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OPTIMIZED DATA CONNECTION FOR A BIM-GIS BASED UNIVERSITY ASSET MANAGEMENT SYSTEM

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Abstract

In large universities' asset management, the lack of accessible connected data is frequently the root of information gaps. The paper investigates the optimization of data connection throughout a web-based platform exploiting BIM-GIS integration and Business Intelligence Tools. Data connections in BIM were managed through visual programming language with customized nodes, exploited for assigning parameters to categories, comparing parameter lists, and connecting data to modeled elements. GIS enables data visualization of the university asset and queries at the urban scale. The platform based on data integration provides an efficient asset management system with easily updatable information about buildings, spaces, and uses.

Introduction

The boost of technological advances in the Architecture, Engineering, Construction, and Operations (AECO) sector allowed a continuously increasing availability of data and sources. Quality data are core for the informed and effective decision-making process in the AECO sector, particularly in the fields of facility management (FM) and asset management (AM) of diffused building stocks.

Among new technologies and working approaches, Building Information Modeling (BIM) and Geographic Information Systems (GIS) recently demonstrated significant development potential (Wang et al., 2019). BIM and GIS are two powerful tools that can be integrated to provide a comprehensive view of building assets and their features.

BIM involves the creation of a digital model that includes both geometric and non-geometric data of a building which can support building management in the O&M phase, from energy and space handling to safety and security fields (Cao et al., 2022).

On the other hand, GIS enables to store, analyze, and visualize data in a spatial environment (Zhu et al., 2018). GIS is usually adopted in urban planning, but thanks to its capacity of managing large amounts of data and integrating different types of information (textual, spatial, geometric), it finds also application in construction project management (Li and Wang, 2022).

Thus, BIM and GIS integration provides the connection of buildings or infrastructure models with both spatial and aspatial data. The information resulting from this combination may be utilized to manage and maintain building assets, as well as to simulate and optimize building performance (Zhu and Wu, 2022). Furthermore, it enables the creation of a comprehensive, accurate, and updated digital model of a facility and the analysis of data from multiple sources including sensors, energy management systems, and maintenance records, gaining a more comprehensive understanding of buildings' performance.

Despite the significant benefits that BIM-GIS integration brings in the development of an AMS, their different nature requires consideration of some factors that could compromise its optimal implementation.

First of all, the two terms refer to different subjects: while GIS is a system and looks at the urban scale, BIM deals with a methodology most focused on single buildings (Ohori et al., 2018). Thus, there are significant differences not only in terms of the representation of the geometric elements and levels of detail but also in the semantics of the datasets (Beck et al., 2020).

Another relevant point, in which integration might be difficult, concerns the georeferencing entities, essential in the GIS environment (Noardo et al., 2019). According to Diakite and Zlatanova (2020), georeferencing consists in aligning an object on a map thanks to coordinates application following a reference system, in order to have location correspondence in the real world. In the aim of avoiding integration issues, the data setting up and the workflow definition are crucial.

Additional support in the FM in the AECO sector may come from exploiting the Internet of Things (IoT).

IoT, which refers to the interconnection of physical items through the Internet, enabling the collection and exchange of data, can facilitate data collecting (Wong et al., 2018). Predictive maintenance and asset management are enabled through the integration of IoT-based sensors and digital devices, which can deliver real-time data about asset performance and condition (Wong et al., 2018).

Thus, building operations and maintenance (O&M) can be supported by the integration of BIM, GIS, and IoT sensors in the field of FM, enabling better asset tracking, maintenance planning, and resource administration. The incorporation of these techniques supports the evaluation and appraisal of building assets as well as the creation of management and disposal strategies in that field.

Because of the large amount of data involved in the construction field (Munawar et al., 2022) data management should be considered from the building design stage throughout the construction, operation, and maintenance stages. Moreover, good data quality and management showed great potential to increase productivity, save costs and improve project outcomes in the AECO sector (Munawar et al., 2022). However, in the construction industry, the integration and analysis of data were historically struggling due to the fragmented nature of the supply chain and the lack of standardization (Qian and Papadonikolaki, 2020).

The collection, storage, and analysis of large amounts of data from various sources and their transfer between different software were demonstrated to be challenging due to the different formats used and potential data loss or corruption (Noardo et al., 2020).

Therefore, strong data management processes are key to ensuring the integrity and reliability of the data. This is due to its continuity over time, not only concerning database feeding and updating but also correct data maintenance and security (Klidas and Hanegan, 2022).

In this context, a previous research project developed at the University of Turin (UniTO) aimed to create an Asset Management System (AMS) based on BIM and GIS integration and Business Intelligence (BI) Tools through a web platform able to collect data from various sources and deploy useful information displayed on informative dashboards (Accardo et al., 2023).

A critical phase in the development process relates to the data and informative model connection, which must ensure avoiding data loss and a correct parameters association.

Thus, with the aim to explore enhancing possibilities in data connections, this paper supplies a brief description of the methodology followed to develop the AMS-Web App for the UniTO Campus. Then it provides a dissertation about data connection to BIM and GIS, and their visualization, underlining and discussing weak points. Finally, it proposes a new tailored solution developed exploiting Visual Programming Language (VPL) through a new demonstrator, selected among the UniTO buildings.

The main objective is to outline and discuss the improvements made to the past workflow, highlighting the key role of the strengthened connection between data and the integration of BIM, GIS, BI Tools.

The AMS-Web App for the University of Turin Campus

The research project for the University of Turin Campus, presented by Accardo et al. (2023), and Meschini et al. (2022), aimed at creating an AMS to meet the brief-term need of having the quick perception of the university asset's consistency, distribution and attributes. The long-term objective deals with the aim of developing a smart campus for the predictive management of the operation and maintenance phases. As a result, the Web App was created by integrating BIM, GIS, and BI Tools, enabling both urban and local data queries and analysis, supporting the reading of data with the adoption of dashboards, and 3D visualization.

Meschini et al. (2022) also provide a valuable example describing how the system's main database could be exploited to investigate the fire emergency management efficiency of the whole UniTO's assets through crowd simulation and analytic dashboards. It also showed the system's potential to develop future Digital Twins aimed at improving fire emergency management.

Figure 1: Web App View

The workflow defined and exploited to develop UniTO's AMS-Web App can be summarized in the following 5 phases (Meschini et al., 2022):

- Phase 1: Analysis of the asset in terms of building stock consistency, data availability, and management system.
- Phase 2: Definition of an integrated database through data relations. Starting from data collected in Phase 1, it was defined how data must be structured and organized in order to generate connections between different sources and information completeness. The aim was to integrate both data which tend to remain unchanged over time (property name, address, areas, etc.) and those that might change frequently (occupancy, real-time data related to environmental comfort from sensors). It was also defined the coding structure of the different components of the building's stock, enabling more efficient data relations.
- Phase 3: Building information modeling. Each building was modeled in the Autodesk Revit environment divided into three components: mass (for the entire volume), floors, and rooms. Then, information was added with the parameters' assignment through the VPL tool Dynamo.

- Phase 4: BIM-GIS Integration. Each BIM model was imported into the GIS, where it was georeferenced according to the coordinates World Geodetic System 1984 (WGS84) and Universal Transverse Mercator (UTM) projection. This integration correlates the single building with the entire university building stock, both in terms of localization and attributes, enabling data comparison and territorial analysis.
- Phase 5: Data Visualization. Data were elaborated in analytics dashboards through BI Tools, developing an interactive interface of the AMS-Web App, in accordance with the map previously created.

The work presented in the following sections slightly revises the workflow and adds a Phase 6, to revise and optimize some parts of it, mainly focusing on a better data connection (concerning BIM, GIS, and BI Tools).

The final result is a Web-App that maintains its initial peculiarities of providing an overview of the university asset consistency with the information and analysis related to its buildings better connected and more easily upgradable.

The improvement outlined in this paper will provide an easier implementation of the AMS-Web App with new BIM models and data from several sources, providing greater efficiency and a better database with easily updatable interconnected data.

The case studies

Due to the large number of buildings that compose the UniTO asset and the extension of the area in which they are located, the first 5 Phases exploited two buildings as demonstrators (Pier della Francesca Center and Palazzo Nuovo) with different levels of complexity, both in terms of geometry and available data. The first demonstrator, simpler and smaller, was used to quickly and easily test the methodology, while the second, more complex and larger, verified its effectiveness and replicability on more challenging cases.

However, in the aim of adding the whole university building stock to the platform, some operations might be inefficient, leading to the definition of their optimization (Phase 6) which was tested through a third case study: the main building of the Luigi Einaudi Campus (CLE). This building was chosen for its geometric complexity, the variety of available information, and because it has one of the highest number of UniTO's users hosting the 25 degree courses and the 3 Departments of the School of Law, Political and Economic-Social Sciences. The three cases study already developed deal with almost 50% of the whole UniTO users (over 40000 out of a total of almost 83000). The tests on CLE enabled to improve replicable methodology defined so that it can be easily applied on a large scale to georeferencing and visualizing the whole asset through the Web App. Thus, dealing with such numbers and articulated cases study could ensure fairly guarantee that the methodology and workflows developed will be easily replicable for the other less complex buildings.

The Data Connections

In the presented project, data connections were possible mainly thanks to semantic association, consisting of the association of data through common values. That association gives the possibility of collecting datasets from different sources and integrating them into a main structure database.

Spreadsheet form is the most-liked structure used on current UniTO's datasets, which, once collected, need to be organized and cleaned of unnecessary information.

In particular, collected data can be summarized in the following table:

Table 1: Information identified through data collection

Source	Information
OpenSIPI	BUILDING INFORMATION: name, code, address, city name, state of use, area, perimeter, geometric data
	STOREYS INFORMATION: name, floor code, state of use, area, geometric data
	SPACES INFORMATION: coded name, state of use, department assignment, area, geometric data
University website	BUILDING INFORMATION: prevalent use, property state, location expenses
	SPACES INFORMATION: rooms names, equipment, capacity, use, room state (free or reserved)
Department offices	SPACES INFORMATION: courses schedules, timetables, number of occupants
IAQ Platform	SPACES INFORMATION: air quality, environmental comfort
Google Maps	SPATIAL INFORMATION: building coordinates, basemaps
Regional Geoportal	SPATIAL INFORMATION: building coordinates, basemaps, open datasets

As shown by Table 1, besides the university's sources and in the aim of integrating table datasets with 3D models in a geographic environment, there were also exploited Google Maps and the Piedmont Regional Geoportal for the spatial data collection. The Geoportal was used, for example, to have the cartographic database used in the GIS and the spatial information of the city of Turin, a context that includes most of the UniTO's building stock. The Geoportal allows free access to data, both in visualization, download, and GIS connection through the Web Map Service (WMS).

Retracing the phases of the project workflow, it can be noticed that Phase 2 deals with the creation of a structured database. It refers to the creation of databases tailored to allow the information enrichment of the BIM models, in which the information almost unchangeable over time (e.g. property, name, coded name, area, location, etc.) was collected. On the other hand, changeable information (e.g. occupancy rate, lecture schedule, etc.) were organized according to their sources, selected, and then correlated to the main database through the semantic association of the different elements codified in the following phases.

Particular attention was also paid to the type of data that was collected in addition to values. In fact, in the aim of generating actions through coding in a programming language, whether traditional or visual, it's key to know which kind of data to work with. For example, the VPL application used for the project (i.e. Dynamo) required specific types of data to input some actions. In particular, these types can be classified in four "Primitive data types" (Strings, Integers, Doubles, Boolean) (Pellegrino et al., 2021). Even in GIS, the attribute table creation is based on primitive data types and indirectly the same in BIM for parameter definition.

Data Connections to BIM

In order to define an information model as afore-illustrated, each modeled geometry needs to provide some information. In the case of UniTO's asset, each 3D-modeled building must enable the association of the information structured in the main database (Phase 2). Such association can be provided through Dynamo, the VPL application integrated into Autodesk Revit, enabling operation through visual objects called nodes (The Dynamo Primer, 2019).

As discussed in (Pellegrino et al., 2021) programming language facilitates information exchanges: thanks to textual algorithms, an action can be generated based on an input, which in turn generates an output. On the other hand, in the visual programming language, the process is not text-based but graphical, so the algorithm and its connection can be visualized by the users, returning a clearly illustrated and easily understandable process.

The VPL was used to define BIM model parameters starting from the structure database. At this aim, the first step concerned the creation of the parameters by defining for each of them: Name, Parameter Type, Group Name, and Group Type, in addition to the reference element category.

It is worth remembering that creating parameters (instances) is intended as creating the container first, while the value (content) referred to them is treated later. Concerning the encoding system of the database used for the parameter creation, there is the name of the parameter as the first row, the element identification in the first column, and the values to associate in the cells.

Another crucial step revised and improved during parameters' creation, concerns the category assignment. In the original workflow, the parameters with the same features were created separately for each element category, causing repetitions with parameters common to multiple categories. For example (Figure 2), when a Parameter A, like the "Building Encoded Name" parameter, needs to be associated with both the masses,

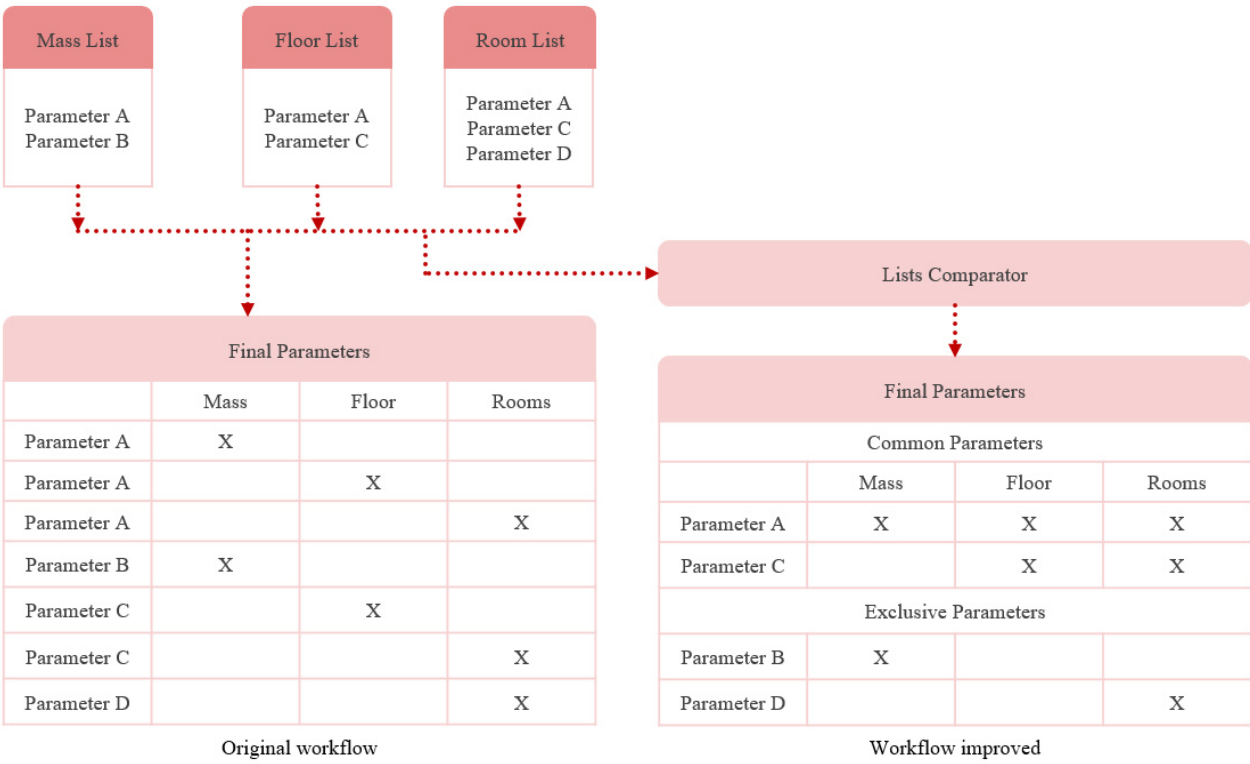

Figure 2: Parameter creation without and with list comparator. Parameter A need to be associated with all the categories (e.g. Building Encoded Name), Parameter C is common to floors and rooms (e.g. Floor Encoded Name), Parameter B is exclusive for masses (e.g. Building Name), while Parameter D is exclusive to rooms (e.g. Room Encoded Name).

the floors, and the rooms, originally 3 separated parameters were created: one for masses, another one for floors, and one more for rooms. The work was pursued to avoid such repetitions by associating the parameters to multiple categories simultaneously, exploiting the software potential.

Dynamo provides a series of available operations related to the creation, modification, and most important comparison, between lists. Thanks to these operations, it was possible to create custom nodes, used to compare the parameters list of all the categories of elements involved (mass list, floors list, rooms list), automatically identifying which parameters were common to two categories (e.g. "Floor Encoded Name" for floors and rooms), to three (e.g. "Building Encoded Name") and which were exclusive (e.g. "Building Name" for masses, and "Room Encoded Name" for rooms). Due to the multiplicity of the lists involved, it needed more than one operation in order to align the values based on their exclusivity. Thus, customized nodes were created, starting from the ones already available in the software, to process the different parameters. This led to an optimized parameter definition, in which, for common parameters such as Parameter A, there is a unique parameter common to three categories (Figure 2).

After the parameter creation, the datasets values were associated with them. Both the connections between the different databases and those between the database and the BIM model or the GIS system were relational and based on the association of the different elements' coded names.

However, in the case of the building's spaces revision and accordingly to the information model, the right attention should be paid to avoid errors within the compiled database. For example, if a room changes its name or is merged with another one keeping only one name, this could lead to errors due to the change of the "data bridge" used for associations in the first case and a wrong or missing data connection in the second one. To overcome this problem, the first associative data-BIM model bridge was modified, connecting the values to the parameters with the element ID generated by the modeling software instead of the encoded names (Figure 3).

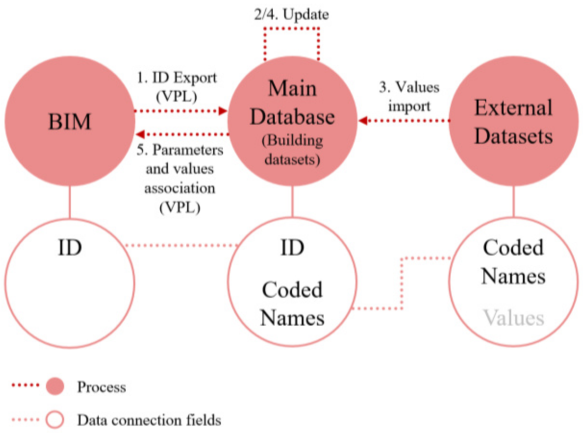

Figure 3: Connection scheme

The Element ID is an identification number assigned by the software at the creation of each Autodesk Revit element for their identification so it is unique and remains unchanged when the model is shared. Following this path and taking up the examples reported, in the first case (change of the room name) the information would be kept as it cannot be traced back to another element ID. In the second case, the changes to the geometries of the building model create a new element leading to a new ID, targeting the attention to the line with missing data.

Like the ID, the spaces' coded name is unique for each space and allows the integration of the collected datasets in the main database. This allows avoidance of data loss that can arise using the space name (e.g. the same room can be named in several ways in different datasets like "Aula A1", is also called "A1 V. Pareto", or "D204" etc. which can imply mismatching in the datasets).

The structured database, in which the selected information from various sources is conveyed, is the base for the data and BIM association. In fact, the information for the parameter generation (both name and values) can be traced back to it. Moreover, in the generation of the parameters through VPL, both the nodes which identify the names and the ones which identify the value, refer to the same database. When this is updated with new parameters or with changes in values, the model can be easily updated too. However, if the structure that each building datasets should follow is well-defined from the beginning, it's possible to identify any discrepancies with the main tables. In order to avoid overloading the software in the data reading phase, it was considered appropriate for each building to have its own BIM datasets.

Data Connections to GIS

Due to the different nature of GIS and BIM, connections have been handled quite differently. While in the BIM model, data are related to the single building (coding, space name, space use), GIS enables the hosting of both specific data of the different entities and geographical data. The spatial data were entered using the WMS and the download service of the Piedmont Geoportal, thus obtaining a complete and updated cartographic and informative base, from which deriving the location of the different buildings (latitude and longitude) and other information such as their average height.

With the import of the BIM model within the GIS, it was also possible to report the information previously entered in the 3D model. To avoid any issue in the interoperability with BIM during this operation, Esri ArcGIS Pro was chosen as GIS software.

In the past workflow, all further information was then added in the GIS environment with analytic dashboards, linked to the building attribute tables through an URL field. Nevertheless, those dashboards, created with BI tools, show the already analyzed data without giving the possibility of querying directly the original dataset if not expected from the dashboard design. This approach, used for the first two demonstrators can be useful for the analysis of specific topics, but not for the datasets full visualization and comparison.

Therefore, after the workflow review, it was proposed an implementation of the GIS system with datasets uploaded as standalone tables. Employing the software tools, the datasets were associated with the BIM model attribute tables through joining and relating operations creating semantic relationships based on selected field recognition.

The relationship between tables is identified with the term "cardinality" and might be: one-to-one, one-to-many or many-to-many (ArcGIS Pro Documentation). Due to the database structure adopted with element coded names bridging several ordered data, the relationship type will usually be one-to-one, one-to-many, and less frequently many-to-many.

This strategy was tested to relate, for example, occupancy and sensor detection data to the third demonstrator (CLE building) attribute table, allowing a system updating with the frequent database changes.

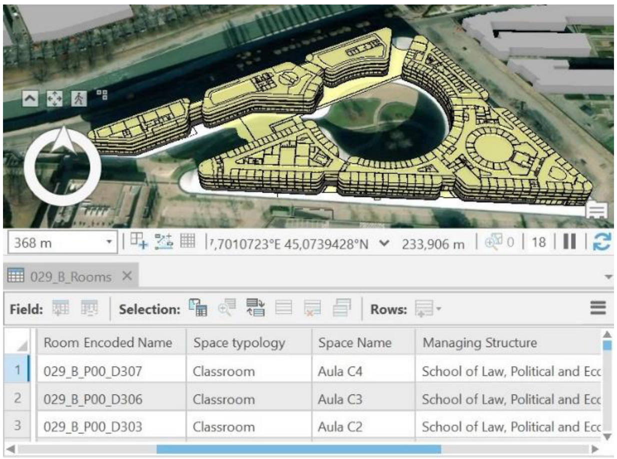

Figure 4: CLE BIM model in the GIS environment

The possibility of visualizing the sensors' dataset and combining it with the occupancy information, both for the CLE and for all the university buildings, allows for example an overview of the indoor quality of the used spaces featured by the query settings.

Data in Business Intelligence Tools

Due to the effectiveness of BI solutions, organizations frequently use them to provide data insights and support decision-making. BI tools rely on data to provide firms with insights and support in decision-making. The relationship between data and BI technologies is key to driving their efficiency since the accuracy and value of the insights provided by the tools depend on the quality and relevance of the underlying data.

In particular, Microsoft PowerBI enables users to manage data, analyze them, create reports and diagrams, and share them thanks to different tools called visual objects. It was chosen for BI analysis due to both its ability to elaborate data, and its interoperability with Microsoft Excel, the software used by the university administrators for managing and sharing data, and with other data sources.

Power BI is a native software for data management, but it also allows data relations with two-dimensional geometries through specific visual objects. This type of visualization can be useful in the integration of the plan of a building or a portion of it in the data analysis.

In this way, it's possible, for example, to view information like the booking schedule and the booking rate in percentage, of a selected room, and simultaneously his location on the building plan (Figure 5).

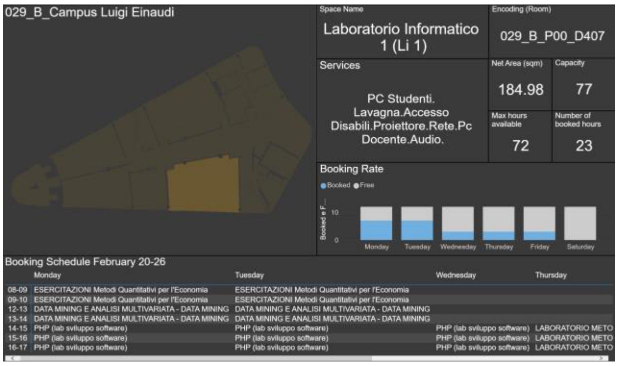

Figure 5: PowerBI Dashboard. CLE Occupancy analysis

As the data and the geometries are related, it's possible to visualize data both by space selection (Figure 5), then by value selection from the other visual objects. For example, if we select the field "Monday" in the booking rate visual object of Figure 5, it's possible to visualize in the plan all spaces that have at least one hour booked on that day.

The plan visualization is feasible thanks to a visual object called "Synoptic Panel" that reads Scalable Vector Graphics (SVG) images that have already associated some information to geometries. Before the workflow reviewing phase, the operation of generating the SVG file was done manually, drawing each space in the plan.

Thus, the research made improvements in order to avoid the manual drawing process of spaces and it was identified a way to export an SVG file plan from the objects already defined with Autodesk Revit. Pellegrino et al. (2021) proposed a solution for this issue, providing a Dynamo file, based on nodes and scripts, which creates an SVG file by converting rooms' geometries and associating selected parameters. To achieve this goal the workflow requires to enter manually the names of the parameters to be related. Then it generates an Excel file containing this information, which is later re-imported to create the association.

To reduce manual data entry to avoid mistakes, the previously developed workflow was modified to include the aforementioned part. The change deals with inducing the software to take parameters' names from the project's main database, used also for BIM. In this way, the risk of inconsistencies between existing and searched parameters decreases considerably, avoiding data loss. Then, other data were connected to the SVG file in PowerBI through the semantic association of the elements' coded names, increasing the available information that can be interrogated through the dashboards.

Results and discussion

The paper presented the optimization made in the workflow defined to develop the UniTO AMS-Web App, with a particular focus on data connection and visualization operations at various steps of the workflow.

Three demonstrators' cases were developed so far, defining a methodology replicable on a large scale enabling an efficient implementation of missing 3D models and data. Although the research concerns various tools and software, it should be noticed that the semantic association between databases joins the different processes and applications, thus, its optimization was crucial to improve the methodology.

For the optimization proposed, in the data connection to BIM, the parameter names and values assignment came to the ID association. In addition, during the early phase of creation, the lists of the parameters were compared and separated depending on the element categories they referred to. A Dynamo customized node for list comparison allows parameters selection for their exclusivity, avoiding repetition in their creation. Consequently, the number of BIM model parameters drops from 46 in the first demonstrator to 32 in the CLE information model, without compromising the correct categorization or data loss, rather providing benefits in file size and software data management. Names and values were also picked out by the same table, lowering data loss probability and a more suitable updating. Indeed, this optimization allows a large autonomy in managing the main database. Parameters' names compilation, errors in the Dynamo node, updates, or specific changes in the database will no longer compromise the readability of the data by the software. Moreover, the aforementioned dataset was used to pick parameters' names in the Dynamo script for the SVG file creation. This file type, which can contain both 2D geometries and information, was loaded in PowerBI to develop plan visualization on dashboards. In this way, the process bringing data visualization is more effective and secure as the BIM model, avoiding the manual drawing of the building plan and data association needed in the original workflow, takes both data and geometry automatically.

Thus, the results of these optimizations will be respectively a BIM model with no needed repetition in parameters lists and connected to the main database, and a planimetric schema in SVG format related to the BIM model itself and its information which can be used in supporting data visualization in analytics dashboards.

In GIS, data were at first imported into the system with the georeferenced BIM model, and other information was available only on the dashboard's link after have been analyzed. So, it was proposed to implement the buildings attribute tables with further datasets exploiting the join and relate functions. Although this increased the number of data to be handled by the software, the benefits in information comparison and analysis are significant. In fact, tables are connected both to other tables in the GIS environment through semantic association of the coded name, and to the main database spreadsheets, allowing an immediate update of system data when the information changes. In the first case study, the association of data was made outside GIS, leading focused analysis of the single building. Bringing data in the GIS allows not only queries at the building scale, but also to visualize full datasets, relate multiple tables and, compare data of different buildings, enabling urban analysis.

The results obtained highlight how the optimizations provided an improvement in the implementation of the platform, ensuring better control of data and more efficient workflow phases, providing the latest information about space occupancy, costs, environmental quality, etc., fundamental for the effectiveness of the decision-making process during the O&M phase.

The optimizations are slight but significant to manage such a complex and large-scale project with multiple data and sources highly variable.

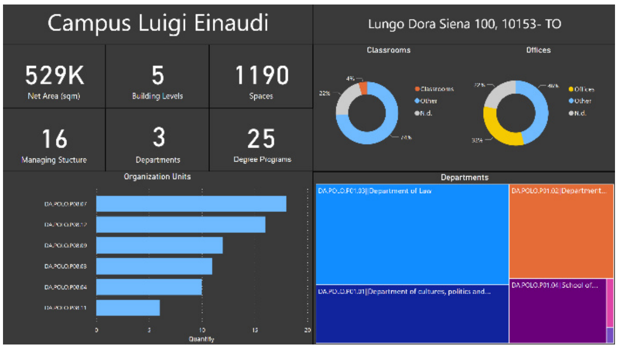

Figure 6: PowerBI Dashboard. CLE Spaces analysis

Conclusion

Retracing the workflow that led to the definition of the AMS-web based platform created for the O&M phase of the diffused UniTO campus, it emerges that an optimal connection between the different parts of the platform is fundamental. Data connection in BIM, GIS, and BI tools integration is very effective but must be carefully checked at each phase to preserve data value and prevent their deterioration, loss, or redundancies. The software used are very different from each other but also the types of data to relate are very heterogeneous. For this reason, data must be structured and organized according to their intended use and the connections they will face to produce the final information.

The paper results showed how optimization brought a significant benefit to the previously defined workflow, providing more agile data connecting and updating, where the increased efficiency achieved can improve analysis to support O&M phase decision-making.

From the perspective of making successive improvements to the platform and its workflows, the research aims to investigate methodologies for further simplifying the relationship between the tools used and for automating data overwriting and feeding supported by Machine Learning. This together with IoT (Internet of Things) would provide many possibilities such as the continuous integration of sensor data into the platform enabling their real-time consultation. This enables the expansion of the research also to cloud systems for data storage and management, due to the large amount of data involved, providing further optimization in repository governance.

In addition, open standards will be considered with the aim of giving alternatives to authoring software to improve interoperability.

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