Indoor Positioning System for Occupation Density Control

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1 Indoor positioning system for occupation density control, concept drawing.

ABSTRACT

The reported research focuses on occupational density as an increasingly important architectural measure and uses occupancy simulation to optimize distancing criteria imposed by the COVID-19 pandemic. The paper addresses the following questions: How to engage computational techniques (CTs) to improve the accuracy of two existing types of indoor positioning systems? How to employ simulation methods in establishing critical occupation density to balance social distancing needs and the efficient use of resources? The larger objective and the aim of further research is to develop an autonomous system capable of establishing an accurate number of people present in a room and informing occupants if space is available according to prescribed sanitary standards. The paper presents occupancy simulation approximating input that would be provided by the outlined multisensor data fusion technique aiming to improve the accuracy of the existing indoor localization solutions. The projected capacity to capture information related to social distancing and occupants' positioning is used to ground a method for determining a room-specific occupational density threshold. Our early results indicate that the type of activities, equipment, and furniture in a room, addressed through occupants' positioning, may impact the frequency of distancing incidents. Our initial findings centered on simulation modeling indicate that data, composed of the two sets (occupant count and the number of recorded distancing incidents) can be overlapped to help establish room-specific standards rather than apply generic measures. In conclusion, we discuss the opportunities and challenges of the proposed system and its role after the pandemic.

INTRODUCTION

The reported research focuses on occupational density as an increasingly important architectural measure in the context of the COVID-19 pandemic. This paper examines the role of computational techniques (CTs) in making buildings less hospitable to viruses, and how autonomous and noninvasive occupancy detection systems can inform the way buildings are used and designed in the future. The ability to measure data from the built environment has rapidly increased, but occupancy analytics and indoor positioning systems' role in making buildings comply with infection control measures are not sufficiently explored nor fully discussed.

This paper outlines the research as follows. A brief literature review establishes state of the art on occupancy detection and indoor localization systems in the first section. The second section introduces the concept of real-time occupational density control applicable to school buildings and how simulation is employed. An examination of challenges follows, and the research method is described. The aim is to establish what instruments and techniques may be used, how to employ known indoor positioning systems, and what level of positioning precession is required to determine room-specific distancing criteria to help minimize the spread of infectious diseases and maintain efficient space usage. The data obtained would inform occupants and be used to train the system to determine dynamic occupancy limits in compliance with Workplace Directions (Public Health and Wellbeing Act) for Victoria, Australia. The next section presents the computational framework and simulation modeling for the Melbourne School of Design (MSD) building. Our research indicates that data—composed of (1) occupants or "available slots" count and (2) the number of recorded distancing incidents—can be overlapped to help optimize standards for individual rooms, rather than apply generic measures. In conclusion, we discuss results obtained by simulation and the benefits of the projected solution.

Related Work

Recent research involving occupancy data and indoor positioning can be categorized according to three questions: how to measure occupancy (Hobson et al. 2020; Sardar, Mishra, and Khan 2020; Sun, Zhao, and Zou 2020), how to clean and structure information once it is measured (Dai, Liu, and Zhang 2020; Datta and Chatterjee 2019; Liang, Hong, and Shun 2016; Saha et al. 2019), and finally how to use it to solve real-life problems (Hanse 2015; Hsu, Chen, and Perng 2020; Ouf, O'Brien, and Gunay 2019; Pallikere et al. 2019; Suzuki et al. 2015). Techniques most commonly applied for occupancy measuring include the use of passive infrared (PIR) sensors, carbon dioxide detectors, radio-frequency identification (RFID), Wi-Fi counters, optical and infrared cameras, and sensor fusion approaches involving a combination of devices to compensate for their individual insufficiencies (Hobson et al. 2019). Occupancy data is elusive and difficult to capture with high-level accuracy (Sun, Zhao, and Zou 2020). The proximity between occupants and dealing with a high number of people in the same room are particularly challenging (Berry and Park 2017). Inherent noise and occlusion in dynamic environments pose challenges for reliable occupancy measuring (Abbas et al. 2019; Großwindhager et al. 2017). The occupancy attribute indeed has two values only, occupied or not occupied (Kumar et al. 2018), but measuring and processing occupancy information may be complex when associated with time and space, and occupancy detection may be classified as tracking (Saha et al. 2019). Advanced computational techniques for data structuring and prediction are employed to improve accuracy and robustness and reduce operation costs of indoor positioning systems. There is an increasing number of studies (2,142 studies recorded in 2019 alone) into machine learning models such as logistic regression, artificial neural networks (ANN), the Markov chain model, decision trees, k-Nearest Neighbor (kNN), and support vector machines (SVM) related to buildings (Dai, Liu, and Zhang 2020). Finally, occupancy data is still primarily focused on the performance of building automation systems (BAS), resulting in energy savings. However, there are growing indications that occupancy data is valuable to architectural design (Gomez-Zamora et al. 2019), user experience (Hansen 2016), security, resource management (Suzuki et al. 2015), and public transportation (Hsu, Chen, and Perng 2020). This paper addresses challenges related to the accuracy and reliability of indoor positioning systems. It describes simulation methods to examine the potential of CTs to improve the usage and well-being of occupants. At the time the research was conducted and this paper submitted, workplace and activity directions issued by the Department of Health and Human Services, Victoria State government, restrict access to university buildings. Therefore, we relied on simulation modeling to develop the system and test its viability before real-life implementation is possible.

RESEARCH AIMS

This study aims to provide a crucial contribution to the development of a prudent solution for implementing social distancing measures in response to the COVID-19 pandemic. Our initial research recognizes challenges faced by current indoor localization systems, namely positioning accuracy and dealing with multiple occupants. In response, we propose the use of a multisensor data fusion approach to improve location precision and reliability of results. The principal aim is to ground the method for determining the room specific occupancy limits, using the rule of 1.5 m distance between users, or 4 m^2 per user as a departing point of the study. The paper addresses the following research questions: How to employ simulation methods in establishing a room-specific occupation density to balance between social distancing needs and the efficient use of resources? How to engage CTs to improve the accuracy of two existing types of indoor positioning systems?

This study aims to answer research questions by simulating an occupancy detection system operation at the micro level and in an indoor environment to benefit the use of educational buildings, where the introduction of social distancing rules imposes a new usage norm. The goal is to use findings obtained through simulation to enable further research leading to the development of an autonomous system capable of establishing the exact number of people present in each room or zone of the school and of informing occupants if space is available in that classroom, lab, or studio according to health and safety standards prescribed by Workplace Directions (Public Health and Wellbeing Act) for Victoria, Australia. To that end, we outline a computational technique to reduce measurement inaccuracies of the two existing occupancy detection systems. And we use simulation modeling to examine occupancy scenarios and set the foundations of a method for establishing a room-specific maximum of occupants while maintaining adequate distancing measures.

METHOD

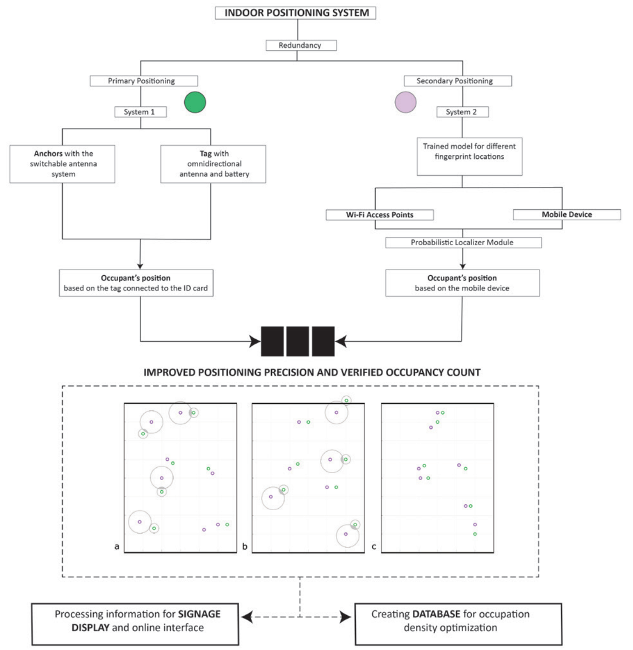
An Approach to Improving the Positioning Precision

Our background research suggests that the existing indoor positioning solutions would require further development to facilitate studies related to social distancing requirements imposed by the COVID-19 pandemic. Therefore, we propose a technique that relies on an overlap between two existing types of occupancy detection systems, one employing RFID anchors and tags, and the other one based on the use of Wi-Fi counters and individual mobile devices (Fig. 2). System 1, such as Decawave DW1000, is a low-cost indoor positioning system based on the off-the-shelf ultra-wideband transceiver (Kulmer et al. 2017). It uses a single anchor and multipath wall reflections to establish an accurate position of a tag. The system operates up to a decimeter accuracy to update the position tags in real time while not requiring additional infrastructure. The frequent use of ID cards in school buildings eases implementing a solution based on personal tags. System 2, such as WiDeep, is a deep learning-based localization system with high accuracy (Abbas et al. 2019). It is designed to deal with inherent noise and device heterogeneity in counting mobile device signals to establish the number of people present in a specific room.

The two systems are based on related principles, employing different but well-known devices. The first uses an anchor or antenna and high bandwidth signals to locate tags or agents. The second utilizes a transmitter or a signature collector module, which scans for access points and analyzes signal strength to determine the distance and thus the location of individual mobile devices. However, both solutions employ advanced computational techniques to improve positioning accuracy. System 2 utilizes a two-phase fingerprinting-based approach of localization, composed of offline training and online localization. During the training phase, the signature collector module scans for access points, allowing the computational systems to learn their signal strengths and, in this specific solution, to building a deep neural network per each point of interest (Abbas et al. 2019). It is reported that the proposed CT improves traditional techniques' accuracy by 29.8%, with a consistent mean accuracy of 121 cm for the spatial configuration of interest to our study (Abbas et al. 2019). System 1 exploits signal reflections by incorporating floor-plan knowledge and using a positioning algorithm to improve accuracy (Kulmer et al. 2017). It is reported that the proposed technique demonstrates reliable results at an accuracy of 50 cm (Kulmer et al. 2017).

The initial plan to build the prototype and use data acquired by two systems for further research is replaced with simulation modeling due to the ongoing lockdown restrictions. The developmental framework for the multi-sensor data fusion technique involving the simultaneous and correlated operation of two systems, enhanced by CT to alleviate their limitations and increase the reliability of data needed for the next research phase, is outlined as follows.

The proposed input information consists of two categories, the number of people in the room and their location, established by each system separately. The output information is a verified number of occupants and a median position of each occupant measured by two systems. The number of occupants is verified when the count by two systems is the same, while occupants' position is determined at the intersections of two location areas established by two systems. Measurements from two systems are compared, and the average value is calculated to compensate for their individual insufficiencies and minimize a potential mistake. The two occupancy detection solutions' measurements are operating with acceptable tolerances of 0.5 and 1.2 m. However, neither one of the two systems on its own would be able to determine occupants' position with a needed



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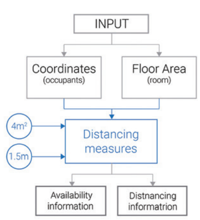

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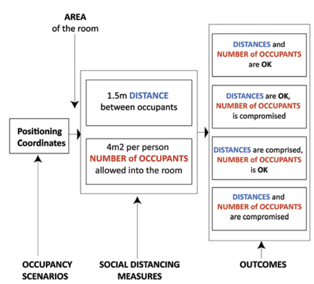

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2 An approach to improving positioning precision.

3 Computational framework to examine current distancing measures.

4 Simulation framework for indoor positioning for MSD studio room.

level of accuracy to help implement social distancing rules. Their limitations are also related to dealing with multiple occupants. Previous studies involving these two systems (Abbas et al. 2019; Kulmer et al. 2017) and other research efforts related to indoor positioning (Berry and Park 2017) report challenges in establishing an occupant count when as little as three people are present in the same room.

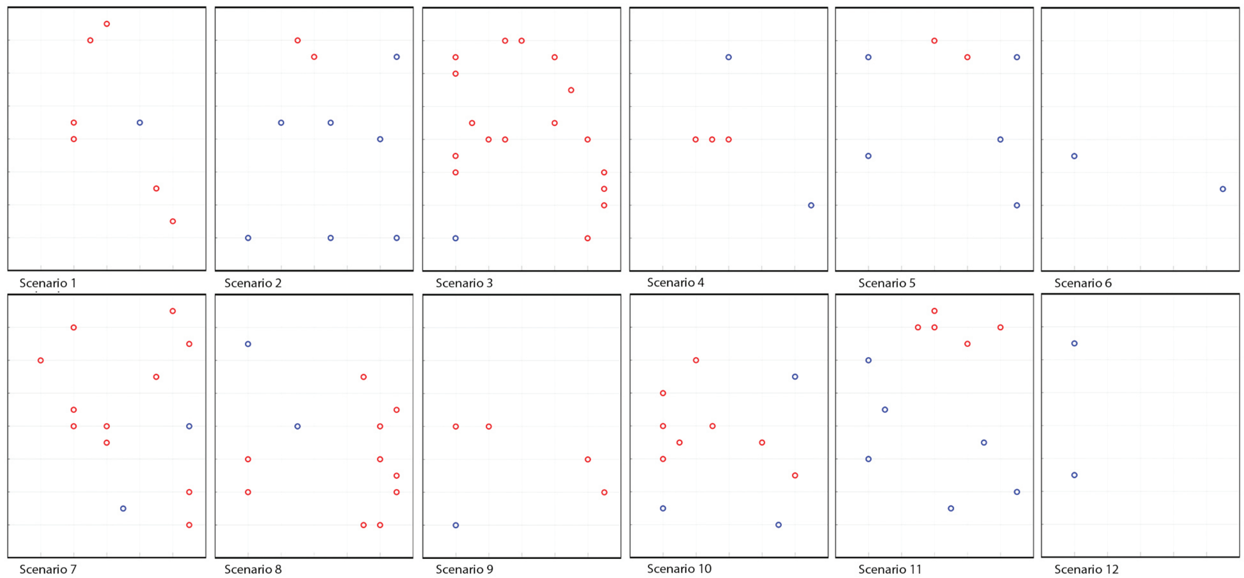
The proposed CT is to reduce any potential error arising from the limited accuracy of sensing devices in establishing and confirming the location of Wi-Fi access points and RFID tags. Measurements from both systems are taken into account with their accuracy threshold. Each occupant's location is recorded as a circle area, R1.2 m for System 1, and R0.5 m for System 2, instead of a single point. It is anticipated that the two detection systems will provide marginally different locations, resulting in different centers and, therefore, misaligned areas of two circles. An intersection of these two areas is the increased precession zone. Initially, the count of people in the room as well as occupants' positioning may not coincide with the two systems. A signal passing through partitions may contribute to two systems giving different occupancy counts. A person standing close to the dividing wall may be accounted for as standing inside or outside a room. Both positioning and counting of occupants are essential to disease prevention measures, and this is how the proposed multisensor data fusion technique increases the positioning precision to help implement social distancing measures.

When information obtained by the two indoor positioning systems is compared and verified, it is processed as follows: the established number of occupants is checked against the maximum allowed in that room, calculated when the floor area is divided by an area designated for each occupant as an effective disease prevention measure. The result would be communicated as an instant message via a purpose-developed signage system, positioned at the room entrance and operating much like a street traffic light. Also, the number of occupants in each room would be displayed online in real time, allowing remote planning. At this research stage, occupancy data is randomly generated to enable the development of the intelligent and room-specific occupational density control presented in this paper. The following section presents the computational framework and introduces simulation modeling carried out to date.

Computational Framework

The computational framework shows how information that would be gathered by sensory devices, RFID anchors, and Wi-Fi counters is processed to create two valuable data sets. The input consists of the precise positioning for each occupant given with their coordinates and floor area. The maximum number of people allowed in that room is calculated when the floor area is divided by an area designated for each occupant as an effective COVID-19 prevention measure. There are two output categories, availability information, expressed as available slots, and distancing information, expressed as distancing incidents (Fig. 3).

More importantly, the overlap of these two categories is recognized for its potential to help optimize the number of people allowed in any room. While it is understood that fewer people in the room will result in easier distancing, we aim to establish an evidence-based technique for finding a critical threshold at which the distancing incidents rate



Scenario	Sc.01	Sc.02	Sc.03	Sc.04	Sc.05	Sc.06	Sc.07	Sc.08	Sc.09	Sc.10	Sc.11	Sc.12
Occupants allowed 4 [m²]	12	12	12	12	12	12	12	12	12	12	12	12
Occupants present	7	9	20	6	7	2	14	12	5	11	11	10
Distancing incidents 1.5 [m]	6	2	19	3	2	0	12	10	4	8	5	0

5 Visual output and data overview for 12 simulated scenarios for MSD studio room with a varied number of occupants.

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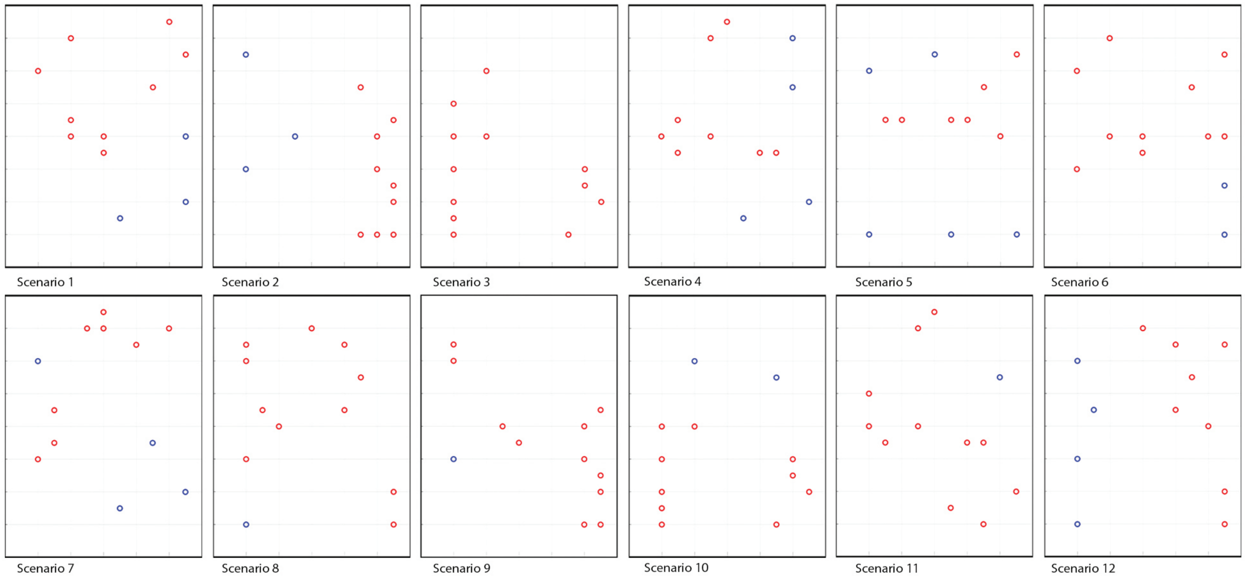
starts to peak. The aim is to maximize the number of people and minimize the number of distancing incidents through the dynamic and responsive implementation of infection control measures. The study focuses on the micro environment of the MSD building. It examines one of many studio rooms measuring approximately 48 m^2 with a single doorway to the gallery-type access. Studios are designed with a capacity of 16 students. Under the new usage norms imposed by disease prevention measures, capacity is reduced by 25%.

Modeling Indoor Positioning at MSD Building

The simulation examines the correlation between distancing incidents and a generic density norm, converted to the number of people allowed in any room (Fig. 4). The objective is to simulate a number of occupancy scenarios to examine the efficiency of current distancing measures and establish a method for determining a room-specific maximum occupancy while maintaining adequate distancing measures. Social distancing measures of 1.5 m distance between users and 4 m^2 per user are employed as initial parameters, resulting in one of four possible outcomes because compliance with one measure does not necessarily mean compliance with the other. The two measures, distancing between occupants and area allocated per each occupant, do not impose the same occupancy limits. While the area of 4 m^2 can be notionally allocated to each user, human behavior is a lot less predictable and may often result in the 1.5 m distancing rule's breach. The type of activities, equipment, and furniture in a room may all impact the frequency of distancing incidents. In the end, people are not always able to judge the distance with sufficient accuracy or may not always be aware that another person is behind them. To that end, the record of distancing incidents and the number of people in the room at the time of the incident is important to establish an efficient occupancy limit. The simulation aims to establish the ratio of distancing breaches to the number of people present in a specific room. It is assumed that different occupational densities may be recommended for two rooms of the same size, in addition to generic prevention measures.

RESULTS

At the time of this paper's submission, university education in Victoria is delivered solely via online teaching mode, with a much expected return to the campus according to the new usage standards scheduled for early 2021. Therefore, we rely on simulation modeling to examine the correlation between availability and distancing data sets. The simulation model is developed to process data that would be provided by the proposed multisensor fusion technique, given as coordinates of occupants in the room and the room's occupational capacity derived from its size and social distancing parameters. For the purpose of presented research, the input data is generated randomly but in line with the plan acquisition to enable the objective to explore the overlap between distancing incidents and the number of people in the room (or the number of available slots). The simulation's visual output shows a schematic floor plan with occupants' locations recorded in three-minute



Scenario	Sc.01	Sc.02	Sc.03	Sc.04	Sc.05	Sc.06	Sc.07	Sc.08	Sc.09	Sc.10	Sc.11	Sc.12
Occupants allowed 4 [m²]	12	12	12	12	12	12	12	12	12	12	12	12
Occupants present	12	12	12	12	12	12	12	12	12	12	12	12
Distancing incidents 1.5 [m]	9	9	12	8	7	10	8	11	11	10	11	4

6 Visual output and data overview for 12 simulated scenarios for MSD Studio with the maximum number of occupants according to the current norm.

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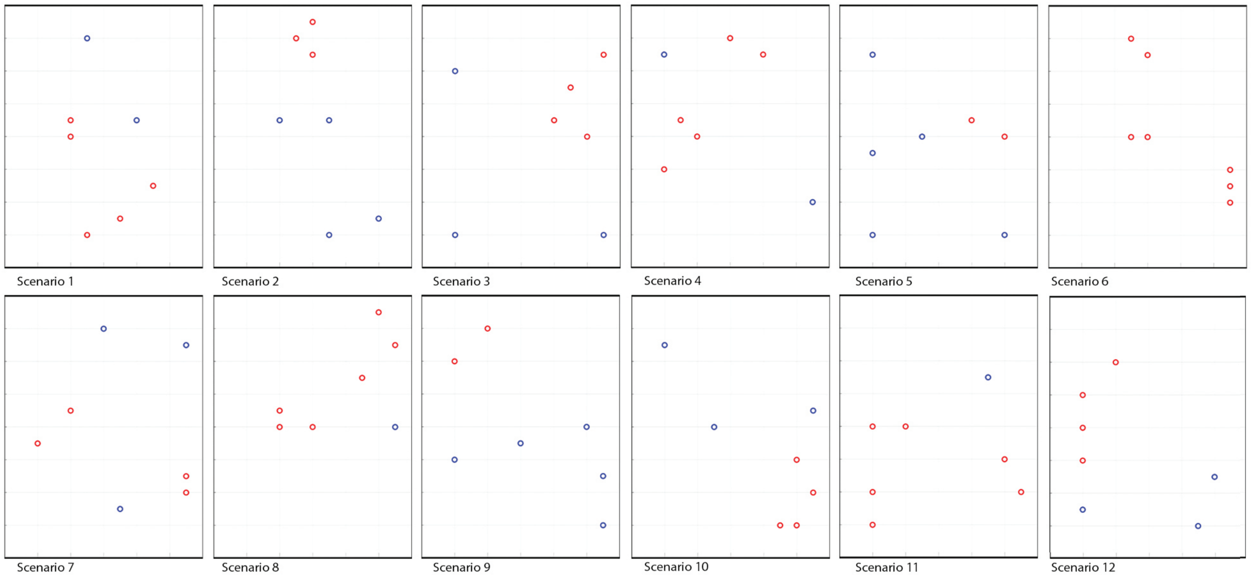
intervals. Color coding is used to mark compliance with distancing measures. Blue is for occupants complying with measures and red for those at a distance less than 1.5 m.

Initially, location modeling was conducted with a varied number of occupants in the room. As expected, a higher number of people in the room resulted in a higher rate of incidents. However, 12 scenarios (Fig. 5) show that distancing breaches may occur even with very few people in the room. Further location modeling was conducted to continue the probe into the correlation between the number of people in the room and distancing incidents. The next step in location modeling included the maximum allowed number of occupants, according to the prescribed occupancy density of 4 m^2 per person. Results show a high number of distancing incidents (Fig. 6). In the third step, location modeling was based on the revised norm and a lowered maximum of occupants, according to the corrected occupancy density norm of 7 m^2 per person. Results show a lower number of distancing incidents (Fig. 7).

CONCLUSION

The location modeling shows different occupancy scenarios for a studio room at the MSD building. Three groups of scenarios, differing by the number of occupants in the room and distancing norms, are presented to prove the validity and suitability of current prevention measures and develop a technique for establishing room-specific standards. The first group of scenarios shows the occurrence of distancing breaches under different occupancy counts. The second set shows distancing incidents when current occupational density norms are applied, and the third group shows the rate of incidents when corrected and more stringent occupancy norms are applied. It leads to the conclusion that maintaining social distancing will be challenging in practice, but also that current generic measures are inadequate for a studio room of the MSD building. Our research reveals that neither generic density norms (1.5 m distance between users and 4 m^2 area per user), nor synchronized measures to maintain social distancing may be adequate. Those norms are not context-aware, as they do not account for the type of activity, furnishing, and many other factors. Our study is based on the context of an educational building, and the simulation is employed to examine the correlation between distancing incidents and occupancy count to determine a room-specific maximum of occupants while maintaining adequate social distancing measures. The presented findings address the first research question to balance social distancing needs and the efficient use of resources.

Our second research question, related to improving the precision levels of known occupancy detection systems (Berry and Park 2017; Sun, Zhao, and Zou 2020), is addressed with an outline of a technique employing two already developed but not sufficiently tested indoor poisoning solutions (Abbas et al. 2019; Kulmer et al. 2017) to help manage occupation density and implementation of social distancing measures. The paper outlines how CTs would be used to compensate for sensing devices'



Scenario	Sc.01	Sc.02	Sc.03	Sc.04	Sc.05	Sc.06	Sc.07	Sc.08	Sc.09	Sc.10	Sc.11	Sc.12
Occupants allowed 7 [m^2]	7	7	7	7	7	7	7	7	7	7	7	7
Occupants present	7	7	7	7	7	7	7	7	7	7	7	7
Distancing incidents 1.5 [m]	5	3	4	5	2	7	4	6	2	4	6	4

7 Visual output and data overview for 12 simulated scenarios for MSD studio with the maximum number of occupants according to the revised norm. 7

insufficiencies and improve indoor positioning accuracy while maintaining a noninvasive approach. It is indicated that further development of the proposal would lead toward a fully functional solution that would be used to inform occupants and thus help preemptively and noninvasively, rather than relying on location history, tracking, and tracing methods to minimize the spread of infection. In the latter study, we have employed simulation to compensate for the lack of real-life data imposed by the lockdown. Simulation has unlocked the possibility to probe further into the relation between distancing incidents and generic occupancy norms. The reliance on the simulation method imposes limitations, as many aspects of human behavior were not taken into account. Therefore, the presented method sets the ground for further research and establishes the optimal number of occupants specific for each room, which would indirectly consider the type of activity, occupants' awareness and preferences, and other more elusive aspects of human behavior. Further research would also focus on developing the proposed technique to address the needs of more complex spatial configurations such as open-plan space located in the central atrium of the MSD building.

This study's contribution is in developing a method for occupancy detection and employing occupancy information to help disease prevention in educational buildings while maintaining efficient use of resources. The findings presented in this paper demonstrate how computation is used to structure data and to enable evidence-based inquiry into occupation density as an increasingly important architectural measure. The research relies on the simulation method, replacing access to restricted spaces, providing hard-to-get data, and enabling timely development of the solution and its examination before real-life implementation. The resulting data sets could also be used for an accurate overview of usage to help facility management through more efficient occupancy scheduling and occupation density minimization. Occupancy data recorded over a more extended period would also enable designers to understand behavior patterns and what happens after building buildings. It provides a means to develop predictive analysis tools and evidence-based design methods centered on occupants' behavior. In the longer run, the database created through continual occupancy monitoring would help future research in several increasingly converging areas such as architectural design, facility management, learning environments, and health and disease prevention.

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IMAGE CREDITS

All drawings and images by the authors.

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