Digitization and Energy Transition of the Built Environment – Towards a Redefinition of Models of Use in Energy Management of Real Estate Assets

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Abstract. Thousands of years of progress in urban development led to complex urban environments that can be considered as complex systems. The management of complex systems must account for uncertainty, unpredictable future states and nonlinear behaviour. In this context, digitalisation can play a key role in the development of innovative tools to support strategic decisions and emergency management. In particular, the management of university building stocks can be facilitated with the creation of digital environments.

In the Italian case, university campuses are often complex assets composed of widespread buildings and the management process is still based on fragmented databases handled by different administrative divisions resulting in a lack of information among stakeholders.

The integration between Building Information Modeling (BIM) and Geographic Information System (GIS) is already making some steps towards the creation of a digital model of the city. The combination of BIM-GIS with a platform for the data management is the base to develop an Asset Management System to exploit Business Intelligence (BI) tools for Operation and Maintenance (O&M) in smart campuses.

This research aims to integrate BIM, GIS and BI tools in a digital framework for the development of an AMS and web-based application for the improvement of the experience among users and the optimal use of resources. A real case study is proposed for the development of the research project, namely the University of Turin building stock, in Italy.

Keywords: BIM-GIS · Asset management · Energy transition · Information value · Sustainability

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1 Background

University campuses are difficult to maintain since they are made up of many diverse buildings, many of which were erected at various times, especially in Italy. Their administration is frequently structured on fragmented databases that are difficult to access and are still document-based, resulting in insufficient and asymmetrical information that leads to unproductive choices and resource utilization, particularly during the operation and maintenance (O&M) phase. In terms of the total cost of the asset life cycle, this period proved to be the costliest [1]. Building usability and energy consumption are strongly influenced by the effective use of spaces (i.e., space management connected to occupancy flows), users' behaviour, and the demands for supply and services. As a result, if they are not properly managed, they can waste resources and raise management, operating, and maintenance expenses. The digital transformation of process management has become critical in the development of digital Asset Management Systems (AMS) as decision-support tools for managing and optimizing university spaces and activities [2, 3]. To make the transition to full digital management easier, a method for Information Management (IM) and information protocols for tailored data modelling are required. These methods and protocols must ensure the availability of accurate information at the right time and in the required format for the appropriate subject [4]. To construct digital AMS solutions capable of managing all the data required over the whole university asset lifespan, information regarding how and when data exchanges should occur, as well as among which stakeholders, must be established.

The combined use of BIM (Building Information Modelling) and GIS (Geographic Information System) has shown promise in the development of Smart Cities and Digital Twins (DTs) in recent decades [5, 6]. BIM is essential for creating extremely complex architectural models, whereas GIS allows them to be managed and analysed using a worldwide geographic reference system [7–9]. Furthermore, the BIM-GIS merger, also known as GeoBIM received little attention in the field of Asset Management (AM) [10]. The current availability of both new technologies and large data quantities, along with BIM-GIS compatibility, can optimize management operations, particularly during the O&M phase. It can also help to design successful AMS [11]. The capacity to digitally manage the asset from the geographical macroscale to the microscale of the single asset component is one of the major capabilities of BIM-GIS integration [12].

Based on these assumptions, the research project intends to design a digital and repeatable approach for developing an AMS based on BIM and GIS integration via a web platform (i.e., AMS-app) targeted at improving information management and decision-making processes in large and distributed assets. The AMS app should collect all the data that is presently managed independently by multiple administrations, allowing for independent yet collaborative management. As a result, rather than managing each building, the building asset may be managed at the system level. Another significant result of the study is the creation of an information protocol to improve distributed university asset modelling using BIM-GIS platforms. The study focuses on the tremendous effort to aggregate data from multiple separate databases into a consolidated and easily accessible one, and it describes the reproducible methodological approach used to construct the AMS app. It's also shown how the AMS app was created using a centralized database to enable real-time representation of the whole distributed asset in an interactive 3D map. The product is a "GeoBim" system that allows users to store, examine, and exchange continually updated geometric, spatial, and functional data, which will help the institution manage its assets more efficiently and sustainably. Finally, the paper demonstrates how to put the theory into practice. Furthermore, the study describes how to apply the stated technique using two demonstrators, highlighting preliminary findings, potentials, and limits. The two demonstrators are part of the University of Turin building stock, which is a pilot use case. It is one of Italy's most dispersed campuses, with a large catchment area and unstructured management. Due to these characteristics, there is a significant information asymmetry, which prevents knowledge of its consistency and usage, resulting in resource waste and efficiency losses. Furthermore, one of the targeted aims in the University's strategic plan, which stands out as a novelty in the Italian panorama, is the digitalization of building stock and the employment of digital technologies for AM.

2 Methods and Data

Starting with a state-of-the-art examination of methodologies and tools for producing AMS of large building stocks using BIM-GIS integration, the research approach was designed. In the second phase, which focused on the examination of the pilot use case, namely the University of Turin building stock and its present management practices, the real definition of the methodological approach began. Following the analysis, processing, and structuring of the collected data, a centralized relational database was created to collect all the disparate data about the asset's geographical and functional features. Finally, a unique BIM-GIS online platform was created to allow the university's building assets and characteristics to be seen in an interactive 3D digital environment. Figure 1 depicts the study methodology, which might be applied to various scenarios.

The examination of the asset's consistency and the identification of the administrations engaged in its management were the initial phases of the analytical approach. The major goal was to determine which data were required, from which administrations, which were previously available or not, how they were maintained and shared, and where the missing data might be gathered. To achieve this, the institution's communication channels (i.e., the website and its Transparent Administration section, which contains official documentation related to the institution's core activities and people working there) were investigated to collect data and identify administrations involved in the management processes (Table 1). Subsequently, it was investigated how a web platform called Opensipi was being used to handle data on the building stock (e.g., dimensions, occupancy, mechanical assets, and so on). The "Information systems and e-learning portal Directorate" was in charge of this platform, which may be updated by the "Building, logistics, and sustainability Directorate". Academic activity data was also discovered to be held in heterogeneous excel sheet files handled by administrative workers from the "Educational Services Directorate." Finally, an external database, namely Cineca, was recognized as having students' data handled through specific interfaces but not available for consultation.

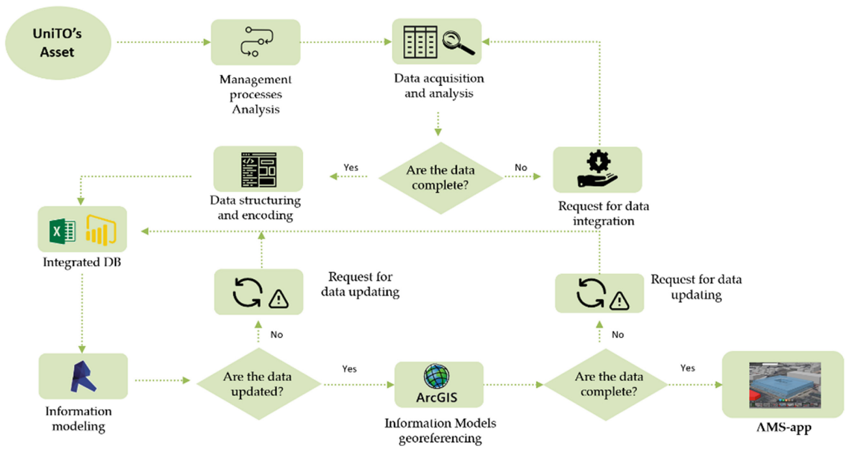

Fig. 1. Methodological approach

The interviews with administrative and managerial professionals from numerous departments verified this fragmentation and underlined the difficulty in acquiring the necessary data because extrapolation must be done on purpose, resulting in extended wait periods. Then, to identify which data should be linked and connected for the effective administration of the University's assets and operations, an in-depth investigation of the databases was done.

The Opensipi platform was created to make a GIS-based solution for space and asset management. Using Google Maps, Opensipi allows to search and see the whole University building stock. The software also displays spatial features and specific premises of each building via digital interactive plans (Table 1). It's worth noting that the functional characteristics of places (such as occupancy, furniture, and mechanical systems) that are important during the O&M phase aren't present. Another issue is that the platform is not updated regularly, therefore its data may not reflect the current state of the spaces. Subsequently, current building stock data and plans were acquired through short interviews and documentation requests to the technical office.

The "Educational Services Directorate" employed heterogeneous excel sheet files to manage schedules and course data, as shown in Table 1. On the other hand, Cineca, which is also responsible for data storage, provides a specific application for managing data linked to students' careers, fees, and course catalogues. Short interviews with workers were also done in this case to better understand which data they manage and how various administrations interact. It was noted that the "Educational Services Directorate's" excel sheet files were not linked to the data given by the database supplier Cineca.

As a result, there was a lack of communication across administrations, resulting in highly fragmented data, which added to staff workload and inhibited job automation. Cineca, as previously stated, is a third-party software and service provider in charge of data administration. The administrative staff cannot directly alter data contained in the database; instead, a specific program is required to see information, and Cineca must be queried using bespoke queries, resulting in high processing times and inefficient administration. Direct access to a centralized database and the necessity for efficient

Table 1. Administrations involved in management processes and dedicated databases

Database	Data	Administrative directorate
OpenSIPI	Building name Geometric data Building location State of use	Information systems and e-learning portal Building, logistics and sustainability
Excel sheet files	Timetables Courses	Educational services
Cineca	Student career Course catalogue Fees	Not directly accessible

functionality is critical for developing AMS for scattered and heterogeneous building stock [13]. Therefore, an integrated database was required, in which data from Cineca and other databases converged, resulting in a data source that was easily accessible and queryable. Such an AMS may be a game-changer for the "Educational Services Directorate," which would be able to rely on a single source of data on the number of students, available spaces, and courses.

The structure of the centralized database was established considering the existing situation while keeping in mind the possibility of future deployments. Following the acquisition of the data, a state-of-the-art study was undertaken to determine the optimum approach to preserve them to give flexibility, easy updating, and user accessibility. Relational databases (RDBs), which enable data to be structured according to a specific hierarchy, resulted to be a well-established method of storing data [14]. RDBs allow numerous sorts of connections between data to be established, allowing for customised queries as well as the ability to filter and aggregate data based on the intended purpose. The database structure was separated into 9 tables that were supplied with the acquired data and were also based on future database usage and queries related to asset management operations (Fig. 2).

This allowed us to see how the various levels and types of data should be linked. The initial stage was to select the primary data to which additional data would be linked. Because spatial data are required for most management operations, it was chosen to start there. As a result, the database structure was built on spatial data in a core table called "Building Stock". Then, on the left side, there were connections to more information regarding "Spaces", "Occupancy" and "Timetables". Data regarding "Real property titles", "Rental revenues", "Rental costs," and "Degree programs" were branched out on the right side.

One of the most important steps in identifying the building's areas was to create a custom encoding system that could also connect data through the database. It is arranged as follows, according to the various building stock levels of definition:

$$\mathrm{PR}^1\_000^2\_000^3\_\mathrm{A}^4\_\mathrm{P}00^5\_0000^6$$

Province 1; venue 2; settlement 3; building code 4; floor 5; rooms 6.

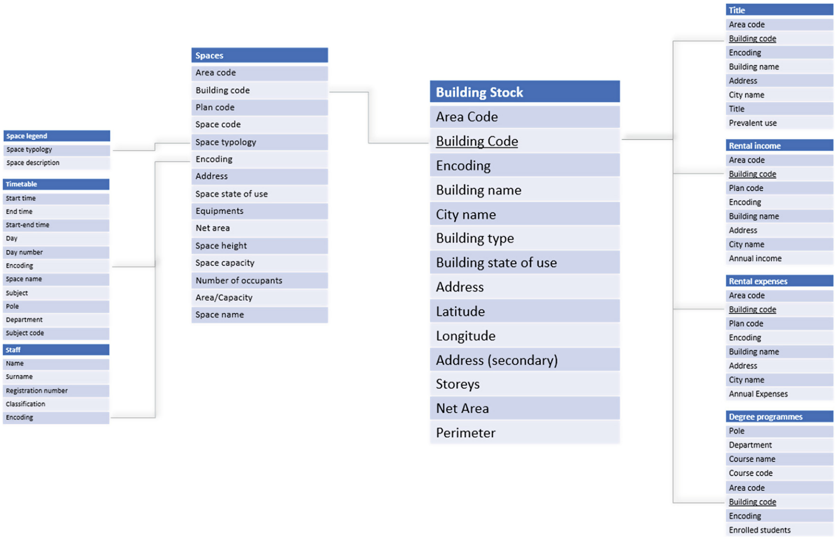

Fig. 2. Database structure

This technology allowed data to be connected following the building's level of detail. Both the encoding strategy and the centralized database structure were important in the AMS app since they allowed users to filter shown information using the single data set described above. The assignment of the semantic data recorded in the centralized database to the building stock was the fourth phase. The initial step was to create BIM models that were to be enhanced with building characteristics, beginning with two pilot cases: the Faculty of Computer Science's headquarters and the Faculty of Humanities' headquarters. The major goal of this early phase was to get a level of data that was appropriate for representing the entire university asset without being burdened by an excessive volume of data. As a result, a significant decision was to model the building stock using masses, floors, and rooms rather than a high level of detail. The Autodesk Revit® authoring tool was chosen, which is one of the most widely used BIM tools in the AEC sector. This decision was based on three factors: the ability to represent only the main volumes of the university building stock as masses, floors, and rooms (which will be implemented in the future); the availability of the Dynamo plugin for Revit®, which automates both modelling and parameter assignment processes; the high level of interoperability between Revit® and GIS platforms (such as Esri's ArcGIS Pro), which allows for the import of BIM Models [15].

The individual categories of created elements (i.e., masses, plans, rooms) were assigned to the spatial and functional attributes previously stored in the centralized digital database using VPL (Visual Programming Language) [16], which is widely used in the AEC industry with significant improvements both in modelling and data management [17]. VPL is a programming language that substitutes ordinary computer programming with special objects (i.e., nodes) that have unique functions. Dynamo is an open-source

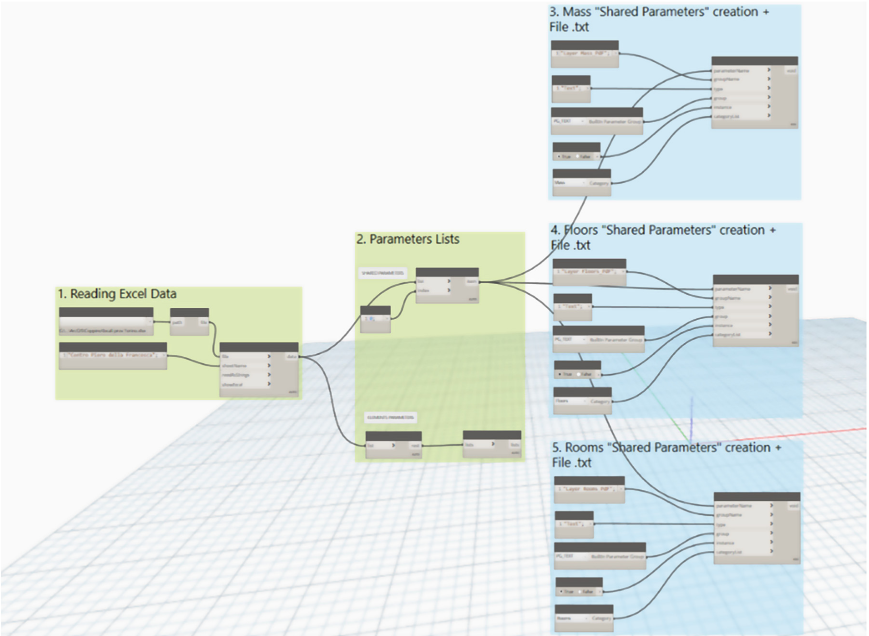

Fig. 3. Dynamo nodes

interface that connects VPL and Revit API nodes to construct highly customizable algorithms [18]. The geographical and functional data were first organised separately before being coupled to the parametric models. Extrapolating data from spreadsheets, creating new-shared parameters in.txt format, and assigning them to three kinds of parametric components (masses, planes, and rooms) in BIM models were all done with customized nodes (Fig. 3).

The fifth phase of this research project focused on the creation of a web-based BIM-GIS platform (i.e., AMS-app) that allows for real-time display of assets and their properties in a 3D digital map (Fig. 4). This platform may be thought of as a GeoBIM system since it allows users to link information models, geographical data, and functional data all at once. Therefore, georeferenced masses with geometric and semantic information were imported into the GIS platform. The building stock may be explored and filtered at several information levels (asset, single building, floor, and local), allowing for asset analysis and strategic decision-making by gathering and visualizing only the information required.

Finally, through business intelligence (BI) technology, it was feasible to turn data into meaningful information and give important instruments to assist strategic choices. Microsoft Power BI® was chosen to provide the best interoperability with excel sheet files used by administrations and minimize data loss. It is often regarded as one of the best ideal applications for managing massive amounts of data [19], and it supports the presentation of Arcgis maps via a custom plugin.

Fig. 4. University of Turin's asset in the AMS-app with an example of a summary table

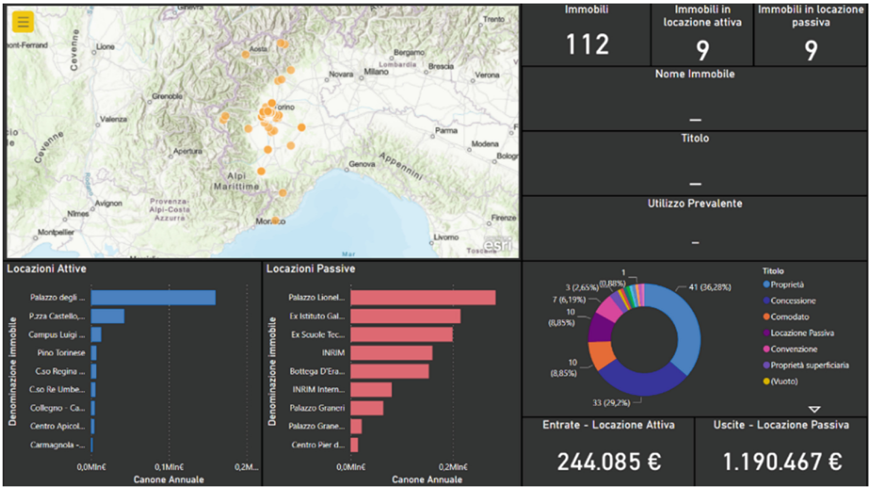

Fig. 5. Building stock dashboard 1

The capacity to work on datasets without altering the data source is an important advantage. Using this functionality and the previously mentioned centralized database, various interactive and detailed dashboards are offered to let university building users visualize and interpret relevant information (Figs. 5, 6, 7 and 8).

A first dashboard was constructed containing the asset's general analytic features (Fig. 5). It shows an interactive map with connected data (e.g., number of buildings, building name, building title, prevalent usage, rental revenue, rental expenditures) and certain user-interactive components. Data may be filtered or aggregated by clicking them, and key performance indicators (KPI) can be changed interactively via maps, bar graphs, and ring graphs. As a result, without having to wait for reports, the online application provides a comprehensive picture of the building stock consistency, allowing administrators to better allocate resources.

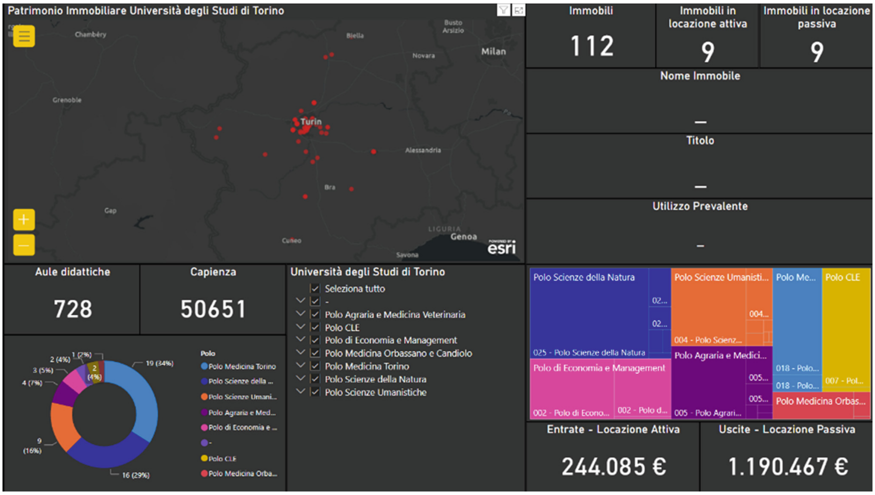

Fig. 6. Building stock dashboard 2

In a second dashboard (Fig. 6) assets and associated information might be sorted by educational pole or department for the depiction of the whole building stock. These data, when combined with information on classroom occupancy and course schedules, allow for better course allocation, facility use, and user mobility around the campus, resulting in a more sustainable campus. Then, for the examination of the first demonstrator, two further types of dashboards were created (Fig. 7 and 8).

The first dashboard provides for a more detailed study of the various activities at the building space level (Fig. 7). Some classes were underutilized, while others were

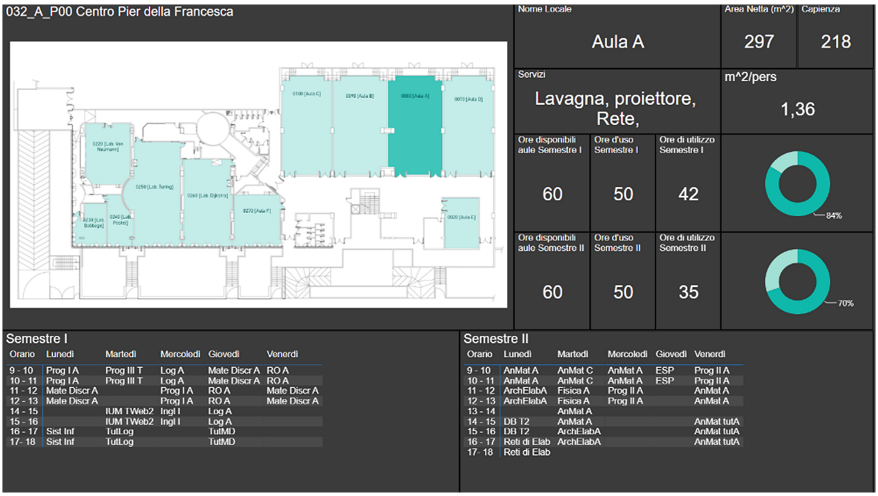

Fig. 7. Piero della Francesca centre's dashboard 1

overutilized, resulting in user discomfort and leasing costs for exterior areas. The Educational Services Directorate and other authorities may now readily examine and reference this data to allocate study courses optimally based on real space availability.

The last dashboard (Fig. 8) was dedicated to the offices' floor in which a detailed analysis regarding the utilization of the space could be done, visualising briefly the distribution of persons and the percentage of spaces used by role.

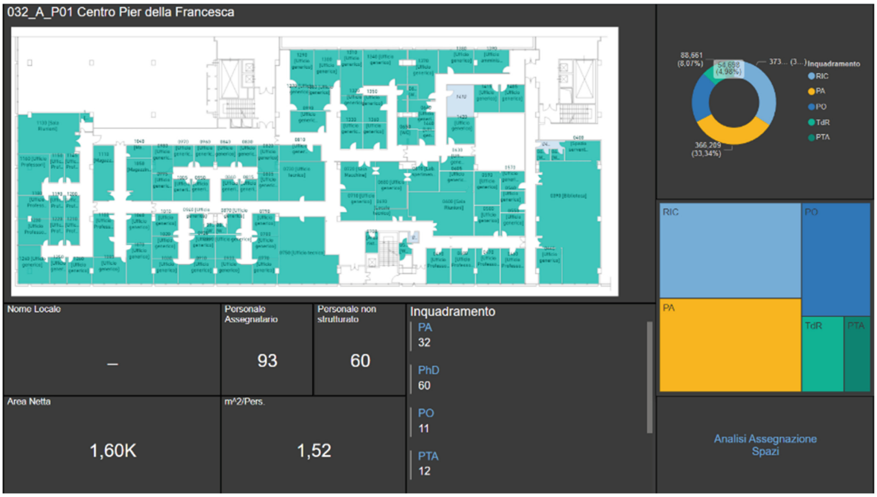

Fig. 8. Piero della Francesca centre's dashboard 2

3 Results and Conclusions

The main output of this research is the AMS app that allows users to view the whole University of Turin building stock and its properties in a 3D interactive map. It is now confined to authoring formats, but open standards may be used in the future to enable more compatibility between BIM and GIS (e.g., IFC, CityGML). The established AMS allowed for the resolution of present fragmented and document-based management challenges. It enabled effective decision-making and management operations by storing comprehensive and up-to-date data in a centralized and easily implementable database. Useful strategic data and graphs might be shown using synthetic dashboards and BI tools linked to the AMS app. These characteristics allowed for improved financial and geographical resource management at the institution, as well as waste reduction and cost reductions. It is possible to: rationalize space use based on actual availability, course schedules, and occupancy; optimize real estate investments by visualizing over or under exploitation of both buildings and spaces; manage maintenance and cleaning operations optimally about actual space use. Furthermore, thanks to the unified database, energy bills are also linked to each building, making it possible to highlight anomalies in energy consumption compared to the average per square metre. The AMS-App allows users to access information through a webapp without any installation requirement. With different levels of permissions every stakeholder can access to valuable information and participate in its improvement through dedicated text boxes. Sensor networks to detect thermal comfort, energy consumption, people presence, and any other valuable data for effective management of the O&M phase are scheduled to be installed in most major buildings in terms of dimension, occupancy and complexity. These data will be collected using the database that has been created and displayed using custom dashboards. As a result, BIM models might be used to create important DTs that allow for real-time optimization of internal comfort conditions, energy consumption, emergency evacuation, supported maintenance operations, and optimal occupancy using VR/AR tools. As a result, real-time or predictive building management might be given, along with improved user experience and lower administration costs and resource usage.

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