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# TOWARDS A USER-CENTERED FRAMEWORK TO SUPPORT PROACTIVE BUILDING OPERATION AND MAINTENANCE: PRELIMINARY RESULTS OF A COMMUNICATION PLATFORM BETWEEN USERS AND STAKEHOLDERS

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**Highlights**

A user-centered approach includes users' impact on building Operation & Maintenance.
A framework is proposed to include users' monitoring and engagement in O&M.
A users-stakeholders communication platform is developed to report building failures.
A web-based application is implemented and applied to a complex building case study.
It supports corrective maintenance and provides data for proactive O&M.

**Abstract**

Users' needs and behaviors can alter the building efficiency, thus leading to significant efforts to support Building Operation & Maintenance (O&M) tasks. This work develops the preliminary concepts of a framework for O&M including users' monitoring and engagement strategies. In the context of a complex university building, we developed and tested a users-stakeholders communication platform including a web-based application to report and check failures and damages to building's components and devices.

**Keywords**

Building maintenance, Occupants' behavior, Users' engagement, User-centered approach, Proactive maintenance.

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## 1. INTRODUCTION

Designing sustainable buildings, from the environmental, social and economic perspective, and considering the whole life cycle, is a priority objective, which should increasingly consider the effective occupants' behavior, in both normal and emergency conditions [1–3].

As a response to environmental stimuli, building users can decide to perform specific actions and interactions with building components and systems to achieve or restore optimal conditions in terms of well-being and safety. As a consequence, behavioral tasks modify environmental and/or building components conditions, thus generating a gap between the expected (planned) and effective (in-use) performances [4].

Building Operation and Maintenance (O&M) tasks are widely affected by such behavioral issues related to occupants' tasks and flows [5, 6]. A relevant example in this sense is the action of windows opening, which can be due to different occupants' needs and preferences (e.g. air change, temperature regulation, pleasure) and strongly influences the energy consumptions because of the indoor air temperature variation [7]. In working places and public buildings, the room occupancy can be organized according to specific schedules, thus also affecting occupants' flows. For instance, the elevator use is affected by the occupants' motion, with different solicitation levels depending on the distribution of people over time and space inside the building [8].

Methods, tools and integrated systems to support building O&M should take into account such effective occupants' responses [1, 3, 9, 10], including monitoring, modeling and users' engagement as key design and planning factors. Such a "user-centered" approach has been considered by many types of research on building energy efficiency [11–13], as well as on building safety in emergencies and evacuation process [3, 14, 15]. In the context of building O&M, in general, the "user-centered" approach aims to the optimization of related tasks, according to the following main aspects [1, 3, 16]. "Monitoring" of buildings and components allows defining the effective building conditions and users' actions to define representation models. Such "models" can be used to assess the impact of the occupants' behaviors on O&M tasks and evaluate the effectiveness of O&M strategies. Then, "Building Automation Systems" (BAS) could be connected to such models to support building stakeholders in adopting proper O&M strategies [10, 11, 17]. Finally, a direct "interaction with the users" can be useful to increase their awareness, to lead them to perform "proper" behaviors and to rise their satisfaction level in the building use [18–21].

This approach should be extended to the whole number of ordinary and extraordinary O&M tasks involving building components and systems (e.g. elevators, doors, flooring, electrical devices, etc.), as well as building management activities (e.g. cleaning, occupants' flows in the building, occupancy, etc.), since these tasks highly impact on the overall building life cycle impacts and costs [16]. Public buildings are the most significant application contexts because of the continuous presence of occupants (both visitors and frequent users), combined with the possibility to reach overcrowd conditions over space and time (e.g. large offices, universities, transport stations, etc.) [1, 22].

Hence defining fruition and maintenance priorities is a key issue for public buildings. According to EN 13306 standard [23], during the life cycle of an activity, "maintenance" tasks include the combination of all the technical, administrative and management actions aimed at maintaining the activity functional level (i.e. the building) or bring it back to a correct functional state. In this context, maintenance tasks should be conceived as an organized set of actions (and not as the sum of single corrective interventions) that involves technical and management aspects, within a life cycle perspective. In this view, *preventive maintenance* (before the system failure, to avoid its degradation) and *corrective maintenance* (after the failure has occurred, to restore the conditions) should be strictly linked [5, 10, 22, 24] by optimizing the organization of preventive actions (to limit unexpected failures due to the elements degradation) and providing immediate interventions to restore the functional conditions of the building element.

In this sense, maintenance strategies can take advantages of control-based (or rather, "cognitive") approaches, such as those related to: 1) *BAS* and *internet of things* (*IoT*)-based technologies [10, 25]; 2) direct communication from and to the users and the professionals within the maintenance team [19, 26]. BAS can manage data on the condition of the components, especially for those that can be directly and remotely monitored (e.g. lighting and cooling), eventually merging the information within Building Information Modeling (BIM)-based systems [25, 27]. Nevertheless, some building components cannot be directly monitored by BAS (i.e. "passive" components like doors, floorings, façade elements) or, in case of existing buildings, introducing BAS is challenging due to e.g. technical or economic issues.

Hence, previous studies underlined the importance of maintenance teams' actions, which can provide specific data from direct inspections (when and where they are necessary), as well as from direct involvement of the occupants, since they use the space daily and are the first subjects who directly suffer from the elements failures [20, 25–27]. Indeed, the participatory engagement of users in maintenance management processes (i.e. failures signaling and checking) makes them "aware" in the use of the building, thus supporting the stakeholders in identifying the scheduled or extraordinary actions to be taken. According to a "user-centered" approach for O&M, such communication framework could be additionally backed up by the monitoring of the occupancy conditions, so as to generally trace all the man-built environment interactions which can stress the overall system [10, 20, 28].

Finally, the possibility to combine and analyze all these data can ensure to move from a simple "planned" and "corrective" maintenance approach to proactive and predictive ones [1, 16, 20, 22]. In this sense, data on the current state and the ongoing failures of the building components/systems can be merged to the building use monitoring information, providing integrated simulation tools to forecast future maintenance needs and optimize time-based maintenance actions. Meanwhile, the proactive perspective could be improved because of the interaction between the stakeholders and the "maintenance-aware" occupants, in the building use. The advantages of such O&M method have been widely demonstrated in manufacturing [29, 30], but they could also be extended to buildings O&M to decrease impacts and costs of O&M tasks and to increase the users' satisfaction.

This work focuses on the development of proactive and predictive O&M strategies for complex buildings. The overall research aims at adopting the "user-centered" methodological approach based on the combination of data from cognitive building-integrated systems (for monitoring: users' presences, flows and behaviors; building components/systems state and degradation) and management communication platforms (involving building stakeholders, professionals of the maintenance teams and, mainly, the users). A merged control-based (to improve "conditions-based maintenance" and quick response to needed corrective actions) and a simulation-based framework is then developed to move towards proactive strategies in O&M. According to the methodological bases (Section 2), as a result the general operative framework is provided (Section 3.1), especially focusing on the development and testing of a web-based communication platform (Section 3.2). Such platform is applied to a significant case study, the Faculty of Engineering at Università Politecnica delle Marche (Ancona, Italy) (Section 3.3).

## 2. PHASES AND METHODS

The current work is divided into three main phases (in brackets, M refers to the methodological section, while R to the result section):

1. definition of the general user-centered framework for building O&M, combining condition-based and proactive criteria with cognitive building automation systems and users-stakeholders communication tools (M: section 2.1; R: section 3.1);
2. development of the platform for communications between the users and the stakeholders about failure signaling and conditions checking, within the context of a relevant case study (a university building) (M: section 2.2; R: section 3.2);
3. application to the case study to demonstrate the capabilities of the proposed communication platform, by performing a long-lasting testing campaign (M: section 2.3; R: section 3.3).

### 2.1. CRITERIA FOR THE OVERALL FRAMEWORK DEFINITION

The user-centered operational framework should dynamically collect data about [3, 4, 13, 20, 25, 28, 29, 31, 32]:

1. the users' occupancy and behaviors, over time and in space (including the interactions with building components and technological systems), in relation to the environmental conditions;
2. the "active" building systems (electrically supplied, connected to BAS via wireless or LAN connections) operation and state, through automatic and remote-control solutions (e.g. "on board" sensors), plus direct inspection processes (e.g. by the professionals of the maintenance team);
3. the "passive" building components status (those not provided with direct electrical connection) and the building management elements (e.g. cleaning), by means of the control on the users' actions, data on scheduled activities, direct inspection processes;
4. the users-stakeholders communication to report systems abnormalities and failures, through communication platforms, which can also be used for further feedback on occupants' satisfaction level.

According to a "cognitive" building perspective [3, 25], the collected data must be immediately shared with the stakeholders and analyzed to predict future scenarios in the building use, thus enabling the detection of critical conditions towards the alarms signaling and the application of conditions-improvement measures (i.e. interventions by the building O&M teams; automatic actions by the "cognitive" building elements).

### 2.2. CRITERIA FOR THE DEVELOPMENT OF THE COMMUNICATION PLATFORM WITHIN THE CASE STUDY APPLICATION

The campus of the Faculty of Engineering at the Università Politecnica delle Marche (Ancona, Italy) has been chosen as a relevant case study for the development of the framework, and especially of the communication platform. It includes several multi-story buildings, with an overall area of about 150000 $m^2$, hosting both teaching, laboratory, and office spaces, with an overall presence of over 5000 people per day. The presence of university staff members and students, as well as the size and the mixed-use of the structures, make the case study particularly relevant for the application of the O&M framework and, in particular, for the users-stakeholder communication platform.

The Faculty's Technical Department (FTD) is the stakeholder in charge of collecting failures and abnormalities reports from the users and addressing them to the maintenance service teams. In a period of about 15 months between 2018 and 2019, over 2100 O&M failures reports (intervention "request tickets") were made in the Faculty of Engineering, by covering the 40% of the total reports of the University. In this period, the management of the request tickets was quite complex and obsolete in terms of users-stakeholder communication (e-mails, phone calls), while an automatic process to manage the requests was limited to the FTD-maintenance service team interactions. Hence, to identify the requirements of the overall communication platform, the aforementioned general criteria [13, 25] have been combined with the outcomes of an interview with the FTD.

According to the interview, the new communication platform should: 1) trace unambiguous request data (in terms of type of intervention request, time of signaling, position of the damaged/not working element within the campus layout) and identity the user to activate a direct contact for further information requests from the FTD; 2) immediately inform the FTD of the failure signaling, and keep a copy of it in a shared central database; 3) immediately send a confirmation to the user and track the progress in the O&M activity state according to the FTD-maintenance service team interaction; 4) allow failures' signaling from different devices (including smartphones) only to a limited number of users who have a recognized rule within the Faculty (e.g. representatives of the student body, teachers and researchers, technical and administrative staff members).

### 2.3. TESTING CAMPAIGN

The new communication platform has been preliminarily tested by a limited number of users, which is representative of the building occupants' typologies (51 volunteers within professors, researchers, and representatives of the student body), from January to August 2019. Such a choice allowed improving the system by direct feedback from them, and different releases of the platform have been then published thanks to their support. However, during the test phase, the traditional communication channel between users and the FTD was still maintained.

Results collected from the communication platform in the considered period of 10 months are analyzed in absolute and percentage terms according to: the type of intervention, to evaluate the incidence of each considered building element; the building area where it occurs, to evidence which part of the buildings are most affected by the failures; the rule of the user, to evaluate the related engagement per typologies; the number of requests which needed additional information from the users to the FTD.

## 3. RESULTS

### 3.1. USER-CENTERED FRAMEWORK FOR BUILDING O&M

Figure 1 represents the schematics of the user-centered operational framework for building O&M proposed by this work. The framework is based on 4 main pillars (P), which are described in relation to their main elements and functions (evidenced in italics in the following).

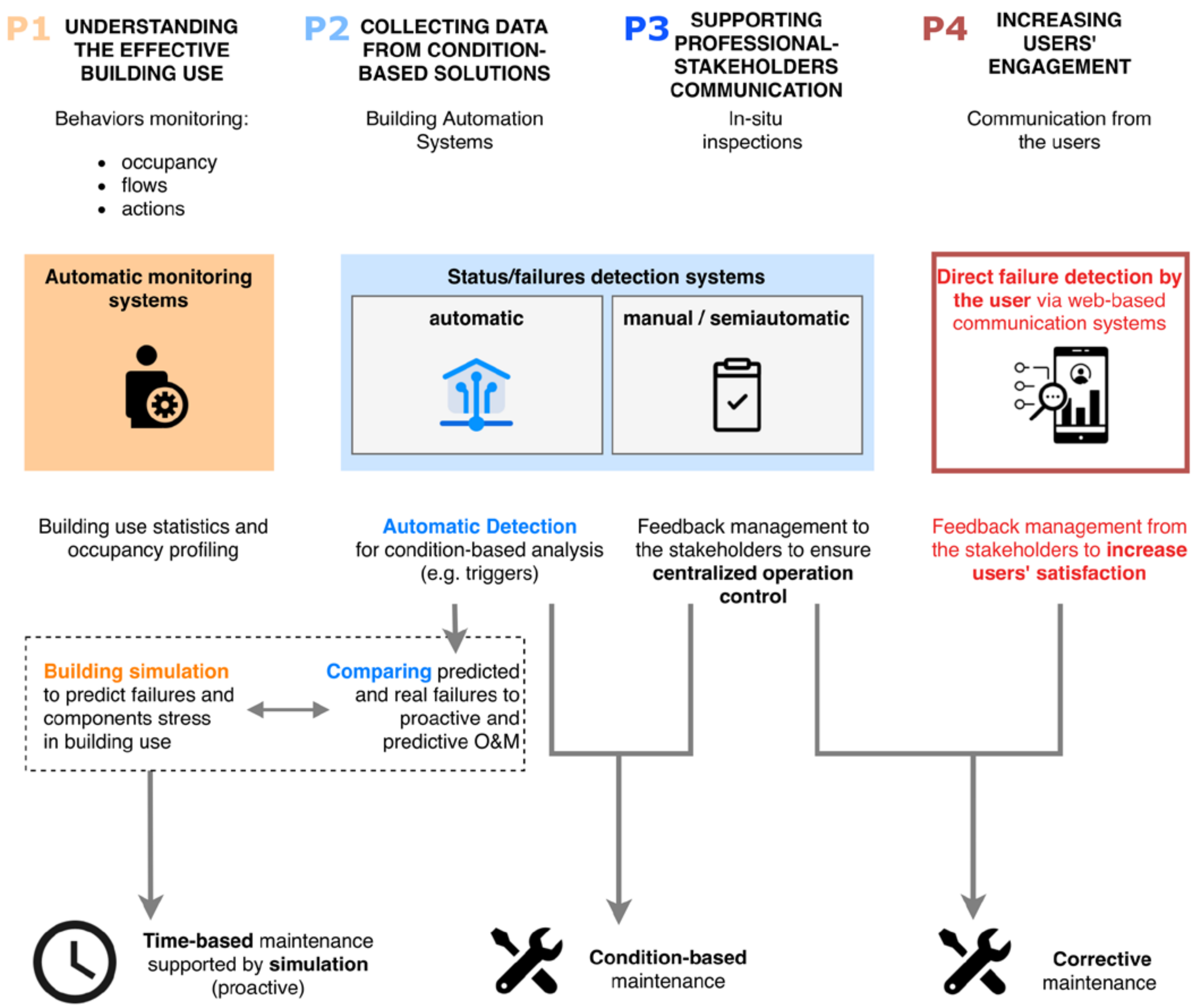


Fig. 1. *Overview of the proposed user-centered operational framework according to the main discussed pillar (P1 to P4 on the top) and towards the maintenance strategies (on the bottom).*

From a general point of view, *Understanding the effective building use* (P1) and *Collecting data from conditions-based solutions* (P2) can be achieved by means of BAS-based solutions, and should be integrated by *Supporting professionals-stakeholders communication* (P3). Furthermore, *Increasing users' engagement* (P4) will ensure system redundancy and quick-detection of failures, by promoting users' awareness towards O&M issues and checking their level of satisfaction while using the communication systems.

Monitoring systems aimed at P1 and P2 should be modular, easy-to-implement and maintain, as well as directly connected to a central elaboration unit within the BAS (e.g. by using wireless or low-energy communication systems; LAN and power-by-ethernet solutions), especially by considering "active" building systems and devices, such as the electrically-supplied ones (i.e. cooling, heating, lighting, elevators) [1, 3, 10]. The collected data allow defining if (and how) the monitored element is used by the occupants, so as to define occupancy and flows-related actions of the users, but also to check the state of the components in an automatic manner and additionally supply information on failures. For instance, the integration of sensors in lighting systems within a BAS-network would both allow to roughly estimate the lighting time due to the presence of individuals inside the room. Data for *automatic monitoring systems* of human behaviors and presence in the building space connected to P1 will support such kind of analysis (in the previous example, by giving additional data on the effective occupancy time). These sensors could also be used to trace the use of "passive" elements (e.g. doors, windows, flooring) by the occupants, which can stress the building components during the time (e.g. for door: number of openings; for floorings: users' flows density) [1, 13]. P1-related systems can use [10, 13, 33, 34]: "collective" monitoring solutions (per room/space/component, e.g. elevator), such as ultrasonic or infrared sensors; "object-based" monitoring solutions (per building component/device, e.g. windows, shadings), such as on/off (open/close) or power-based control systems; "individual" monitoring solutions (per occupant), such as those based on badges or personal devices tracking (e.g. via wireless connections) of occupants' position during the time. "Individual" solutions have a prominent rule in all the spaces where access control strategies are activated (also due to individuals' safety issues) and allow to include tools for users-stakeholder communication, also according to P4.

Data from such monitoring systems in P1 and P2 can be linked to derive occupancy profiles over space and time, depending on the activities carried out in the building spaces, in order to create a database concerning the effective use of the structure by the occupants [1]. This possibility is essential in complex buildings (such as universities) where different modes of use over time can exist, both in the short term (e.g. daily use for students, researchers and visitors; correlation with the lessons during the year) and in the long term, that is during the life cycle of the building (e.g. in relation to the number of students over time). *Building simulation* models can assess how future scenarios could be managed in terms of O&M tasks (but also in an individuals' safety perspective), so estimate the possible components failures or unacceptable stress levels due to the building use. This would lead towards the quantification of maintenance, renovation and building interventions/modifications tasks over time and space (e.g.: planning the replacement of building components; coordinate the cleaning tasks according to the presence of occupants over time; interventions on elevators due to different users' flow density) [10, 35–37]. *Comparing predicted and real failures* (and other maintenance actions) allows validating the simulation process, according to an experimental-based approach in a long-term perspective. Then, simulation data will support *time-based maintenance* (thus moving towards a proactive approach) [16, 20].

Merging P2 and P3 tools allow a complete control on condition-based maintenance tasks. In particular, the *automatic detection tools for condition-based analysis* (e.g. triggers connected to stress conditions and failures of the components) can be supported by *in situ-inspection* (through manual/semiautomatic methods, including both scheduled and one-off inspections) by [10, 38, 39]: creating *centralized operation control* platforms to connect the professionals of the maintenance teams and the stakeholders; managing the staff assignment for building maintenance when and where they are effectively needed. In this sense, the use of tools based on a multi-dimensional BIM approach can be useful for managing inputs in structured databases (by component, system, use) [25, 37].

Finally, P3 could be supported by P4 tasks because of the direct involvement of the users as active subjects into the failures signaling process for *Corrective maintenance* actions [1, 13, 25, 40]. Such an approach is relevant especially in case of limitation of implementation of BAS (P2), as well as with respect to the aforementioned "passive" elements to be monitored. The specific elements of such pillar P4 for the case study application of this work are discussed in Section 3.2.

### 3.2. COMMUNICATION PLATFORM

P4-related tasks shown by Figure 1 are aimed at encouraging the participation of users with regards to the maintenance issues and at increasing the interactions with the building stakeholder. Simple communication platforms can be implemented at this aim to: gather information on the failures and degradation/abnormality state of the elements; gather feedbacks on users' satisfaction; interact with occupants to support "good practices" in the building use, making occupants aware of the surrounding conditions and benefits of a proper maintenance in respect to

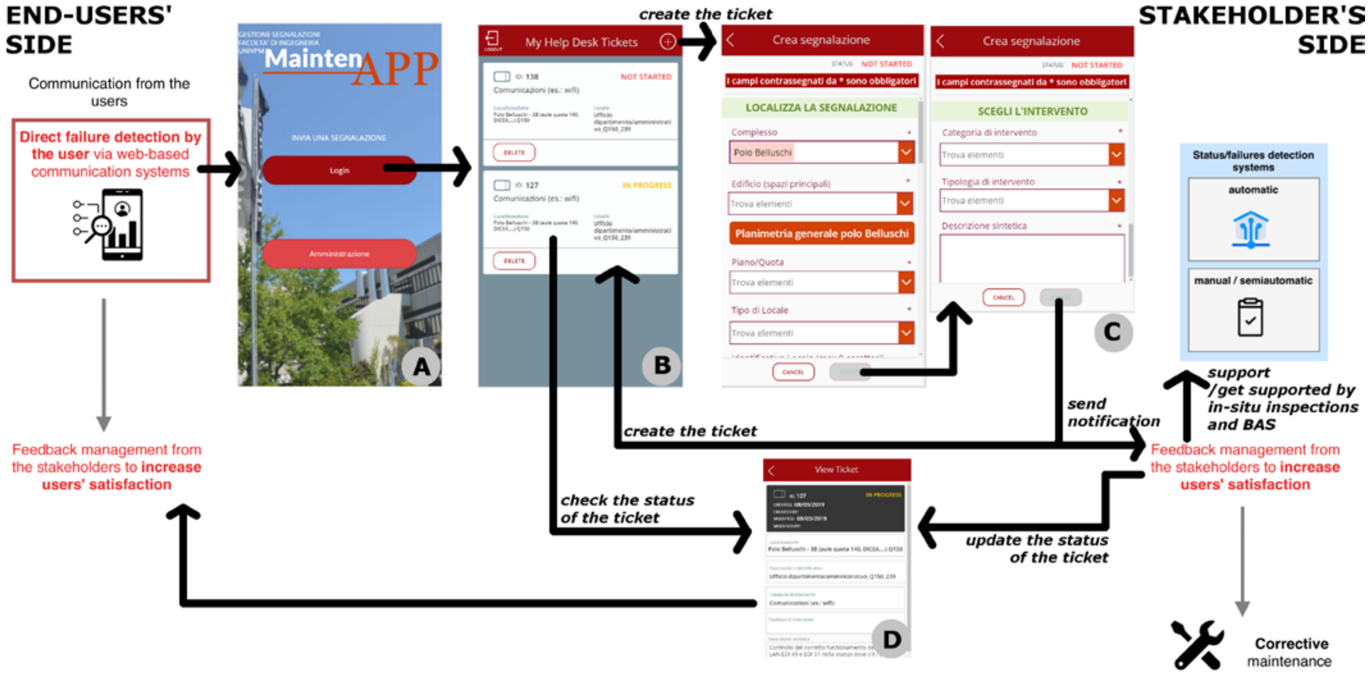


Fig. 2. *Communication platform for the failures signaling and checking according to the general framework perspective and by defining the relations (black arrows) between the end-users and the stakeholder. The main interfaces of the web-based application are described: after the login page (A), the main page lists the current users' request tickets (B), allows creating new ones (C) and checking the status of the existing ones according to the manager updates (D).*

their activities inside the building (e.g.: increased comfort, safety and productivity).

According to the general framework of Figure 1 and the methodological criteria of Section 2.2, the communication platform developed in this work is based on a web-based application, which is actually focused on the users-stakeholder interconnection for failures signaling. Figure 2 traces the general functioning of the platform from the end-users' and the stakeholders' sides.

According to the FTD requests, the access to the platform is only possible for university staff members and students, through individual access credentials, in order to ensure consistency between reported maintenance requests (called "tickets") and effective building users, in a traceability perspective in the flow of information.

As shown in Figure 2, the users can log into the platform by using an application called "MaintenApp" (Figure 2-A). The app is available both by smartphone, tablet and personal computers and was developed within the *PowerApps* platform of Microsoft Office 365. In the main app page, each user is informed of the state of his/her "ticket" (Figure 2-B).

While creating a new "ticket", the user is guided to fill in different form fields, which ensure the introduction of all the required details for the univocal identification of the intervention request (Figure 2-C). Firstly, to provide the location of the failure, a map of the campus is provided, in combination with information on the building level and room typology (via drop-down menu). More precise indications can be provided through an identification of the element or the room, thanks to the existing identification codes placed on the specific element or on the access door of the room. In view of BIM-based solutions for data storage, this choice could allow a direct integration between the location of the element, its characteristics and the related history of the "tickets", thus allowing failures reports and analysis, which can also be used to support simulation models (see Section 3.1).

Depending on the type of room and element, different lists of intervention categories are activated (e.g. fire-fighting system, mobile components, building components, electrical system, etc.). The exhaustive list is reported in Figure 4, according to the testing campaign results. A cascade correlation is established between type and subtype of interventions, e.g. for electrical faults, the types include interventions on lighting bodies, audio system, electrical outlets. In this way, the users are guided towards a proper compilation of the form by ensuring the consistency between the input data. Nevertheless, a further field of "free description" is introduced to obtain further detail on the failures. Then, the user provides contact information (e-mail address; for employees, internal phone number), to guarantee the possibility of contact by the FTD in case of need for further information.

Once the "ticket" has been completed, the user receives an immediate notification to the inserted e-mail address, while another communication is sent to the stakeholder. Then the online database where the "tickets" are organized is automatically updated (i.e. using the *Sharepoint* platform of Microsoft Office 365). The stakeholder can access the complete list of "tickets" from the webpage or through the dedicated section of the app.

Finally, the stakeholder can update the "tickets" state via the central online database, to notify the users about the resolution of the failure conditions (Figure 2-D). According to a BIM-based approach, the online database can be directly connected to BAS-related ones to ensure an automatic update of the elements state.

### 3.3. RESULTS FROM THE APPLICATION TO THE CASE STUDY

During the testing campaign, although the small participants' sample dimension, 151 "tickets" have been managed via the developed communication platforms, thus involving the 15% of the maintenance requests for the whole campus of the Faculty of Engineering. 37% of the "tickets" did not report any information on the "free description" field. Nevertheless, only 14% of the whole 151 needed further intervention by the FTD to check or request further data to correctly identify the failure (all of them were related to Plumbing, Cooling and Heating systems, characterized by a certain complexity within the building structure). 62% of "tickets" were sent by the representatives of the student body, thus highlighting a greater engagement of students with respect to the university employees. The majority of the "tickets" refers to failures located in the building floors with a mixed-use (classrooms and offices: 86%), while office spaces (9%) and labs (5%) were limitedly reported, also depending on the user-type related engagement results previously mentioned.

Figure 3 traces the "tickets" percentage in relation to the type of space where the failures occur. Most of the "tickets" are related to common spaces, i.e. corridors, staircases, elevators, main halls, and other open spaces where students can wait before and after the lessons. This result can be essentially due to the high flows of users inside the structure during the building opening time, as well as to the limited control of such intermediate spaces with respect to activities rooms. The same trend involves the toilets, where similar issues exist. Classrooms and offices show the same "tickets" percentages, while labs refer to minimum "ticket" percentage thanks to the high level of control inside such spaces (i.e. maintenance support by the lab technicians).

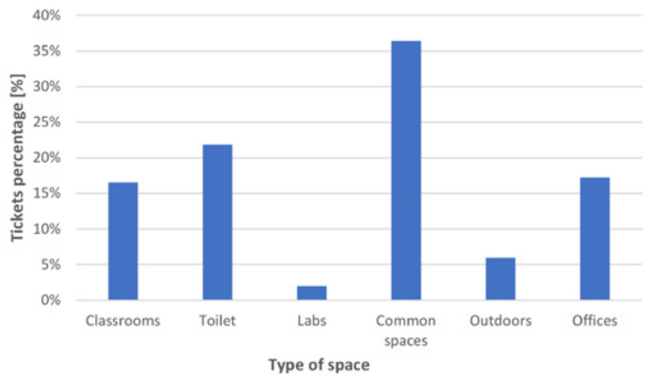


Fig. 3. *Statistics of the maintenance/failures "tickets" percentages in reference to the type of space in the university campus buildings. Common spaces include corridors, staircases, elevators, main halls within the building and other open spaces where students can wait before and after the lessons.*

Figure 4 shows the "tickets" percentage in relation to the type of intervention. Plumbing, Cooling and Heating (PHC) systems are considered within the same type of intervention according to the FTD interviews. This choice implies the higher number of failures signaling, essentially due to subtype of intervention concerning Cooling/Heating systems. In fact, Heating and Cooling related "tickets" correspond to the 17% of requests (see the light blue area for HC in Figure 4), thus being comparable to the intervention requests on the electrical systems. From a time-based point of view, requests on Cooling/Heating systems were essentially linked to the winter season (Heating systems; about 55% of the PHC system-related "tickets") rather than to the summer season (Cooling systems). The "free description" fields (combined with the subtype of intervention list) allowed a complete definition of the requests.

According to Figure 4, a significant part of the "tickets" is referred to "passive" components (Building components plus Windows and doors refer to about the 25% of the "tickets", and to about 35%, if also including furniture), thus evidencing the utility of the communication platform for the control of such elements. Finally, "tickets" organized in the "Others" type are essentially due to requests about the inaccessibility of some parts of the buildings during the opening time (e.g. some rooms are closed or unusable): such kind of requests e affects the operational tasks inside the spaces (performing activities by the users) and not to direct maintenance issues. In this case, the "free description" field allowed a complete definition of the intervention requests.

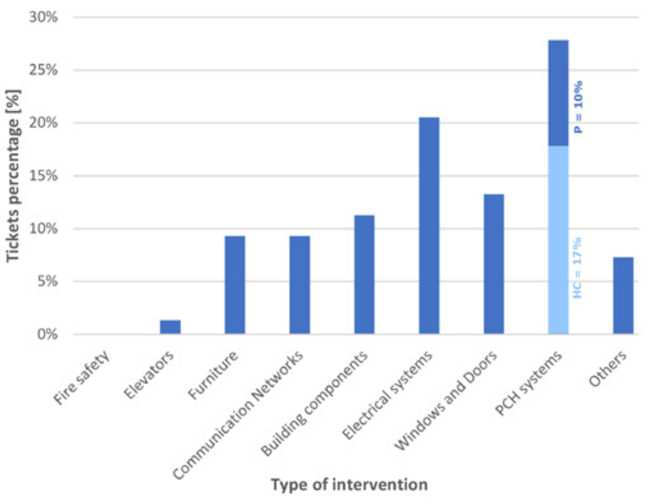


Fig. 4. *Statistics of the maintenance/failures "tickets" percentages in reference to the type of intervention. PHC systems include Plumbing (P, dark blue area), Cooling and Heating (HC, light blue area) systems, according to the FTD requests. "Others" includes additional kind of interventions.*

## 4. CONCLUSIONS AND REMARKS

Sustainable building management combines the optimization of available resources, the minimization of related costs, and the guarantee of a high level of satisfaction for users. In this context, Building Operation and Maintenance (O&M) tasks are one of the most relevant, during the whole building life cycle, and should jointly consider building components/systems oriented-strategies (e.g. based on a "condition-based" approach, by using building automation systems) and the actions of occupants inside the spaces (e.g. based on a "user-centered" approach). Linking these two key factors will also allow improving O&M tasks by including estimations of the impact of users' occupancy and actions, by means of simulation tools, to move from a corrective (and simple time-based) approach to a proactive one. Meanwhile, engaging the users in the O&M process can ensure a higher level of satisfaction due to the improved engagement.

This work provides a contribution in this sense, by proposing a methodological and operational framework according to the existing literature. In particular, the first results involve the development and implementation of a users-stakeholder communication platform based on a web application, for reporting building components/systems failures and abnormalities and checking the O&M action performance. The platform has been tested within a significant case study (a university campus), by involving a reduced number of users, so as to evidence its capabilities and create a reliable system.

Results evidence how the system can support the O&M process, especially for "passive" components (e.g. doors, windows, ceilings and floorings, walls, furniture), which cannot generally be monitored by building automation systems. Future activities will involve an extensive application of the platform within the university spaces used as a case study, to evaluate its effectiveness as the main O&M communication tool, over a broader time horizon, as well as the implementation on other significant public buildings. Occupancy schedule and spaces use modes (e.g. activities-based calendar, such as teaching for universities) can be implemented to correlate occupancy statistics and failures to O&M tasks. In this way, the system will provide data for simulation-based approaches in O&M. Furthermore, automatized communication between a central O&M control station and the users could be included in the communication platform, especially for the issues related to occupancy of rooms (also in the view of the optimization in the number of occupants inside each space, e.g. due to airborne disease mitigation or individuals' emergency safety) and users' flows inside the buildings (e.g. elevators' failures in combination to the planning of travel paths). Statistics on the "building needs" (efforts and costs for e.g. energy, maintenance) will be shared with the users to increase their awareness towards O&M tasks. Finally, the implementation of technologies for behavioral monitoring in strategic areas of the building will be implemented to pursue a proactive approach as a whole.

## 5. ACKNOWLEDGMENT

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## 6. REFERENCES

[1] Dong B, Yan D, Li Z, et al (2018) Modeling occupancy and behavior for better building design and operation-A critical review. Build Simul 11:899–921. https://doi.org/10.1007/s12273-018-0452-x

[2] de Wilde P (2019) Ten questions concerning building performance analysis. Build Environ. https://doi.org/10.1016/j.buildenv.2019.02.019

[3] Bernardini G, Santarelli S, D'Orazio M, Quagliarini E (2019) A cognitive approach for improving built environment and users' safety in emergency conditions. TEMA Technol Eng Mater Archit 5:47–60. https://doi.org/10.17410/tema.v5i1.214

[4] O'Brien W, Gaetani I, Carlucci S, et al (2017) On occupant-centric building performance metrics. Build Environ 122:373–385. https://doi.org/10.1016/j.buildenv.2017.06.028

[5] Lind H, Muyingo H (2012) Building maintenance strategies: Planning under uncertainty. Prop Manag 30:14–28. https://doi.org/10.1108/02637471211198152

[6] Suweero K, Moungnoi W, Charoenngam C (2017) Outsourcing decision factors of building operation and maintenance services in the commercial sector. Prop Manag 35:254–274. https://doi.org/10.1108/PM-06-2016-0028

[7] Stazi F, Naspi F, D'Orazio M (2017) A literature review on driving factors and contextual events influencing occupants' behaviours in buildings. Build Environ 118:40–66

[8] Tukia T, Uimonen S, Siikonen M-L, et al (2016) Explicit method to predict annual elevator energy consumption in recurring passenger traffic conditions. J Build Eng 8:179–188. https://doi.org/10.1016/j.jobe.2016.08.004

[9] Yan D, O'Brien W, Hong T, et al (2015) Occupant behavior modeling for building performance simulation: Current state and future challenges. Energy Build 107:264–278. https://doi.org/10.1016/j.enbuild.2015.08.032

[10] Burak Gunay H, Shen W, Newsham G (2019) Data analytics to improve building performance: A critical review. Autom Constr 97:96–109. https://doi.org/10.1016/J.AUTCON.2018.10.020

[11] D'Oca S, Hong T, Langevin J, et al (2018) The human dimensions of energy use in buildings: A review. Renew Sustain Energy Rev 81:731–742. https://doi.org/10.1016/j.rser.2017.05.175

[12] Yan D, Hong T, Dong B, et al (2017) IEA EBC Annex 66: Definition and simulation of occupant behavior in buildings. Energy Build 156:258–270. https://doi.org/10.1016/j.enbuild.2017.09.084

[13] Naylor S, Gillott M, Lau T (2018) A review of occupant-centric building control strategies to reduce building energy use. Renew Sustain Energy Rev 96:1–10. https://doi.org/10.1016/j.rser.2018.07.019

[14] Groner NE (2016) A decision model for recommending which building occupants should move where during fire emergencies. Fire Saf J 80:20–29. https://doi.org/10.1016/j.firesaf.2015.11.002

[15] Marzouk M, Mohamed B (2019) Integrated agent-based simulation and multi-criteria decision making approach for buildings evacuation evaluation. Saf Sci 112:57–65. https://doi.org/10.1016/j.ssci.2018.10.010

[16] Bernardini G, Di Giuseppe E (2020) Towards a user-centered and condition-based approach in Building Operation and Maintenance. In: Littlewood J, Howlett RJ, Capozzoli A, Jain LC (eds) Sustainability in Energy and Buildings. Proceedings of SEB 2019 (Series title: Smart innovation, Systems and Technologies - vol. 163 - Series ISSN: 2190-3018), 1st ed. Springer Nature Singapore Pte Ltd, pp 327–337

[17] Degha HE, Laallam FZ, Said B (2019) Intelligent context-awareness system for energy efficiency in smart building based on ontology. Sustain Comput Informatics Syst 21:212–233. https://doi.org/10.1016/j.suscom.2019.01.013

[18] Bernardini G, Lovreglio R, Quagliarini E (2019) Proposing behavior-oriented strategies for earthquake emergency evacuation: A behavioral data analysis from New Zealand, Italy and Japan Saf Sci 116:295–309. https://doi.org/10.1016/j.ssci.2019.03.023

[19] Pontan D, Surjokusumo S, Johan J, et al (2018) Effect of the building maintenance and resource management through user satisfaction of maintenance. Int J Eng Technol 7:462–465. https://doi.org/10.14419/ijet.v7i2.11247

[20] Silva A, de Brito J (2019) Do we need a buildings' inspection, diagnosis and service life prediction software? J Build Eng 22:335–348. https://doi.org/10.1016/J.JOBE.2018.12.019

[21] Rafsanjani HN, Ghahramani A, Nabizadeh AH (2020) iSEA: IoT-based smartphone energy assistant for prompting energy-aware behaviors in commercial buildings. Appl Energy 266:114892. https://doi.org/10.1016/j.apenergy.2020.114892

[22] Ruparathna R, Hewage K, Sadiq R (2018) Multi-period maintenance planning for public buildings: A risk based approach for climate conscious operation. J Clean Prod 170:1338–1353. https://doi.org/10.1016/j.jclepro.2017.09.178

[23] CEN - European Committee for Standardization (2018) EN 13306:2017 Maintenance - Maintenance terminology
[24] Shin J-H, Jun H-B (2015) On condition based maintenance policy. J Comput Des Eng 2:119–127. https://doi.org/10.1016/j.jcde.2014.12.006
[25] Tang S, Shelden DR, Eastman CM, et al (2019) A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends. Autom Constr 101:127–139. https://doi.org/10.1016/j.autcon.2019.01.020
[26] Cha H-S, Kim J, Kim D-H, et al (2018) Mobile application tool for individual maintenance users on high-rise residential buildings in South Korea. MATEC Web Conf 167:01002. https://doi.org/10.1051/matecconf/201816701002
[27] Gao X, Pishdad-Bozorgi P (2019) BIM-enabled facilities operation and maintenance: A review. Adv Eng Informatics 39:227–247. https://doi.org/10.1016/j.aei.2019.01.005
[28] Ahmadi-Karvigh S, Becerik-Gerber B, Soibelman L (2019) Intelligent adaptive automation: A framework for an activity-driven and user-centered building automation. Energy Build 188–189:184–199. https://doi.org/10.1016/j.enbuild.2019.02.007
[29] Vogl GW, Weiss BA, Helu M (2019) A review of diagnostic and prognostic capabilities and best practices for manufacturing. J Intell Manuf. https://doi.org/10.1007/s10845-016-1228-8
[30] Muller A, Suhner M-C, Iung B (2008) Formalisation of a new prognosis model for supporting proactive maintenance implementation on industrial system. Reliab Eng Syst Saf 93:234–253. https://doi.org/10.1016/j.ress.2006.12.004
[31] Bernardini G, Di Giuseppe E (2019) Towards a user-centered and condition-based approach in Building Operation and Maintenance. In: SEB 19. In press
[32] Zhao Y, Li T, Fan C, et al (2019) A proactive fault detection and diagnosis method for variable-air-volume terminals in building air conditioning systems. Energy Build 183:527–537. https://doi.org/10.1016/j.enbuild.2018.11.021
[33] Teixeira T, Dublon G, Savvides A (2010) A survey of human-sensing: Methods for detecting presence, count, location, track, and identity. ACM Comput Surv 1
[34] Chen Z, Jiang C, Xie L (2018) Building occupancy estimation and detection: A review. Energy Build 169:260–270. https://doi.org/10.1016/j.enbuild.2018.03.084
[35] Cauchi N, Macek K, Abate A (2017) Model-based predictive maintenance in building automation systems with user discomfort. Energy 138:306–315. https://doi.org/10.1016/j.energy.2017.07.104
[36] Gregorini B, Gianangeli A, Bernardini G, et al (2018) Building Heritage cognitivo: un sistema per la gestione e la conservazione dell'edificio storico. In: Cuboni F, Desogus G, Quaquero E (eds) Colloqui.AT.e 2018. Edilizia Circolare, 1st ed. Edicom edizioni, Cagliari, 12-14/09/2018, pp 529–539
[37] Blanco Cadena JD, Moretti N, Poli T, Re Cecconi F (2018) Applicazione dei sensori ultrasonici per l'ottimizzazione della manutenzione degli edifici intelligenti. In: Cuboni F, Desogus G, Quaquero E (eds) Colloqui.AT.e 2018. Edilizia Circolare, 1st ed. Edicom edizioni, Cagliari, 12-14/09/2018, pp 623–642
[38] Chen Y-J, Lai Y-S, Lin Y-H (2020) BIM-based augmented reality inspection and maintenance of fire safety equipment. Autom Constr 110:103041. https://doi.org/10.1016/j.autcon.2019.103041
[39] Mo Y, Zhao D, Du J, et al (2020) Automated staff assignment for building maintenance using natural language processing. Autom Constr 113:103150. https://doi.org/10.1016/j.autcon.2020.103150
[40] Bernardini G (2017) Fire Safety of Historical Buildings. Traditional Versus Innovative "Behavioural Design" Solutions by Using Wayfinding Systems, 1st ed. Springer International Publishing