BIM-GIS AND BI INTEGRATION FOR FACILITY AND OCCUPANCY MANAGEMENT OF UNIVERSITY ASSETS: THE UNITO PILOT CASE

Giuseppe Martino Di Giuda, Daniele Accardo & Paola Gasbarri
Department of Management, University of Turin, Turin, Italy

Silvia Meschini
Department of Architecture, Built environment and Construction engineering, Politecnico di Milano, Milan, Italy

Lavinia Chiara Tagliabue
Computer Science Department, University of Turin, Turin, Italy

Laura Scomparin
Department of Law, University of Turin, Turin, Italy

ABSTRACT: *The integration of Building Information Modelling (BIM) and Geographic Information System (GIS) with Business Intelligence (BI) is promising for managing vast and diffused assets. It enables valuable insights into asset performance and resource uses, supporting savings, improved efficiency, and sustainability. The research proposes a web-based Asset Management System application (AMS-app) via BIM-GIS-BI integration, providing an updated digital representation of university assets by combining spatial, performance, and operation data with related analytics. The AMS-app was developed in the context of the University of Turin's strategic plan as a pilot case to improve asset management procedures through a data-driven approach. Indeed, campuses are complex assets managed by multiple actors through still document-based and fragmented databases, often leading to ineffective and untimely decision-making processes. The AMS-app represents a valuable decision support system for facility managers aimed at asset monitoring and user experience improving through better and more sustainable decisions concerning space, occupancy, and indoor environmental quality (IEQ). To demonstrate the effectiveness of the BIM-GIS-BI integration through the AMS-app, several case studies were implemented with the following objectives: (i) the digitalization of university building data, (ii) the optimization of courses timetables according to space availability, (iii) the optimal workstations management, and (iv) the analysis, monitoring and optimizing of IEQ and comfort via IoT networks. The paper illustrates the advantages and applicability of the developed methodology through the case studies, and further developments in university asset management.*

KEYWORDS: *Asset Management System, BIM-GIS integration, Business Intelligence, Information management*

1. BACKGROUND AND MOTIVATION

University assets, especially Italian ones, are characterized by strong management complexity due to their diffused buildings, often built in different eras with various construction technologies and high heterogeneity. The management is often based on fragmented, incomplete, and hardly accessible databases, preventing the correct definition and optimization of usage patterns, as well as the normalization of management processes (Qian and Papadonikolaki, 2020). This results in inefficiencies in services and maintenance activities, leading to wasted resources and inefficient decisions concerning the expected performance, user comfort, and economic and environmental sustainability. Thus, university assets represent a crucial opportunity to propose a solution to the information gaps currently found in managing large assets. There is an increasing need for the adoption of information management strategies aimed at shifting from highly document-based and fragmented approaches to digital and collaborative ones (Chen et al., 2015). Digital tools and effective information management strategies enable data integration, ensuring the availability of accurate information with various granularity levels, at the right time, in the required formats, and throughout the asset lifecycle. Despite its application in asset management is still rare (Moretti et al., 2021), BIM-GIS integration provides high potential (Liu et al., 2017; Beck et al., 2020), especially in borrowing the Smart City concept at the Campus scale, improving the management of such complex assets for a better user experience and optimal resource utilization (Lu et al., 2020; Ward et al., 2021; Wang et al., 2019). BIM enables the development of highly detailed building information models, while GIS allows their management and analysis through a global spatial reference system (Zhu et al., 2021). BIM-GIS integration combined with BI tools can be exploited to optimize the management of large assets and to foster the development of AMS tools as concrete decision support systems (Pärn et al., 2017). The further integration of IoT and digital devices can facilitate data collecting, providing a better maintenance and asset management through the monitoring and analysis of real-time data about asset performance and condition, enabling timely interventions (Wong et al., 2018).

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The research project exploits BIM-GIS integration with BI tools to develop an interactive, web-based 3D map (AMS-app) for the management of large and diffused university assets. The main objective consists in facilitating information management and decision-making processes by improving information accessibility and sharing among stakeholders, and normalize management processes. The paper illustrates the replicable methodology developed to define and implement the AMS-app within the management system of the University of Turin (i.e. UniTO), an emblematic case for testing and demonstrating the potential offered by such a decision support system. Then it describes how data are collected from various siloed databases and integrated, providing an easily accessible and implementable knowledge base. Indeed, the AMS-app collects all the data currently handled separately by different administrative offices, providing a still independent but collaborative management system. Thus, the asset can be managed at the system level, rather than at the level of individual isolated buildings. The potential that such an AMS-app can provide to asset and facility managers of large university assets is described through the illustration of several case studies implemented so far, selected based on the management needs encountered within UniTO. Finally, the results are discussed, and the potential future developments and implementations are reported. Further objectives concern the development of information modelling protocols and guidelines to facilitate the adoption and transition to such a digitalized and shared management approach. In this way, the data can be modeled and structured ensuring the availability of accurate information at the right time, in the required format ,throughout the asset lifecycle, and the method can be easily replicated.

2. METHODOLOGY

The main steps of the methodology adopted to develop and implement the AMS-app in the university organizational structure are illustrated in the following paragraphs.

2.1.1 Main objectives and needs definition

The first step concerns the definition of the main objectives and needs that the organization intends to handle via the AMS-app. The organizational structure was analyzed to understand the management issues faced by UniTO and to define the relevant case studies to be implemented and tested through the AMS-app. Consequently, meetings and interviews with the managers of the technical areas in charge of the university asset management, its maintenance, information systems management, as well as teaching and educational services were conducted.

2.1.2 Current database structure and dataflow management strategies investigation

An investigation of the procedure currently adopted by the university to manage the information flow has been conducted to identify which information and data are handled by the different technical areas, as well as the methodology used to produce, store, and exchange them. One of the main aims of the analysis concerned the identification of the tools and formats currently exploited by the areas so that the AMS-app could be developed without disruptively changing current workflows, facilitating its adoption.

2.1.3 Organization information exchange and information requirements formalization

Once identified the organization's current database structure and dataflow management strategies, the analysis and formalization of the information exchange among the technical areas have been performed. The main aim was to ensure the easy integration of modifications occurring over time, providing a constantly updated digital representation of the building asset. The information exchanges were formalized to ensure that the technical areas can continue to rely on current tools and procedures with minor changes in data production and management. Then, the Information Requirements (IRs) have been defined to foster communication and support the creation of a coherent database to feed the AMS-app. Table 1 provides an example of an exchange information requirement schedule.

Table 1: Example of an exchange information requirement in the standardized form for data collection.

Field	Data source	Note	Type
Building code	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Building coding (Settlement_Building: e.g. 029_B)	Text
Building name	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Free field	Text
Main address	OpenSIPI, Technical Areas: EDISOS,	Free field	Text

	SILOM, SIPE, Asset Management		
Municipality	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Extended name, es. Turin	Text
Main use	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Free field	Text
Building Type	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Bound field: Building, Portion of Building, Agglomeration of Buildings, No Type, ND	Text
Status	OpenSIPI, Technical Areas: EDISOS, SILOM, SIPE, Asset Management	Restricted field: Decommissioned, In use, Under construction, No Status, NDo	Text

Furthermore, a possible change in the university's organizational structure was investigated for better supporting the AMS-app adoption.

2.1.4 AMS-app development: approaches, technologies, and tools selection

As stated before, the scientific literature has widely discussed how BIM and GIS integration can bring significant benefits in the field of asset management. BIM enables an overview of a single building and GIS allows the contextualization of each building, enabling analysis at a territorial level. Thus, the two resources optimally lend themselves to the university campus management, which, given its complex infrastructure, the amount of heterogeneous data, and spaces spread over a vast territory, needs systems that can facilitate the management, use, and maintenance of their assets at different levels. The proposed system integrates these resources providing the necessary tools for understanding, visualizing, and analyzing information related to the university building stock, its services, and infrastructure, thanks also to the support of BI tools. Data are core to the system, populating it and being the key to the different components' connections. The platform integrates data of various nature and from multiple sources: geographic data, geometric and functional data, as well as data concerning IEQ derived from sensors (Table 2).

Table 2: Data sources, information and types.

Source	Information	Type
Piedmont Territorial Geoportal	Building location, heights, geometries, restrictions	Text, numbers, coordinates, shape files. Static data.
OpenSIPI	Name, encoding, address, floor numbers, state of use, geometries, area, department assignment	Text, numbers, drawing. Static data.
Department offices	Courses schedule, personnel employed information, buildings construction site	Mainly text. Sheet-form organization. Dynamic data (on long term)
University website	Timetables, organizational units, building property state and expenses	Mainly text. Sheet-form organization. Dynamic data (on long term)
IAQ Platform	Environmental sensors measurement (CO2, humidity, temperature, VOC, PM2.5, etc.)	Numbers. Dynamic data (on brief term)

The different datasets are then collected from various sources, processed, and stored in a cloud repository so that data can be queried by any operator without duplicates, errors, or information loss. Aiming at the optimal integration between the different data, information sheets have been prepared and provided to the technical areas, asking for their fulfillment. Nonetheless, their compilation is not always possible such as in the case of geometric data derived from drawings or models, or geographical data from cartographic services such as the Geoportal of the Piedmont Region. In these cases, the sheets have been compiled manually by the authors.

Once the needed data have been collected, they are interlinked thanks to the semantic association of encoded names. An encoding system was defined for each city, building, and space, which is part of the university asset, starting from the one currently used by the university's administration to promote a smooth integration process. The encoding system was also key for data association in GIS. The entire campus buildings were identified, geolocated, and associated with their encoded names. The map was developed in a 3D view, aiming at offering a better perception of urban space, asset consistency, and distribution. Thanks to the geolocation of the encoded buildings through a 3D environment, and to the association with functional data, various analyses were developed at the territorial level, providing the depth knowledge of the university asset with information on its use and consistency, useful to support decision-making processes.

QGIS was selected for the shape files creation and first population, while Mapbox was exploited for the 3D map development and visualization. It was chosen for its easy integration with Microsoft Power BI, thanks to the opportunity to generate a customized web map based on the created shape files, shareable through URL and carrier of selected information. In addition to the GIS representation of the university asset, BIM was exploited for the analysis and visualization of each single building at different levels. The modeling phase succeeded in exploiting the Autodesk Revit Software for geometrical construction and the Visual Programming Language Application Dynamo for information population. The BIM modeling and the Dynamo nodes were developed with the aim of generating a replicable workflow, adaptable at each building of the asset. So, each BIM model presents three different levels of consistency: the building volume, the building levels, and the building spaces, modeled as mass, floors and rooms, respectively. Each element is firstly associated with the corresponding code, then the encoded name and the Revit Element ID are exported for each geometry modeled. The encoded name association ensures the association between the different datasets, but the connection between the BIM geometries and the information occurs via the Revit Element ID association. It is needed for various reasons, for example, some rooms may temporarily present the same encoded name during a space renovation, or their geometry can change throughout the building lifecycle, as well as their name. Despite the mutability of information such as the name, the Revit Element ID remains unchanged over time.

The BIM model is then associated with information related to the standard use of the building and its characteristics. During parameters' creation, a parameters comparator enables to individuate the shared parameter between masses floors and rooms, avoiding repetition that could lead to association errors or can compromise the final model quality. Both the Revit parameters and the associated values are extrapolated by the same dataset, stored in the cloud repository, and in the future, each building of the university asset will have its own datasets for better management. At this stage, the association of the most dynamic information, such as the real-time collected data, has been avoided. In this way, the model can represent the basis for multiple analyses related not only to environmental quality but also to space occupancy or educational and working spaces management. This choice provided also lighter models, with smaller file sizes and greater smoothness. Finally, with the aim of facilitating BIM and Microsoft Power BI integration, the BIM model was exported with Proving Ground Tracer. This software allows the exportation of both 2D and 3D geometries with related information, all preserved in an SQL database generated by the software itself. At the end of the process, the BIM is then ready to be imported and visualized in Microsoft Power BI. It demonstrated great capacity in data analysis and visualization, allowing information sharing between different stakeholders through analytic dashboards which can involve data, BIM models, and GIS maps. So, it represents the preferential software for web-app structure development.

2.1.5 Data visualization, analytics, and dashboard structure definition

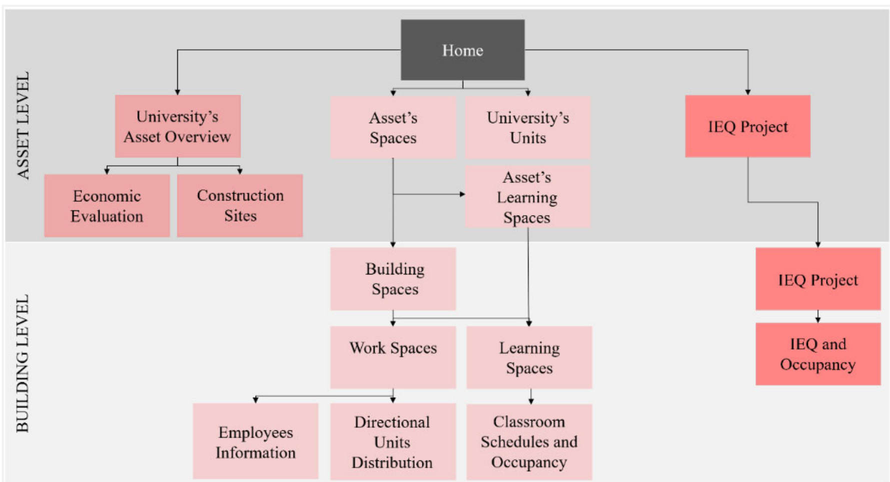

Fig. 1: UniTO's asset management system platform based on BIM-GIS-PBI integration

Power BI was chosen not only for data analysis and visualization but also as the software to generate the AMS-app main structure. The dashboards created are directly connected to datasets stored in the cloud repository and can be integrated with BIM and GIS maps. Thanks to these connections, based on the relationship of the encoded names, it's possible to associate the resources, the data previously excluded, such as the dynamic data related to real-time environmental quality measurement, the course timetables, the occupancy rates, etc. The platform is structured so that the dashboards are gathered in thematic reports (asset consistency, economic evaluation, construction sites, IEQ, spaces' occupancy, etc.), classifiable also into territorial and building reports, depending on the level of information visualizable. Each report is correlated to the others based on a predefined structure (Fig. 1), but still independent, allowing to introduce different accessibility levels according to the requesting user.

3. RESULTS AND DISCUSSION

The proposed methodology and AMS-app are being applied as a pilot study to the UniTO asset management, as described in the following sections.

3.1 UniTO pilot case

3.1.1 Main objectives and needs definition

UniTO aims to create an integrated AMS-app that enables updated data visualization to optimize the management of its diffused asset, providing information about performance and resource utilization, to promote cost reduction and improve efficiency. The main goal consists in improving the management of spaces and resources. The AMS-app enables to identify and monitor the asset over time, leading to better decision-making concerning space, occupancy, and IEQ management. It was applied to digitalize the whole UniTO building stock, providing an overall view with data about its consistence and usage (i.e., geolocation, building asset consistency, geometrical and financial data, building performances, rooms capacity, equipment, and performances, occupancy level, and usage, etc.). The updated visualization of the building portfolio through a 3D map with data and information handled through GIS, BIM, and BI systems aims to support the:

- Management of university facilities at the territorial and building levels allowing to produce data analytics at different layers for improved facility operation;
- Optimization of university teaching timetables based on the actual teaching space availability and capacity;
- Optimization of workstations management by introducing remote working strategies;
- Analysis and optimization of IEQ to improve users' comfort and safety through IoT monitoring.

3.1.2 Current database structure and dataflow management strategies investigation

Currently, the university technical areas handling data and documentation about facilities, spaces and related equipment, performance, capacity, workstations' number, and concerning the teaching timetables' definition, rely on a document-based system characterized by siloed information. Data about spaces and related usage are stored and exchanged via semi-structured formats such as .xls or .csv. Information exchanges take place mainly via traditional communication systems (printed reports, e-mails, calls, in-person or remote meetings, etc.), and data are not shared between stakeholders or administrative offices, resulting in struggling or absent analysis of integrated aspects and information to support the decision-making processes. Thus, a data integration system is proposed with the aim of creating an updated tool collecting data from several sources, shared among the whole UniTO staff. The different data silos are integrated by exploiting BI tools and methods, enabling to collect and integrate data from the various Excel sheets produced by the technical areas. In this way, it is possible to maintain the current processes adopted to manage space, staff, and usage data, avoiding disrupting the management procedures. Furthermore, it is possible to avoid the effort of creating a structured DB (e.g., a relational SQL database) that would have been more disruptive and difficult to integrate within the UniTO management system. This allows for the gradual and low-impact integration of the AMS-app and the system, with a greater likelihood that it will be concretely used by UniTO staff.

3.1.3 Organization information exchange and information requirements formalization

The data integration system has been set up by a cross area within the UniTO organization represented by a research group of seven people which acts as a data analysis area. The authors are part of this research area that collects the different data from UniTO areas integrating them through the proposed system (AMS-app) according to the schema illustrated in Figure 2.

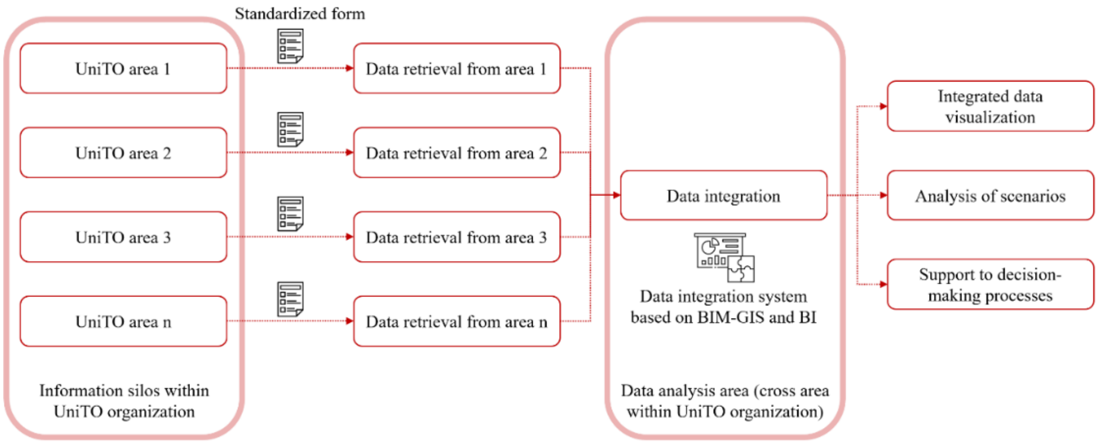

Fig. 2: Information exchanges and data processing schema within UniTO organization.

Data are retrieved from UniTO technical areas via standardized forms (Table 3), and the data analysis area receives information concerning buildings, spaces, capacity, occupancy, people occupying the spaces, etc. through similar forms. This enables quick data management via structured data sheets and avoids the cleaning and processing of data first. The integrated data, the resulting information, and knowledge are made available and displayable via the platform, enabling scenario-based analysis to support the decision-making processes of the UniTO's asset management staff.

Table 3: Example of standardized form for collecting data about some of UniTO facilities, collected in the.

Building code	Building name	Main address	Municipality	Main use	Building type	Status
001_A	Palazzo del Rettorato	Via Verdi 8	Torino	"Uffici a supporto didattica e ricerca	Fabbricato	In uso
020_A	Palazzo Nuovo	Via Sant'Ottavio 20	Torino	Dipartimenti / Biblioteche / Aule / Uffici a supporto didattica e ricerca	Fabbricato	In uso
021_A	Palazzetto Aldo Moro	Piazzale Aldo Moro	Torino	Uffici a supporto didattica e ricerca / Aule / Dipartimenti	Fabbricato	In uso
029_B	Campus Luigi Einaudi	Lungo Dora Siena 100	Torino	Dipartimenti / Biblioteche / Aule / Uffici a supporto didattica e ricerca	Fabbricato	In uso
032_A-B-C	Centro Pier della Francesca	C.so Svizzera 185/Via Pessinetto 12	Torino	Dipartimenti / Aule / Magazzino / Rimessa / Uffici a supporto	Porzione di fabbricato	In uso
064_A	Torino SUISM	Piazza Lorenzo Bernini, 12	Torino	Aule/Uffici a supporto didattica e ricerca	Fabbricato	Dismesso

Specific applications of the proposed data integration system and AMS-app are described in the following sub-sections, including advantages and limitations. The case study selected as a demonstrator for such applications at the building level is the Campus Luigi Einaudi (CLE). The main facility of CLE is located in the northeast area of Turin, with a total net area of more than 36,000 square meters. The facility hosts the Department of Law, the Department of Political and Social Sciences, and the Department of Economics and Statistics "Cognetti de Martiis", hosting more than 500 research fellows. In addition, there are numerous administrative areas with around 100 administrative employees dealing with the management of spaces, people, contracts, and related bureaucratic matters. Furthermore, the CLE has 47 lecture halls and hosts around 16700 university users, so it represents a significant case study with a large catchment area and many activities within it.

3.2 Real estate asset management at territorial level

Real estate asset management at the territorial level deals with the storing and managing of data concerning the location, the type of building property (e.g. owned, rented from another institution or a private subject, partially owned or partially rented, etc.), the overall occupancy, the presence of listed buildings, and other facility management data. This kind of data regarding UniTO facilities currently are stored in siloed documents or .xls files, preventing the integrated analysis needed to support decision-making processes. Thus, overall dashboards regarding the whole UniTO's real estate property are produced to investigate multiple data at once. The dashboard maps provide an overview of the entire territory over which UniTO buildings are distributed, useful to investigate data at a territorial level. All the views provided on the dashboard pages (e.g., maps, charts, graphs, and cards) are dynamic and interactive. A selection in one view, acts as a filter for all other views of the page or of the entire dashboard report, according to the specific requirements. The dashboards at the territorial level support the decision-making processes regarding the strategies to be pursued at a high level on the whole university facilities.

Figure 3 shows the dashboards at the territorial level with general data regarding UniTO real estate propriety. Other information, such as UniTO facilities under refurbishment and data concerning specific interventions or the listed buildings are visualized in other tailored dynamic dashboards, allowing an integrated analysis of the data and supporting complex decisions of the UniTO's administrative areas.

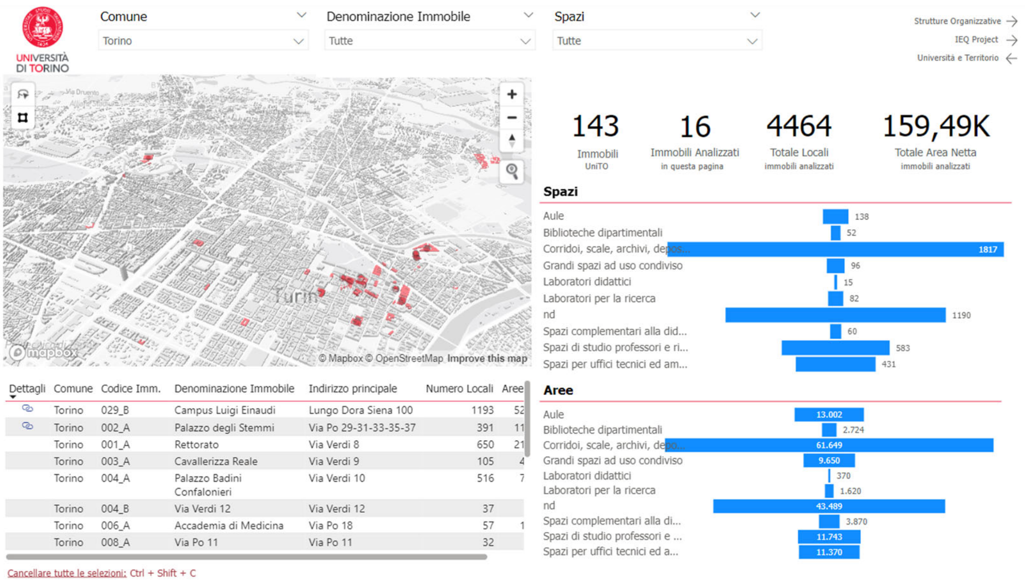

Fig. 3: AMS-app dashboard at territorial level regarding general data of UniTO real estate propriety.

3.3 Lecture hall spaces and teaching timetable management

Managing teaching spaces and, specifically, organizing lesson timetables, poses a multifaceted challenge. The problem is intricate due to the numerous and diverse variables involved, especially concerning CLE. Notably, the presence of various departments and their distinct methods of allocating the timetable adds to the complexity. Additionally, the extensive range of teaching hours dedicated to different subjects and the diverse nature of activities carried out further necessitate a highly varied schedule even within the same building.

The current process for creating class schedules and allocating spaces seems to be structured in stages, with three distinct directorates/offices involved. Firstly, the "*Educational Services Directorate*" supplies information regarding course enrolments, course codes, and academic credits assigned to each course. This data is then passed on to the "*Degree programs office*" which operates under the school's guidance, serving the departments and is tasked with creating the teaching timetable. Finally, a local branch of the "*Building Logistics and Sustainability Directorate*" is responsible for space allocation based on the received teaching timetables.

The entire process is characterized by fragmented data handling and manual switching between different software, which could increase the risk of errors. Thus, the primary objective was to consolidate the data into a single data analysis platform, ensuring more secure management and facilitating the analysis of teaching space utilization. To achieve this goal, a dashboard was developed, providing a comprehensive view of various data that would otherwise require gathering from three different offices. This single dashboard allows users to access information about the teaching spaces, including classroom names, room codes, capacity, classroom equipment, and net area. Moreover, the dashboard also offers insights into space utilization and teaching hours, enabling the estimation of the percentage of hours during which classrooms are booked, optioned, or available for use. This centralized and user-friendly approach streamlines data access and analysis, enhancing overall efficiency and accuracy in managing teaching spaces. Figure 4 illustrates the flexibility of viewing rooms in both 3-dimensional and 2-dimensional formats. Regardless of the chosen view, users have the option to select specific rooms and access detailed data. The interactive line graph enables direct interaction with the data, and users can also apply filters based on the building's floors. At the room level, the scheduled time for each room throughout the week, month, or year can be displayed, as depicted in Figure 5.

Fig. 4: AMS-app dashboard at building level with the analysis of lecture hall spaces and occupancy.

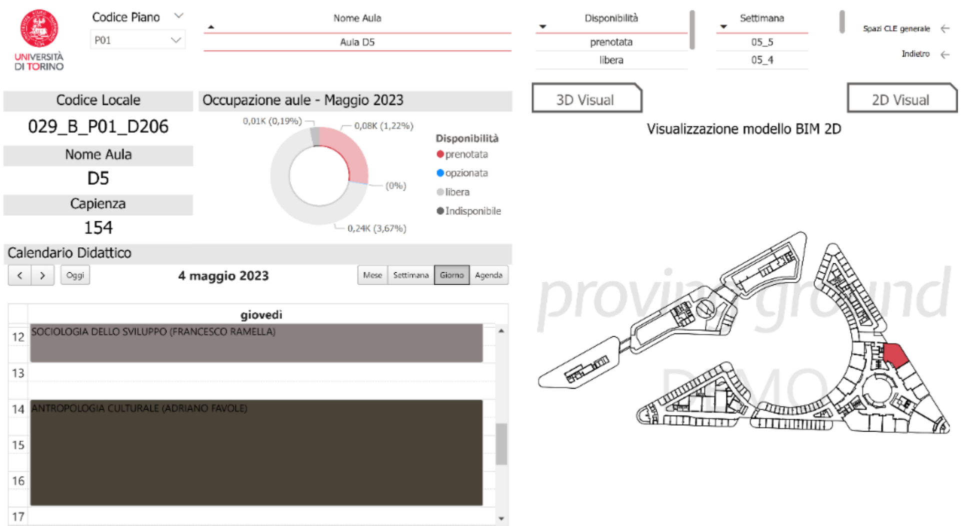

Fig. 5: AMS-app dashboard at room level allowing the analysis of lecture hall spaces, occupancy and timetable.

3.4 Real estate asset management at building level

Real estate asset management at the building level refers to multiple activities necessary to operate a facility and can include the following: people management including contract management, space and equipment allocation; space management including space allocation to the departments and areas hosted in each building. As of now building operation at UniTO is performed by the same departments or administrative staff hosted in each facility.

Except for space codes, the structure of which is common to all UniTO administration, all other space management information is managed locally by each building's space management staff. There is no central structure that manages all UniTO facilities at the space level.

The main objectives of this application are to support the decision-making processes regarding UniTO facilities, collect all the necessary information, and produce dashboards at the building level to investigate space, occupancy, and people management via BIM-GIS integration and BI technology. The data that are treated are the following:

- Space data regarding the location inside the building, area, and space typology;
- Allocation of spaces to the departments or administrative areas;
- Allocation of spaces to specific people and their role inside UniTO, contract typology, affiliation to a department or administrative area.

Figure 6 and Figure 7 show the AMS-app dashboard at the building level regarding all the spaces of CLE and the specific analysis of occupancy and staff allocation in the offices respectively.

Figure 6 allows the analysis via dynamic maps and charts of the spaces in terms of space typology and number of rooms, the allocation of the spaces to the departments or administrative areas, and single data points concerning the space net area and the number of rooms. The page allows the overall analysis of the building and the consultation of the general data regarding spaces, as well as the distribution of the space typologies on each building floor and the summary of the total building net area and number of rooms.

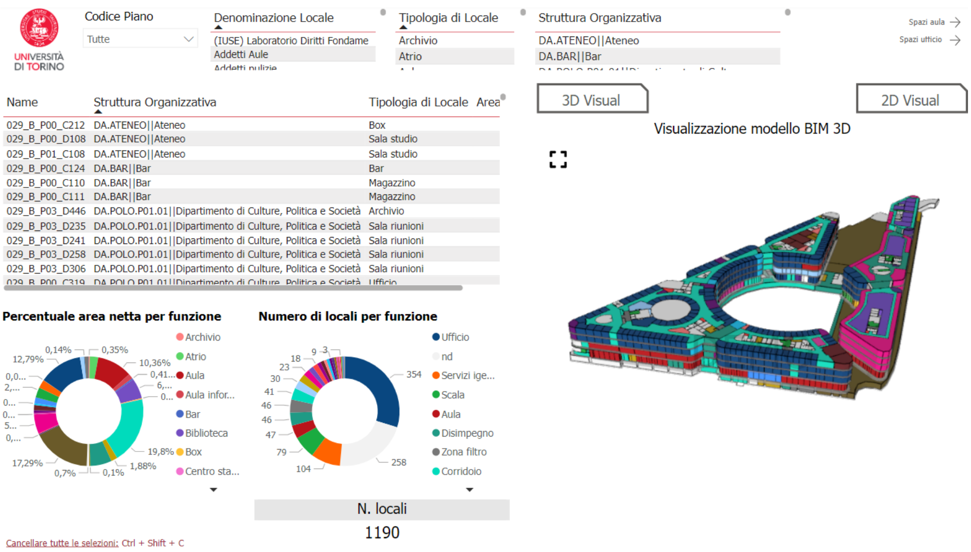

Fig. 6: AMS-app dashboard at building level allowing the analysis of space features and allocation of CLE.

Figure 7 enables a more specific analysis of the offices at CLE, including the percentages of area and staff assigned to each department and administrative area. A graph allows the comparison among the employee and research fellows allocated to the spaces and the maximum number of people that can be hosted according to the net area of each room, supporting the decisions related to the new staff that can or cannot be allocated in a space. In addition, an equal distribution of the spaces among departments and areas can be ensured based on the analyses

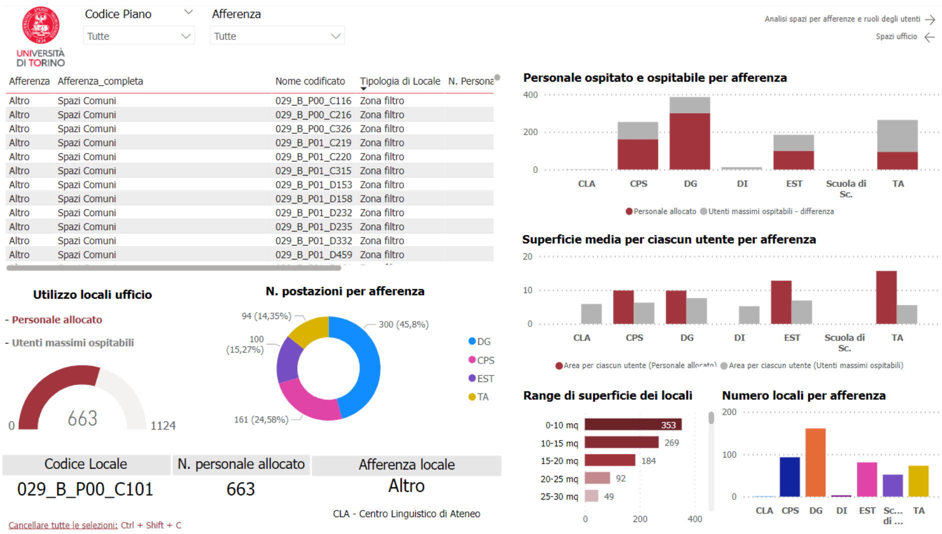

Fig. 7: AMS-app dashboard at building level with the detailed analysis of office and staff allocation at CLE

3.5 Space management improvement

Space management improvement in UniTO pilot case refers to the study of strategies to improve space occupancy, allocation, and usage with the introduction of work from home (WFH) practices. The contracts of professors, research fellows and PhD students already include flexibility as regards working hours and location, consequently, WFH is already allowed. On the other hand, concerning administrative employees, WFH practices have been introduced due to the recent COVID-19 pandemic events and then maintained for a total of two days a week. However, as of now, no improvement in space management has been introduced related to flexible work scheduling.

This application of the UniTO AMS-app aims at improving space management by hypothesizing a homogenous distribution of WFH days of the employees/researchers of the same office over the working week. As a consequence, the maximum occupancy of a single office can be increased. All the occupants are never present in the office at the same time, while WFH days are planned so that in each day of the week a certain number of office occupants work at home. As a results, the overall occupancy in a building can be increased. Considering two days a week of WFH for each worker in a five-day working week, the overall occupancy of the building increases by around 60% (Figure 8). This ensures that in the case of recruitment, workstations are already available in the existing facilities, without the need of acquiring or renting new spaces.

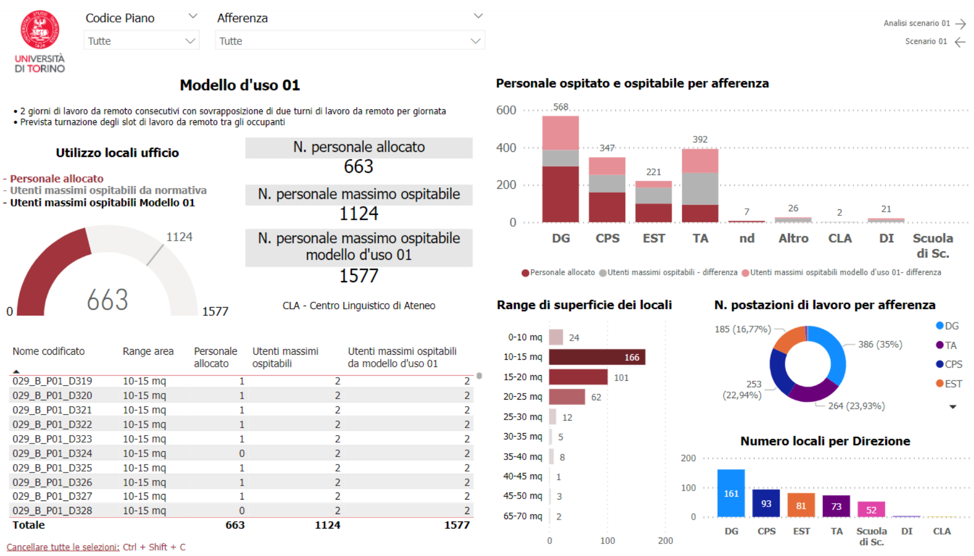

Fig. 8: AMS-app dashboard analyzing space allocation and current number of occupants, the maximum capacity of each space, and the maximum one with WFH and strategies to improve CLE space usage.

3.6 Indoor environmental quality monitoring and optimization

Monitoring data related to environmental quality data monitoring within educational spaces is of utmost importance. It serves two primary purposes: ensuring a healthy learning environment for conducting lessons and detecting any anomalies that may indicate system faults or the need for system remodeling. This approach also contributes to energy conservation and the reduction of heating and cooling systems' emissions. Over the past two years, several UniTO's buildings have been equipped with IEQ sensors. Among these, the CLE buildings serve as an excellent testing ground for evaluating the effectiveness of these systems due to the high number of sensors and the presence of classrooms with different capacities and orientations. UniTO has chosen IoT devices from Aircare® that can capture 15 types of measurements, including air quality, environmental comfort, and electro-smog indicators. Notably, the devices' accuracy and reliability have been scientifically validated by the Italian Society of Environmental Medicine (SIMA) for PM2.5 and CO2 measurements. A total of 39 IoT devices were strategically installed across 37 classrooms within the CLE, focusing on the ground and first floors, dedicated to teaching activities. Once installed, the data generated by these devices was directly streamed to a cloud platform, facilitating data collection. The collected data are accessible through reports, providing valuable information via an experimental platform managed by the ICT directorate, and at this stage data aren't shared publicly or with other directorates.

The objective was to optimize the AMS-app potential by linking the data to specific spaces and creating interactive dashboards to display real-time data from the continuously flowing information from the IoT devices. To maximize the advantages of measuring multiple types of data with a single IoT device, it was decided to associate viewable spaces with data related to CO2, CO2e, VOC, PM10, and PM2.5. A dashboard was developed to integrate the data with floor plans, clearly indicating the locations of installed sensors in the respective classrooms. By selecting a specific classroom, users can readily access and visualize the recorded values throughout the week (Figure 9).

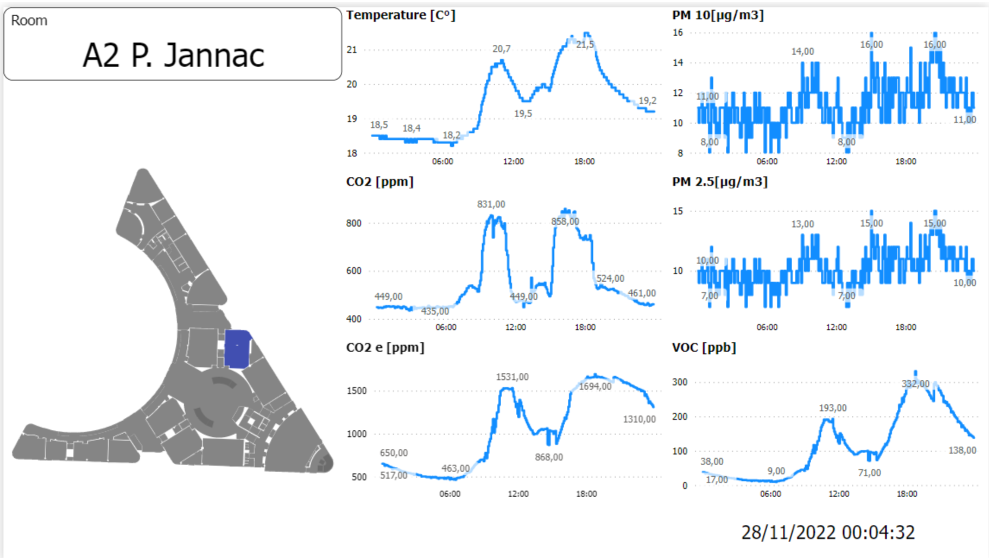

Fig. 9: AMS-app dashboard at room level allowing the visualization of spaces and data acquired from sensors.

To serve as alert indicators, specific limit values were established for the main parameters. During the heating season, temperature values between 20 and 22 degrees Celsius were selected, while for the cooling season, the range was set between 22 and 24 degrees Celsius. The CO_2 concentration threshold was defined at 1000 parts per million (ppm). As for particulate matter, the limit values suggested by the World Health Organization were adopted: below 25 µg/m^3 for PM_{10} and below 50 µg/m3 for $PM_{2.5}$. Furthermore, for volatile organic compounds (VOCs), the limit of 550 parts per billion (ppb) was chosen, following the guidelines of the US Environmental Protection Agency (EPA). This solution offers various advantages: firstly, it allows immediate visualization of the data collected by IoT devices and their correlation with specific spaces; secondly, it facilitates the analysis of recorded anomalies in relation to occupancy and class schedules of those spaces. This comprehensive approach provides valuable insights for maintaining a healthy and optimized teaching environment.

4. CONCLUSIONS AND FURTHER DEVELOPMENTS

The paper illustrated the research conducted under the umbrella of the UniTO's strategic plan, aimed at developing an AMS-app to optimize the management of one of the largest university assets in Italy. The replicable methodology developed for the definition of the app and its implementation in the organizational system was illustrated. The BIM-GIS-BI integration enabled to systemize the various information currently siloed managed, providing an integrated decision-support tool accessible starting from the territorial level to the single building and component. Through the illustration of several case studies implemented so far on selected buildings, the potential of this management system was illustrated, also highlighting the difficulties encountered and the margins for improvement. Such a system is easily replicable and showed true potential in being able to manage the available resources optimally and consciously. Both in terms of space and economics, it also allows for the optimized management of facility services and improved IEQ performance for the end-user experience, leading to effective and sustainable management. In the future, information protocols and guidelines will be developed for the proper adoption of such an AMS and the correct definition of the IRs. Furthermore, it is envisaged that the management processes currently underway will be reviewed in consultation with the heads of the technical-administrative areas aiming at the optimal adoption of the system, as well as the implementation of a data-sharing system exploiting a data lake from which to extrapolate the targeted information, identified based on the management processes and the defined IRs.

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