Towards Space Mining: A Smart Space Management Solution to Minimize Indoor Spreading Risk of COVID-19

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Abstract. Policies to fight COVID-19 have largely targeted at indoor spaces. Abundant empirical evidence showed that COVID-19 spreads more easily through aerosols in closed rooms. We have been utilizing Design Science Research (DSR) to develop a smart space management solution that draws from space-related trace data to prevent the spread of COVID-19 in indoor environments. At the heart of our solution is a digital device that mines and visualizes these data to create awareness about the spreading risk of COVID-19 at a given point in time and encourage those physically present in the room to take relevant actions (e.g., opening a window). In this research-in-progress paper, we report on the first design cycle and deliver (1) design requirements, (2) an initial set of design principles, and (3) a prototypical implementation of a solution that brings to awareness when COVID-19 is likely to spread in indoor environments. Our research highlights the importance of examining space, which has received very little attention in the information systems field.

Keywords: COVID-19 · Space Mining · Design Science Research

1 Introduction

Information systems scholars have been encouraged to become involved in fighting the pandemic [e.g., 1]. This call was primarily driven by the fact that digital technologies have proven powerful to inform and evaluate policies [e.g., 4].

In this research-in-progress paper, we are reporting on an ongoing Design Science Research (DSR) project where we develop the idea of *space mining*. Space has been playing a key role in all major policies to fight COVID-19. Most regulations and policies have attempted to restrict social interactions in physical space. Overall, these measures proved useful in terms of lowering virus transmission numbers [e.g., 2]. Current space management research deals mainly with the development and implementation of technical systems [e.g., 3, 5, 13]. We extend these works by explaining how we can address the pandemic with a sociotechnical system that is readily applicable to a large variety of indoor environments [1, 11]. In analogy to the technology of process mining in the field of business process management [15], space mining refers to collecting, mining and visualizing space-relevant data in order to analyze the current situation in a room to prevent the airborne transmission of SARS-CoV-2. Like Omicron and Delta, new variants of the SARS-CoV-2 virus, which causes COVID-19, result in even more infections and spread faster [e.g., 8].

We elaborate on the following question: *How can we design a sociotechnical system for mining space-relevant data and recommending actions to prevent virus transmission in indoor environments?* We showcase our ongoing research project that we are currently pursuing in a student dormitory in Central Europe. Following the process proposed by Vaishnavi & Kuechler [14] we deliver (1) design requirements, (2) an initial set of design principles, and (3) a prototypical implementation.

2 Related Work

The ongoing spread of COVID-19 has directed much attention to the role of space in our everyday interactions. Recent studies show that indoor spaces are significant catalysts for the airborne transmission of respiratory viruses [e.g., 8, 17]. As SARS-CoV-2 is transmitted through aerosols, many initiatives, policies, and regulations have targeted at restricting physical presence in indoor spaces. In cases where this cannot happen, there are recommendations to open windows on a regularly basis [e.g., 18]. The risk of infections can be significantly reduced through timely ventilation and under consideration of specific spatial parameters (e.g., room size) and specificities of room use (e.g., number of people present in the room) [3, 8, 17]. Particularly carbon dioxide can be utilized as a proxy for SARS-CoV-2 concentrations in crowded indoor spaces since it is co-exhaled with aerosols by COVID-19-infected persons [9].

Smart environments in open and public spaces are playing an increasingly important role by meeting the need for real-time monitoring that leads to increased awareness of infection risks [5, 13]. Wright & Steventon [19], for example, have highlighted the importance of monitoring and measuring space through a large number of sensors and devices which, in turn, can become part of a broader global information network. Smart spaces can have digital representations, monitor what is happening in them and communicate with those who are present in a specific room. In this way, the use of smart objects creates the foundation for smart spaces to enable timely and effective decision-making [5, 16].

These observations provide the foundations for the development of our solution, which we refer to as *space mining*. Space mining can be seen in analogy to process mining [15], a technology that analyzes digital traces from business processes to visualize the as-is situation and provide recommendations for improvement. Our solution entails sensors, a software platform and a digital device that presents meaningful parameters through real-time monitoring as well as recommended actions to those who are present in a room (e.g., office room) at any given point in time. Some research exists in the area of smart home [e.g., 12] and smart device [e.g., 7] implementation that informed our research with regards to the instantiation of the IT-artifact, its network components, and the associated infrastructure. Current restrictions and guidelines thus become visible and 'actionable' to individuals at any point in time. Indoor carbon dioxide measurements and recommendations for the behavior of those who are physically present in the room based on spatial data therefore play a crucial role in preventing COVID-19 diseases, as individuals spend most of their time in indoor spaces. The latest IoT technology and LoRa wireless connectivity provide a scalable platform for the development and implementation of our space management system [7, 12]. Furthermore, space mining will integrate data mining techniques to find patterns in large datasets and provide additional recommendations for action [15].

3 Research Approach

In response to the ongoing pandemic, and in line with space management literature introduced above, we derive an initial set of design requirements (DR). The degree of infection risk of COVID-19 depends mainly on the amount of people in a space relative to its size and the air pollution of the space [8]. Thus, following the DSR paradigm, we formulate to the following basic requirements for space mining:

DR1: *The system should perform real-time measures of the number of people present in a defined space.*

DR2: *The system should perform real-time measures of the air quality of this defined space.*

The virus of the current pandemic is constantly evolving and so are the regulations provided by the governments or recommendations of health organizations, for example, the WHO [18]. This leads to the third requirement:

DR3: *The system should evaluate the measured real-time data against current regulations and recommendations.*

To provide immediate feedback to users the measured space data along with their evaluations should recommend effective actions, such as opening windows or putting on face masks [17]. The fourth and fifth requirements are:

DR4: *The system should provide a (real-time) visualization of the measured data of spaces.*

DR5: *The system should use the measured data to provide recommendations for those who are physically present in spaces.*

In order to evaluate the effectiveness of changes in regulations or initiatives on spaces post-hoc, the data, along with practical recommendations and evaluations, needs to be measured and stored [2, 8].

DR6: *The system should support logging of space measurements to evaluate the effectiveness of changes in COVID-19 regulations or initiatives.*

DR7: *The system should support logging of measured violations regarding COVID-19 space regulations or recommendations.*

Based on the above derived requirements we propose an initial set of design principles summarized in Table 1.

Table 1. Initial set of derived design principles and the related design requirements.

Design Principle	Description	Related Design Requirement
DP1	The system should perform multisensory real-time measurements to capture different physical states of spaces.	DR1, DR2
DP2	The system should provide a dashboard to visualize the current state of the space as well as recommendations to those physically present in the space.	DR3, DR4, DR5
DP3	The system should capture and visualize the dynamic of spaces based on the real-time data.	DR6, DR7

4 Results and First Evaluation

We have instantiated the derived design principles in a web-based space mining platform. Figure 1 illustrates the underlying architecture.

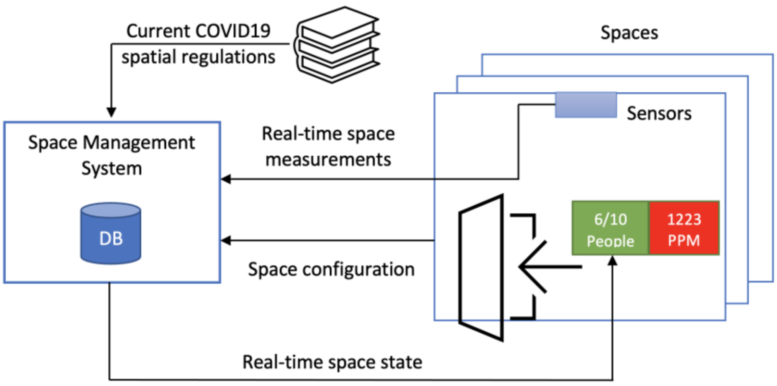

Fig. 1. Space management system architecture.

Regarding DP1 (related design requirements are DR1 and DR2, see Table 1), we selected and integrated two different sensors to measure the space occupancy and air quality. To measure space occupancy, we use the people counter sensor provided by IMBUILDINGS[1]. In order to measure space air quality, we integrated the ERS carbon dioxide sensor provided by elsys[2]. Both sensors are using LoRa to transmit the measured data to a central storage in the cloud. Due to its low energy consumption and its wide range of connectivity, LORA-based sensors are particularly easy and flexible to install, for example, for retrofitting, in smart home [12], or smart city [7] applications.

The sensors are transmitting the data to a central data base where they are stored. The central system stores information about specific rules that apply in each space (e.g.,

[1] https://www.imbuildings.com/lorawan-people-counter/
[2] https://www.elsys.se/shop/product/ers-co2-v1-5/?v=f003c44deab6

how many people are allowed to be present in the room), or general conditions that have to be kept (e.g., the distribution of carbon dioxide).

Regarding DP2 (associated design requirements are DR3, DR4 and DR5, see Table 1), the current state in a room and the corresponding COVID-19 regulations (e.g., allowed space occupancy or mask requirements) are displayed on a real-time dashboard that is placed in the respective room (e.g., hung upon the wall). The key purpose of this device is to provide rapid and easy-to-understand feedback so that those physically present can immediately recognize the state of the room. The dashboard along with the visualization of the live data indicates a red coloring scheme when certain limits are exceeded, for example, the warning limit of the amount of people, or the warning limit of the carbon dioxide level are exceeded.

Furthermore, the system collects and stores all measured values and events of sensor equipped spaces. Regarding DP3 (associated design requirements are DR6 and DR7, see Table 1), the system provides visualizations of the single space measures and enables analyzing the dynamics of spaces, e.g., carbon dioxide, or humidity time series charts of spaces measured over a specific period.

In a first evaluation, we installed the system in a student dormitory in Central Europe to assess the usefulness, discover failures, and find means for improvement [6]. This case proved particularly suitable to evaluate our solution. Students who stayed in this dorm during the pandemic were required to follow certain regulations. One of these regulations referred to the kitchens that are found on each floor of the dormitory. Because kitchens are generally seen as a shared space where students cook, but also eat and watch TV, students were asked to keep the number of people simultaneously present in the kitchen low (a maximum of 5 people). We installed the sensors and placed a tablet serving as visualization device for the real-time dashboard in the kitchen. The dashboard informed the students about the space measurements and the current COVID-19 rules.

Over the period of one year, we collected over 660426 data points and 31464 rule violations are reported. After a one-year period we conducted structured interviews with five students living in the dormitory, to evaluate the solution. The system, especially the dashboard, was well perceived and the students stated that they acted in accordance with the recommendations provided by the space mining solution (opening windows/doors to ventilate). Furthermore, our system supported their awareness of infection risks and raised their sensitivity for the respective room and space.

5 Discussion and Further Research

Our solution is intended to solve the pressing problems of the ongoing pandemic by mining space-relevant parameters and providing effective recommendations. Our work contributes to recent calls in the information systems field to tackle real world problems, especially in regard to COVID-19. In this research-in-progress paper we deliver (1) design requirements, (2) an initial set of design principles, and (3) a prototypical implementation, and we report on our first design cycle. We plan to revise the design principles based on the preliminary findings and further develop the artifact in future design cycles, in order to help reducing virus transmission in indoor spaces and to further elaborate space mining solutions. From a more abstract perspective, our research explores the evolving role of space and spatial data for the information systems field. We see myriad of possible research directions emerging in response to ubiquitous sensors and data [10, 11].

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