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Tracking users' behaviors through real-time information in BIMs: Workflow for interconnection in the Brescia Smart Campus Demonstrator

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Abstract

An intelligent building supports the needs of its occupants by data analytics. Nowadays, buildings are evolving from being products to become effective service providers for end-users: thus, occupancy topics become crucial. The paper focuses on building operations, pointing out how advantages in supporting the needs of users could be derived through the implementation of Building Management Systems (BMS) into a Building Information Modeling (BIM) environment, connecting real-time information collected by sensors to a BIM database. The connection and the integration of information between BIM and BMS have been established based on the Industry Foundation Classes (IFC) neutral data format; moreover, web-interfaces and apps have been tested for enhancing information to be visualized by different end-users. The ongoing research has a twofold scope: 1) to point-out how buildings should evolve, managing knowledge coming from sensors in order to anticipate the needs of users, and 2) to analyze whether and how the centrality of users should change the building process. The proposed workflow has been tested on the Brescia Smart Campus Demonstrator, a building equipped with 94 off-the-shelf sensors.

Keywords: Building information modelling; building management systems; intelligent building; behavioural modelling; interoperability

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1. Introduction

The proficiency to take advantages of an ordered collection and fruition of great amount of data is gaining importance within the building sector, where recent processes and technologies for the acquisition, storage, analysis and mining of big data are affecting the Architecture, Engineering and Construction (AEC) industry. In fact, the great amount of data collected during the entire building life cycle is modifying the way buildings are conceived and developed, being designed and managed not only as financial products, but also as service providers to support the needs of the occupants.

In order to benefit of these data for satisfying the requests of end-users, the occupants have to be considered and actively involved from early design stages to operational ones. Nowadays, augmented reality and immersive environment support this novel approach, even though the use of these technologies is generally a prerogative of big developers, designers and engineers. The relationship between building and user through Internet of Things (IoT) and Artificial Intelligence (AI) is a scenario that is rapidly growing up and it is shaped by new devices able to track, anticipate and dialog with the user. The IoT application domains empower the vision of a built environment pervaded by sensors and actuators in which homes do not waste energy, where interactive walls display useful information, as well as pictures of art or videos of friends. Even more potentialities could be exploited through data collection, considering that the connected devices have an annual growth more than 10%, and over 500 billion connected devices are expected worldwide by 2025 [1]. However, massive automation systems are not yet possible with current technologies. The connectivity should be collaborative and service oriented protocols can support the challenge [2].

As first, it is important to derive knowledge from data for providing adequate services and comfort conditions to users, as the indoor built environment plays a critical role in their well-being. People spend about 90% of the time indoors, and buildings influence the health, positively or negatively, at level of cognitive performance [3]. During operational stages, significant energy consumptions and environmental impacts are registered [4] [5]; it has been estimated that users waste 30% of energy in buildings because of their behavior [6]. Moreover, during the occupancy phase, a significant portion of building spaces is not used and great amount of energy is wasted (e.g., 60% of European offices are not used even in working hours and 50% of residential dwellers sustain they live in too much space) [7] [8]. All these aspects could be investigated as potential and concurrent causes of the building gap between predicted performance in design stage and measured performance in operation. Anyway, the occupant variable and the behavior tracking are crucial to define an operational rational use and tailored services on the real needs of users, avoiding wastes of energy [9] [10] in a lean vision of the buildings management [11]. The life cycle management of the building in the smart city vision is thus essentially based on virtual environment and IoT, bridging the gap between physical assets and virtual control of the whole parameters which characterized the city space.

The smart city is made of productive business environment where offices turn into smart and interactive assets; factories relay real-time production data; face-to-face meetings are established through holograms and documents are fully integrated in the workflow [12]. In such a city, the IoT technologies enhance the productive areas, retail, residential and green spaces that collaborate and efficient logistics environment embeds safety and environmental concerns all over the process. In the concept of cognitive city, the environment learns inputs from users and promotes smart health, nonintrusive monitoring system, preventing serious illness by adjusting the environment and selecting appropriate drugs and diet based on food information and user preferences and needs [13].

Within this context, the research defines a digitally enabled framework for operating cognitive buildings, presenting a case study by which it has been possible to analyze how the information collected during the operational stage could enlighten end-users about the behavior of both buildings and occupants. Therefore, advantages in tracking the behavior of occupants and in satisfying the needs of users should be derived through the availability of real-time information (e.g., data collected by sensors measuring and reporting outdoor conditions, indoor comfort parameters, system efficiency factors).

Components of a building could be automated in order to adapt the indoor conditions to the thresholds identified for user satisfaction. In this way, the information collected is communicated to actuators to promote an action aimed in defining new and more favorable conditions. This is the smart building concept. The cognitive concept goes ahead and couples the building with IoT and machine learning systems, enabling the assets to gain cognitive abilities that will allow them to learn how to deliver the best possible performance regarding the designed task. Nowadays, several buildings are built from the ground up with nearly one IoT-enabled sensor per square meter monitoring temperature, humidity, the weight in the trash cans, how many people are in a room, and on and on. Managers can thus control the building on a computer, through a digital twin of the building itself, that is the virtual building model. The digital twin finds ways to adapt and adjust to whatever the priority or emergency that is thrown at it, like any thinking being. The BIM model of a building can represent its digital twin, as it enables the intelligence of the building by storing information in a central repository (i.e., database with geometric and alpha-numerical information underlying the 3D representation of a BIM model).

Within this context, it should not be sufficient to design intelligent buildings, but it should be essential to design also their interactions with users, defining who the users are, what their needs are and what kind of tools is adequate to pursue set objectives. In this way, information can be differently made available to building occupants, designers, owners and facility managers, i.e., through the definition of BIM model uses [14]. The definition of the selected information to be accessed by different users is based upon their needs that improve user comfort and productivity, supporting operation and management of the buildings during the entire lifespan. Nowadays, the need of discussion, sharing, feedback-based choices changes the human interaction, and the communication between human and building is expected to be held in the same way. It is no more conceived as a single directed flux or command, but it is shifting towards a bi-directional interaction (e.g., the user commands to the building the layout and arrangement to adopt in order to define the desired indoor environment and the building adjusts its conditions).

Through interface devices and a virtual model of the asset, user needs can here and now cooperate with building systems (e.g., HVAC and electricity distribution) and components (e.g., shading devices, windows and plugs) to improve the offered conditions and increase both the efficiency of the building and the users perceived capability to act informed choices. The topic of awareness and education on environmental and energy targets as an example is driver for improving building performance and sustainability.

The presented paper aims to define the way to organize and structure the monitoring of the behavior of both buildings and users during the in-use phase, when many inefficiencies of the building process arise and when it is crucial to tailor the services to the occupancy variable patterns [15].

1.1. The evolving concept of building

Several enhancements have characterized the evolution of the concept of building toward the meaning of cognitive asset, taking advantages of the availability of real-time information. Initially, automated buildings had been equipped with Building Automation and Control Systems (BACS) to improve energy efficiency. Then, smart buildings enhanced operations through Building Management Systems (BMS). Later, predictive buildings anticipated the occupancy needs and set themselves to face environmental and behavioral inputs using Information and Communications Technology (ICT) to support managers and operators. Nowadays, cognitive buildings learn from the user behavior and traduce the data coming from the outdoor, the indoor and the social environment using an IoT approach. In this way, the responsiveness is reset in time, making the building autonomous to react in some situation.

Within this scenario, user behavior could be tracked in order to define customized operations in which the building measures the number of people inside and adjusts heating and lighting accordingly, turning an empty building off, as a computer goes into standby mode. Moreover, it is possible to localize the heating and cooling systems, providing a detailed, individual climate for each user by means of arrays of responsive infrared heating elements that are guided by sophisticated motion tracking providing thermal “clouds”, following people through spaces and ensuring pervasive comfort whereas improving overall energy efficiency.

1.2. The essential involvement of users

The basic objective of interaction design is to create dialogues between objects and users. In other words, interaction design is the language that makes a system accessible to the users. In the late 1980s, the concept of SoftFace brought up [15]: it stands for the very beginnings of interaction design. SoftFace describes what today is commonly referred to as User Interface (UI). By the acceleration of technological progress in the tele-communication sector, this field has become more and more important generating many new interdisciplinary topics. However, well-conceived interaction design always considers different disciplines at a time. From latter, it is possible to deduce important rules for the creation of an UI. An important role is played by psychology which can be seen as one important source of the following basic rules: Fitts' Law [17] [18] is widely used in interfaces. It defines that the time one needs to reach a target in an interface is function of the distance to the target and the dimension of the target. For example, the menu and auxiliary functions of a computer interface is always on the edge of the screen because the mouse cannot exceed the screen area; therefore, users can reach the target function precisely and efficiently.

Hick-Hyman's Law [19] represents the rule that the larger the number of alternative stimuli, the longer takes the time to respond. Therefore, if an interface offers many options, it will take the user longer time and it will be more difficult to choose an option.

In designing an interface between the user and the building through an app, as an example, it is very important to keep the options essential and minimal, as the goal is the users to make frequent use of the app in an efficient way and to promote the enriching experience of interaction. The need of clear objectives of the interaction are the basis on which to design the interface and at the end of the process of the success of user involvement [20]. Other rules coming from cognitive psychology ascertain that the human brain can memorize between 5 and 9 information sets at first glance [19]. For this reason, usually there are less than 9 options in a menu bar of a website.

Interaction design is tightly connected with the vision of cognitive buildings. Cognitive buildings are organisms where buildings operate proactively with the human activity within them. The interchange happens via data collection and data processing. As the environment has notorious effects on the human activity (e.g., considering a school building, the attention of students diminishes if the air quality does as CO_2 concentration grows), a cognitive building tries to implement rules for different scenarios and to react respectively. The scenarios are created with data gathered through sensors installed into the building. As an example, in the scenario of the school, when a sensor gives feedback that the air quality in the classroom is getting worse, ventilation will be triggered and the room will improve its air quality. Cognitive buildings are also highly feasible [21] as most modern buildings have already a series of sensors implemented in them when they are finished [22] [23].

In the case study of the present research, the Smart Campus Demonstrator of the University of Brescia is used as a pilot building to implement this bi-directional relationship between user and asset through the BIM model [24] and by an app [25] (Fig. 1).

Fig. 1. Information about the App for the Smart Campus Demonstrator, University of Brescia, Italy: advertising to involve the users (a) and start screen of Smart Campus Bi-Directional App (b).

The idea is to introduce the user in the loop of information and connect the body of knowledge about the building. Objective data coming from sensors and subjective data coming from students and visitors can be collected directly, i.e., by the user definition of the comfort conditions, and indirectly, i.e. through the sentiment analysis [26]. This kind of analysis is based on perceptions interchange operated through machine learning software and could be implemented into the app. The complex information gathered by the users should promote a data driven environment to enrich the users' experience and "learnscape".

2. Methodology

The research analyses in which way buildings are managed and how operations can be improved, by coupling technologies for data acquisition, storage, analysis and mining with methods and tools for parametric modeling and information management. The research tests different alternatives for populating BIM models with data retrieved through sensors and proposes several uses of these data for different end-users. In this way, the importance of using and updating BIM models arises also in operational stages, suggesting an extended use of BIM beyond comparing alternatives and design optioneering or evaluating design choices.

The implementation of advanced computing technologies and real-time metering and monitoring devices allows retrieving data from several sources and in different formats about the current state of buildings and gathering information, not only at building level, but also at urban scale. As an example, data could be gathered through sensors, could be encoded in language (e.g., textbooks, formulas, conversation) or could be captured in sight, sound and motion [27]. By adequately processing these data, it is possible to assess building performances, to evaluate user levels of satisfaction, to estimate occupant preferences or to track user behaviors.

However, the great amount of information gathered through sensors cannot be fully interpreted and utilized by building users, as it is often not accessible or not comprehensible. Therefore, driven by customer requirements, the next generation of systems will be even more powerful, intelligent, and easy to use [28]. A way towards the improvement of the fruition of these data has been recognized in the integration of sensors in BIM models by means of customized model views based on parametric filtering rules. Through BIM models, it is possible to transform collected data in usable information to gain deeper insights on how buildings perform throughout their life cycle, i.e., by extending the interoperable and neutral schema of IFC [29].

The research aims to define a workflow to populate BIM models using data gathered through remote sensors, driving parameters in BIM models, changing parameters in digital models to provide input and possibly modifying physical models. In this way, users become aware of their behavior and should interact with buildings, i.e., through online dashboards or apps, improving their behavior and increasing their awareness. Moreover, designers benefit of an improvement of the building process not only collecting and filtering feedback of users in operation, but also checking and verifying instantaneous and historical values of defined parameters. Finally, facility managers are instantly informed about failures or damages and the process can support rapid fault detection.

Moreover, the research aims to take advantages of digital capabilities with the power of cognitive computing. For this reason, the collaboration with international stakeholders (as IBM) specialized in cognitive systems has been essential for defining requirements to be fulfilled. As an example, IBM Watson™, the Q&A system available from International Business Machines (IBM) Corporation of Armonk, N.Y., analyzes unstructured textual content of electronic documents to answer questions and derive conclusions from the textual content [30]. These systems are an application of advanced natural language processing (NLP), information harvesting, knowledge representation and reasoning, and machine learning technologies to the field of open domain question answering.

A digitally-enabled framework has been developed and tested on a building, at the University of Brescia, where data gathered from sensors and other devices (e.g., smartphones and wearable devices) are stored into the BMS that is in charge both to store data and to provide base analysis to allow the control of the HVAC systems. Moreover, geometric and non-geometric data regarding the building (e.g., temperature, relative humidity, CO_2, VOC emissions) are stored into the BIM model. The information owned by the BMS is embedded into the BIM model, that is the central repository and that can be accessed by different points of view.

3. Case study building: The Brescia Smart Campus Demonstrator

The integration of real-time information in BIM models and their use from several perspectives have been tested on an existing building of the University of Brescia, used for lectures and laboratories, namely the Brescia Smart Campus Demonstrator. The Smart Campus is composed of a set of buildings properly sensorized and automated, able to interact among them and with the local energy provider. One of these buildings has been analyzed as a case study, providing insights about smart control and optimization of the building management by detailed data acquisition and modeling. The building has been equipped with 94 off-the-shelf sensors within the project “Smart Campus as Urban Open LAbs” (SCUOLA project). Among the sensors, the attention has been focused on devices to track the user behavior, detecting indoor temperature, relative humidity, illuminance, carbon dioxide, volatile organic compounds, and occupancy (Table 1).

Table 1. Monitored parameters at the Brescia Smart Campus Demonstrator building.

Parameter	Unit of measure	Threshold
Indoor temperature	°C	20-22 Winter 26-28 Summer
Relative humidity	%	40-65
Illuminance	lx	300
CO_2 concentration	ppm	1000
Occupancy	number of people	Available desks

The selected technology for the communication of the sensors with the rest of the communication infrastructure is Z-wave. Z-wave sensors are connected to the reminder of the information system by means of Z-wave gateways, which collect information from the sensors and transmit the aggregated data to the BMS by means of RESTfull web services.

A BIM model has been generated from geometric data captured with Terrestrial Laser Scanner (TLS) and Building Energy Models (BEM) have been developed and will be calibrated with real data acquired in the monitoring phase [30].

The integration of BIM and IoT is the core of the interaction between user and asset and enables to visualize and manage information and to empower knowledge into actions and services (Fig. 2).

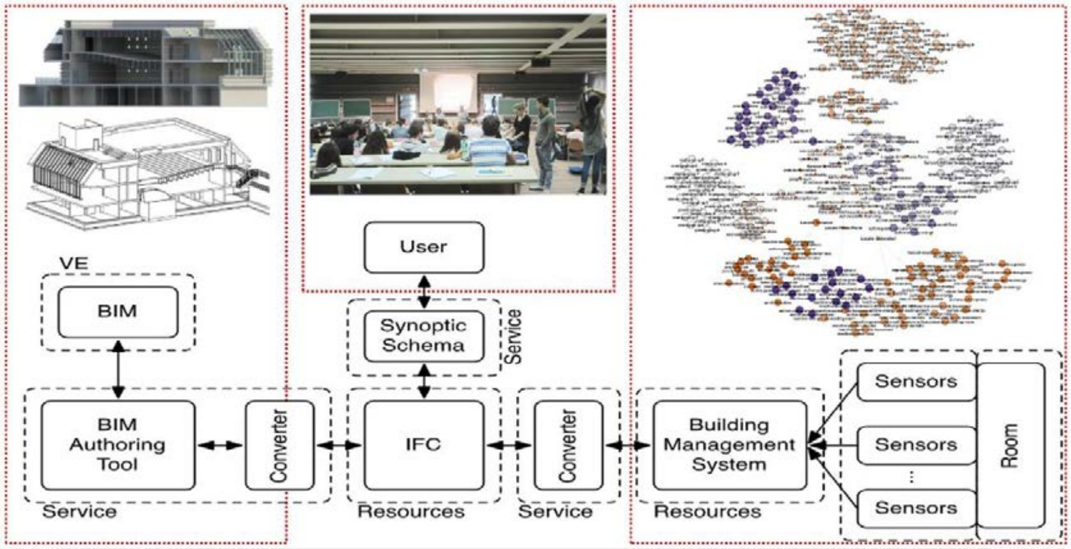


Fig. 2. The proposed architecture mapped into the IoT Domain Model in the Brescia Smart Campus Demonstrator [31].

4. Preliminary results

The collection and analysis of data gathered through sensors could be visualized in different ways for several uses, providing varied services to end-users.

A BIM model has been created in order to be the central repository of all the collected data [32]. However, as not all the users of a building are familiar with BIM Authoring Tools, the information stored in the BIM database can be accessed also through apps and web-interfaces. Moreover, apps introducing augmented reality provide additional information, not necessarily stored in the BIM model, although potentially interacting with it through interconnection software (e.g., Flux) to provide users data mapping.

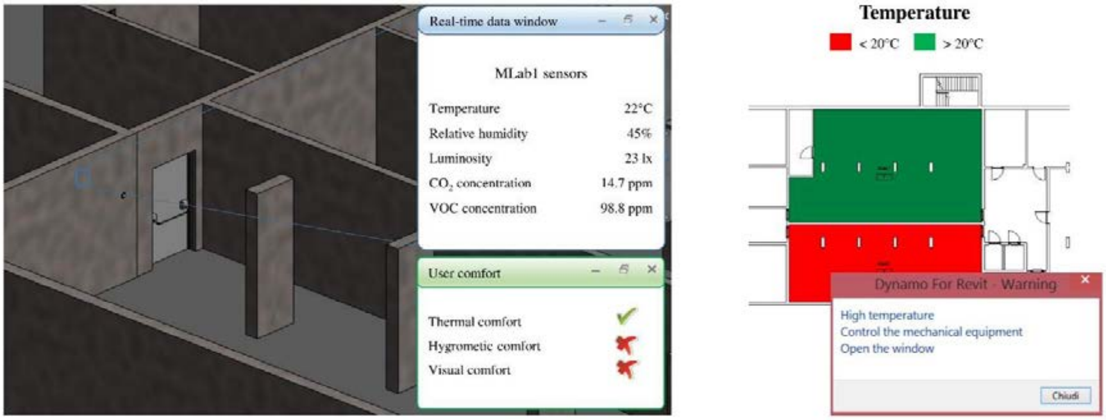
4.1. BIM models

The data collected by the sensors are included into the BIM model (Fig. 3), allowing to visualize information through thematic plants depending on registered values with respect to thresholds of comfort or indoor air quality through, as an example, a color schema (e.g., based on values of temperature set-points, ventilation rate, illuminance).

Moreover, information can also be used to create real-time synoptic charts to visualize an easy access to the building status or to be used to tune the control of the BAS (e.g., lighting systems, heating ventilation and air conditioning system).

Finally, warnings can be automatically generated when parameters reach set-up fixed values.

In order to connect BIM models and data gathered through BMS, some preliminary tests have been carried out, analyzing the IFC schema and mapping built-in Revit parameters and the relative IFC objects. Future activities would allow an improvement of the regular and automatic updating of values in the model, through the IFC representation, retrieving constantly data from the BMS.



Real-time data window

MLab1 sensors

Temperature 22°C
Relative humidity 45%
Luminosity 23 lx
CO_2 concentration 14.7 ppm
VOC concentration 98.8 ppm

User comfort

Thermal comfort ✓
Hygrometic comfort ✗
Visual comfort ✗

Dynamo For Revit - Warning

High temperature
Control the mechanical equipment
Open the window

Fig. 3. BIM models for visualizing real-time information (a) and reporting alerts (b).

4.2. Apps

Through ad-hoc apps (Fig. 4), it is possible to access sensors data, retrieved from the BMS or directly from the sensors through the Z-wave gateways and to provide feedbacks of the students on comfort level in the classrooms, interacting with the building. In this way, it should be possible to develop strategies such that buildings could adapt their behavior depending on the user needs, communicated via app.

The bi-directional interaction through the app embodies the introduction of the human factor into the IoT structure to enable the cognitive building to learn from behaviors providing data in real-time with the capability to process them into adaptive and predictive strategies for improved comfort and servitization. With the app, the users become heterogeneous mobile sensors that reveals perceptions and gives input defining a dynamic “learnscape” for the cognitive building. In this way, the scenario changes from a static IoT system to a dynamic IoT application, in which the building is continuously reconfiguring itself (or a single sub-system) depending on user behaviors.

The app should be developed for all the main mobile platforms using the Java language for Android platforms, and Swift for iOs, to ensure its widespread use, and, consequently, its effectiveness in putting the users into the IoT loop. The app should handle different protocols, from the traditional web protocols, such as HTTPS and database sockets, to message-oriented protocols, such as AMQP or MQTT, and websockets, in order to guarantee the interoperability between different data sources and services.

Fig. 4. The proposed interface of the web app and the mobile device layout in which the monitored data are displayed for the user awareness and feedback; the advanced idea is to introduce a community in which to implement the IoT Watston by IBM to perform sentiment analysis.

4.3. Web-interfaces

The whole amount of information is also accessible through web-interfaces (Fig. 5), by which it is possible to query the database underlining the 3D representation of the building. In this way, users always and wherever can obtain information about the real behavior of the building.

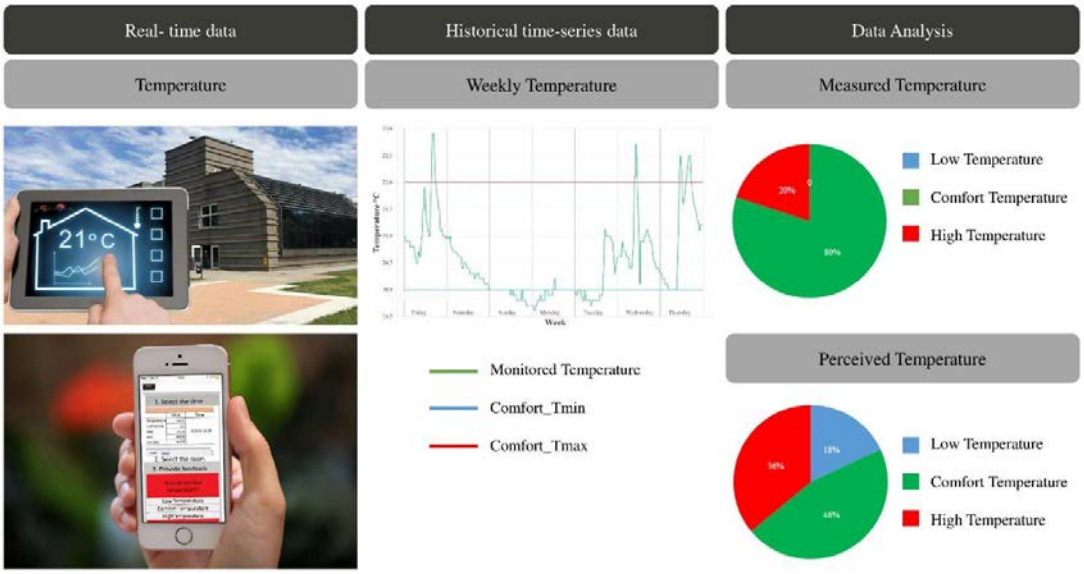


Fig. 5. Online dashboards connected to BIM databases.

Through the interface the user is enabled to:

- obtain information concerning real-time data: as an example, users can know the definition of the comfort conditions or the occupancy rate of a selected room;
- have a forecast situation for the following hours to plan the activities (e.g., occupancy in the computer lab and thus availability of leaning facilities);
- provide an instantaneous feedback about the indoor condition, populating the database of user-source perception and information;

- access historical time-series data, monitoring if and when a selected parameter exceeds or is inferior to a fixed threshold value;
- visualize data mapping, easing the comprehension of the ongoing building behavior from crowdsourcing;
- data mining; as an example, a comparison between measured (through sensors) and perceived (as resulted from user feedback) parameters is available to set-up knowledge about indoor environment as a basis to implement adaptive strategies and promote energy saving and awareness.

4.4. Augmented reality

In order to provide users with additional services in relation to the occupied spaces, it is possible to customize the offered information in relation to the needs. In this way, information could enrich a building through augmented reality. As an example, classrooms could be provided with ad-hoc codes, by which users could obtain more information concerning the topics explained during the lesson. In canteens, devices could access customized information on menus, calories and prices, and users could schedule their lunch before reaching the canteen.

5. Conclusion

The interconnected city needs to lay on a network of connected cognitive buildings in which the user involvement and control is enabled. The managers have to access data to implement better performance and define maintenance plans and custom services; the owners can promote a servitization of the assets to promote extended uses to increase income and the users can enrich their experience by the reaction to their own behavior of the built environment. These scenario is enabled by the virtual environment mirroring the actual building and able to dialogue with technological communication devices collecting information by different layers (e.g., sensors, users, post processed data by AI). This environment can be the BIM model of the building as powerful field of exchange, monitor and control. Real-time information connected to the BIM informative content should support reporting discomfort or user behaviors through thematic maps based on parametric filters.

The results should allow:

- to compare how buildings in use deviate from the expectations of their design bridging the performance gap;
- to provide feedback to users, increasing their awareness and encouraging sustainable behaviors;
- to define control strategies for the reduction of building impacts and refining monitoring plan to integrate information to promote extended interconnection and collaboration for a sustainable lifestyle.

All the proposed considerations point out the importance of a bi-directional link between buildings and the users within them. Occupants become conscious of their behavior and can adjust it, but also buildings can adapt themselves in response to different conditions and tailored needs to deliver a custom service, optimize the use of spaces, reduce energy wastes and adapt comfort conditions.

Next activities will evaluate if and how learning capabilities of users are influenced by conditions of buildings [33], also analyzing if cognitive buildings can support and be adaptable to changing educational scenarios and community activities.

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