complies with social distancing rules and when disinfecting or cleaning protocols are not unfolding.

The research question, on what information is relevant, and how it is processed to create a disease prevention computing context is answered with a formulation of an algorithmic framework, identifying input information structured across three conditions or layers of inquiry before the actuation, lock/unlock door status could be granted. The second research question on what sensing tools and CTs are employed to facilitate an intelligent access system within the defined context is answered by structuring the relationship between conditions and occupants' identity, redacted and reduced to one of the predefined roles.

The proposed framework sets grounding for further research and developing a fully functional prototype that could be useful to the Melbourne School of Design building. At this stage, the study results with a concept seeking further development through evidence-based research. The study reported in this paper relies on known RFID techniques and explores the combined use of different data sets to establish a decision-making context. However, the correlation of data acquired by the network of sensory devices and data extracted from class timetabling and disinfection protocols is not fully resolved at this stage. The study's further limitations include dealing with a high flux of students and staff in the school, potentially resulting in colliding signals and interference between different systems in close proximity to each other

Beyond improving infection control measures in school buildings, this study's contribution is in expanding the architectural meaning of the context through sensing devices and CTs. It probes into human-building interaction and suggests a way to study the built environment through human behaviour. In the longer run, data acquired with the proposed wireless sensor networks could provide valuable insight into how buildings are used and help both researchers and designers explore context-sensitive and intelligent solutions to improve indoor environmental quality

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