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# TOWARDS A DIGITAL TWIN FOR IAQ MONITORING AND CONTROL IN EDUCATIONAL FACILITIES THROUGH ASSET MANAGEMENT SYSTEM PLATFORM

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## Abstract

This study evaluates the potential of Internet of Things (IoT) devices for building automation and the creation of a Digital shadow for Indoor Air Quality (IAQ) at the University of Turin, Italy. Data was collected on temperature, carbon dioxide ($CO_2$), $PM_{2.5}$, $PM_{10}$, and Volatile Organic Compounds (VOC) levels in three classrooms and connected to the BIM models in an Asset Management System platform. The methodology for connecting the data flow to the model and developing information dashboards is described, highlighting its advantages and critical issues. The study underlines the benefits of connecting data streams to building models for identifying criticalities and improving indoor environmental quality and users' comfort, as well as learning performance, which is crucial in educational facilities.

## Introduction

The research illustrated in this paper inspires from sustainability goals in the built environment, as indicated in relevant governmental acts, such as the European Green Deal (The European Green Deal, 2019), which aims to reduce by 2050 that 40% of greenhouse emissions attributable to buildings. It is widely recognized how the improper management of constructions can result in waste of resources and in subsequent raise of operation and maintenance expenses and environmental impacts. Indeed, it can be acknowledged how human presence strongly influences space management issues, related to multiple variables related to behaviors, needs and habits of occupants (Belafi et al., 2017).

The current case study focuses on managing university building assets, on whose agenda there are energy-reduction goals, to be tackled through the assessment of building energy performance and prioritizing efficiency upgrades across them. To do so, the Architecture Engineering Construction Operation (AECO) sector can count on a range of digital methodologies and tools, such as Building Information Modelling (BIM), Geographic Information Systems (GIS), and IoT devices, whose adoption in the latest years is increasing and which can enable the creation of a Digital Twin (DT).

It is to be noted how diverse among them university buildings can be, both in terms of space function (classrooms, labs, administrative offices, all with different usage habits) and regarding the physical characteristics (due to the age of the building, internal spatial distribution, geographical location, etc.). For instance, older structures result in more demanding heating and cooling provisioning, therefore increasing their carbon impact and managerial concern on sustainability and energy efficiency issues. This intrinsic heterogeneity must face the needs of a plethora of agents, from those regarding the management of the facility (energy managers, facility managers and personnel) to those regarding the comfort of the educational environment (students, teachers, researchers), which affect the productivity of the workers and the learning performance of the occupants/students. Digital instruments, both in-field sensors and actuators, and remote visualization platforms can help manage this complexity, participating as actors in the management process. Literature refers to the physical educational environment as complex adaptive systems (CAS) or "complex self-similar collectivity of interacting, adaptive agents" (Zaballos et al., 2020), also capable of learning and self-organizing under arisen circumstances. Some authors view the Internet of Things, which is a technology that enables Smart Campuses, as a complex system as well, when juxtaposed to the concept of Smart Campuses as CAS (Abbasi et al., 2019).

As revised by Botín-Sanabria et al. (2022) there are different integration levels between digital models and information flow on the path to the Digital Twin development: Digital Model: there is no integration between information flow and digital model; Digital Shadow: the integration of information flow is unidirectional; Digital Twin: information flows automatically in a bidirectional way between virtual and physical world.

The current work takes from an Asset Management System (AMS) platform being developed at the University of Turin, based on the integration of BIM and GIS technologies, whose aim is to recreate a Digital Shadow of the university campus, in order to allow multiple stakeholders interact with the models and the data stored in it. In detail, users can interrogate the models and visualize dashboards aside, created through Business Intelligence (BI) software, while the totality of data, static and dynamic, cannot be altered and lies in a centralized relational database (Accardo et al., 2023).

Leveraging the aforementioned digital tools, in addition to IoT technology sensors, it has been possible to integrate data gathered from sensors, therefore temporal series of physical measurements, allowing insights visualization inside the AMS platform. Hence, for the purpose of this research project and with the vision of arriving at the development of a Digital Twin in the future, the present case study can be considered as a Digital Shadow in which data flow unidirectionally from the sensors to the digital model. Such a result tries to suggest a practical solution to monitoring and improving buildings' indoor comfort conditions and energy efficiency.

Literature acknowledges how spatial information integrated with live data from sensors can "provide an outline picture of how well a workspace is performing" (Zaballos et al., 2020), highlight energy usage and comfort patterns thanks to data provided by indoor and outdoor sensors (Dave et al., 2018), therefore allowing real-time monitoring of buildings and enabling facility managers to reduce delays in decision making when it comes to maintenance activities (Tagliabue and Yitmen, 2022) also detecting eventual cases of failure of malfunctioning of the system. Visualizations produced from data collected might be related to occupancy, highlighting if buildings change in performance not only seasonally but also whether occupied or unoccupied.

Francisco et al. (2020) showcased how targeting efficiency opportunities involves distinguishing between efficiency levels during occupied and unoccupied states. It has been shown how a building's overall benchmark generally masks periods in which a building is overperforming or underperforming during the day, week, or month; thus, proving temporally segmented energy benchmarks more specific and accurate in measuring a building efficiency.

Evidence has demonstrated how environmental parameters can directly influence productivity, enabling further analysis in educational premises from an energy efficiency point of view, as well as from a social one (Zaballos et al., 2020), integrating the collection of subjective data from questionnaires.

This project pays attention to indoor environmental quality (IEQ), considering multiple parameters regarding thermal comfort (TC) and indoor air quality (IAQ). The overall goal of the platform being tested is providing benefits for multiple stakeholders, allowing real time access to information, comfort level monitoring, building performance monitoring and subsequent decision-making in terms of investments and operational processes.

## The Asset Management System Platform

The subject of this research, under development at the University of Turin, is the implementation of the AMS, with the intention of collecting, merging, and relating data from various administrations and departments of the public institution. The vision of the project was to obtain valuable information from the relationships between different types of data and the quick and easy consultation that would follow, thanks to dashboards and BI tools.

The development of the platform was intended to be easily replicable and scalable to other European universities that might adopt it. Another important aspect was the upgradability of the platform and the possibility of implementing other types of data, as in the case of the present study.

Meschini et al. (2022) described in detail the phases of the methodology, which were the starting point for the development of the entire platform. To summarize the most important steps of this methodology, the following should be highlighted: data collection and interviews with the various administrative departments; creation of a common relational database capable of receiving data from different sources; modelling of buildings using BIM; research and application of BIM and GIS integration solutions for the geo-referencing of the University of Turin's property assets; analysis of the data flow from the BIM model to the GIS, and its subsequent use on the BI platform; publication of the information on consolidated dashboards.

After these phases, the data collected so far was mainly static and did not come from IoT sensors.

With the idea of a digital twin of the campus, the research project is progressing by starting to connect data to the building aiming to a real time connection in the future.

## The Luigi Einaudi Campus

The building adopted as case study for sensor analysis is the Luigi Einaudi Campus. The campus, opened in 2012, covers an area of 45000 $m^2$ and was designed to host about 10000 users (over 12% of the UniTO population). The building has been designed according to environmental sustainability and adopting bioclimatic strategies to ensure high indoor comfort. In fact, the building is characterised by glass facades that develop linearly for about one kilometre on each floor, ensuring an optimal balance between natural and artificial light. However, during the first years of operation, analyses of the building's consumption showed a significant impact on the university's costs.

Therefore, the campus has undergone several interventions aimed at improving energy efficiency and energy management and enhancing internal comfort: in 2017 experimental and educational activities, which included the involvement of campus users to collect feedback on indoor comfort and the organization of didactic afternoons, focused on campus methodologies in energy efficiency fields; during 2018 transparent solar shielding films for the windows facing south of the E3 building section were tested with success; from 2019 to 2021 some management efficiency measures were implemented, including the creation of an EOS[3] (EURIX) web platform for monitoring and storing data over time, with the aim of improving air conditioning systems, rooms temperature control, and actions for the automated management of air conditioning and lighting systems in relation to the effective rooms usage; in 2022 the interventions included the design of modules for the placement of a photovoltaic field , the interventions in the lighting system including the installation of presence and illuminance sensors, the extension of the installation of solar films for all buildings facing south, and the integration of the sensor system.

## IoT Devices and data collection

As explained above, the University of Turin had undertaken various initiatives to improve indoor comfort conditions as well as to lower energy consumption with a view to improve energy efficiency at the Luigi Einaudi Campus, which is being used as a sort of University living lab. Among other initiatives, IoT devices were installed in some rooms, in order to monitor environmental data and make improvements in energy systems. This was also an opportunity to enrich the AMS platform with real-time data.
When choosing the IoT device, the university of Turin selected a device capable of acquiring 15 different types of data, namely AirCare® pro+ (Figure 1) (Aircare srl, 2023). The device has also obtained scientific validation from SIMA (Italian Society of Environmental Medicine) for $PM_{2.5}$ and $CO_2$ measurements. AirCare® are IoT devices designed to monitor the air quality inside a building and they can detect various environmental factors related to air quality, environmental comfort and electro smog.
This information can improve users' health and comfort within a university building, as air quality and environmental comfort are crucial for a healthy environment. For example, if the humidity level is too high, it can cause the proliferation of moulds and allergens, while if the concentration of particles is too high, it can be detrimental to the users' respiratory health. Collecting this type of data within a university building can help prevent these problems and improve the quality of life for users.

*Figure 1: AirCare® pro+ IoT device (Aircare.it)*

Cross-referencing IoT sensor data with classroom occupancy data can be useful to gain a deeper understanding of the air quality inside a university building. For example, if the IoT device indicates a high concentration of particles in a classroom during a lecture, cross-referencing this data with classroom occupancy data can help determine whether the presence of many people is the cause of the high particle concentration. This information can help identify factors that affect the air quality inside a classroom, such as insufficient ventilation or the use of chemicals. This can help make informed decisions to improve air quality and the health of users within the university building.
On the Luigi Einaudi Campus, a total of 37 IoT devices were placed. The majority of them are situated on the ground floor and first floor of the building, in an area that is typically utilised for teaching activities.

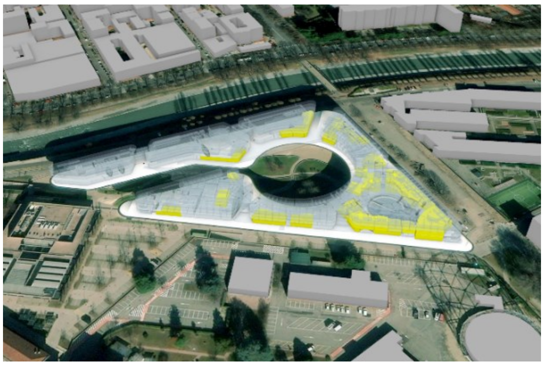

*Figure 2: sensorized rooms at Luigi Einaudi Campus in the AMS Platform*

The rooms in which the sensors were installed (highlighted in yellow in Figure 2) were identified within the model on the AMS Platform and, using the encoding created for the management of the platform, it was possible to create relationships between the pre-existing data and the data acquired from sensors.

## Indoor Air Quality and Thermal comfort

It might be acknowledged that thermal comfort depends both on hydrothermal conditions of an indoor environment, as well as on subjective factors of the occupants, such as activity levels and cloth insulation. The environmental factors of fundamental interest are measurable Indoor Environmental Quality (IEQ) factors, which can be distinguished in: thermal conditions (temperature, relative humidity, air movement); Indoor Air Quality (IAQ) (ventilation and indoor pollutants, including biological, chemical and particulate pollutants); noise; light.
For the purpose of this study, factors concerning thermal conditions and air quality will be analysed in particular.

### Thermal conditions

Guidelines on thermal conditions in classrooms focus on conditions of overheating in the non-heating season, although there is evidence of occurrence of winter overheating in temperate climates (Department for Education and Skills, 2018). Validated studies indicate evidence that children prefer lower temperatures compared with adults, in particular they suggest that lower temperatures in the range between 25°C to 20°C improved student performance by 2% to 4% for every 1°C reduction (Wargocki and Wyon, 2013). It was also suggested that keeping the air dry and cool may improve cognitive performance and reduce Sick Building Syndrome (SBS) symptoms among children. It is therefore necessary that schools do not allow temperatures to drift above the recommended range of 20-22°C in the winter season and 22-24°C in the summer. The observed effects of temperature on performance could be caused by physiological effects of thermal discomfort (feeling too warm or too cold), while optimum performance can be achieved slightly below neutral thermal sensation (Sadrizadeh et al., 2022).

### $CO_2$ and Ventilation

In-situ measurements of $CO_2$ can be performed to efficiently measure bio-effluents (Dodd et al., 2021), since they are both by-products of human respiration, but the latter often results in unpleasant odours. Moreover, higher indoor $CO_2$ levels have been associated with increased probability of communicable infection, asthmatic symptoms, absenteeism, as well as impaired attention span and increased concentration loss and tiredness. Overall evidence suggests limiting average indoor $CO_2$ concentrations in all teaching and learning spaces to an average of 1000 ppm (with a minimum fresh air supply rate of 8 L/s-p) during a teaching day, associating it with at least 1.0% to 2.5% relative decrease in illness absence of students. There is evidence that increasing ventilation rates from 5 L/s-p to 15 L/s-p was associated with a 7% improvement in academic performance. In addition, increased ventilation rates can reduce indoor mould concentrations (an increase of 1 CFU/m3 of microbial concentrations for every 1 ppm increase in $CO_2$) (Chatzidiakou et al., 2014).

Current BB101 guidelines (Department for Education and Skills, 2018) though define broader thresholds: minimum ventilation rates of 3 L/s-p, while maximum $CO_2$ concentration levels during a typical teaching day not exceeding 2000 ppm for more than 20 minutes at a time.

In general terms, design ventilation rates, according to EN 18798-1, can be estimated using three methods: Method 1 is based on perceived air quality and refers to the capability of the ventilation system to remove emissions, such as bio-effluents, from the building, providing ventilation rates for different IAQ categories; Method 2 is based on limit values of a substance concentration in indoor air (e.g. $CO_2$) and can be used to design a ventilation system for a specific occupancy rate in a zone; Method 3 is based on predefined airflow rates for each IAQ category.

### Volatile Organic Compounds

VOC content refers to the amount of chemicals that a product can potentially off as gases during installation or use. Construction and cleaning materials used in the classrooms should be screened based on both content and actual measured emissions, to avoid the usage of harmful ones.

Currently, national and European guidelines on Volatile Organic Compound (VOC) concentrations focus on industrial environments, and there are no studies regarding the effect of VOC levels on the cognitive performance of students.

Higher levels of Total Volatile Organic Compounds (TVOCs) were associated with SBS symptoms and dissatisfaction with IAQ, exhibiting a moderate positive relationship as well with $CO_2$ concentrations. Apart from controlling indoor TVOCs sources, the overall evidence suggests that $CO_2$ levels below 1300 ppm may result in indoor TVOCs below 200µg/m3, which is the lowest threshold to prevent sensory irritations (Salthammer, 2011).

Depending on the different source and organisation, there are different TVOCs limits that are advised for indoor environments.

Nonetheless, the US Environmental Protection Agency (EPA) suggests that for health and comfort, indoor TVOCs levels should be kept below 500 ppb (parts per billion). To lower the danger of sensory irritation, the World Health Organization (WHO) suggests a more conservative limit of 200 ppb.

### Traffic related pollutants

Exposure to traffic related pollutants, such as Particulate Matter ($PM_{2.5}$ and $PM_{10}$), nitrogen dioxide ($NO_2$), ozone ($O_3$) and carbon monoxide (CO), is scientifically proved to be linked to increased illness-related absenteeism and asthma incidence. Indoor levels of traffic related pollutants shall be monitored routinely, yet considered separately, because low $CO_2$ levels do not guarantee a healthy environment, although they provide a first indication of exposure. Indoor concentrations shall comply with World Health Organization (WHO) 2006 and 2010 guideline values, as presented in table 1 (World Health Organization, 2006, 2010).

*Table 1: Maximum acceptable levels of indoor pollutants according to WHO guidelines*

| Pollutant | Units | Short-term Exposure | Annual Average Exposure |
|---|---|---|---|
| $PM_{2.5}$ | (µg/m$^3$) | 25 (24-h mean) | 10 |
| $PM_{10}$ | (µg/m$^3$) | 50 (24-h mean) | 20 |
| $NO_2$ | (µg/m$^3$) | 200 (1-h mean) | 40 |
| $O_3$ | (µg/m$^3$) | 100 (8-h mean) | |
| CO | (mg/m$^3$) | 100 (15 minutes)<br>35 (1-h)<br>10 (8-h)<br>7 (24-h) | |

Along with the design of ventilation rates, supply air (SUP) categories for each zone should be considered. SUP categories define the intended use of the ventilated

space and its PM requirements. In any office or living spaces SUP 2 air will be needed, which means that supplied air is < 50% of the PM2.5 and PM10 limits (Eurovent Recommendation 4/23 – 2018).
As emerged in a literature review (Chatzidiakou et al., 2012) summarizing previous studies and IAQ monitoring surveys in school settings, interlinked with environmental and behavioral factors affecting pollution levels, daily mean concentrations of pollutants often exceeded recommended guidelines and schools in proximity to streets with high traffic intensity presented three to four-fold higher nitrogen dioxide levels, compared with urban background schools. As a matter of fact, NO2, often adopted as an indicator of traffic intensity, is primarily produced by motor-vehicle emissions and depends on proximity to pollution sources.
Filtration of outdoor air can deal effectively with airborne particles but not with other chemicals while it introduces further challenges (increased running costs, source of contamination if filters are poorly maintained). Location of school buildings should be considered in relation to outdoor pollution sources. More broadly, policy should be directed towards citywide level planning, such as urban greening programs around school buildings, which are likely to decrease outdoor pollution levels reducing prevalence of respiratory illnesses.

## Business intelligence tools integration and data connection

For several reasons, BI solutions are essential for monitoring indoor environmental conditions in public buildings:

- Data gathering and analysis: BI technologies make it possible to gather and examine information from a variety of sources, including temperature and humidity sensors, ventilation systems and other environmental monitoring equipment. Then, this data is processed to create reports and actionable insights on the indoor environment;
- Real time monitoring: BI systems make it possible to observe environmental conditions in real-time, enabling building managers to see problems as they develop and take immediate action. This makes it easier to maintain interior environmental conditions within reasonable bounds and to preserve the health and safety of building inhabitants;
- Predictive analytics: BI systems may foresee and stop possible issues with indoor environmental conditions. For instance, they can examine previous temperature and humidity data to spot patterns and trends, and then utilise this knowledge to forecast future circumstances;
- Regulation compliance: Various rules governing indoor environmental conditions, such as air quality standards established by government organizations, must be followed by many public buildings. Building managers may monitor and record adherence to these standards with the aid of BI technologies, lowering the likelihood of fines and legal obligations.

Thus, BI tools are crucial for monitoring indoor environmental conditions in public buildings because they give building managers the information and analysis they need to make decisions about indoor environmental management to maintain the environment safe, comfortable, and compliant with regulations.

### Data connection methodology

The following methodology was adopted to obtain a direct link between the data flow from the IoT devices and the AMS platform database and consequently the BI solution used (i.e.: Microsoft PowerBI®):

- Obtain the data from the website: an "http" request was set up using the python language and in particular the "*requests*" library (a module enabling HTTP requests in Python) in order to access the website and subsequently send a "post" request with username and password;

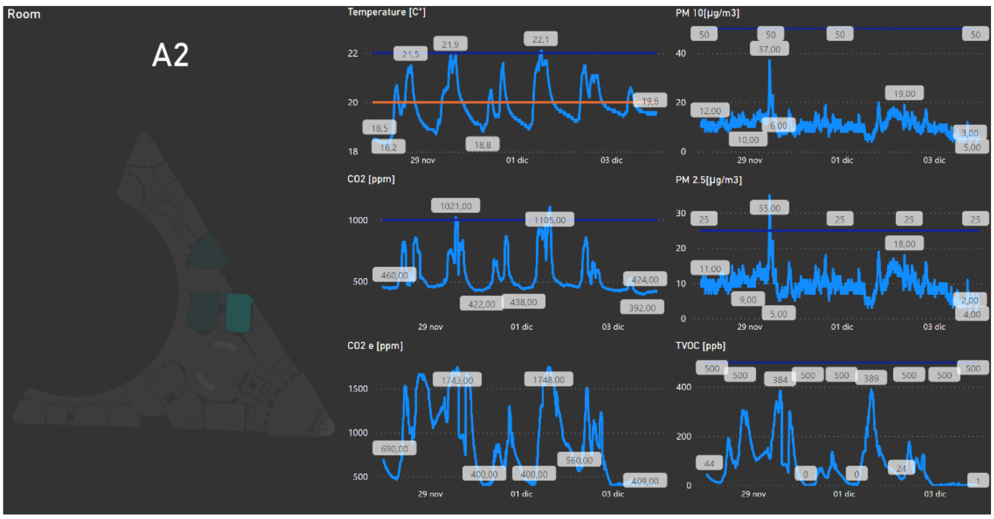


*Figure 3: Real-time data monitoring in the A2 Room*

- Navigation to the download page: a "get" request was set up in order to navigate to the URL of the page where the ".csv" file can be downloaded;
- Download and parse of the ".csv" file: another "get" request was set up in order to download the content of the ".csv" file present at the URL and subsequently, using "*pandas*" library (an open source data analysis and manipulation tool, built using Python programming language) it was possible to parse the ".csv" file and extract data;
- Data storage: data were saved in the database in csv format for quick use in PowerBI®;

Load the data into PowerBI®: using the aforementioned "*pandas*" library, it was then possible to read the data from the file and then, using "*pyodbc*" library (an open source Python module that simplifies accessing ODBC databases) and executing SQL queries, it was possible to insert data into PowerBI® dataset.

In order to automate all steps, it is necessary to set up a "task scheduler" and subsequently also set up an automatic data update by PowerBI®. The first problem was solved by using the *"schedule"* library (an in-process scheduler that runs Python functions at pre-determined intervals) and running the functions on a periodic basis. To refresh the data in the PowerBI® software the refresh service was set. The service also offers the possibility to consult the "refresh history" report.

**Dashboard development**

After connecting the data stream to the digital model, it was important to understand how to create relationships between the data to create useful information and be able to visualise it quickly and effectively. Indeed, an important part of the architecture of a digital twin is the development of data visualisation tools for the involved stakeholders (Botín-Sanabria et al., 2022).
To take advantage of the real-time data linked to the BIM models, the idea was first to briefly have the monitoring of the main parameters: Temperature, $CO_2$, $CO_2$ e, VOC, $PM_{10}$ and $PM_{2.5}$.
For this purpose, an initial dashboard, that could link the floor plan and highlight classrooms where sensors were present, was created. By selecting the classroom of interest, it is possible to immediately view the values over the course of a week (Figure 3).
As for the classrooms involved in the experimentation, these are 3 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) (Figure 4).
The development of the dashboards then involved overlapping data of different types to create information that would otherwise be difficult to find. An example is the cross-referencing of data regarding air quality and thermal comfort with data regarding scheduling and thus classroom use (following the university schedule).
In the specific case study, the week from November 28, 2023 to December 4, 2023 was analysed, a period in which teaching activities are in full swing. A threshold was also added to the graphs indicating the optimal levels for each parameter measured.

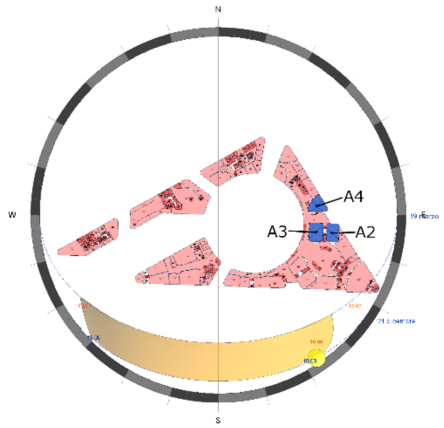


*Figure 4: Sensorized rooms at Luigi Einaudi Campus*

Thanks to the rapid, contextual visualization, it is therefore possible to understand the state of the rooms and find correlations between indoor comfort conditions, air quality, and occupancy levels inside the classrooms.

## Results and discussion

The installation of IoT devices is an important step toward creating digital twins. At present, the data flow is unidirectional but still allows glimpses of important future functionality.
The connection of data to BIM models and the subsequent ability to link and correlate them to the overall database and thus to the data present on the AMS is certainly an important automation that makes information available quickly and easily to support more timely strategic decisions.
Regarding data monitoring during the week under study, it is interesting to observe some correlations. Regarding temperature, it was observed that classroom A2 complies with the temperature range during class hours throughout the week by not going above 22°C while with regard to classrooms A3 and A4 they systematically exceed 23/24°C. It is important to note that Classroom A4 has a fully windowed side facing northeast and thus the possibility of opening windows. Classroom A3, on the other hand, is located in an interior area of the building with no direct outward facing, and classroom A2 has a very limited eastward facing. In addition, there is a clear correlation between the temperature peaks and the presence of classes inside the classrooms.
Indeed, human metabolism contributes to an increase in temperature and $CO_2$ levels. As people breathe, they exhale $CO_2$ and produce heat, which raises the temperature in the room. The more people in a classroom, the higher the temperature and $CO_2$ levels will be. If the room is poorly ventilated, the $CO_2$ levels can become dangerously high, which can cause drowsiness, headaches, and reduced cognitive function.
Regarding $CO_2$, Classroom A2 again turns out to be the one with the best performance by managing to stay below

the 1000 ppm threshold during the week during classes. Classrooms A3 and A4, on the other hand, have peaks that are around 1300/1400 ppm during scheduled class hours. Regarding the values of $PM_{2.5}$ and $PM_{10}$ in general the trend respects the limits, below the average of 25 µg/m3 for $PM_{2.5}$ and below the average of 50 µg/m3 for $PM_{10}$. Interestingly, at the peaks of $PM_{2.5}$ and $PM_{10}$ inside the classrooms there was also a concomitant drop in temperatures and $CO_2$ suggesting user intervention by opening windows. Indeed, if there are high levels of $PM_{2.5}$ in the surrounding environment, some of that pollution can enter the classroom through open windows or doors. This can be especially problematic if outdoor air pollution caused by traffic or industrial activities nearby is high, as is the case in the city of Turin.
Finally, in the case of VOCs, the weekly average is certainly acceptable standing below 500 ppb. VOC monitoring therefore provides no alarm for the levels recorded within the 3 classrooms.
The main advantages of connecting the data stream to the model is therefore the possibility of immediately associating the data collected by the IoT devices with the correct space within the building and visualizing at a glance possible criticalities due to the overrun of the main indicators of environmental quality and thermal comfort.
The critical issues mainly encountered during the data connection phase concern the management of large data streams considering that IoT dispositions record the situation every 5 minutes. In this regard, automated data storage could be entrusted to a cloud service that is also able to act as a database for the sensor part.

## Conclusion

The research addressed the implementation steps for connecting data from IoT devices to an AMS platform for real estate asset management, accordingly to Digital Shadow's principles, one step toward the development of a smart and connected campus.
The ability to connect heterogeneous data opens new scenarios in the real estate management field. The help of digital technologies appears very useful in the case of particularly large real estate patrimony and with complex dynamics.
IoT devices are currently among the most interesting solutions as they allow direct data transmission to a cloud environment, thus avoiding additional data handovers between different platforms. The connection of IoT-sampled data to BIM models and subsequent correlation with AMS data has enabled quick and easy access to information that might supports timely strategic decisions. Through the monitoring of IAQ parameters, a clear correlation between the presence of people and an increase in temperature and carbon dioxide ($CO_2$) and volatile organic compounds (VOC) in university classrooms appears, more in general underlining the impact of human presence and external factors on indoor air quality and thermal comfort.
The main advantage of connecting the data stream to the model is the ability to associate data with the correct space within the building, visualizing possible criticalities due to the overrun of key indicators. However, the management of large data streams remains a critical issue that needs to be addressed. Overall, the use of IoT devices in building automation has the potential to improve indoor environmental quality, promote energy efficiency, and enhance occupant comfort and productivity.
It is a matter of fact that actual occupation rates and activities significantly influence IAQ, deviating from original design assumptions and therefore highlighting the necessity to monitor the building spaces.
Further developments of the present research process might follow steps suggested in Level 3 of EU Commission user manual on IAQ (Dodd et al., 2021), which fits in a common EU framework of core indicators for assessing the sustainability of buildings in their whole life cycle, not only in terms of environmental performance, but also in correlation to health and comfort, life cycle cost and potential future risks to performance. The main objective of such a project is enabling actions to be taken at building level that can make a clear contribution to broader European environmental policy objectives. In fact, Level 3 (Dodd et al., 2021) suggests a "two-pronged approach" aimed at assessing IAQ in an objective way: air sampling and monitoring with a quantitative and objective approach; Occupants feedbacks collected through online-delivered surveys during the occupation.
Both types of collected data can be subsequently cross-referenced with occupation rates and usage patterns, delivering meaningful suggestion for possible remedial actions on the HVAC system.
Future research could investigate on the development and implementation of machine learning systems and provide opportunities to learn from user behavior and data collected from the building, thereby enhancing the effectiveness and efficiency of increasingly automated and accurate systems.

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