DEVELOPING A DECISION SUPPORT SYSTEM AND A BUILDING MANAGEMENT SYSTEM FOR BUILDING PORTFOLIO MANAGEMENT

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Abstract

The organizational effectiveness and functioning during the Operation and Maintenance (O&M) phase are influenced by occupancy and space use, which are highly variable over time. Therefore, spaces can be inadequate for actual uses, leading to poor levels of space use and cleanness. This, as well as Indoor Environmental Quality (IEQ), affects user well-being, satisfaction, and productivity. Real-time occupancy and IEQ monitoring and analyses are needed to achieve effective and efficient asset management and user well-being. The article presents an ongoing research project to define a Decision Support System and a Building Management System for Facility Management based on IoT sensor networks and a dashboard. Recent updates concern: the integration of modules to monitor man-down and social-distancing, as a consequence of COVID-19 pandemic-related situation; the installation of sensors to monitor IEQ in a limited number of rooms; the definition of the dashboard enabling data analytics at floor and building level, and simulations of what-if scenarios. The methodology is being applied and tested in a pilot study building. The research aims to support the optimization of buildings operational stage regarding space use, O&M activities, and indoor conditions, increasing workplace adaptability to changing conditions and needs, and ensuring increased user satisfaction and well-being.

Keywords: *Building Management System, Decision Support System, IoT sensor network, Digital Twin, Indoor Environmental Quality, Facility Management, occupancy.*

Resumen

La eficacia y el funcionamiento organizativo durante la fase de explotación están afectados por la ocupación y el uso del espacio, que son variables con el tiempo. Por eso, los espacios pueden ser inadecuados para los usos reales, provocando niveles inadecuados de uso y limpieza. Esto, además de la Calidad Ambiental Interior (IEQ), afecta al bienestar y la productividad de los usuarios. Para conseguir una gestión eficiente del edificio y el bienestar de los usuarios, se necesita monitorizar y analizar la ocupación y la IEQ en tiempo real. La investigación aspira a definir un Sistema de Apoyo a las Decisiones y un Sistema de Gestión de Edificios basado en redes de sensores y un tablero de mandos, y se está probando en un caso de estudio. Recientemente se ha integrado la monitorización del hombre caído y del distanciamiento social, en relación con la pandemia COVID-19, y los sensores para monitorizar la IEQ, y se ha definido el tablero de mandos, que permite el análisis de datos, y la simulación de escenarios hipotéticos. Este estudio se propone optimizar la fase de explotación sobre el uso del espacio, las actividades y la IEQ, aumentando la adaptabilidad del espacio a las condiciones variables y garantizando una mayor satisfacción y bienestar de los usuarios.

Palabras clave: *Sistema de Gestión de Edificios, Sistema de Apoyo a las Decisiones, Red de sensores, Gemelo Digital, Calidad Ambiental Interior, Gestión de edificios, ocupación.*

Introduction

Asset management, and the effectiveness and functioning of an organization, are strongly affected by occupancy and space use (Bento Pereira 2016; Zimmerman 2001). Space use, cleanness, and Indoor Environmental Quality (IEQ) are, in turn, related to user well-being, satisfaction, and productivity (Agha-Hossein 2013; Al horr 2016). Consequently, it is critical ensuring an efficient asset management during the Operation and Maintenance (O&M) phase and to ensure user satisfaction and well-being regarding their workplace.

During the design phase occupancy and space uses are typically sized according to use-based standardized data, such as expected values for energy models (Dong 2018), while, during the O&M phase, they are typically represented by static schedules. However, occupancy and space uses are highly variable over time. In addition, user need and space organization requirements are not considered as design parameters or, by the time the building is constructed and operated, they have changed (Zimmerman 2001). Consequently, occupancy and space uses typically differ from the values considered during the design phase, causing poor levels of space use and cleanness. Additionally, since early 2020 the current COVID-19 related situation strongly affected asset management and workplaces organization. Many workers have been forced to remote working practices (Kniffin 2020), drastically accelerating the spread of remote working, a slowly growing phenomenon in the last 10 years (European Union 2020). Recently, in the Italian context, governmental policies tried to facilitate a return to normality by revoking the adoption of remote working practices for Public Administration workers (Italian Parliament and Government 2021). On the other hand, remote working practices have been partially maintained in private companies. In addition, some companies or institutions have decided to convert some underutilized spaces into spaces that can be used by reservation via app. Consequently, it has become even harder to predict workplace occupancy and to consider fixed scheduled occupancy as a reliable information to define and manage FM activities and space organization. Another critical aspect considering facility management and user flows in the current COVID-19 related situation is linked to the respect of social distancing, the use of masks, and temperature monitoring (World Health Organization 2021). Furthermore, another aspect strongly influencing user well-being, satisfaction, and productivity regarding their workplaces is represented by IEQ (Al horr 2016; Choi 2012). A continuous evaluation of IEQ factors, such as thermal and lighting conditions, air quality, and space assessment, during the building lifecycle, is a key strategy to guarantee building quality and sustainability (Parkinson 2019).

All the above highlights the need of continuous real-time building monitoring of occupancy and indoor conditions, and data analysis to achieve effective and efficient Facility Management (FM) processes, to improve existing buildings' use and space organization, and to ensure user satisfaction and well-being. In addition, space monitoring is fundamental to guarantee safety in existing buildings, especially considering the current sanitary emergency related to COVID-19 pandemic (Capolongo 2020).

The research investigates the definition of a Decision Support System (DSS), supporting facility managers in the decision-making process during the O&M phase, and of a Building Management System (BMS), allowing to monitor and control space uses and indoor environmental conditions. The system includes Post-Occupancy Evaluations (POEs) and IoT sensor networks for building monitoring, integrating occupancy levels, indoor environmental conditions, and additional relevant building data. The research aims to manage and optimize existing buildings' FM activities and services, space organization, and IEQ according to actual occupancy and user needs. The research project will lay the groundwork for the definition of a Digital Twin for occupancy-oriented FM to monitor, analyze, and optimize existing building space management and organization, and FM activities and services according to actual user needs, occupancy, and indoor environmental conditions.

The paper briefly introduces the general methodology of the ongoing research project, then focuses on latest updates concerning the integration of modules to monitor man-down and COVID-19 related measures, the installation of sensors to monitor IEQ in a limited number of rooms, and the definition of the first prototype of the dashboard enabling data analytics at floor and building level.

1. **Literature review**

The literature review briefly investigates past and current approaches for building and occupancy monitoring and optimization in relation to occupancy and IEQ, focusing on Post-Occupancy Evaluations (POEs), Building Information Modelling (BIM), and Digital twins (DTs).

POEs have been applied for about 50 years with several projects all over the world (Li 2018) aiming at assessing building performances, users' behavior and feedback during the O&M phase (Di Giuda 2020; Hadjri 2009). In recent years they have been applied to assess building energy performances and user satisfaction (Agha-Hossein 2013; Day 2019; Straka 2009), to investigate the gap between actual energy performances and design targets (Agha-Hossein 2013), and to optimize the design phase (Daher 2018). POEs can be performed at three levels, i.e., Indicative, Investigative, and Diagnostic POEs, with increasing level of detail, but also of user privacy invasiveness and implementation costs (Hadjri 2009). Main limitations of POEs are users' reluctance to POE applications due to privacy issues, implementation costs (Leaman 2010), liability for building owners and facility managers, lack of benchmarks to evaluate POE results (Zimmerman 2001), and limited research on techniques to visualize and communicate POE results (Li 2018).

The application of BIM for FM results in several benefits, such as time and cost savings resulting from better planning, higher data consistency (Codinhoto 2014; Oti 2016), having a single source and storage of geometrical and O&M data, thus enabling the visual representation of POE data and detected issues in the building space (Pin 2018; Rogage 2019). However, a BIM approach for FM lacks information richness, analysis and simulation capabilities, that are typically manually implemented and time-consuming. In addition, effective and efficient FM during the O&M phase strongly relies on real-time building data continuous flows (Lu 2019, 2020), and BIM models lack integration with different data sources, e.g., sensor data, and automatic updating over time (Lu 2020).

DTs allow to connect a physical system to its virtual counterpart through bi-directional communication, using temporally updated data, enabling data analytics and simulations, thus supporting optimization processes and prediction of future states (Al-Sehrawy 2021; Boje 2020). DTs can be considered as an evolution of POEs, since they enable building continuous monitoring and analysis while connecting the physical entity to its virtual counterpart. DTs can include: an acquisition layer, such as an IoT network (Bolton 2018); a dashboard to visualize and manage sensor data, and return insights, simulations, and predictions (Tomko 2019); a BIM model as starting point for the geometrical virtual building replica (Boje 2020; Lu 2020); tools to provide predictions, simulations, and data analytics (Lu 2019, 2020); actuators and other tools to act on the physical world and apply data-driven decisions (Al-Sehrawy 2021). Some challenges for DT definition are: the integration and automation of the functioning of actuators and other tools to act on the physical world, the selection of sensor types most suitable for specific applications (Boje 2020), the proper spatial distribution of sensors (Tomko 2019), IoT sensor network calibration (Yan 2017), collected data quality evaluation (Manngård 2020), and the integration of different data sources in the DT (Al-Sehrawy 2021; Lu 2019).

2. **Methodology**

The ongoing research project aims to define a comprehensive methodology, integrating different methods and tools, to perform efficient building monitoring, management, and optimization in relation to actual occupancy.

The system will act as a Decision Support System (DSS) supporting decision makers during FM processes, and as a Building Management System (BMS) for facility managers to monitor and control building conditions. It is based on Post-Occupancy Evaluations (POEs), IoT sensor networks, integrating building data, real-time occupancy and IEQ monitoring, and a dashboard enabling data visualization, analytics, and comparison of occupancy scenario simulations.

The methodology is divided in four main steps as presented in Figure 1.

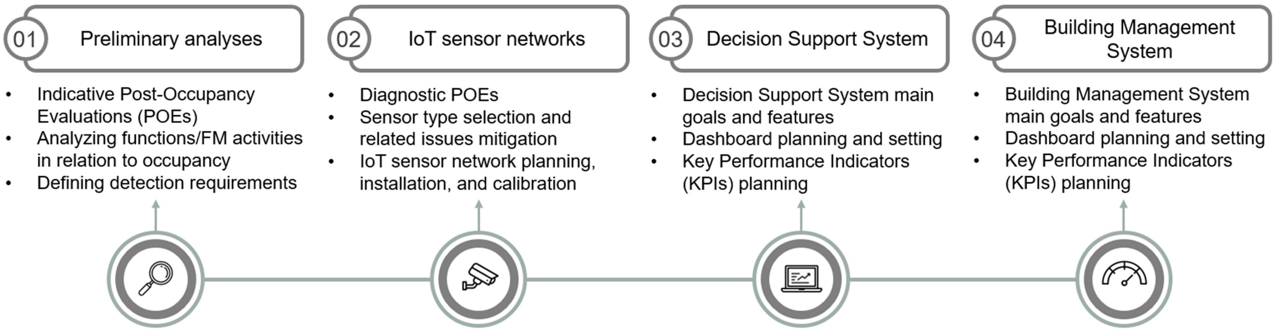

Figure 1. Methodology main steps

2.1. **Preliminary analyses**

The first step of the methodology (Figure 1) has been previously published in (Seghezzi 2021). It includes Indicative POEs, i.e., non-invasive, quick, and inexpensive building surveys to briefly analyze building performances, and the analyses of functions and FM activities in relation to occupancy. The first step aims to define the building critical areas to be analyzed through the system. Areas characterized by variable occupancy, that will be further monitored and analyzed, and the monitoring network requirements are defined.

2.2. **IoT sensor networks**

2.2.1. IoT sensor network for occupancy monitoring

The second step of the methodology (Figure 1) enables to perform Diagnostic POEs in existing buildings through continuous monitoring and evaluating actual conditions and usage of buildings during the O&M phase by means of sensor networks. The Diagnostic POEs aims at deeply investigate building conditions related to occupancy, space usage, and indoor environmental conditions affecting user comfort and satisfaction, in order to optimize building use, space organization and user satisfaction regarding their workplaces. The second step has been partially published in (Seghezzi 2021) as regards the occupancy monitoring sensor network, including the selection of the most suitable sensor type for occupancy monitoring, the analysis of possible issues, in particular privacy issues and user data protection, and strategies to overcome them. In addition, the network installation, testing, and calibration phases have been investigated.

The IoT sensor network allows to anonymously monitor occupancy at floor and building level. Internet of Things (IoT) sensor networks have been widely adopted for occupancy monitoring (Wang 2019) and are characterized by the universal presence of objects, such as sensors, with digital identification and addressing schemes enabling them to work together to achieve some common objectives (Giusto 2010). Cameras with an embedded deep learning algorithm, installed in corridors and common areas, allow to detect people moving and immediately converts them into anonymous agents, avoiding capturing or storing any real image or videorecording. The network calibration phases ensure the collected data quality, i.e., reliability and accuracy, and proper functioning of the network for the subsequent phases of the methodology (Seghezzi 2021).

The IoT sensor network is assessed and maintained through an online platform. The platform enables to verify all cameras' location, orientation, settings, functioning, and connection with the other network components. In addition, the platform allows to visualize in real time the anonymous movement of users, represented by anonymous agents, and is used to test and calibrate the sensors and the whole network.

2.2.2. IoT sensor network for Indoor Environmental Quality monitoring

The second step of the methodology has recently been further developed by investigating the planning of sensors to monitor IEQ, including the selection of the spaces to be monitored, the definition of the necessary components and the related features. Unlike sensors to monitor occupancy, which are installed in corridors, IEQ monitoring sensors are installed inside rooms to monitor the indoor environmental conditions of workplaces, i.e., temperature, humidity, and CO_2 level. A limited number of rooms is selected to test the system. The selected rooms must be representative of all possible conditions of building spaces in order to properly test the system, including different orientation, number of users typically occupying the room, and frequency of room usage. The last two values are identified through the first data analysis from the occupancy monitoring system. As regards the system necessary components, they include: sensors to monitor selected IEQ parameters, and converters to connect sensors to the local servers of the occupancy monitoring system.

2.2.3. Integration of modules to monitor man down and COVID-19 related measures

Due to the current COVID-19 related situation, some modules have recently been integrated in the system to monitor social distancing, the use of masks, and temperature monitoring. In addition, man-down is monitored for safety reasons, allowing to intervene in a short time in case of illness of users. This is especially useful in the early hours in the morning and in the late hours in the evening when office buildings are typically occupied by fewer people. Social distancing and man-down are monitored in corridors and common areas through the same cameras of the occupancy monitoring network. Social distancing is monitored by checking the interpersonal distance between two people moving or standing still. An alarm is triggered when a distance inferior to 1 meter is detected for more than five seconds. The delay can prevent alarms from being triggered every time two people walk by each other in corridors without stopping or interacting. Similarly, aiming to monitor man-down, an alarm is triggered every time a single person remains still in a corridor or common area for more than three minutes. The two types of alarms are notified directly in the online platform, allowing the FM staff to intervene. In addition, social distancing is displayed in the platform in the real-time user movements visualization page through a line connecting two anonymous agents approaching each other in corridors. The line is displayed as green when social distancing is observed, and yellow otherwise. Finally, a tablet is identified as a tool to measure body temperature and to verify the proper use of masks for people accessing the building. Similarly to IEQ sensors, a building area which is most used according to first analysis of occupancy data, is selected to test the check-in tablet, which is located at the entrance of the selected area. In particular, the correct check of body temperature below 37 °C and the proper use of the mask unlocks the door allowing the user to access the area, which normally only requires the verification of the personal identification card.

2.3. **Decision Support System**

The third step of the methodology (Figure 1) includes the strategies to plan and set the Decision Support System (DSS) which is based on data from previous steps and on a dashboard integrating building data from preliminary analyses, and occupancy and IEQ monitoring data from the IoT sensor networks. Data analytics and occupancy scenario simulation through the dashboard, and the evaluation of scenarios by means of KPIs define the DSS. The DSS is intended to support facility managers' decision-making, particularly decisions related to planning FM services and organizing and redistributing space over time, including assigning functions and number/type of users to spaces, and monitoring and controlling IEQ.

2.3.1. Dashboard for data analytics and simulation

The dashboard is composed by two modules. A data analytics module includes selected graphs, charts, and visuals built on collected data, aggregating data and investigating occupancy and vacancies at floor and building level, on daily, weekly, and monthly level, and in relation to functions and user roles inside the organization. Collected data on IEQ are also included in the data analytics module to monitor space conditions through graphs and charts. A simulation module enables to compare alternative occupancy scenarios: the facility manager can hypothesize new occupancy values for the spaces, based on insights from the data analytics module, and then compare through the dashboard the hypothesized scenarios with actual building usage, investigating the effects of the hypothetical scenarios on FM services, in terms of time of performing and costs, and on the overall building occupancy and vacancy rates.

Facility managers will be supported by the insights from the data analytics module of the dashboard that will uncover actual building occupancy patterns and possible issues of over- or under-utilization of spaces. Consequently, it will be possible for the facility manager to plan optimizations of FM services and space organization by investigating strategies and scenarios with the support of the dashboard simulation module.

The tools to define the dashboard are selected considering the following critical aspects: data analytics capabilities, visualization and communication proficiencies, accessibility and usability by non-experts, such as building owners, need for a license and related costs, availability of developers/online community support, learning curve and level of necessary skills.

2.3.2. Key Performance Indicators

The third step of the methodology includes the definition of Key Performance Indicators (KPIs) in relation to which evaluating the proposed occupancy scenarios. Each hypothetical occupancy simulation from the dashboard will be evaluated in relation to the defined KPIs. Based on the evaluation results, the facility manager will be able to select the most suitable strategy to be applied on the actual building.

The proposed KPIs are the following:

- KPI_1: percentage of use of building available spaces. The lower this value, the higher the percentage of vacancies;
- KPI_2: evaluation of FM activities and services time of performing. It is a percentage of the current total FM activity time (representing the 100%), that can be reduced or incremented, considering actual occupancy and space uses, or the hypothetical occupancy scenarios;
- KPI_3: evaluation of the economic aspects related to the analyzed FM activities. It is a percentage of the total costs resulting from the updated FM activities costs, deriving from the updated FM activities time (KPI_2), plus a percentage considering the added costs for the system implementation.

2.4. **Building Management System**

The fourth step of the methodology (Figure 1) defining the Building Management System (BMS) is still under development. It will enable to monitor and control indoor environmental conditions of spaces. The BMS will be supported by the dashboard for IEQ data visualization and analytics. The BMS will then enable to optimize IEQ and to avoid energy and resource waste through system local controls. It will allow to optimize indoor conditions and use of systems according to actual occupancy, space organization and user need.

3. **Pilot study**

The building selected as pilot study hosts the Department of Architecture, Built environment and Construction engineering (DABC) of Politecnico di Milano. It is a four-story building, with a total of 4300 square meters of gross floor area. The building has a symmetrical layout, with a common space in the center and two side corridors. Offices and workspaces are located on either sides of the two side corridors, while in the common space in the center are located the entrance hall at the ground floor, and connections and snack areas at the other building floors.

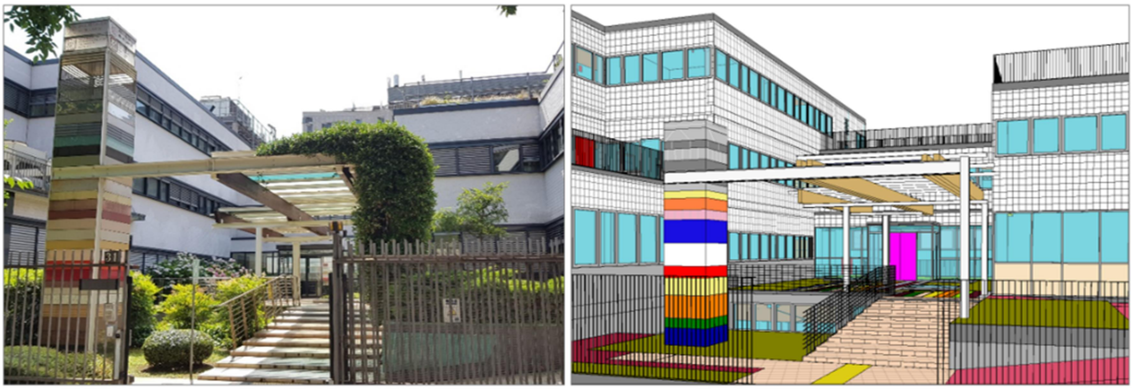

Figure 2. Pilot study: DABC of Politecnico di Milano (left) and related BIM model view (right).

The presented research is integrated into a departmental research project for facility management optimization with the goal of testing the proposed methodology and evaluating advantages and disadvantages, to assess further application to other university facilities. In addition, a BIM model of the building was already available from a previous research project (Figure 2) (Di Giuda 2020).

4. **Results and discussion**

4.1. **Preliminary analyses and IoT sensor network for occupancy monitoring**

The first step and partially the second step of the methodology application to the pilot study have already been published in (Seghezzi 2021). The application of Indicative POEs allowed to identify the critical areas to be analyzed in the subsequent phases, i.e., administrative offices, research spaces and laboratories, meeting rooms, university staff offices, and restrooms, for a total of 70 out of 87 spaces of the building. The selected spaces are characterized by variable occupancy in terms of number of people and/or time of occupation, as defined through the functions/spaces and occupancy analyses. The analysis of FM activities in relation to occupancy investigated FM services and the use of systems, to identify which type of occupancy, i.e., in real-time, on hourly or daily basis, influences them (Seghezzi 2021). Cleaning services and space organization are selected among the FM services trying to optimize them through the pilot application, according to actual occupancy or hypothesized occupancy scenarios. The selected FM activities are influenced by real-time and on hourly basis occupancy respectively, which represent the detection requirements for the sensor network.

As regards the planning and setting of the occupancy monitoring IoT sensor network, cameras were selected among the sensor types considering their high accuracy for real-time occupancy monitoring and the possibility to perform other kind of analyses, such as security and safety monitoring, allowing to increase the scalability of the system. The selected sensors are High Quality Bullet Pro Camera PoE: they provide HD quality images, have a 110-degree view angle, and a Wide Dynamic Range (WDR) to compensate issues due to exposure to light. The network is installed in a dedicated and private Virtual Local Area Network (VLAN), and a static IP is provided for each network element. Cameras are installed only in common spaces and corridors (Figure 4). This phase also included the mitigation of some issues of cameras (Seghezzi 2021):

- Detection only within sensor field-of-view, through the use of the building BIM model to optimize location and orientation of sensors and to maximize the area covered by the sensors' field-of-view;
- Privacy issues, by avoiding monitoring private workstations, by setting up the system to anonymously monitor users and not save nor store any image in the process. The system never displays any image to the system operators nor to the department staff responsible for the network, not allowing to recognize users directly or indirectly, thus the system is fully compliant with EU General Data Protection Regulation (GDPR). In addition, users have been fully informed of the system before its installation. Finally, information signs to be displayed in the monitored areas and a document, describing system goals, features, data anonymization process, and how data is

processed, and identifying the people responsible for the system, are under revision and will soon be implemented and made available to users.

An online platform, set up along with the occupancy monitoring IoT sensor network, shows the building blueprints and the real-time anonymized user movements, displayed as anonymous icons. The platform webpage is accessible and used by department staff to monitor sensor functioning and manage network settings. The only data collected by the system and stored in a database (DB) are the following:

- occupancy values, i.e., number of people, at room level (O);
- period of time (T) during which one or more agents occupy a room.

Data in the DB are only accessible by the facility manager and department staff, and they are then additionally anonymized by aggregating them at floor and building level for the subsequent phases of data analysis and simulation, to avoid any association of occupancy data with specific rooms. The system was calibrated through three calibration test campaigns performed in June 2020, in November 2020, and in May 2021, with three-month data collection for each test campaign (Seghezzi 2021).

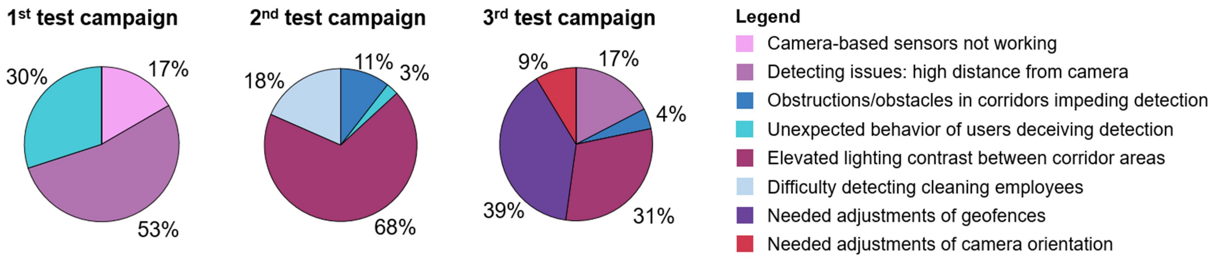

Figure 3. Three test campaigns to calibrate the IoT sensor network.

4.2. **IoT sensor network to monitor Indoor Environmental Quality**

The planning of the IoT sensor network to monitor IEQ included an initial investigation to identify the most suitable spaces to test the sensors. Spaces are analyzed in terms of space features, functions, and occupancy. Similarly to the occupancy monitoring network, spaces with variable occupancy and, among them, spaces with workstations, i.e., offices, laboratories, and administrative offices, have been considered. The selected space types have been analyzed in terms of occupancy for a five-month period between June and October 2021 through the installed and calibrated occupancy monitoring network and dashboard. Two spaces have been identified as of interest for monitoring the IEQ, also considering the orientation and floor:

- N. 1 Office with variable occupancy in terms of time, with presence of users for average values of 50% of the weekly working hours, and in terms of people, with variable presence of two to ten occupants; the office has orientation South-East and is located on the first floor;
- N. 1 Administrative office with fixed presence of occupant in terms of time, around 100% of weekly working hours, but variable presence of users from one to two people due to remote working practices; the Administrative office has orientation North and is located on the ground floor.

Once identified the spaces in which testing the new sensors, the network components have been selected:

- N. 2 sensors, one for each selected space, composed by: temperature sensor (0-50°C) – humidity sensor (0 - 100% RH, accuracy ≅2%) – CO_2 level sensor (0-2000 ppm) – touchscreen to visualize values and locally control system functioning – BACnet and Modbus protocols (via RS485);
- N.2 converters, one for each space, being the two spaces not close, with the following features: ethernet gateway – 2 ports and PoE (Power over Ethernet) – converter from Modbus RS485 to tcp-ip.

After the selection of spaces and network components, some tests to define the specific location of the sensors inside the rooms have been performed using the BIM model (Figure 4), considering the following main rules:

- Sensors should be located at around 150 cm from the ground for accurate IEQ monitoring;
- Sensors must be located approximately in the center of the room, away from windows, doors, and heat sources that may affect the accuracy of collected data;

- Converters should be located close to the sensors to limit the use of serial cables to connect them.

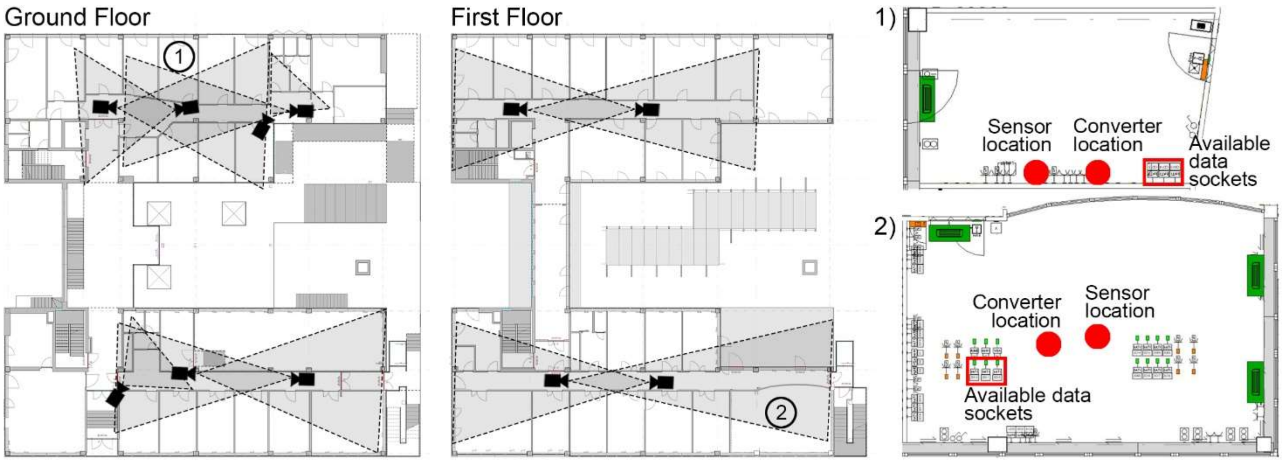

Figure 4. Location of cameras of the IoT occupancy monitoring network in the corridors of the ground and first floors (left and center); IEQ monitoring sensors and converters locations (right) in the Administrative office (n. 1) and university staff office (n. 2).

Regarding the university staff office (Figure 4), the sensor could not be placed on any of the walls due to the presence of doors, windows or heat sources. Consequently, sensor and converter are planned to be located on a stand on one of the workstations, in a central position in the room to ensure accurate collected data. The testing and calibration phase of the IEQ monitoring sensor network will be performed in the coming months.

4.3. **Integration of modules to monitor man down and COVID-19 related measures**

Regarding the integration of man down and COVID-related measures modules in the system, the requirements defined in the methodology section have been entirely observed. The system is set to monitor and notify social distancing below 1 meter of interpersonal distance, and man down after three minutes a person is standing still in common areas and corridors. In addition, a notification via e-mail to a selected mail address of one person among the security personnel has been defined.

In addition, the check-in tablet was located at the entrance of one corridor hosting Administrative offices. The same analysis performed in the five-month period between June and October 2021 through the occupancy monitoring system enabled to define the check-in tablet location. An Administrative area has been selected being one of the most used building areas from the analysis. The testing and calibration phase of the integrated modules will be performed in the following months.

4.4. **Decision Support System and dashboard definition**

After the planning and setting of the IoT sensor networks, the dashboard has been planned and set. The dashboard is easily accessed and used by non-experts to visualize and analyze building conditions and to select and take data to perform simulations of what-if scenarios. According to the requirements for the selection of the dashboard tool provided in the methodology section, Microsoft Power BI was selected to set the dashboard, allowing to produce shared reports containing dynamic charts and graphics. Reports are communicative, easily accessible and usable, and can be retrieved and shared with authorized people, who can view data and results without the need to install the software or own a license. Finally, Power BI does not require advanced coding skills and it is comparatively user friendly. In addition, data extracted from the dashboard are managed and processed by calculation models implemented by data sheets. Similarly, sensor data cleaning and processing is performed through data sheets, before being analyzed through the dashboard. The dashboard data analytics module has been set in a first configuration to analyze and manage occupancy data. Different web pages allow for collected data visualization, query, aggregation, and analytics through selected graphics (Figure 5), with data collected from June to October 2021.

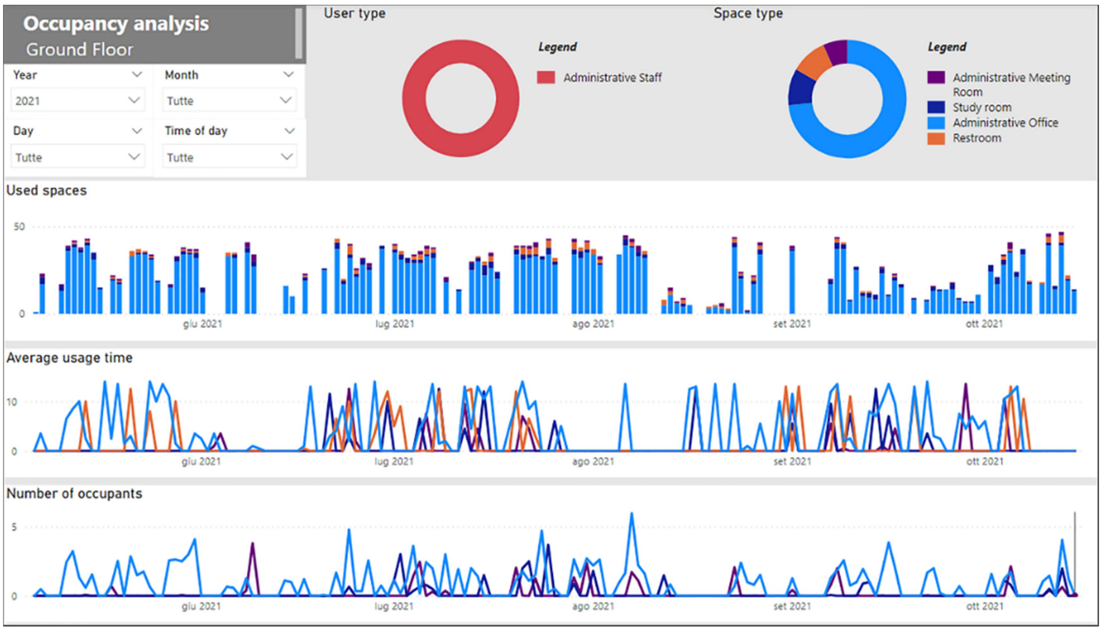

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Figure 5. First configuration of the dashboard data analytics module of the ground floor.

The dashboard data analytics module allows to visualize and filter data according to space and user type, date, and time. The ground floor mainly hosts administrative staff and spaces are administrative offices, meeting rooms, study rooms, and restrooms. The graphics analyze used spaces, average usage time, and average number of users along the selected period. From this first data analysis some considerations can be made. There is a large variability in the use of offices especially in the period August-September probably due to summer holidays. However, most spaces are still used even if by fewer people and for less time. Regarding meeting rooms and study rooms, they are rarely used and by a highly variable number of users. Finally, the use of restrooms is proportionate to the use of other spaces. This first data analysis may highlight the lesser need to clean the study and meeting rooms which are currently cleaned as frequently as the offices and restrooms. On the other hand, during the summer period, offices and restrooms cannot be cleaned less since they are still used for the most part, albeit for less time and by fewer people.

The implementation of the simulation module and the integration of IEQ data in the dashboard is still under development and, once completed, data collected of all building floors and for a longer period (around one year since the last calibration test) will be analyzed. The simulation module will enable to simulate different space organization strategies, by inputting new occupancy values and time periods of use for spaces at floor and building levels. In addition, it will allow testing different occupancy scenarios, and consequently different cleaning strategies. Collected IEQ data analysis will allow to monitor and control indoor conditions over time. The proposed simulation scenarios will then be evaluated according to the KPIs described in the methodology section, investigating and evaluating the scenarios according to the results of the KPI application, defining a hierarchy of scenarios and acting as a DSS for facility managers and building owners. They will be able to select the most suitable strategy for testing and application in the building, supported by the DSS.

4.5. **Building Management System definition**

Monitoring, analyzing, and controlling IEQ, and consequently controlling building systems will enable to define the BMS for the building, which is still under development, aiming at optimizing space IEQ and reduce resource and energy waste over time, while increasing user satisfaction regarding their workplaces.

5. **Conclusions and further developments**

The proposed system will act as a DSS and BMS during the O&M phase, enabling an optimized management of spaces and indoor environmental conditions according to actual occupancy values. Building spaces will be organized and managed depending on the simultaneous use of rooms by multiple users and on the time they actually occupy them, considering actual user needs in terms of spaces and IEQ. Space reorganization and redistribution due to staff or activities changes over time will be supported by analyses and occupancy scenarios development through the DSS, consequently increasing the workplace adaptability to changing conditions and needs. In addition, insights and occupancy trends from the dashboard will allow to optimize cleaning activities and contracts that are currently based on building floor areas, allowing to optimize cleaning services based on actual space occupancy, therefore ensuring cost savings and increased comfort from reduced cleaning of underutilized spaces, and improved cleaning of the most used spaces. At the same time, this will ensure an increased satisfaction and well-being of users, also considering increased IEQ of spaces.

In a short-term view it will be possible to define optimizations and savings, accordingly enhancing facility managers and building owners awareness about the possible advantages of occupancy and IEQ monitoring, analysis, and simulation over time. Possible further developments of the research are the automation of the data cleaning and classification phase from the database of the sensors system, for the subsequent actuation of a real-time management through the dashboard. In addition, the simulation of occupancy, space use, and cleaning scenarios could be automated and performed directly by the dashboard on the basis of collected data analysis. Consequently, it could provide the operator with the simulation results and possible optimization strategies and suggestions. In addition, the possible implementation of a dashboard section gathering user opinion regarding IEQ and space organization would increase the system reliability by integrating the user perspective and satisfaction level. Furthermore, the integration of system controls and other tools to act on the physical building, e.g., an application for cleaning service staff notifying them of which spaces to clean according to actual occupancy, will enable to create a Digital Twin for occupancy-oriented FM and to directly optimize building use and FM services over time. In a long-term view the methodology will enable the definition of criteria for optimized design of future similar office buildings. In addition, it will be possible to define guidelines for occupancy monitoring, analysis, and simulation during the O&M phase, ensuring continuous improvement of existing buildings use and increasing building adaptability to changing needs over time.

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