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DECISION SUPPORT SYSTEM FOR OCCUPANCY-ORIENTED FACILITY MANAGEMENT: METHODOLOGY AND FIRST RESULTS

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Abstract

Occupancy and space uses affect the organizational effectiveness and functioning during the Operation and Maintenance phase. They are highly variable and can change over time. Consequently, spaces can be inadequate for actual uses, affecting space use, cleanness, and user well-being, satisfaction, and productivity. The research defines a Decision Support System for facility managers based on occupancy patterns analyses and simulations, including Post-Occupancy Evaluations, an IoT sensor network, and a dashboard. First results of system setting and pilot study application are presented. The research aims to support space reorganization and Facility Management activities optimization, increasing workplace adaptability, user satisfaction and well-being.

Introduction and Problem Statement

It is crucial to ensure an actual and efficient management of buildings during the Operation and Maintenance (O&M) phase. Occupancy and space uses, that are highly variable, and that can change overtime, strongly affect the organizational effectiveness and functioning during the O&M phase (Zimmerman and Martin, 2001, Bento Pereira et al., 2016). In addition, actual occupancy and space uses may significantly differ from the setup considered during the design phase. During the design phase spaces are typically sized according to use-based standardized occupancy data, such as occupancy levels in compliance with fire regulations or expected occupancy values from energy models (Dong et al., 2018). User and space organization requirements are either not specified or, by the time the building is constructed and operated, they have changed (Zimmerman and Martin, 2001). Furthermore, occupancy levels during the O&M phase are typically represented by static schedules. All the above leads to actual occupancy values that may be different from those considered during the design phase. Consequently, existing spaces may result as inadequate for actual uses and occupancy. This, in turn, can result in poor levels of space use and cleanness, which are related to user well-being, satisfaction, and productivity (Agha-Hossein et al., 2013). Additionally, since early 2020 the current COVID-19 related situation have forced many workers to remote working practices (Kniffin et al., 2020). This drastically accelerated 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 Facility Management (FM) activities and space organization over time.

The increasing variability of workplace occupancy, and the gap between design and actual occupancy levels highlighted the limitations of FM strategies based on historical databases and fixed and static occupancy values. Continuous real-time building monitoring and data analysis can support the achievement of effective and efficient FM activities and processes, and the improvement of existing buildings' use and space organization. In addition, space monitoring is fundamental to guarantee safety in existing buildings, especially considering the current sanitary emergency related to COVID-19 pandemic (Capolongo et al., 2020).

The ongoing research project here presented investigates the definition of a Decision Support System (DSS) for facility managers, integrating occupancy levels and additional relevant data from Post-Occupancy Evaluations (POEs) and an IoT sensor network. The research aims to manage and optimize FM activities and space organization of existing buildings according to actual occupancy and hypothesized occupancy scenarios.

The DSS is intended to support the decision-making process of facility managers, in particular decisions about:

- reorganizing and redistributing spaces over time;
- assigning functions and user number/type to spaces;
- planning and managing FM activities over time.

The DSS by means of a dynamic dashboard will provide analyses, visualizations, and insights on actual occupancy patterns, simulations of hypothesized occupancy values, with the possibility of optimizing FM activities and plans according to actual or hypothesized occupancy patterns.

The system will allow to optimize building uses and FM activities, and to move towards more flexible occupancy-oriented FM processes during the O&M phase.

Literature review

A literature review has been performed investigating past and current approaches for building and occupancy monitoring and optimization in relation to occupancy, focusing on Post-Occupancy Evaluations (POEs), Building Information Modelling (BIM), Digital Twins (DTs), and sensor systems, by analyzing features, applications, advantages, and limitations.

POEs are mature approaches that have been applied for about 50 years with several projects all over the world (Li et al., 2018). POEs aim at assessing building performances, users' behavior and feedback during the operational phase (Hadjri and Crozier, 2009). In recent years they have been applied aiming at assessing building energy performances and user satisfaction and perceptions (Straka and Aleksic, 2009, Agha-Hossein et al., 2013, Day et al., 2019), investigating the gap between actual energy performances and design targets (Agha-Hossein et al., 2013), and optimizing the design phase (Daher et al., 2018). Three levels of POEs are defined with increasing level of detail, nevertheless likewise of invasiveness for user privacy and implementation costs, i.e. Indicative, Investigative, and Diagnostic POEs (Straka and Aleksic, 2009). Main limitations of POEs are: users' reluctance to POE applications due to privacy issues and implementation costs (Leaman et al., 2010), liability for building owners and managers and lack of indicators and benchmark to evaluate POE results (Zimmerman and Martin, 2001), and limited research on POE results visualization and communication techniques (Li et al., 2018).

The application of BIM for facility management results in several benefits: customer services improvement, time and cost reduction resulting from better planning capabilities, and higher data consistency (Codinhoto and Kiviniemi, 2014, Oti et al., 2016). In addition, the integration of building data in a BIM approach allows to have a single source and storage of geometrical and FM data, thus enabling the visual representation of POE data and detected issues in the building space (Pin et al., 2018, Rogage et al., 2019). However, a BIM approach for asset management lacks information richness, and analysis and simulation capabilities, that are typically manually implemented and time-consuming (Lu et al., 2020). In addition, the achievement of effective and efficient management of buildings during the operational phase strongly relies on continuous flows of real-time building data (Lu et al., 2019, 2020). However, BIM models lack integration with different data sources, e.g., sensor data, and automatic updating over time (Lu et al., 2020).

DTs allow to connect a physical system to its virtual counterpart via bidirectional communication, with or without humans in the loop, using temporally updated data, enabling data analytics and simulations, thus supporting optimization processes and prediction of future states (Boje et al., 2020, Al-Sehrawy and Kumar, 2021). DTs can be seen as an evolution of POEs, since they enable building monitoring and analysis, by adding dynamic analysis and simulation capabilities, and the bidirectional communication between the building and the virtual counterpart with the possibility to act on the physical world. To do that, DTs include: an acquisition layer such as an IoT system (Bolton et al., 2018); a dashboard to visualize and manage sensor data, and return insights, simulations, and predictions (Tomko and Winter, 2019); a BIM model as starting point for the geometrical virtual replica of the building (Boje et al., 2020, Lu et al., 2020); additional tools to provide predictions, simulations, and data analytics (Lu et al., 2019, 2020); and, a fundamental part, actuators or other tools to act on the real building. Some challenges for the definition of a DT are the integration of different data sources in the DT for further data analysis (Lu et al., 2019, Al-Sehrawy and Kumar, 2021) and the proper selection and integration of actuators or other tools to act in the physical world.

Finally, occupancy detection and modelling have been investigated. Occupancy identifies the amount of people and time they spend in spaces, while occupancy patterns collect occupancy factors, i.e., occupancy values at room level, for a whole building or selected building areas (Barbosa et al., 2016). The Internet of Things (IoT) concept refers to the universal presence of "things" or "objects", e.g., sensors and actuators, with digital identification and addressing schemes allowing them to work together to achieve some common goals (Giusto et al., 2010). IoT sensor networks have been widely applied for occupancy monitoring in the scientific literature (Wang et al., 2019). As regards the analysis of sensor types, camera-based, PIR, and CO_2 sensors have the highest accuracy, however some privacy issues are identified (Wang et al., 2019): camera-based sensors present limitations for user detection only within the field-of-view, like PIR sensors, in addition to privacy issues and the Hawthorne effect, which causes alterations of behavior when users are aware of being observed and, if ignored, can affect the reliability of collected data (Yan et al., 2017). Some challenges for sensor network planning and setting are: the selection of sensor types that are most suitable for specific applications (Boje et al., 2020); proper spatial distribution of sensors in indoor spaces (Tomko and Winter, 2019); IoT sensor system calibration (Yan et al., 2017) and collected data quality evaluation (Manngård et al., 2020).

Methodology

The research investigates the definition of a comprehensive methodology, integrating methods and tools to perform efficient building monitoring and optimization of space management and FM activities planning in relation to actual occupancy. In particular, the research aims to define a DSS based on occupancy patterns and simulations, enabling data visualization and analytics through a dashboard, integrating building data from POEs and databases, and real-time occupancy monitoring from an IoT sensor network. The proposed methodology is divided in four main steps (Figure 1), namely preliminary analyses, IoT sensor network, DSS and dashboard; and Key Performance Indicators (KPIs), which are described in the following sections.

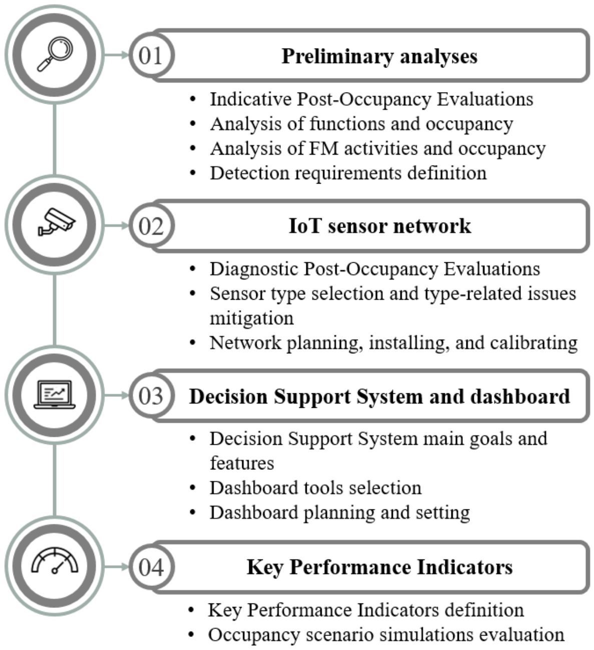

Figure 1: Main steps of the proposed methodology

Preliminary analyses

The first step of the methodology includes the preliminary analyses to be initially performed on the building. Indicative POEs are applied being low cost, minimally invasive, and rapid analyses. The applied Indicative POEs include: a photographic and blueprint analysis of the building, obtaining a general survey of the building layout and space features; a documentary analysis, investigating the building main flows, functions, and FM activities.

The functions and FM activities are then analyzed in relation to occupancy. Functions, and consequently spaces, are analyzed in relation to variable occupancy (O1.1), absent occupancy (O1.2), fixed and constant occupancy (O1.3), or authorized occupancy (O1.4), i.e., functions performed in spaces that are accessible only by specific authorization. The only spaces considered for occupancy monitoring are the spaces affected by variable occupancy. Then, FM activities are analyzed in relation to occupancy, which is considered on two levels: activities influenced by the specific number of users (O2.1), activities influenced by the generic presence of occupants, but not by the specific number of users (O2.2), and activities that are not influenced by occupancy at all (O2.3); the second level distinguishes between occupancy on a real-time (O3.1), hourly (O3.2), or daily basis (O3.3). For each FM activity the analysis highlights the type of occupancy that influences it, by selecting one of the three options for the first level (O2.1-3), and one for the second level (O3.1-3). For instance, heating, cooling and ventilation systems functioning are typically influenced by the number of users (first level, O2.1) and by real-time occupancy (second level, O3.1). On the other hand, security and emergency lights systems, typically placed in corridors and hallways, are not influenced by occupancy (first level, O2.3), therefore none of the columns O3.1-3 of the second level is selected.

The two analyses allow to define the sensor system detection requirements. The first analysis allows to identify the functions, and consequently spaces affected by variable occupancy for the subsequent monitoring phase. Therefore, the FM activities which are performed in the identified spaces are selected. These FM activities are in turn influenced by a certain type of occupancy, as identified by the second analysis. The sensor network should allow to monitor the identified occupancy type, i.e., the requirements for the sensor network are defined.

IoT sensor network

The second step of the methodology 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 an IoT sensor network. The Diagnostic POE aims at deeply investigate building conditions related to occupancy and space usage affecting user comfort and satisfaction, in order to optimize building use, space organization, and user satisfaction regarding their workplaces. The second step investigates the strategies and methods for:

- selecting the sensor type;
- mitigating sensor type-related issues;
- planning and installing the IoT sensor network;
- calibrating the IoT sensor network.

The sensor type is selected according to the necessary detection requirements, considering the pilot study specific spatial features, and based on the sensor features' investigation described in the literature review section.

The main sensor type-related issues to be mitigated are implementation costs and privacy issues. The Indicative POE performed as first step of the methodology allows to identify the critical areas for monitoring, already representing a strategy to mitigate costs. Regarding user privacy issues, the use of cameras in the IoT network is especially critical and therefore a focus on studying the final solution in relation to how workers' data are treated is needed. To this end, a document is produced for the system analyzing features, whether and how workers' data are saved and/or treated in any way, and if and how building users are informed of the monitoring network.

After installing the IoT sensor network, the network calibration is critical to ensure the collected data quality, i.e., data reliability and accuracy, and the proper functioning of the network (Seghezzi et al., 2021). It is an iterative process including five steps: data collection; data evaluation through qualitative analysis to identify major errors; real-time on-site testing to verify the error causes; correction of the error causes; and data collection to check for further errors. The calibration process is iterated until the system is calibrated, thus ensuring the data quality.

Decision Support System and dashboard

The third step of the methodology includes the strategies for planning and setting the DSS. It is defined as a dashboard, i.e., a dynamic tool integrating building data from preliminary analyses and initial Indicative POEs, and occupancy monitoring data from the Diagnostic POEs performed via the IoT sensor network. It aims to support the decision-making process during the O&M phase through data analytics and simulations of possible occupancy scenarios, thus supporting the optimization of FM planning strategies and space organization.

The dashboard has the following necessary features:

- It is user-friendly: it can be easily accessed, read and used by non-experts, who are not required to possess any piece of software or license.
- It allows to analyze and simulate building occupancy through data analytics, aggregation, and filtering.
- It is temporarily updated to accurately represent building conditions over time.

Therefore, the tool to produce the dashboard is selected considering: analytics, visualization, and communication capabilities; usability by non-experts; need for license and costs; availability of developers/online community support; and learning curve and level of necessary skills.

Key Performance Indicators

The fourth step of the methodology describes the KPIs in relation to which evaluating each hypothetical occupancy scenario. The proposed system considers three KPIs:

- KPI_1: percentage of use of spaces. The lower this value, the higher the percentage of vacancies.
- KPI_2: percentage of total current FM activity time of performing (representing the 100%). Reduced/ incremented time results from actual occupancy and space uses or from hypothetical occupancy scenarios.
- KPI_3: percentage of total current FM activity costs (representing the 100%). Reduced/incremented costs result from the updated or hypothesized FM activity time of performing (KPI_2), including a percentage which represents system implementation costs.

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, and before the current research project it has never been monitored. 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. The proposed research project is integrated into a departmental project for FM optimization aiming to test the methodology and evaluate the advantages and disadvantages. In addition, a BIM model of the building was already available from a previous research project (Di Giuda et al., 2020).

Preliminary analyses application

The first step of the methodology allows to perform an initial analysis of the building, to define main user flows and to define which spaces and FM activities could be analyzed through the proposed system. The application of Indicative POEs with photographic and documentary analyses allowed performing a non-invasive, quick, and inexpensive survey of the building. The Department office building hosts different types of users: administrative staff, teaching and research staff (e.g., professors, researchers, PhD candidates). There are several space types: administrative offices, research laboratories, meeting rooms, technical rooms, university staff offices, storage rooms, server rooms, and restrooms.

In addition, the Indicative POE allowed for some major observations: there is an extensive use of the ground floor and a more variable and unpredictable use of other building floors; FM activities are planned without considering actual occupancy; and flexible space utilization is considered only for three co-working spaces located at the ground floor.

The analysis of functions in relation to occupancy allowed to identify the administrative offices, research laboratories, meeting rooms, university staff offices, and restrooms as critical areas for occupancy monitoring, for a total of 70 out of 87 spaces of the building. The selected spaces are in fact characterized by variable occupancy in terms of number of users and/or time of occupation (Table 1). The other functions and related spaces are not considered in the following steps.

Table 1: Function-occupancy table.

Functions/spaces - occupancy	O1.1	O1.2	O1.3	O1.4
Administrative office	X			
Research laboratory	X			
Meeting room	X			
University staff office	X			
Storage room		X		
Technical room				X
Server room				X
Restroom	X			

The analysis of FM activities in relation to occupancy highlighted that the use of almost all systems and cleaning and sanitization services are influenced by real-time occupancy; lighting and power systems, and space organization are influenced by occupancy on hourly basis; system maintenance is generally planned regardless of actual levels of occupancy and use, nonetheless it could be optimized by planning it based on, or cyclically revised according to, occupancy on a daily basis; and lighting systems and emergency lighting in common areas are not influenced by occupancy (Table 2).

Table 2: FM activity-occupancy table.

FM activities - occupancy	O2.1	O2.2	O2.3	O3.1	O3.2	O3.3
Heating system use	X			X		
Heating system maintenance*			X	-	-	-
Cooling system use	X			X		
Cooling system maintenance*			X	-	-	-
Ventilation system use	X			X		

Ventilation system maintenance*			X	-	-	-
Lighting system use		X		X		
Emergency lighting system use			X	-	-	-
Lighting systems maintenance*			X	-	-	-
Internet connection use	X			X		
Power system use		X		X		
Power system maintenance*			X	-	-	-
Shuttering system use		X				X
Shuttering system maintenance*			X	-	-	-
Furniture use		X			X	
Equipment use		X			X	
Cleaning service**	X				X	
Space organization	X				X	

Table notes:

* Maintenance is typically performed without considering actual occupancy. The proposed system could enable to optimize the maintenance by planning and performing it depending on the actual presence of users.

** Cleaning services are influenced by occupancy on hourly basis, however spaces like restrooms are influenced by real-time occupancy since they are typically used for short time periods, consequently they should be monitored in real-time to count the number of uses, after which the restroom should be cleaned.

The activities selected to be tested through the pilot study are cleaning services and space organization, that are influenced by occupancy in terms of number of users, and on real-time and hourly basis.

Results

The following paragraphs describe the results of the application of the second, third, and fourth steps of the proposed methodology on the pilot study.

IoT sensor network planning, setting, and calibrating

The second step regarded the installation of the IoT sensor network, performing a Diagnostic POE. Cameras were selected among the sensor types considering their high accuracy and the possibility to perform other kind of analyses, such as security and safety monitoring, making it possible to implement new functionalities to the system in the future, increasing the scalability of the system itself. The chosen sensors are High Quality Bullet Pro Camera PoE providing HD quality images, with a 110-degree view angle and a Wide Dynamic Range (WDR) which allows 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. The detection is limited to common spaces, i.e., circulation areas and corridors.

The issues of cameras to be mitigated, deriving from the literature review, are the following:

- detection only within sensor field-of-view;
- privacy issues and Hawthorne effect.

Regarding the detection within the field-of-view, virtual objects representing the sensors were added to the BIM model of the building to check the best positioning and orientation of sensors, and to maximize the area covered by the sensors' field-of-view.

Concerning privacy issues and Hawthorne effect, five strategies were adopted. Firstly, none of the private offices and workstations are monitored, only corridors and common areas. As a second strategy, the system was set up to anonymously monitor users and not save nor store any image in the process. The user is recognized as a human by an embedded deep learning algorithm and translated into an anonymous agent that cannot be linked to a specific user identity. Consequently, the IoT network automatically avoids storing or displaying any real image or video recording, neither to the system operators nor to the department staff responsible for the network, and does not allow recognizing users directly or indirectly. The system is fully compliant with EU General Data Protection Regulation (GDPR). As a third strategy, the users were fully informed of the system before its installation, by presenting them the system features, functioning, and privacy measures. The fourth strategy involves placing information signs in the monitored areas notifying users about: monitored areas, main monitoring goals, how data is processed, and the location of the system detailed report. The latter represents the fifth strategy and it is a document available to the users describing: system goals and features, how data is anonymized, collected, and processed through the dashboard, and the subjects responsible for the system. Information signs and document are being revised and will soon be implemented and made available to users.

In addition, the system includes an online webpage (which was set up along with the IoT sensor network), showing the building blueprints and the real-time anonymized user movements, represented by anonymous icons. The webpage is only accessible and used by department staff to monitor the functioning of the sensors, and to manage the sensor network settings.

The only data collected by the system and stored in a database (DB) are: occupancy values (number of users) at room level (O); period of time (T) during which users occupy a room. The only data stored are in fact the number of people entering or leaving the rooms, which allow to define the occupancy at room-level. Data in the DB are accessible only by the facility manager and department staff. Data are then additionally anonymized by aggregating them at floor and building level, consequently eliminating the association of occupancy data with specific rooms for the subsequent phases of data analysis and simulation.

The network calibration was performed as explained in the methodology, for a total of three calibration test campaigns performed in June 2020, in November 2020, and in May 2021, with a three-month period of data collection for each test campaign (Seghezzi et al., 2021).

Year: 2021

Month: Tutte

Day: Tutte

Time of day: Tutte

Figure 2: First configuration of the dashboard data analytics module of the ground floor of the pilot building.

The following issues have been detected and adjusted to calibrate the system: camera not working; issues in detecting users due to the distance between camera and to-be-detected area; obstructions or obstacles in corridors impeding user detection; user behavior deceiving the camera detection; elevated lighting contrast; difficulty detecting cleaning employees; needed adjustments of geofences which represent the entrance area of each room where users are counted as entering or leaving the rooms.

Decision Support System and dashboard definition

After planning, setting, and calibrating the IoT sensor network, the DSS was planned and set as a dashboard to support the decision-making process of facility managers. The dashboard can be easily accessed and used by the facility managers and 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, as described 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 even without having installed the software or owning a license. Finally, the software does not require advanced coding skills and it is comparatively user friendly; the extracted data 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 is divided in two modules: a data analytics module and a simulation module.

The data analytics module was set in a first configuration: different web pages allow for collected data visualization, query, aggregation, and analytics through selected graphics. They allow to monitor and investigate occupancy and vacancies at floor and building level, visualizing and filtering occupancy on daily, weekly, and monthly level, and in relation to functions and user roles inside the organization. The possible outputs are: percentages of space usage and vacancies; identification of over- and underutilized spaces; prioritized cleaning activities in relation to actual space occupancy.

Figure 2 shows the dashboard web page analyzing data of the pilot building ground floor, with data collected from June to October 2021. 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 could highlight the less need for cleaning study and meeting rooms which as of now are cleaned with the same frequency of 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, even if for less time and by fewer people.

The simulation module is still under development and, once completed, data collected of all building floors and for a longer period (around one year from 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. Dashboard web pages with selected graphics will allow to compare the hypothesized occupancy scenarios with current building occupancy patterns. Consequently, it will be possible to: compare proposed space organization strategies and related cleaning plans with current conditions; test different cleaning strategies according to actual use of spaces or new hypothesized occupancy levels, i.e., according to the number of users and time period of use at floor and building levels.

Key Performance Indicators and evaluation of occupancy scenario simulations

The proposed simulation scenarios will be evaluated according to the three KPIs described in the methodology section, defining a hierarchy of the proposed occupancy and FM planning scenarios. It will be possible to investigate and evaluate the scenarios according to the results of the KPI application. The facility manager and building owner will then be able to select the most suitable option for actual testing and application in the building, supported by the results of the proposed system.

Conclusions

The proposed system will act as a DSS during the O&M phase, enabling optimized management of spaces 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, thus considering actual user needs in terms of spaces. Reorganization and redistribution of spaces due to staff or activities changes overtime will be supported by analyses and occupancy scenarios development through the proposed system, consequently increasing the workplace adaptability to changing conditions and needs. In addition, insights and occupancy trends from the system dashboard will allow the optimization of cleaning activities and contracts that are currently based on building floor areas. This will allow 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 regarding their workplaces. 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 monitoring, analysis, and simulation over time.

Possible further developments of the research are the automation of collected data cleaning and classification processes for the subsequent actuation of a real-time management through the dashboard. In addition, the simulation of occupancy and cleaning scenarios could be automated and performed directly by the dashboard on the basis of collected data analyses. Consequently, it could provide the operator with the simulation results and possible optimization strategies and suggestions. Furthermore, introducing controls and other tools (e.g., a mobile application for space booking) to act on the physical building and integrating them with the proposed system will allow defining a Digital Twin for FM. In a long-term view it will be possible to define criteria for optimized design of future office buildings with similar functions and expected occupancy values and variations. In addition, guidelines for proper occupancy monitoring, analysis, and simulation during the O&M phase could be defined, ensuring the continuous improvement of existing buildings' use and the increase of building adaptability to changing requirements and needs over time.

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