DATA INTEGRATION THROUGH A BIM-GIS WEB PLATFORM FOR THE MANAGEMENT OF DIFFUSED UNIVERSITY ASSETS

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Abstract

High fragmented and hardly accessible information often leads to struggling management of diffused assets. BIM and GIS integration is promising to develop effective digital Asset Management Systems (AMS) to facilitate information sharing and collaborative management. This paper presents a replicable methodological approach to develop a pilot BIM-GIS, web-based AMS for the University of Turin. The main aim is to overcome document-based and fragmented management, avoiding ineffective decisions during the operational and maintenance phase. The key step of integrating data from several heterogeneous sources in an accessible, centralized database is deep in described. Furthermore, two demonstrators are illustrated, discussing the first results and AMS potentials.

Introduction

Over the last decades, the integrated use of BIM (Building Information Modeling) and GIS (Geographic Information System) has been promising to develop Smart Cities and Digital Twins (DTs) (Zaballos et al., 2020). BIM is fundamental in the production of highly detailed building models, while GIS enables to manage and analyse them through a global spatial reference system (Zhu and Wu, 2021). Together with the recent availability of innovative technologies and big data volumes, BIM-GIS interoperability can optimize management activities, especially during the Operation and Maintenance (O&M) phase. It can also promote the development of effective digital Asset Management Systems (AMS) tools (Pärn et al., 2017). The main difference between BIM and GIS also represents their integration strength and lies in the representation scale. GIS works at the district level and building surroundings, while BIM can deeply describe a single building. Thus, the great power of BIM-GIS integration consists in the ability to digitally manage the asset from the territorial macroscale to the microscale of the single asset component. Nevertheless, this is possible only if a centralized, accessible, scalable, and well-structured database is configured and available.

Recently, several universities borrowed the Smart City concept at the campus scale to improve asset management with a more satisfactory user experience and optimal use of resources (Lu et al., 2020, Ward et al., 2021). University campuses are complex assets to manage, made up of widespread buildings and often built in different eras, especially the Italian ones. Their management is often organized on fragmented and hardly accessible databases, still document-based, resulting in incomplete and asymmetrical information that leads to ineffective decisions and use of resources, especially during the O&M phase. This phase proved to be the most expensive concerning the total cost of the whole asset life cycle. The efficient use of the spaces (i.e., space management related to occupancy flows), users' behaviour and the needs for supplies and services have strong impacts on building usability and energy consumption. For that reason, if inadequately managed, they can cause a waste of resources as well as an increase in management, operational and maintenance costs. Therefore, a switch from fragmented document-based approaches to digital collaborative processes is needed. To facilitate the transition to full digital management, it is required an Information Management (IM) method and information protocols for tailored data modelling able to ensure the availability of accurate information at the right time in the required format to the proper subject (Chen et al., 2015). Information about how and when data exchanges should happen and among which stakeholders must be defined to develop digital AMS tools able to manage all the data needed throughout the whole university asset lifecycle. Furthermore, the BIM-GIS merge, also known as GeoBIM, has been rarely investigated in the Asset Management (AM) field (Moretti et al., 2021).

Moving from these assumptions, the research project aims to define a digital and replicable methodology to develop an AMS based on the integration between BIM and GIS through a web platform (i.e., AMS-app) aimed at facilitating information management and decision-making processes in large, diffused assets. The AMS-app should gather all the data currently separately managed by several administrations, to provide a still independent although collaborative management. Therefore, the building asset could be managed at the system level rather than at a single building level. Another major outcome of the research consists in the definition of an information protocol to enhance diffused university assets modelling through BIM - GIS platforms. The paper presents the replicable methodological approach followed to develop the AMS-app, focusing on the description of the significant effort to gather data from several isolated databases in a centralized and easily accessible one. In addition, it is illustrated how the AMS-app was developed exploiting such a centralized database to provide real-time visualization of the whole diffused asset in an interactive 3D map. The result is a "GeoBim" system enabling to archive, consult and share of constantly updated geometric, spatial, and functional data, useful for more efficient and sustainable management of the university assets. Finally, the paper explains the application of the established methodology through two demonstrators, discussing the first results, potentials, and limitations. The two demonstrators are part of the pilot use case that is the University of Turin's building stock. It represents one of the major diffused Italian campuses, with a huge catchment area and quite unstructured management. Due to these features, it involves a strong information asymmetry, which prevents awareness about its consistency and uses, with consequent waste of resources and efficiency losses.

Furthermore, the digitalization of building stock and the use of innovative and digital tools for AM is one of the desired targets in the University of Turin's strategic plan, which stands out as a novelty in the Italian panorama.

Background

The literature review focused on BIM, GIS, and their integration to develop a web-based platform for O&M management. The analysis of past and current approaches, and their applications with related advantages and limitations, was extensively conducted.

It is a matter of fact that BIM enhanced productivity in the AECO industry (*Architecture, Engineering, Construction, and Operations*) promoting collaboration and information sharing among stakeholders (Bryde D, 2013). It was developed with the main aim of managing the whole building lifecycle through parametric models fed with relevant information (Villa and Di Giuda, 2015). Concurrently, GIS emerged as a compelling tool to acquire, store and handle a big amount of data in a relational database, facilitating specific spatial analyses through spatial and non-spatial attributes, assigned to tailored parameters (Burrough, 1986, Liu et al., 2017). In the last few years, the integration between BIM and GIS became a research trend topic as it improved data integration, urban management, and strategic decision-making, providing valuable support for the actual growth of smart sustainable cities (Yamamura et al., 2017). Nevertheless, BIM and GIS exploit 3D information models with two different approaches (Noardo et al., 2020). Their integration is complicated by several differences: users, spatial scales, coordinate system, standards levels of detail, geometric and semantic representation, and granularity levels, in addition to information storage and access method.

Recently, many studies tackled the BIM-GIS interoperability issue with interesting results. (Ellul et al., 2020). Noardo at al. argued that the main issues to be faced are as follows:

<u>Harmonization and consistency of data</u>: all the items and data must fit together, with a specific feature class (i.e., georeferencing, accuracy, geometric and semantic representation, amount of detail etc.);

<u>Interoperability</u>: metadata must be structured, clear and comprehensive to be correctly used in different software. The adoption of open standards such as IFC (*Industry Foundation Classes*) for BIM and CityGML for GIS (Laakso and Kiviniemi, 2012) would facilitate interoperability and unchangeability among heterogeneous dataset process which translates a dataset into a standardized format;

<u>Common guidelines</u>: definition of guidelines shared between actors and stakeholders to avoid loss of information during exchanges, "GeoBIM" models instead of BIM and GIS separately (Floros and Ellul, 2021).

Many studies analysed the most suitable fields where BIM and GIS can be better applied. Ma et al. identified the following three phases: P&D (*Planning and Design*), O&M and the building demolition phase. In particular, the activities, which benefit most from BIM-GIS integration during the O&M phase, are crowd simulation and the management of risks, energy, security, facility, heritage, and many others. Teo et al. (Teo and Cho, 2016) made a great example of crowd simulation. They connected indoor paths generated by exploiting geometric and semantic information from BIM models with outdoor paths from GIS databases to support indoor and outdoor combined emergency planning. Most of the studies which tackled the issue of exchanging data between the two systems highlighted how the best approach consists in extracting data from BIM and importing them into GIS (Al-saggaf and Jrade, 2015, Ma and Ren, 2017), rather than exploiting the reverse process. Similarly, the same studies showed as one of the most suitable paths to achieve BIM and GIS interoperability is ESRI ArcGIS Pro® combined with Autodesk Revit®. Due to the availability of these software at the University of Turin, they were chosen to be exploited for the pilot use case, with the future aim of exploiting open solutions through IFC and CityGML standards.

Methodology

The research methodology was developed starting with the state-of-the-art analysis concerning methods and tools for developing AMS of large building stocks through BIM-GIS integration. The actual definition of the methodological approach started in the second phase which tackled the analysis of the University of Turin's building stock and its current management processes. Following the analysis, processing and structuring of the acquired data, a centralized relational database was set up to gather all the heterogeneous existent data concerning both spatial and functional attributes of the asset. Finally, a custom BIM-GIS web platform was developed to enable the visualization of the University of Turin's building stock and its attributes in an interactive 3D digital environment.

Figure 1 shows the research methodological path which could be replicated for other use cases. The main objective was to develop a customized digital tool (i.e., AMS-App) suitable for several devices (e.g., smartphones, tablets,

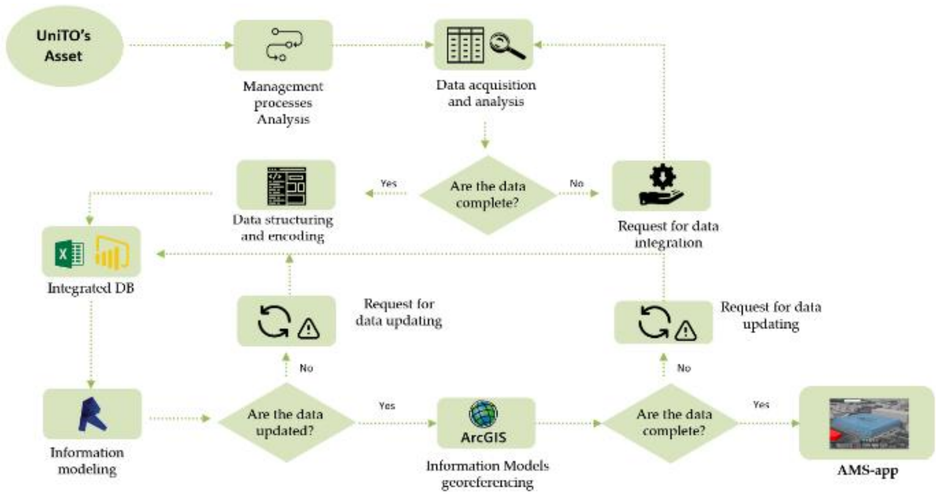

Figure 1: Flow chart

notebooks, etc.) to support the easily consultation and visualization of the information through the interactive 3D map.

Therefore, the interested administrations and stakeholders involved in decision processes concerning the university's assets and activities (e.g., teaching and research staff, students, maintenance staff) could find the required information by querying the building. As aforementioned, the process started with a preliminary analysis of the management processes currently in use. Following this phase, the needed datasets were acquired and there was the first check. If some data were missed, an integration was needed, otherwise, data were structured with a tailored encoding scheme in the subsequent phase. Then, there was the data integration in a centralized database with the development of BIM models fed by customized datasets. After this phase, there was another check to understand whether the dataset was correctly updated concerning data included in the BIM model. Once the dataset passed the check, the models could be georeferenced. Before the final step, concerning the implementation of data and models in the AMS-app, one last check was made to ensure that the data were up-to-date and correct. The following paragraphs provide a deep-in description of each step of the methodological path.

Building stock and management processes analyses

The first phase of the methodological approach concerned the analysis of the University of Turin's asset consistency and the identification of the administrations involved in its management.

The main objective was to identify which data were needed, from which administrations, which ones were already available or not, how they were managed and shared, and it was possible to understand where to gather the lacking data. With this aim, the communication channels of the University of Turin (i.e., the website and its Transparent Administration section which comprises official documentation related to the core activities and people working in the institution), were investigated to collect available data and to identify administrations involved into the management processes (Table 1). It was checked a web platform, namely Opensipi, exploited to manage data about the building stock (e.g., dimensions, occupancy, mechanical assets, and so on). This platform was managed by the "*Information systems and e-learning portal Directorate*" and it can be updated by the "*Building, logistics and sustainability Directorate*". It was also found that academic activities data, were stored through heterogeneous excel sheet files managed by the administrative staff of the "*Educational services Directorate*". Finally, it was identified an external database, namely *Cineca*, with students' data managed through dedicated interfaces and unopened for consultation.

Table 1: Database, information and involved administrations

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

The interviews with the administrative and management staff of several involved areas confirmed this fragmentation and highlighted the struggle in gathering the needed information as their extrapolation must be required on purpose, with long waiting times. Then, an in-depth analysis of the databases was conducted to understand which data should be integrated and connected for the efficient management of the university's assets and their activities. Opensipi platform was developed to create a tool for Space and Asset Management based on a GIS approach. Through Opensipi it is possible to search and visualize the whole university building stock using Google Maps. Through digital interactive plans, the platform also shows spatial attributes and individual premises of each building (Table 1). It is worthy to note that the functional attributes of spaces (e.g., occupancy, furniture, and mechanical systems) useful during the O&M phase are missing. Another issue is that the platform is not continuously updated, therefore its data may not correspond to the real condition of the spaces. Thus, updated data and plans of the building stock were gathered through short interviews and documentation requests to the technical office of the university.

As Table 1 shows, the "*Educational Services Directorate*" used a heterogenous Excel sheet file to manage timetables and courses data. Data related to students' careers, fees and course catalogues are managed through a dedicated application provided by *Cineca* which is also responsible for data storage. Also, in this case, short interviews with the staff were conducted to understand which data they handle and how different administrations interact. It was highlighted that the Excel sheet files used by the "*Educational Services Directorate*" were not connected with the data provided by the database provider *Cineca*. The result is a lack of connection between the administrations, resulting in high fragmented information which leads to additional work for the staff and prevents tasks automatization. As previously described, *Cineca* is an external provider of software and services, responsible for data management. The administrative staff of the university cannot directly manipulate data stored in the database, a dedicated application is necessary to visualize information and customized queries must be asked to Cineca with consequent long processing times which lead to inefficient management. To develop an AMS for distributed and heterogeneous building stock, the direct access to a centralized database and the need for efficient functionality are crucial (Kensek, 2015). Therefore, an integrated database, with data from Cineca and other databases, was necessary. Such an AMS can be a breakthrough for the activities of the "*Educational Services Directorate*" that could rely on a unique source of data concerning the number of students, available spaces, and courses.

Finally, further analyses were conducted to understand which applications were provided by Cineca to the "*Educational Services Directorate*". Two main applications were identified:

- *Esse3*, for the management of students throughout their academic career;
- *University Planner*, for the creation of automated timetables related to courses and assigned spaces, but without optimization of the space occupancy.

In conclusion, university administrations involved in the management of data handled not complete nor always updated information employing heterogeneous interfaces and management systems, often still document based. Consequently, the big amount of data analysed, needed for managing such a complex and diffused university's asset, currently is not easily accessible and informed decisions are hardly achieved.

Data structuring in a centralized database

The structure of the centralized database was defined according to the current situation without neglecting the possibility of further implementations for future developments. The data which feed the centralized database were acquired from various sources, both through direct requests to the competent administrations and by accessing the university's website and databases through specific credentials. Data collected, and their sources are as follow:

- *OpenSipi*: building name, building code, area code, encoding, building type, building state of use, city name, address, floor code, space code, space state of use, space height, space capacity, area/capacity, space name, storeys (building), net area (building), perimeter(building), net area (space).
- *Google maps*: latitude, longitude.
- *New data*: space typology, space description.
- *University's website*: equipment, annual expenses, annual income, prevalent use, title (building).
- *Department office*: number of occupants, start time (timetable), end time (timetable), start-end time (timetable), day (timetable), day number (timetable), subject (timetable), subject code (timetable).
- *Students' registry office*: course name, course code, enrolled students.

Once the data were acquired, it was conducted a state-of-the-art analysis to identify the best way to archive them to provide flexibility, easily updating and accessibility to users. A secure and well-established way of storing data is through relational databases (RDBs), which enable to structure data according to a precise hierarchy (Atzeni and De Antonellis, 1993). In the pilot use case, a RDBs was chosen since it allows the establishment of diverse types of relationships among data which enables tailored queries and the possibility to filter and aggregate data according to the intended purpose. The database structure was divided into nine tables fed with the collected data and it was also based on potential future uses and queries of the database concerning asset management activities. This enabled to understand how the distinct levels and kinds of information should be connected. The first step concerned the choice of the central data to which connect other information. As most management activities need asset spatial attributes, it was decided to start from them. Thus, the database structure was developed starting with spatial information contained in a central table *"Building Stock"*. Then, on one side links to other data about *"Spaces"* up to *"Occupancy"* and *"Timetables"* were branched out. On the other side, data about *"Real property titles"*, *"Rental incomes"*, *"Rental expenses"* and the *"Degree programmes" were* branched out. To identify uniquely the spaces of the building, a key step concerned the set-up of a tailored encoding system, which was also suitable to connect data through the database. It is organized according to the different building stock levels of definition, as follows:

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1: Province; 2: Venue; 3: Settlement; 4: Building code; 5: floor 6: Space.

This system enabled to connect data consistent with the building level of detail. Both the encoding scheme and the centralized database structure played a key role in the AMS-app as it enabled filtering displayed information employing the single afore illustrated data.

BIM modelling and information parameters allocation

The fourth step concerned the attribution of the semantic data stored in the centralized database to the building stock. The first step concerned the development of the BIM models to be enriched with the building's attributes. It was adopted a gradual approach, starting from two pilot cases, namely Piero della Francesca centre, headquarters of the Faculty of Computer Science and Palazzo Nuovo, headquarters of the Faculty of Humanities.

Even if the first one is a modest size building (2850 sqm), it was chosen as the last five years recorded the highest trend of growth of the university population (i.e.,50%) with a constantly increasing demand for new spaces. Thus, new digital and automated tools such as the AMS-app could help to optimize space occupancy and related O&M activities. Moreover, this demonstrator was used to evaluate the developed methodology, further affined with the application on the second demonstrator, Palazzo Nuovo. This building was chosen for its high complexity, due to its exceptionally large dimension (6787 sqm) and complex geometry, besides the presence of a variety of activities both internal and external to the academic life. It is characterized by a complex design, and it hosts four different departments (i.e., Philosophy and Educational Sciences, Historical Studies, Humanistic Studies, Language Department), whose enrolments in study programmes increased about the 15% in the last four years to around 23000 students in 2021, that is the 28% of the total enrolled students. These scenarios created complicate management of the teaching activities and resulted in a greater demand for spaces and classrooms. Thus, it was difficult for both the development of the BIM model and the assignment of a large amount of spatial and functional attributes. In this preliminary phase, the main objective was to gain a level of information right useful to represent the whole university asset, without weighing down with an excessive amount of data. Consequently, a key choice was to model the building stock through masses, floors, and rooms, avoiding an unnecessary level of detail. Autodesk Revit® authoring tool, one of the most used BIM software in the AEC industry, was adopted. This choice was mainly due to three factors: (i) the possibility to represent only the main volumes of the university building stock as masses, floors and rooms (further implementable in the future); (ii) the availability of the Dynamo plugin for Revit® useful to automate both modelling and parameter assignment processes; (iii) the great level of interoperability between Revit® and GIS platforms (i.e., ArcGIS Pro of Esri), which enables to import BIM files (i.e., .rvt and .ifc format) directly in a GIS environment, minimising information losses (Song et al., 2017). Once the modelling was completed, 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, through VPL (*Visual Programming Language*) (The Dynamo Primer, 2021) which is widely used in AEC industry with significant improvements both in modelling and data management (Boshernitsan and Downes, 2004). VPL replaces standard computer programming identified with special objects (i.e., nodes) with specific functionalities. This research adopted the visual programming software Dynamo for Revit® to populate parametric models with the semantic information illustrated in the previous paragraph. Dynamo is an open-source interface between VPL and Revit API (Salamak et al., 2019), where the nodes are connected to define highly customized algorithms. Initially, spatial, and functional data were structured individually, and then they were linked to the parametric models. Customized nodes were used to extrapolate the data from the spreadsheets, create new-shared parameters in .txt format and assign them to three categories of parametric elements (i.e., masses, planes, rooms) in the BIM models.

Development of the BIM-GIS digital platform

As stated in the literature review, recently AECO industry strongly requested improvements to reach a better integration and interoperability between BIM and GIS (Song et al., 2017). Through the integration of GIS and BIM, every single project can be placed in the real context, enabling to monitor, plan and manage all the impacts at the city scale and evaluate the economic, social and environmental aspects (Esri Italia, 2020). Therefore, the fifth phase of this research project concerned the development of a web-based BIM-GIS platform (i.e., AMS-app), providing real-time visualisation of the university's assets and their attributes in an interactive 3D digital map. This platform can be considered as a GeoBIM system where it is possible to connect information models, and spatial and functional data at once. It was crucial to evaluate the level of interoperability between BIM and GIS. A key step concerned the BIM models checking process in the GIS environment, to demonstrate the correct importation of information linked to them, in addition to their accessibility and usability. This checking process followed a specific workflow consisting of Geographical coordinates checking and Attributes checking process. Once the model has been imported into the GIS environment (i.e., ArcGIS Pro), geometrical coordinates of the vertices (X, Y, Z) were extrapolated through the specific tool "Feature Vertices to Points". Then a vertex with known coordinates was identified and used to check its geographical coordinates and correct georeferencing in space (Figure 2).

The summary tables which list all the attributes linked to the BIM models were created through the "Attribute Table panel" in the scene, then it was possible to check if the data entered in the BIM environment were maintained by each attribute. As mentioned in the previous paragraph, the first objective was to represent the whole diffuse asset of the University of Turin.

Hence, it was not possible to include the complete attributes set of each building within the GIS environment, also due to the size and heterogeneity of the University of Turin assets. Then BIM models were imported into the GIS platform just as georeferenced masses with geometric and semantic attributes.

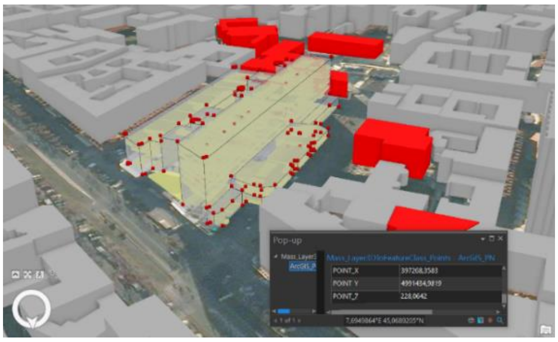

Figure 2: Palazzo Nuovo BIM model geographical coordinates checking process in ArcGIS Pro®.

However, it was decided to fully import the BIM models of the two demonstrators (i.e., Piero della Francesca centre and Palazzo Nuovo), which were detailed with geometric and semantic information from the floors up to the spaces. Once all the buildings were imported into the GIS platform, the entire project was transferred to the web environment, generating an interactive map of the entire asset of the University of Turin. Then, tailored slides were created to facilitate users' navigation throughout the university asset. It can be navigated and filtered at different information levels (i.e., asset, single building, floor and local) enabling analysis of the asset and facilitating strategic decision-making as it is possible to gather and visualize just the needed information.

Results and discussion

The main purpose of this research was to provide innovative methods and tools for the management of the operational phase-in diffused building stocks. The main outcome was a digital and replicable AMS based on the integration between BIM and GIS through a web platform, aimed at facilitating information management and decision-making processes. The pilot use case was individuated in the vast and complex asset of the University of Turin. Now all its 120 buildings were modelled as masses and georeferenced through the AMS-app (Figure 3).

Two of these buildings were chosen as demonstrators of the AMS platform potentials and they were entered into the platform as actual BIM models with detailed information up to the level of the single room. Although their datasets are still incomplete compared to all potential future uses of the AMS-app (Facility and maintenance, emergency management, crowd simulation, occupancy management, etc.), most spatial and functional information were already inserted and displayable. Thus, it was possible to transform data into useful information and provide valuable instruments to support strategic decisions through business intelligence (BI) technology.

Considering that Microsoft Excel® is the main software used by the administrative directorates, Microsoft Power BI®, developed by the same software house, was chosen to obtain the best interoperability and avoid data losses. It is internationally recognised as one of the most suitable software for its ability to manage large quantities of data (Shaulska et al., 2021) and it enables to display Arcgis maps through a tailored plugin. A key feature lies in the ability to work on datasets without modifying the data source.

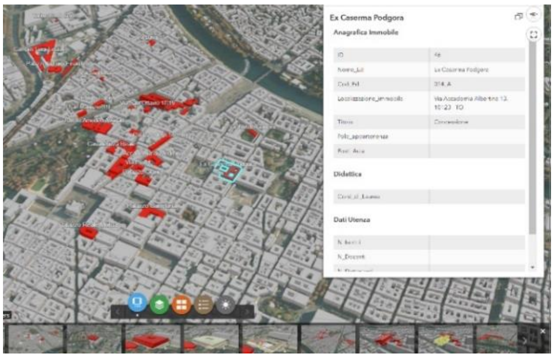

Figure 3: University of Turin's asset in the AMS-app with an example of a summary table.

Exploiting this feature and the centralized database afore illustrated several interactive and comprehensive dashboards are provided to facilitate the visualization and understanding of useful information by university buildings users (Figure 4,5).

In this project, data were analysed at diverse levels of detail, to provide several dashboards and to collect interactive information at various scales, from the whole building stock to the single building. An initial dashboard with overall analytic elements of the whole University of Turin asset was created (Figure 4). It displays an interactive map with linked data (e.g., number of buildings, building name, building title, prevalent use, rental income, rental expenses) and some elements that enable user interactions. By clicking them, data could be filtered or aggregated, and key performance indicators (KPI) interactively change with maps, bar graphs and ring graphs.

Figure 4: Analytic elements dashboard of university assets.

Thus, through the web application, it is possible to visualize information briefly without waiting for reports. This is especially useful for administrators, giving a quick idea of rental costs and incomes. Furthermore, it facilitates a clear view of the building stock consistency and administrators can optimize resources allocation. A second general dashboard was created for the visualisation of the whole building stock. Assets and related information could be filtered by educational pole or department. This allows to immediately visualize in which building a department or a certain course is located. It enables also to understand the distance between buildings or spaces such as laboratories or university residences. These information crossed with that relating to classrooms occupancy and courses timetables, enable to optimize of both courses allocation, buildings exploitation and users' mobility across the campus, making it more sustainable.

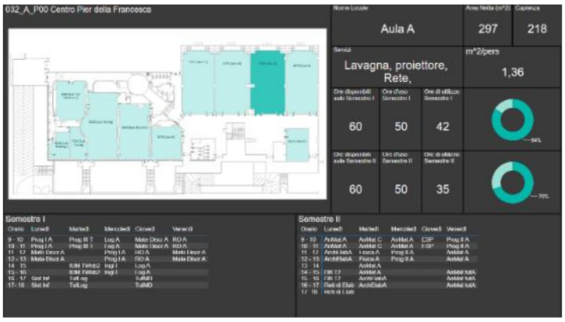

Figure 5: Space analysis dashboard of Piero della Francesca.

Then, two other types of dashboards were created for the analysis of the first demonstrator: Piero della Francesca centre, at the building level. In the first dashboard, it is possible to visualize overall building information and the activities conducted inside, in addition, data can be filtered according to courses or academic year. The last dashboard developed, allows a deeper analysis at the building space level of the different activities (Figure 5). Thus, data previously fragmented are connected and visualized through dashboards and needed information for the correct allocation and occupancy of spaces are provided. Without the AMS-app and this kind of dashboard, it was not possible to get the exact awareness of how and how many spaces were occupied. Some classrooms were under-exploited, others over-exploited with consequent discomfort for users and expenses for external spaces rental. Now the *Educational Services Directorate* and other administrations can easily view and consult these information for an optimal allocation of study courses based on the actual availability of spaces. Furthermore, by visualizing which spaces were partially used during the year, it is possible to reduce rental expenses, raising awareness about the use of the classrooms and management costs (e.g., cleaning, maintenance, heating, and air conditioning) can be optimized.

Conclusion

The paper tackled the development of an innovative digital AMS useful for information management and strategic decision making during the operational phase of diffused assets.

A replicable methodology aimed at the development of an integrated BIM-GIS web platform based on a centralized and accessible database was presented. The developed methodology was applied through two demonstrators with diverse levels of complexity. It was illustrated the great potential of BIM-GIS integration through digital tools. The main output, which is the AMS-app, enables to visualize the whole university building stock with its attributes through a 3D interactive map. Now, it is limited to authoring formats, but in the future open standards will be exploited to ensure greater interoperability between BIM and GIS (e.g., IFC, CityGML). In addition, it is needed a deep analysis to understand how automated data flow could be implemented using Machine Learning systems.

In conclusion, the developed AMS could overcome current fragmented and still document-based management issues. It should provide effective decisions and management processes based on complete and real timed updated data, stored in a centralized and implementable database. Exploiting synthetic dashboards and through BI tools linked to the AMS-app, useful strategic data and graphs could be displayed. These features should enable better management of the university's financial and spatial resources, with a reduction of waste and cost savings. It should be possible to: (i) rationalize spaces use depending on the actual availability, courses timetables and occupancy, (ii) optimize real estate investments by visualizing over or under exploitation of both buildings and spaces, (iii) optimally managing maintenance and cleaning operations concerning the actual spaces use.

It is planned to equip the most significant buildings in terms of dimension, occupancy, or complexity, with sensor networks to detect thermal comfort, energy consumption, people presence and all the useful data for optimal management of the O&M phase. These data will be collected through the developed database and visualized through tailored dashboards. Hence, BIM models could be exploited to develop valuable DTs and enable to real-time optimize internal comfort conditions, energy consumption, evacuation in case of emergency, assisted maintenance operations and optimal occupancy also through VR/AR tools. Thus, the real-time or predictive management of the building could be provided, together with enhanced user experience and further management costs and resources consumption reduction.

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