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Smart digital campus UniTO: data gathering and visualisation to support sustainability and indoor comfort

D Accardo^{1*}, S Meschini², P Gasbarri¹, L C Tagliabue³, G M Di Giuda¹

¹ Department of Management, Università degli Studi di Torino, Turin, Italy

² Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy

³ Department of Computer Science, Università degli Studi di Torino, Turin, Italy

*Corresponding author: daniele.accardo@unito.it

Abstract

This research aims to identify and investigate the best digital tools to improve indoor comfort conditions and sustainability through energy efficiency enhancement in educational buildings, integrating data gathered from sensors. By leveraging an existing asset management platform that integrates Building Information Modelling (BIM) and Geographic Information Systems (GIS), data from Internet of Things devices were linked to the BIM model of a test case building creating a digital shadow in order to gather real-time data on indoor conditions, including temperature, humidity, and CO₂ levels. The methodology enables continuous evaluation of the building's state of usage and calls for automatic and frequent updates of data. The digital shadow can display current usage conditions and alarms when conditions exceed what is comfortable, and it allows for immediate feedback through colours based on the internal detected conditions. The platform can be used with business intelligence tools to support strategic choices and enable future innovations, including machine learning techniques to estimate building occupancy and identify any deviations from expected usage patterns. This study presents a promising workflow for creating sustainable and comfortable educational buildings, which could be replicable and scalable in the future.

1. Introduction

The European Green Deal aims to decrease greenhouse gas emissions by 2050, emphasizing buildings' emissions reduction (at least 40% of emissions) [1]. In Italy, public buildings represent a significant portion of the built environment and constructions are often older and hard to maintain.

In recent decades, the Architecture, Engineering, Construction, and Operation (AECO) sector has seen the introduction of various digital tools and new working methods due to technological advancements. Among others, Building Information Modelling (BIM), Geographic Information Systems (GIS), and Internet of Things (IoT) devices are technologies that are rapidly changing the AECO sector.

Among public buildings, the case of university building management can be particularly challenging, especially in older institutions where there is a need to balance preservation with modernization and upgrades. This can drain resources and increase the university's carbon footprint and, in addition, the comfort within the rooms can be unsatisfactory.

In this context, the built environment's digital and energy transition is paramount to avoid wasting resources and lead to more informed decisions.



The literature shows that the mismanagement of buildings is commonly known to lead to resource wastage and increased operation and maintenance costs, as well as negative environmental impacts. This is largely due to the significant impact of human presence on space management, which is affected by a range of factors such as behaviours, needs, and habits of occupants [2].

According to Botín-Sanabria [3], with regard to the digitalization of buildings and the possibility of linking data to them, three different stages of development are defined:

- Digital Model: it's a virtual model which replicates an object of the real world with no direct information connection with its physical counterpart (BIM model).
- Digital Shadow: the connection with the physical object exists but, the integration of information flow is unidirectional, from the real object to the digital one.
- Digital Twin: information flows bidirectionally and automatically between the virtual and physical worlds.

Furthermore, the literature recognizes the value of integrating spatial information with live data from sensors to assess a workspace's performance [4]. Indoor and outdoor sensors can provide data on energy usage and comfort patterns, allowing for real-time monitoring of buildings and quicker decision-making by facility managers regarding maintenance activities [5,6]. Additionally, the system can detect any malfunctions or failures. Occupancy-related visualizations can also be produced to highlight changes in building performance throughout the day, week, or month [7]. This approach allows for the identification of efficiency opportunities during both occupied and unoccupied states, which may be missed by a building's overall benchmark, thereby providing more specific and accurate measures of building efficiency.

The present study utilizes a platform under development at the University of Turin (UniTO), which proposes an Asset Management System (AMS) for the management of university buildings integrating BIM and GIS technologies and Business Intelligence Tools.

While GIS allows the georeferencing of the campus' assets (over 100 buildings) and spatial analysis, BIM enables the 3D view of the single buildings carrying basic information about space geometries and main uses. The platform aims to store multiple datasets that once connected to the GIS and the BIM, can be analysed and visualized with dashboards.

So, the platform enables multiple stakeholders to interact with the BIM models and the stored data, supported by information visualization on dashboards.

In this context, the paper aims to show how the IoT devices incorporation and the leveraging of digital tools, data collected from sensors, including temporal series of physical measurements, can be integrated and visualized within the AMS platform, providing a practical solution for monitoring and improving a building's indoor comfort and energy efficiency.

2. Methodology

In order to investigate the potential of digitalization on a university campus, and the usage of IoT devices for environmental comfort and energy performance improvement, this study selected one building of the UniTO's assets as a pilot case, the Campus Luigi Einaudi. The building has several IoT devices installed for real-time data gathering. The methodology was designed with replicability in mind, to enable the future expansion of the IoT network. This study presents a workflow for gathering, updating, and visualizing indoor comfort information, including temperature, humidity, and CO₂ levels. To facilitate the ongoing evaluation of the building's usage, the methodology requires automatic and frequent updates of data.

2.1. The pilot case

The Luigi Einaudi Campus (Figure 1) was chosen as pilot case for sensor analysis. The campus, which opened in 2012, can accommodate approximately 10000 users, representing over 12% of the UniTO population. The building has glass facades, which stretch for about one kilometre on each floor, strike an optimal balance between natural and artificial light. However, during the initial years of operation, the building's energy consumption had a significant impact on the university's costs and the campus

underwent several interventions aimed at improving energy efficiency and management, as well as enhancing internal comfort (e.g., installation of transparent solar shielding films, installation of presence and illuminance sensors and educational activities for the involvement of campus users).



Figure 1. Luigi Einaudi Campus (Unito.it).

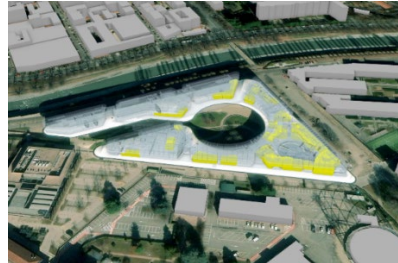


Figure 2. Digital model of Luigi Einaudi Campus in the AMS Platform.

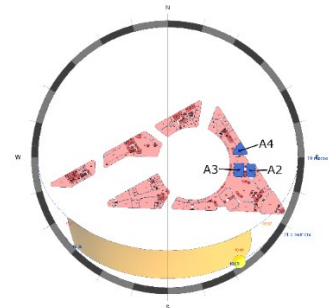


Figure 3. Rooms with active sensors at Luigi Einaudi Campus.

2.2. Data gathering through IoT devices

Among the various interventions, the University of Turin installed IoT devices in selected rooms to track environmental information and to optimize the setting of heating and cooling systems. This presented an opportunity to enhance the AMS platform with up-to-the-minute data. The University of Turin opted for the AirCare® pro+ device [9] that can capture 15 different data types regarding air quality, environmental comfort and electro-smog. SIMA (Italian Society of Environmental Medicine) has endorsed the device's PM_{2.5} and CO₂ measurements scientifically. This data can enhance the health and comfort of users within a university building, as air quality and environmental comfort are critical components of a healthy environment. Acquiring this sort of information within a university building can be instrumental in mitigating indoor air quality issues and boosting the quality of life for users. Furthermore, by cross-referencing classroom occupancy data with IoT sensor data, it is possible to gain a more comprehensive understanding of the air quality in relation with room's occupancy. For instance, if an IoT device detects a high concentration of particles during a lecture, cross-referencing the data with classroom occupancy data can help establish whether the presence of many individuals is responsible for the elevated particle concentration. This knowledge can aid in identifying factors that impact the air quality inside a classroom, including inadequate ventilation or the use of chemicals. Consequently, informed decisions can be taken to improve air quality and enhance the health of individuals within the university building.

At the Luigi Einaudi Campus, a total of 39 IoT devices were positioned, primarily on the ground floor and first floor of the building, which are frequently used for teaching activities. The areas where the sensors were positioned (marked in yellow in figure 2) were pinpointed in the model on the AMS Platform. By leveraging the encoding formulated for platform management, it was feasible to establish links between the pre-existing data and the data gathered from the sensors.

To leverage the real-time data associated with the BIM model, the plan was to focus on monitoring key parameters, including temperature, CO₂, CO₂ e, VOC, PM₁₀, and PM_{2.5}. The experiment involved three classrooms located on the ground floor of the main building of the Luigi Einaudi Campus: Classroom A3 (154 seats), Classroom A2 (134 seats), and Classroom A4 (126 seats) (as depicted in Figure 3).

2.3. Data connection

In the pre-existing UniTO's AMS platform data connections are possible thanks to semantic association between datasets. Data relations are the key to the different connections for all the technologies involved. The BIM model is fed with visual programming language nodes that recognize the element ID and match the correct values. Then, once georeferenced in GIS, it brings the information previously added and

acquires spatial data connection. Moreover, both in GIS and in Business Intelligence tools it is possible to relate datasets tables through the association of the encoded name of spaces.

The encoded name of spaces is also the bridge for sensors' data connection to the platform. In fact, the serial numbers of all environmental sensors are associated with the coded name of the space in which they are installed, allowing the association of the product data with the BIM model and the other datasets. The subsequent approach was implemented to create a direct correlation between the data collected from the IoT devices and the AMS platform database, and subsequently, the BI solution employed (i.e.: Microsoft PowerBI®). To retrieve the data, a "http" request was established employing the python language, with specific use of the "requests" library, enabling access to the website. Following this, a "post" request containing the username and password was dispatched. Subsequently, a "get" request was initiated to access the URL of the page where the ".csv" file is available for download. Then a second "get" request was made to download the content of the ".csv" file from the URL. Utilizing the "pandas" library, the ".csv" file was parsed, and data was extracted. Finally, the data was saved in the database in ".csv" format, facilitating its rapid use in PowerBI® and therefore, to load the data into PowerBI®, the "pandas" library was leveraged to read data from the file. Subsequently, utilizing the "pyodbc" library, SQL queries were executed, enabling data insertion into the PowerBI® dataset.

To automate all the steps, configuring a "task scheduler" and setting up automatic data updates via PowerBI® was essential. To resolve the issue, the "schedule" library was employed, executing functions at predetermined intervals and the "refresh service" was configured in the PowerBI® software. This service also provides access to the "refresh history" report.

2.4. Business Intelligence tools

Once the data stream was connected to the BIM model the digital object can be considered as a digital shadow. At this stage it became crucial to establish relationships between the data to generate useful information and enable quick and efficient visualization. To enable the visualization of the real-time data linked to the digital shadow, an initial dashboard was created, linking floor plans and highlighting classrooms where sensors are present. By selecting a classroom of interest, the values over the course of a week can be viewed instantly (as shown in Figure 4).

The dashboard's development involved overlapping data of different types to create information otherwise challenging to find. For instance, data on air quality and thermal comfort were cross-referenced with university schedule and classroom use data. The analysis was performed for the week from November 28, 2022, to December 4, 2022, a period when teaching activities are in full swing. The graphs also include a threshold indicating the optimal levels for each parameter measured.

By means of the quick and contextual visualization offered by the dashboard, it is feasible to gain insight into the condition of the rooms and identify connections between indoor comfort conditions, air quality, and occupancy levels within the classrooms.

3. Data analysis and Results

The connection of IoT devices data to the digital shadow and the overall database, achieved important automation, allowing for quick and easy access to information to support strategic decision-making in a well-timed manner.

Observing the data monitoring during the studied week, some correlations can be identified. For instance, regarding temperature, it was found that Classroom A2 remained within the optimal temperature range during the class hours throughout the week, not exceeding 22 °C. However, classrooms A3 and A4 constantly surpassed the 23/24 °C limit. It is worth noting that Classroom A4 has windows on one side facing northeast, providing an option to open them. On the other hand, Classroom A3 is situated in an interior area of the building without direct outward-facing, and Classroom A2 has a limited eastward-facing. Furthermore, there is a clear correlation between the temperature peaks and the presence of classes inside the classrooms.

The human body's metabolism leads to an elevation in temperature and CO₂ levels. When people exhale, they release CO₂ and generate heat, which can cause the temperature in a room to rise. As the

number of people in a classroom increases, so does the temperature and CO₂ levels. Inadequate ventilation can result in excessively high CO₂ levels, which may cause lethargy, headaches, and reduced cognitive function.

Classroom A2 performed the best in terms of CO₂ levels, managing to stay below the 1000 ppm threshold during classes throughout the studied week. However, classrooms A3 and A4 had peaks of around 1300/1400 ppm during scheduled class hours. As for PM_{2.5} and PM₁₀ values, they generally remained below the average of 25 µg/m³ for PM_{2.5} and below the average of 50 µg/m³ for PM₁₀. Notably, when PM_{2.5} and PM₁₀ levels inside the classrooms peaked, there was also a corresponding drop in temperatures and CO₂, suggesting that users intervened by opening windows. It's worth noting that high levels of outdoor air pollution can enter the classroom through open windows or doors, especially if pollution caused by traffic or industrial activities nearby is high, as in the city of Turin.

The VOC monitoring reveals that the weekly average is acceptable, remaining below 500 ppb, thus there is no cause for alarm regarding the levels recorded in the three classrooms. The main benefit of connecting the data flow to the model is the ability to immediately link the data collected by the IoT devices to the correct location within the building and quickly identify any potential issues caused by the surpassing of key indicators of environmental quality and thermal comfort. The primary challenges faced during the data connection stage relate to managing large data streams, given that the IoT devices record the situation every 5 minutes. To address this issue, automated data storage could be delegated to a cloud service, which could also serve as a database for the sensor component.

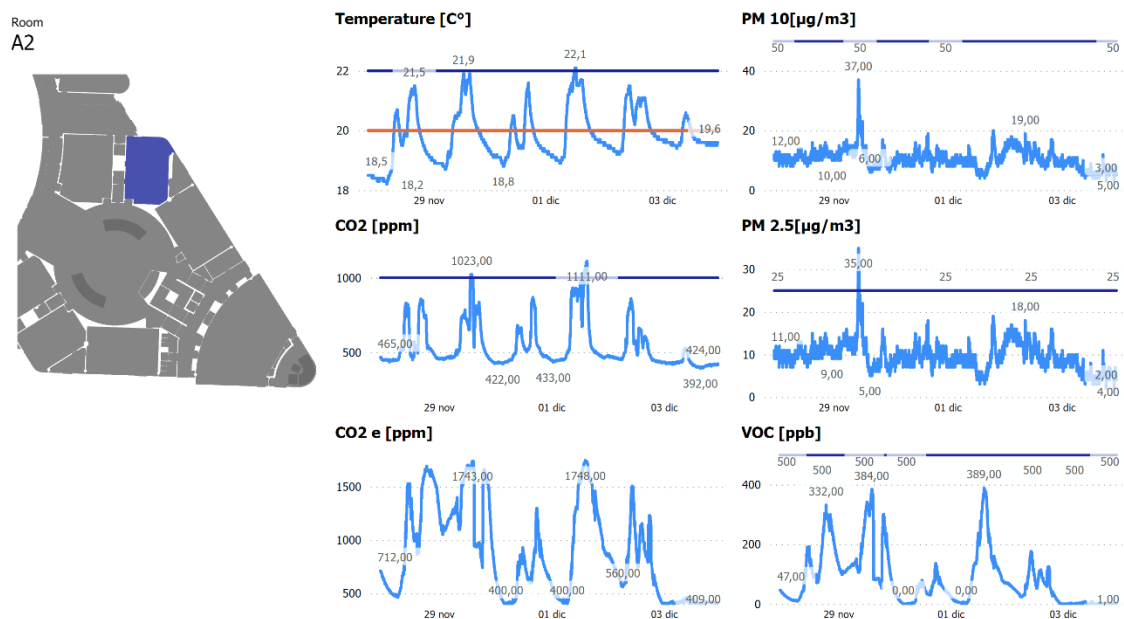


Figure 4. A2 Room dashboard with real-time data monitoring.

4. Conclusion

The study focused on the procedures involved in connecting IoT devices data to an AMS platform that caters to real estate asset management, in accordance with the principles of Digital Shadow. This constitutes a crucial step in the creation of a smart and interconnected campus.

The capability to integrate diverse types of data presents opportunities in the realm of real estate management, especially if the building stock is vast and involves intricate dynamics.

At present, IoT devices are regarded as one of the most compelling solutions owing to their capacity for transmitting data directly to a cloud-based environment, eliminating the need for multiple data handovers between various platforms. By linking data obtained through IoT devices data to BIM models and subsequently correlating it with AMS data, it is possible to gain prompt and effortless access to information that may aid in making timely strategic decisions. The primary benefit of this integration is the capacity to match data with the appropriate space in the structure, which facilitates the identification

of potential issues resulting from the surpassing of critical parameters. Nevertheless, the handling of extensive data streams remains a crucial challenge that requires resolution. In general, the utilization of IoT devices in building automation has the potential to boost indoor environmental quality, encourage energy efficiency, and elevate occupant comfort and productivity. Indeed, current occupancy levels and activities significantly impact IAQ, deviating from the original design assumptions and underscoring the importance of monitoring building spaces. By monitoring IAQ parameters, a clear association emerges between the presence of individuals and a rise in temperature, carbon dioxide (CO₂), and volatile organic compounds (VOCs) in university classrooms, underscoring the impact of external factors and human presence on indoor air quality and thermal comfort.

Possible future developments of the ongoing research process could follow the guidelines proposed in Level 3 of the EU Commission's user manual on IAQ [10], which aligns with a shared EU framework of fundamental indicators for evaluating the sustainability of buildings throughout their life cycle, not solely in terms of environmental performance, but also concerning health and comfort, life cycle cost, and potential future performance risks. The primary aim of such a project is to enable building-level actions that contribute substantially to the broader European environmental policy objectives. Specifically, Level 3 [10] proposes a "two-pronged approach" to objectively assessing IAQ, which comprises air sampling and monitoring using a quantitative and objective approach and collecting occupants' feedback through surveys administered online during occupancy.

The two kinds of collected data can be cross-checked with occupancy rates and usage patterns, thereby providing useful insights for potential corrective measures on the HVAC system. Furthermore, in the future, there may be scope for exploring the creation and integration of machine learning systems, which can learn from user behaviour and the data gathered from the building, taking advantage of increasingly automated and precise systems.

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