Leveraging BIM for digital built environment asset management

Fulvio Re Cecconi[1] · Sebastiano Maltese[1] · Mario Claudio Dejaco[1]

Abstract A National Institute of Standards and Technology (NIST) study shows that all stakeholders in the capital facilities industry waste a huge amount of money looking for, validating, and/or recreating facility information that should be readily available. The total cost of these activities within the capital facilities industries in the United States was conservatively estimated at $15.8 billion in 2002, with two-thirds of that cost occurring during the facilities' operations and maintenance phase. This is confirmed by the International Facility Management Association (IFMA) Maintenance Survey in 2009, which states that the loss of information generates an added cost of 12.4% of total annual mean O&M costs. Nowadays, standards and specifications have been developed about availability, integrity, and transfer of data and information during the operational phase of an asset life. PAS 1192-3, among these, suggests the use of Building Information Modeling (BIM) models to store and access facility information, but the turning point is the ability to provide different stakeholders with different data, which should be targeted to them, easily accessible, readable, and updatable (and up to date). This research started with the collection of asset managers' needs and then the definition of new procedures for assets and facility management in a BIM-based workflow focusing on how to allow users to access, use, and update facility data stored in a BIM model without a BIM authoring tool. Examples are shown for: (1) management of rooms occupancy; (2) management of mechanical equipment status; (3) qualitative condition assessment of buildings; and (4) appraisal of the service life of building components and systems according to ISO 15686-8. These four tools allow to compute and control some key indicators of the asset, with also the possibility to compare them inside a portfolio. This paper presents the four tools, paying also attention to the workflows to be followed and to the different data needs of the stakeholders involved.

Keywords BIM · Facility management · Asset management · Web · Building condition assessment

✉ Sebastiano Maltese
sebastiano.maltese@polimi.it

Fulvio Re Cecconi
fulvio.rececconi@polimi.it

Mario Claudio Dejaco
mario.dejaco@polimi.it

[1] Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via G. Ponzio 31, 20133 Milan, Italy

Introduction

This research aims to prove that transferring existing asset management procedures (and tools) into a BIM environment is feasible. Aziz et al. [1] provided a clear description of the evolution of Facility Management (FM) software, from the beginning (with emails), since to the most advanced solutions (BIM and lean software). According to this scheme, the Italian panorama is characterized, except some excellent examples, by a broad use of Computer-Aided Facility Management (CAFM) software; at the international level, there are many interesting applications of BIM for FM in public and private portfolios. In general, the development of BIM procedures to support FM could lead to different sets of tools, e.g., to simply exchange data with third party plugin to populate spreadsheets or to directly be connected with a CAFM software. No matter

This is a post-peer-review, pre-copyedit version of an article published in INNOVATIVE INFRASTRUCTURE SOLUTIONS, 2017, 2:1. The final authenticated version is available online at: http://dx.doi.org/10.1007%2Fs41062-017-0061-z

the procedure, this kind of connection is important for acquiring spatial information [2].

According to the PAS 1192-3 [3], the BIM model has the same life as the physical building; this implies a great use of the model during building operation. Many researchers and software companies are developing tools to manage building operation with BIM (please refer to the "State of the art" section), while authors tried to demonstrate how current procedures can be translated into BIM ones; so the focus is not on the instruments, but on how actors should modify their habits to cope with new methods and tools.

The first step in a BIM adoption procedure is the implementation of model-oriented tools and workflows [4], this is extremely difficult in the asset management field where current procedures are mostly process-oriented. For example, assessing building condition usually involves:(a) asset survey; (b) filling some documents (diagnostic forms, reports, etc.); (c) taking pictures; and, if need be,(d) calculating one or more Key Performance Indicators (KPIs). In a BIM environment, diagnostic forms must cope with the organization of the BIM model. Data must be organized according to the objects (spaces, building com-ponents, and systems) in the model, so to have the data linked to the right objects, allowing to query them in an efficient way. Another barrier to BIM adoption in the asset management field is the BIM authoring tools themselves; two cases are frequently found: either people are not able to access and modify data using a BIM authoring tool or the information which they need cannot be efficiently stored in a model.

This research proved, also through some case studies, that BIM methods and procedures can be efficiently used to support frequently recurring asset management processes. The research started with the analysis of existing procedures and tools used during asset management. The second step has been the transposition of these procedures into the BIM environment, trying to cope with the boundaries given by the model-oriented approach. The third step consisted in the development of some web tools connected with the BIM model, so to have a dynamic interaction with the model, i.e., the possibility to update and enquiry the model without a BIM authoring tool. This is highly important in the asset management field, because most of the stake-holders either need information that cannot be provided by BIM authoring tools (i.e., synthetic reports on asset per-formances, specific queries, KPIs, etc.) or do not use BIM authoring tools (Fig. 1) [5]. This may happen for many reasons, for example: (a) because it would be too expensive to provide them the tools; (b) because it would be unfea-sible due to the work which they are doing or (c) because they would need too much training (thus, again, it would be too expensive).

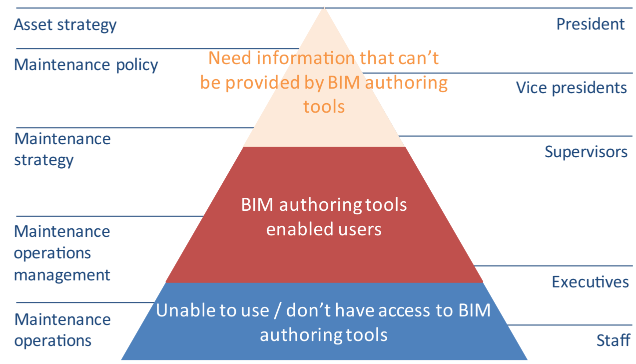


Fig. 1 Information uses and users versus building information modeling in asset management

The tools presented here can be seen as the preliminary results of the research, aiming at demonstrating that BIM can be fruitfully used to improve asset management procedures.

This paper contains a brief state of the art of the main themes discussed, then a description of the four Web tools developed, and an application to a case study. To be noticed that the case study is made to show the Web interfaces of the tools and not to discuss quantitative results coming from the calculations made with the proposed procedures. This work is focused on existing buildings, so the procedures are meant to be used with digital models with a low level of detail (graphical) and a high information content (high level of information); this allows to quickly create a digital model of the building, ready to be used by managers and operators in their daily activities.

Eventually, this research is carried out to fill the lack of instruments and tools to allow people not able to use BIM authoring tools (e.g., high management, maintenance operators, and staff) to access and modify data contained in a digital model of the asset.

State of the art

In this paragraph, the main themes discussed in the article are highlighted with the aim of providing the context of the research. What is the asset management and the first attempts to use BIM in the area are presented in the first part of this chapter. The second part gives an overview of building condition assessment (BCA) and Service Life Planning (SLP), two of the main fields of asset management.

Asset and facility management

Cagle [4] gave a working definition of asset management; he said that it refers to a set of processes or activities addressing the proactive management of infrastructure assets, as follows: (a) maintaining an inventory (saving data about acquisition costs, original and remaining service life, physical condition, and cost history for repair and maintenance); (b) planning asset maintenance, repair, and replacement; (c) supporting the two previous elements implementing and managing an information system. Managing an asset (or a portfolio) means making decisions, more or less important, to meet the objectives given by the asset strategy, as defined in the ISO 55000:2013 [6]. According to a definition given by BBC [7], related to the business sector, "decisions are part of the remit of managers. Difficult choices may have to be made for the common good of the organization". There are three types of decisions, from complex to simple: (a) strategic: long-term, complex decisions made by senior management;(b) tactical: medium-term, less complex decisions made by middle managers; and (c) operational: day-to-day decisions made by junior managers that are simple and routine.

Strategic decisions, in the construction sector likewise in any other business, must be based on reliable data, possibly summarized in some KPIs. The senior management cannot make their decisions based on raw and sparse data, useful for day-to-day operational decisions but not for planning long-term activities. This concept is reported by the EN 15221-1:2007 [8], which divides the Facility Management in strategic (processes), tactical, and operational (activities), with KPIs to control assets and service levels.

Objectives, activities to be performed, and KPIs to be provided are also listed in the ISO 21504:2015 [9]. These objectives, to be set in advance by the portfolio manager, can be summarized in the following: (a) ensure that investment in portfolio components is aligned with the organization's strategy and risk tolerance; (b) optimize organizational capability and capacity; (c) maximize benefits from investment; and (d) identify and manage stakeholders' interests.

Managing an asset is no more a "simple" technical issue, but a complex problem, on which managers must make operational, tactical, and strategic decisions to meet the client's needs. To make these decisions, managers and operators must be provided with data that should be correct, updated, easy-to-use and reliable; currently being able to access asset data in a standardized and effective format is as important as having reliable data [10, 11].

BIM for asset management

Implementing BIM-based asset management procedures needs more effort when dealing with existing building than with new projects, mainly because of the need of surveying the existing building to gather correct data about quantities, dimensions, materials, and technologies (due to the common lack of updated as-built documents). Both academic researchers and software companies are addressing this problem, looking forward to improve tools and methods to gather more precise data and to create a model respondent to the real building [12, 13].

BIM for existing buildings is many times obstructed by the fact that it is seen as an end in itself. BIM models for the real estate should be seen as a starting point for orga-nizing and managing knowledge about assets and portfo-lios, not just as a tool to be used only during refurbishment (as instance to make some renders) and then forgot. A possible interesting use of BIM models for existing buildings is given by sustainability analysis (i.e., energy analysis [13]), which can take advantage of BIM to achieve more precise and reliable results; the issue that tried to solve is the difficult conversion of the points cloud into BIM objects, ready to be used for multiple purposes.

As written before, BIM can be fruitfully used in all the stages of a project, including asset or facility management; the potential is high, even if procedures and tools many times need to be improved. Reference [14] provides an overview on the topic by analyzing some case studies.

Overlooking possible initial difficulties, BIM can seriously improve the current way of working and sharing data among professionals, users, and clients. One for all, it is sufficient to think about the amount of paper documents to be stored in an asset archive, with all the problems related to data acquisition and updating; with BIM, data are stored in a database, so the paper is strongly reduced, with more benefits in terms of updating effort. An example of as-built document management system based on BIM can be found in [15], while information sharing via Virtual Reality and BIM is shown in [16].

Knowledge is the key and BIM can improve the way to access this knowledge by cutting working time and related effort. More generally, BIM technologies can help asset management by allowing to: (1) store customized parameters and KPIs; (2) manage the maintenance plan; (3) keep track of the performed maintenance operations; (4) keep track of components installation date and related issues (warranties, end of life, etc.) [17]; (5) automatic update data after maintenance operations; and (6) prepare service order (maybe through COBie [18]).

A BIM model can also be productively used to manage spaces and connected furniture and materials. Maintenance operations and refurbishment are often related to a single space (or to a zone) and not to a specific component (i.e., internal wall, ceiling, flooring, etc.), so being able to calculate the bill of materials associated with a space in few steps is a great value.

One of the most interesting and important progress is given by the introduction of the Augmented Reality (AR) in the asset management world: software companies [19–21] and researchers [13, 22–24] developed various software and plugins to allow maintenance operators to interact with the building with tablets, smartphones, or even smart glasses. These solutions enable users to query, identify, and enrich objects, by remotely modifying the BIM model contained in a server. AR is really useful when it is hard to identify the element to work on, or when an operation must be signaled to the maintenance manager in real time. In this specific field, software companies and IT developers have a predominant and key role, sometimes even more important than the maintenance manager himself. To avoid this, an optimal BIM asset management system should be developed starting from client's information requirements and then tested and updated periodically, so to be sure to have all the necessary data.

Despite BIM diffusion and stakeholders' interest, there still is a great work to be done to provide stakeholders with instruments allowing an easy access to data contained in a digital model. Gu and London [25] observe that information stored and maintained during the project is useful for later access and retrieval. The model intended as a database is helpful in updating and identifying the information needed for maintaining the building facilities [26]. Nevertheless, authors highlight the absence of standardized procedures to keep the model updated, which is an issue that strongly affects BIM approach efficiency. Moreover, Level Of Detail (LOD) and Level Of Information (LOI) should be defined by facility managers, to be sure to reach the objectives set by the management [27].

Building condition assessment

BCA is a field of study that aims at improving the knowledge of an asset. This is crucial for a correct comprehension of the building behavior and criticalities, so to make correct decisions at the right time.

BCA is part of the asset management system, defined in the ISO 55000:2013 [6] and so, should be conducted in combination with other important activities, like inspections and maintenance operations. Inspections often cause costs overrun if not efficiently organized and must be planned considering what is the subject of the inspection [28]. Maintenance operations, in terms of both schedule and costs, must be planned consequently to the building assessment to be the most effective as possible [29].

BCA techniques have been studied since the birth of the necessity of understanding what are asset performances [4, 30–34] to consequently maintain them in the most effective way. In [35], nine different types of evaluation techniques have been defined, from empirical to theoretical and from internal to external. For example, in [36] some methods, based on qualitative evaluation, criteria (i.e., the surveyor indicates the good/bad state of building compo-nents) are described; in [37], other techniques are defined, based on cost-driven KPIs and physical state rating, in combination with standards and regulatory compliance checking.

Assessment methods can vary also according to level of detail needed: from general (the whole building, if need be, split in macro groups) to particular. In the latter case, each component has a specific and detailed evaluation method, like in [38] for façades evaluation, in [39] for roofs, in [40] for rendering façades predictive maintenance, in [41] for ETICS, and in [42] for the entire envelope. The objective of this work is not to produce a detailed analysis of the degradation of each building component, but a more general and fast analysis of building and building components degradations.

Last but not least, evaluation techniques should give as output an index, a rate, or a mark to enable decision makers to create a building ranking inside the portfolio, to prioritize maintenance works, and to evaluate refurbishment scenarios [43, 44].

The analysis of building evaluation techniques showed the extreme difficulty in achieving a detailed survey with a small effort. To minimize BCA costs, a two-step approach, as suggested by [42], has been adopted in this research: (1) a preliminary survey on the whole building to rate and to compare it with other buildings of the same portfolio; and (2) a detailed survey, focused on the more critical buildings of the portfolio, analyzing more deteriorated components according to the BCA rate. The survey, either preliminary or detailed, must also be reliable, objective and associated with a KPI.

In the current practice, BCA is conducted in several different ways according its objective; most of the times, it is also done implicitly, not considering it a real activity, but just a way to support calculations (e.g., market value appraisal, maintenance, and repair planning, etc.). BCA has to be done to support asset and facility management, but, if planned and performed properly, could lead to significant savings and a better knowledge of the asset (or the portfolio).

BCA report, the output of the assessment, is seldom connected to the as-built drawings (except some references like "plaster detaching in the front façade") or, in case, some data about pathologies are inserted in the drawings, it is difficult to retrieve them and/or to associate them to quantities and repair works. Moreover, diagnostic forms used to survey building components, despite the precision of this kind of document (they can be very accurate), are merely stored as paper beside the as-built drawings, so most of the times they hardly help to keep the history of the asset.

One of the problems of BCA is that data gathered are not directly connected to drawings and reports describing the asset, which are usually not updated or even missing.

This, during building life, causes potential loss of information and so missing performance and costs overrun.

In essence, the current BCA practice, except of some excellent examples, does not help in implementing the data into existing documents, but places useful information aside, causing sometime misleading results. The tool under development, based on a BIM model, wants to overcome this issue, implementing data about condition directly in the model so to be available during the use phase, which is the longest and most important in terms of impacts and expenses.

Service life planning

Service life planning is a design process that seeks to ensure that the service life of a building or other con-structed asset will equal or exceed its design life [45]. Buildings and building components service life are vital information in a design process, because most of the choices to be made during this process are influenced by life cycle costs or by environmental impacts over the life cycle, i.e., elements that are strictly related to the service life of building systems and components. After design and construction, during asset use, service life data are used to plan maintenance and replacement activities.

The ISO 15686 standard series suggests a way to predict the service life of a building components: the factor method, i.e., estimating the service life a construction product would have in a set of specific in-use conditions determined from reference service life data after consid-ering any differences from the reference in-use conditions. The estimation of the ESL is, most of the times [46, 47], carried out by multiplying the value of RSL by numerical factors A to G designated ϕ_A, ϕ_B, … ϕ_G, each of which reflect the relative dependence on the service life of the difference between the object-specific and the reference in-use condition within a respective factor category as given in the following equation:

$$ESL = RSL \times \phi_A \times \phi_B \times \phi_C \times \phi_D \times \phi_E \times \phi_F \times \phi_G. \quad (1)$$

The meaning of each factor, according to [45], is ϕ_A quality of component; ϕ_B design level; ϕ_C work execution level; ϕ_D indoor environment; ϕ_E outdoor environment; ϕ_F in use conditions; ϕ_G maintenance levels.

Although some research claim that the factor method is too simple to cope with complexity of building component degradation phenomena [48] or that it does not give any clue about the reliability of the estimation [49], it is commonly admitted as a general framework for service life prediction [50, 51]. Moreover, the use of the factor method in a BIM-based asset management process is eased by [52], an international standard that provides information and guidance on the use of standards for information exchange [53] for service life planning of buildings and constructed assets and their components. Noteworthy, [52] was conceived to exchange service life information between categories of design and information management software applications that have standard-based information exchange interfaces including: (a) Building construction Information Modeling (BIM); (b) Computer-Aided Facility Management (CAFM).

Web tools

The idea beyond the developed Web tools is to demonstrate the possibility to upgrade some existing asset management procedures to cope with new opportunities and constraints given by BIM. Becerik-Gerber and Jazizadeh [54] affirm that facility management requires extensive information requirements and BIM has a great potential in this field; nevertheless, they identify some constraints that must be taken into account when applying BIM to FM, e.g., accurate as-built BIM models and robust definition of objects requirements are needed for a proper implementation. In addition, non-geometrical data must be organized in a hierarchical structure, together with the connection with a responsibility matrix.

Web tools have been developed to help in four activities that are frequently carried out in the buildings use phase: space management, mechanical equipment status (failure or working condition), BCA, and service life prediction (according to ISO 15686-8 [55]). They all have the same working schema (Fig. 2): (a) the BIM model is created with a BIM authoring tool (Autodesk Revit) according to specifically developed BIM guidelines for asset management; (b) non-graphical data are exported to a database (DB); (c) the DB is published on the Web using Web services allowing to read and modify data; and (d) Web clients use Web services to create reports or to compute KPIs. All these tools have dedicated Web pages and thematic plans (in the BIM model), in which it is possible to update main data and check some KPIs.

In this chapter, all the four tools developed are presented, highlighting main features and characteristics.

Space management

Space management is a frequently underestimated activity: spaces are very important in asset management activities, as they can be associated with maintenance operations, costs centers, people, and activities; moreover, they can contain mechanical, electrical, plumbing (MEP) compo-nents, furniture, and specific finishing. Therefore, being

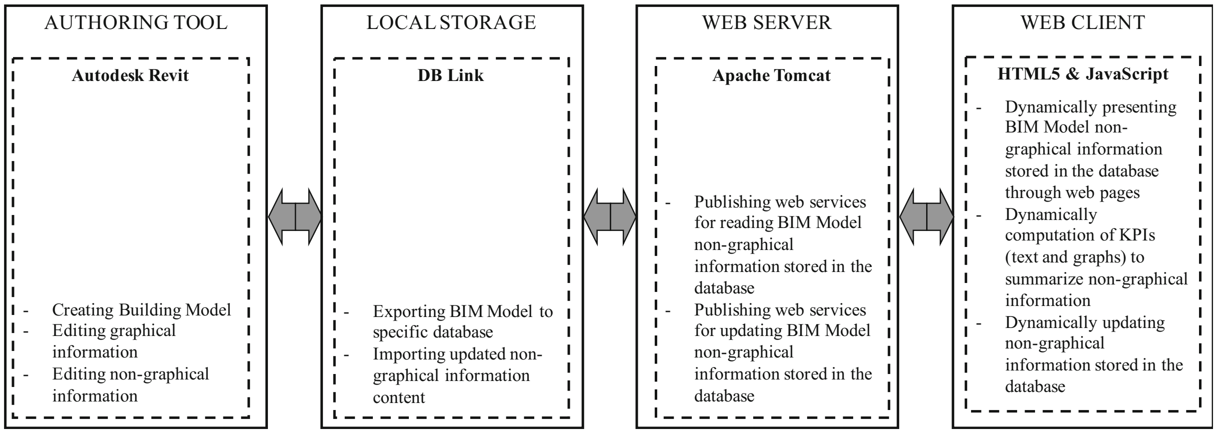


Fig. 2 Web tools working schema, technologies, and software

able to associate and manage information related to spaces or building zone is crucial for the success of an asset management strategy. Moreover, spaces contained in the traditional CAFM software are hard to update if changes occur over asset lifecycle, so having the direct connection with an updated BIM model would overcome this issue.

The main idea is to create a Web tool able to manage the occupancy of a room, so to understand if the space is used or not, overcrowded, or under-used. Updating the current/planned occupancy of a room is just one of the possible activities to be carried out by the asset manager, but it is a good example of how the process can be interactive with the use of a BIM model and a Web page (Fig. 3).

The tool allows to insert two important values: the maximum/planned number of people inside a room and the actual number of people using it; these parameters allow to calculate the occupancy ratio, which can be seen as a KPI of the efficient use of a building.

The calculation procedure in this tool is really simple (and automated in the web page). The only operation done, for each room, is the ratio between the actual number of people in a room and the planned number. This provides the occupancy ratio, which can be 1 (used as planned), 0 (not used), $0 < x < 1$ (under-used), or >1 (overcrowded).

Here, some preliminary activities to be performed to use all the tools developed are presented (1–3 in Fig. 4):

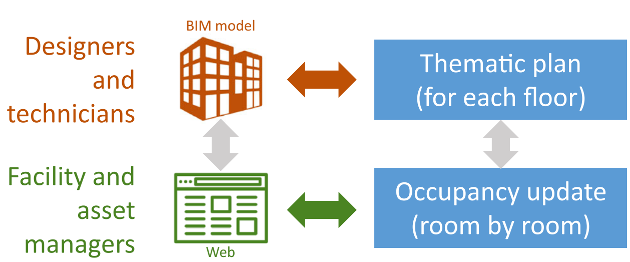


Fig. 3 Scheme of the space management tool

- Creation of the BIM model: this is the first and probably the most effort-consuming activity. Although the cost creating a model of an existing building is getting lower and lower, the money to be spent is not worth if the only purpose of the model is storing BCA data. The asset owner (or manager) must have a long-term strategy plan where the use of BIM is vital for all the asset management and not only for the assessment. In the latter case, this would probably lead to implementation costs higher than the savings.
- The second step consists in creating variables in the BIM model where to save data necessary to make the tool work. This was done creating some parameters for different objects of the BIM model (Autodesk Revit was used in the case study and these variables are called "shared parameters" of Revit entities). These parameters are necessary to assess the building and to provide the KPIs. They can be inserted in the template of the BIM model for a faster and safer adoption during the creation of the model.
- The third step consists in the connection of the BIM model to an external database. For this tool, the connection has been done using Revit DBlink (a plugin) and Microsoft Access. It is important to clarify that the connection is not a simple exportation of the model in a database, so allows users to implement and query data from/to both the BIM model and the database. Some other options are currently under assessment (e.g., direct connection to a MySQL database).

Then, the workflow to be followed to use this tool is quite straightforward (4–6 in Fig. 4):

- The user (facility or asset manager) fills the Web page with the occupancy data about each room, divided by level;

Fig. 4 Workflow of the space management tool

- The user (facility or asset manager) checks the charts in the Web page;
- The technician imports the data from the database to the BIM model;
- The technician submits to the facility manager the updated thematic plans;
- The user periodically updates and controls implemented values.

Mechanical equipment status

The behavior of MEP components can be described with few general conditions: working, working with issues and not working; after this generic assessment, a technician can assess causes and provide specific solutions for the component under analysis. However, during a survey (in case of routine inspection, handover, important maintenance operations, etc.), the operator needs to write down many notes in relation to the equipment analyzed and this could lead to mistakes or imprecise results. Having the complete list of components, associated with the room and the floor in which they are located, would lead to more precise work, better results, and less surveying time. Moreover, the information about components condition can be stored in the BIM model, using it a central information repository.

Despite the fact that it is related to a different topic, this tool is really similar to the previous one. It is made to simply trigger the condition of the mechanical equipment (fan coil, radiator, air terminal, chiller, boiler, etc.) inside each room. There are only three possible states of the component: working, not working, and unknown (not assessed yet). Each component is associated with a room, so to be able to easily find it; moreover, the Web page shows the ID of both components and rooms, so to be able to find them in the BIM model, if need be.

The only parameter that needs to be filled is a Boolean parameter named "Failure".

This tool has no calculation procedure, so the Web page simply counts the number of components, dividing them in working, not working, and not assessed.

The steps from 1 to 3 (Fig. 4) are still valid for this tool. Then, the workflow to be followed to use this tool is quite straightforward (4–6 in Fig. 4):

- The user (maintenance operator or surveyor) fills the Web page with the mechanical equipment condition, divided by level and by room;
- The user (maintenance operator or surveyor) checks the charts in the Web page;
- The technician imports the data from the database to the BIM model;
- The technician submits to the facility manager the updated thematic plans and the web reports;
- The user periodically updates and controls implemented values.

BCA tool

BCA is an activity frequently carried out in case of handover and in general when current asset condition is not known. In general, BCA activities provide a list of pathologies, maybe in combination with quantities and a rating; the results are contained in a report, frequently not directly connected with the as-built drawings. This lack of connection could lead to not updated and incoherent data and so to wrong decisions about maintenance and repair. The tool provided help for both surveyors during the assessment and managers in making their decisions.

The idea is to develop a tool able to make a qualitative assessment of the building and its part. This can be done by linking main components condition (e.g., walls, floors, false ceilings, services, etc.) to the room in which they are located, thus to control a limited number of objects. Therefore, the tool developed consists of three main sections:

- Building site assessment: objects assigned to the external spaces of the building (green areas, benches, external services, etc.) are evaluated with the help of some qualitative indicators;
- Building (as a whole) assessment: building components and systems that cannot be assigned to a single room (e.g., façade, roof, elevators, etc.) are evaluated with a set of qualitative indicators;
- Spaces assessment: each room of the building has a set of qualitative indicators that can be triggered by the

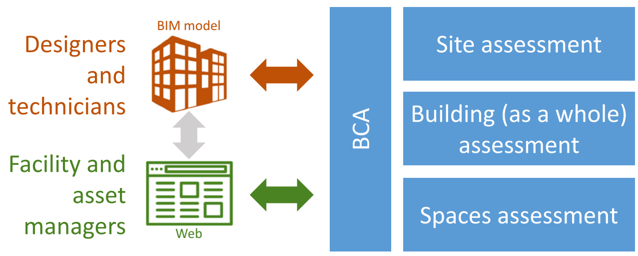


Fig. 5 Scheme of the BCA tool

user to describe (mainly) the condition of the finishing and of the services.

Figure 5 shows a scheme of the general framework of the tool.

The three main set of parameters, respectively, related to building site, building (as a whole), and spaces, are calculated with the support of visual inspections only, as it is a qualitative assessment tool.

For the site, the following parameters related to the condition have to be filled: (1) external furniture, (2) gates and fences, (3) external lighting fixtures, (4) irrigation, (5) flooring and signals, and (6) green areas.

For the entire building, the following parameters related to the condition have to be filled: (1) façades, (2) windows, (3) roof, (4) structures, and (5) elevators.

For each space, the following parameters related to the condition have to be filled: (1) wall finishing, (2) false ceiling finishing, (3) floor finishing, (4) window, (5) door, (6) structure, (7) lighting fixture, (8) plug, (9) heating, and (10) cooling.

Each section has a dedicated interface to be filled by the surveyor, with the possibility of triggering each parameter, assigning the correct value, out of a qualitative scale composed by five options: (1) optimal condition, (2) good condition, (3) light maintenance required, (4) working but in bad condition, and (5) not working—major maintenance works are required. This scale is slightly different according to the object of the assessment. There is also the possibility of indicating that the parameter is not evaluated (either because it is not possible or the object of the assessment is not present in the room). Each of the five values is associated with a score from 1 (best) to 0 (worst), so to be able to calculate an indicator for each category of objects and for the whole building. By filling all these parameters, the surveyor has all the raw data about the qualitative BCA; these values must be elaborated to become readable and comprehensible.

The idea beyond this BCA tool is to use simple procedures: the asset KPI is the simple average of Building (as a whole), Site, and Spaces KPI. The last KPI is a weighted mean of all single spaces KPIs, i.e., the KPI of each room of the asset, which is the average of the ten parameters previously described. Building (as a whole) and Site KPI are given by the simple average of the corresponding parameters. Main passages are highlighted in Fig. 6. Side by side to the KPIs, this tool is designed to measure how much of the building has been assessed; this is made possible by the list of rooms coming from the BIM model.

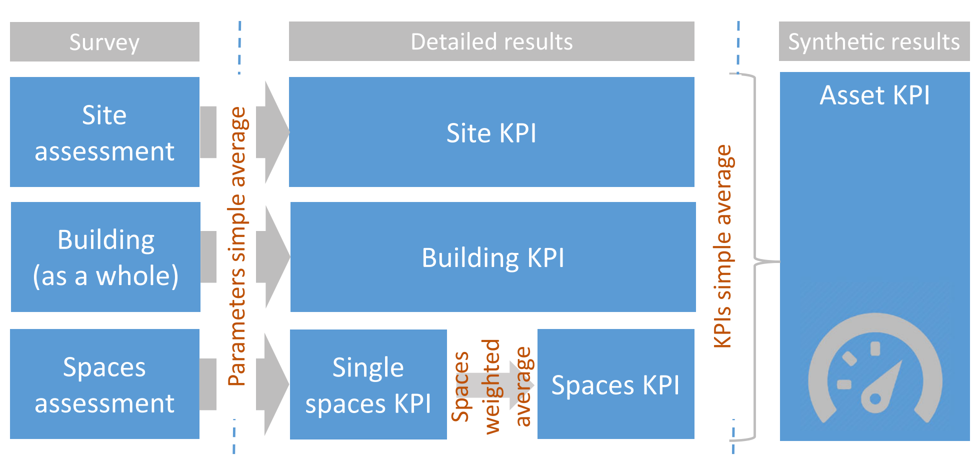
All the KPIs are computed by a Web application retrieving data from a database connected to the BIM model and then are saved back in the BIM model, in which they are used to produce and update thematic plans (plan views with color schemes) and schedules, according to users' needs.

The BCA workflow used is quite different from the ones found in literature and described in the state of the art because of the decision of using a BIM model to store asset data.

The steps from 1 to 3 (Fig. 4) are still valid for this tool. The main steps of the workflow are as follows (4–6 in Fig. 4):

- The fourth step is to survey the building to check the condition of the various parts. There is the possibility to insert the data coming from the survey in three different ways: (1) directly in the BIM model; (2) in the database

Fig. 6 Main step of the calculation process



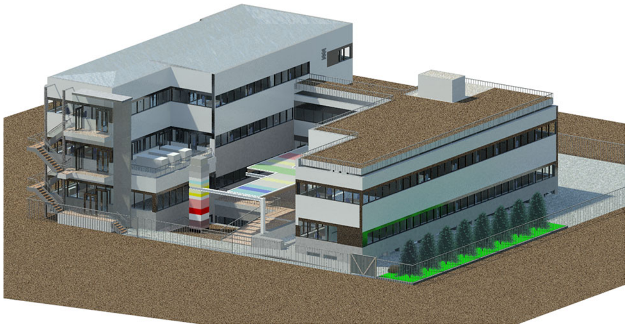


Fig. 7 BIM model of the case study

connected to the BIM model; and (3) using Web applications. The third option is the one developed by the authors, because it allows to interact with the model directly on field, saving time during the survey and providing more accurate and unequivocal data;
- The fifth step consists in the analysis of the results. This can be done in two ways: (1) directly from the model using thematic plans, i.e., plans that show graphically the BCA results highlighting, for example, rooms where the condition is lower than a minimum acceptable value or where a critical component is failed; and (2) checking the results online, within a Web application retrieving data from the database and computing the KPIs;
- The sixth last step is to periodically repeat the assessment (maybe before and after major works), so to always have the data aligned with the real condition of the asset. According to building type, extension, function, age, and maintenance policy, it is possible to schedule the periodic surveys, so to minimize users' disruption and costs overrun.

It is important to clarify that the Web interface and the database are not mandatory for the calculation of the BCA indicators, but they allow multiple categories of users to access information contained in a BIM model without a BIM authoring tool and even during the survey on site.

Service life planning

Service life planning is an activity that should be carried out during design (better early stages), before important maintenance and replacement works and even before transactions, to define what will be the useful service life of the components built or installed; in case of existing components, this activity is useful to compare the Estimated Service Life (ESL) with the Actual Service Life (ASL) [45]. This activity requires a big effort, as the same components in different parts of the building could have a different service life (as instance according to building orientation, height, function, etc.).

This tool is made to support facility and asset managers in scheduling maintenance and replacement operations. It allows to calculate the ESL (please refer to the "Mechanical equipment status" section) and to compare it with the actual service life (ASL) of a component, retrieved directly from the model. The output is the number of components with ASL $<$ ESL and with ASL $>$ ELS; the latter need to be maintained or replaced or, anyway, special cares as they could be probably affected by obsolescence (in terms of performances and functions).

The tool is set to implement data related to architectural components: walls, windows, and roofs; it can be easily implemented to manage data related to MEP components.

The user can insert, for each occurrence (instance of wall, window, roof), the 7 factors influencing the service life, while the ASL and the Reference Service Life (RSL) are not editable.

For each of the components analyzed, the equation described in the "Mechanical equipment status" section is automatically computed. The Web page then only counts the number of components under or above their RSL limit. It is possible to perform this assessment incrementally, as instance when a component is replaced or during inspections.

The steps from 1 to 3 (Fig. 4) are still valid for this tool. Then the workflow to be followed to use this tool is quite straightforward (4–6 in Fig. 4):

- The user (designer or facility manager) fills the Web page with the SLP planning data, divided by components types and categories;
- The user (designer or facility manager) checks the charts in the Web page;
- The technician imports the data from the database to the BIM model;
- The technician submits to the facility manager the updated thematic plans and the Web reports;
- The user periodically updates and controls implemented values.

Case study

The case study presented in this paper has the purpose of showing the possibility of an efficient implementation of BIM in the current asset management practice.

The building under analysis is an office building belonging to the Politecnico di Milano, built in the 60s and initially used as a steel warehouse. It has three stories above ground and one partially underground. Structures are mainly in reinforced concrete, while the internal partitions are made of clay bricks and gypsum boards.

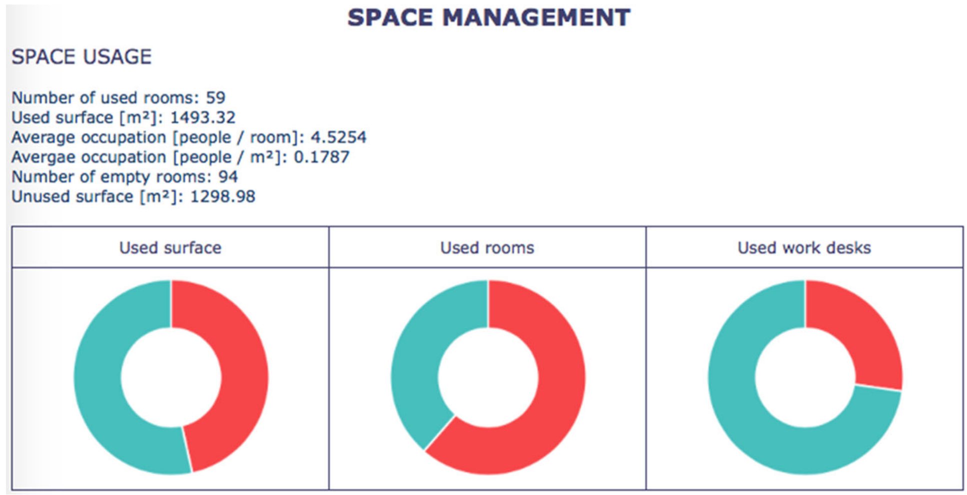


Fig. 8 Web interface of the space management tool

In this paragraph, the BIM model and the Web interface described above are presented, with the aim of clarifying the use and potentials of the tools and procedures developed.

The BIM model has been created with the aim of testing some tools and procedures under development and to periodically store and update data about the existing building.

The model (Fig. 7) has two main characteristics: (1) low Level of Detail (LOD, is the description of graphical content of models at each of the stages PAS 1192-2 [56]); and (2) high Level of Information (LOI, is the description of non-graphical content of models at each of the stages PAS 1192-2 [56]). The reason of this choice is that the case study is an existing building and a really onerous survey would be required to produce a model with high LOD. This would be different in case of new construction, with the possibility of gradually improving the model during design, construction, and use.

All the parameters described in the "Web tools" section have been implemented in the model, with the possibility to manage them from the model views (plans and project information). Then, the model has been linked to an external database using the Revit DBlink plugin. The database needs some adjustments to units of measure and numerical formats to be used (these changes can be imported from another template), but it is useful for three reasons: (1) it easily allows to compute the KPIs associated with the building and its parts; (2) it allows users to interact with the model without a BIM authoring tool; and (3) it is able to store life cycle data.

The main Web interfaces developed are presented in this paragraph aiming to show their functionalities and the potential of this kind of tools. The thematic plans can be considered the output of the tools inside the BIM model; they have the same importance of the Web pages, as they can show the building current situation at a glance.

Space management

A single Web page is used to enter the data related to occu-pancy, elaborate them, and check the results with a graph and some synthetic indicators (Fig. 8). The user can enter data related to maximum and actual occupancy of all the spaces that allow presence of people. The assessment can be incre-mental and the rooms not analyzed are considered not used.

The thematic plan (Fig. 9) shows the rooms with available desks or the rooms with a number of people higher than the planned. This plan is automatically updated each time the data are imported from the database to the BIM model; data are overwritten each time the model is updated, so this and following tools must be used following specific procedures, also developed by the authors.

Mechanical equipment status

A single Web page is used to enter the data related to mechanical equipment status, elaborate them, and check the results with a graph and some synthetic indicators (Fig. 10). The user can enter only one parameter related to the condition of the mechanical equipment (working/not working); it has been developed as an extremely simple procedure, to be used in the daily routine and not for a specific assessment (a specific BCA procedure is developed in the next paragraph).

The thematic plan (Fig. 11) shows the mechanical components working (green) or not (red). The plan involves a simple filter that marks as green or red the mechanical components, leaving blank the ones not assessed. This can be implemented further, inserting also

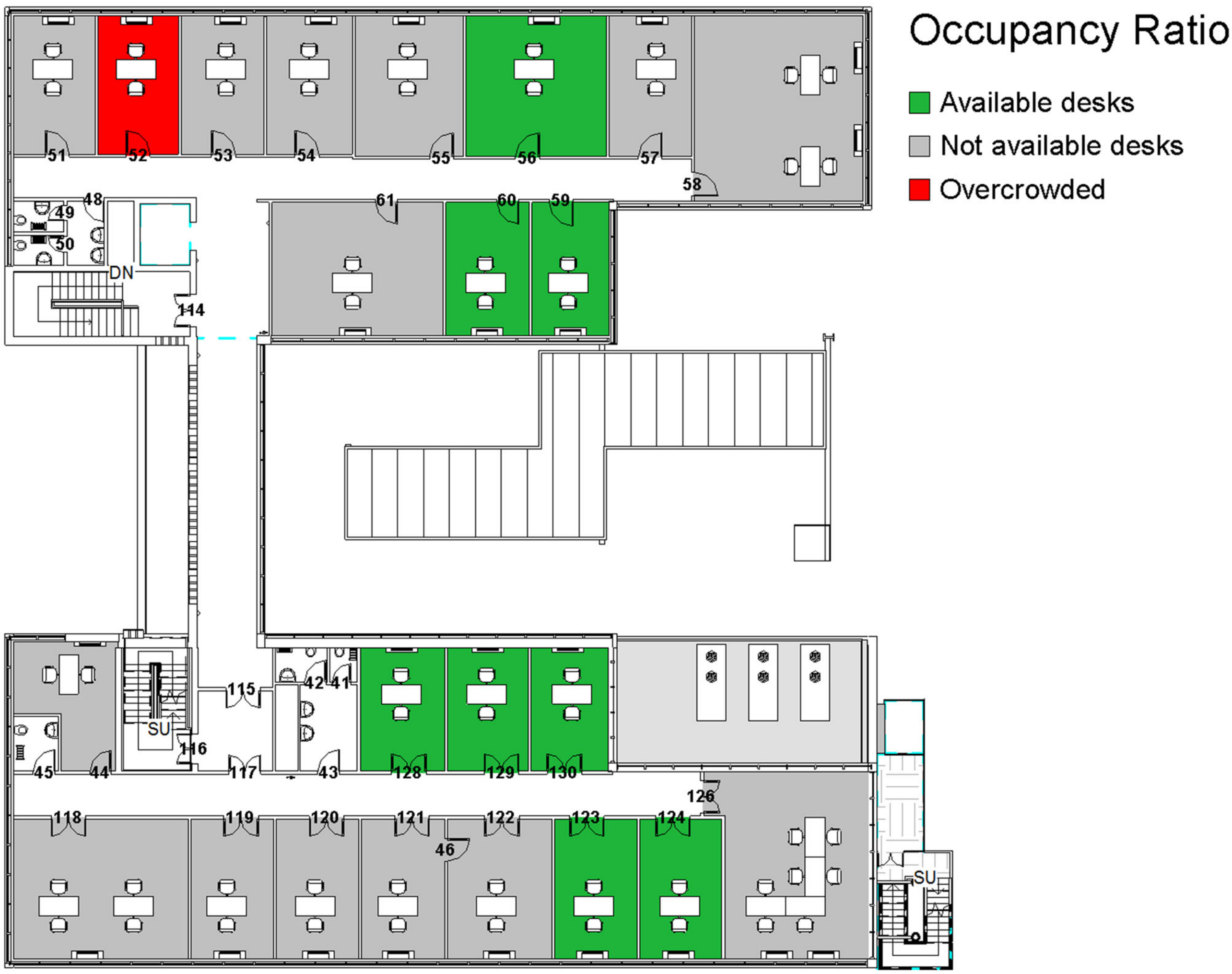


Fig. 9 Thematic plan of the space management tool

other relevant data, as instance: installation date, number of failures, maintenance expenditure, etc.

BCA tool

Some Web applications are used as database Web interfaces (an example is provided in Fig. 12) to: (1) read and update data from the database; and (2) compute KPIs and present data in an efficient way, allowing users to check and update building condition.

The results can be also seen in the BIM model as colored thematic plans (Fig. 13).

The thematic plan shows the rooms colored from green (good condition) to red (bad condition); the white rooms are not surveyed, as far as this work can be done incre-mentally. The data shown in the thematic plan do not reflect the real condition of the spaces; they have been inserted only to show the functionality of the tool (the real building has a score greater than 80% according to this procedure).

Service life planning

A single Web page is used to enter the data related to service life planning, elaborate them and check the results with some graphs (Fig. 14). Users can fill the data in specific sections provided. The data to be inserted are related to each single instance, because orientation, posi-tion, and maintenance level internal and external environ-ment change, as they are not related to the type of component. The tool allows to make an incremental assessment by marking in orange the components not analyzed.

The thematic plan (Fig. 15, left) shows the components within their RSL (blue) or not (red); components to be assessed are marked in orange. There is also the possibility

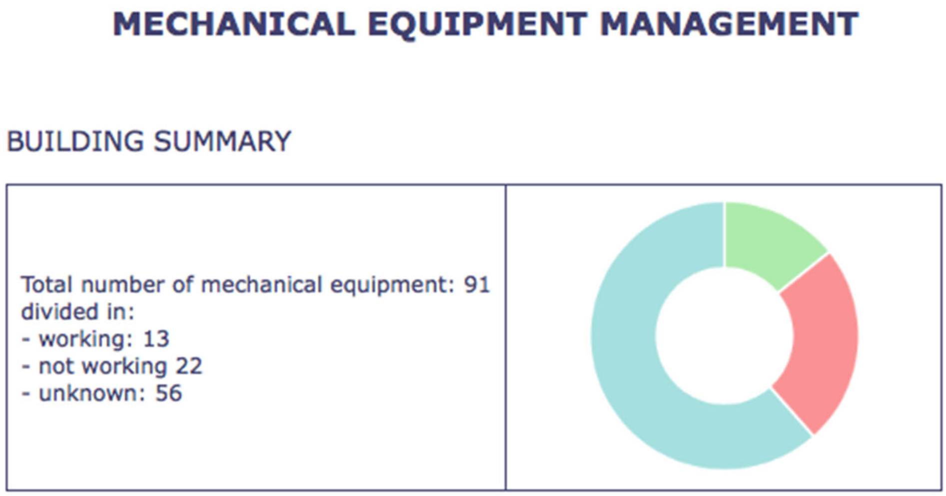


Fig. 10 Web interface of the mechanical equipment tool

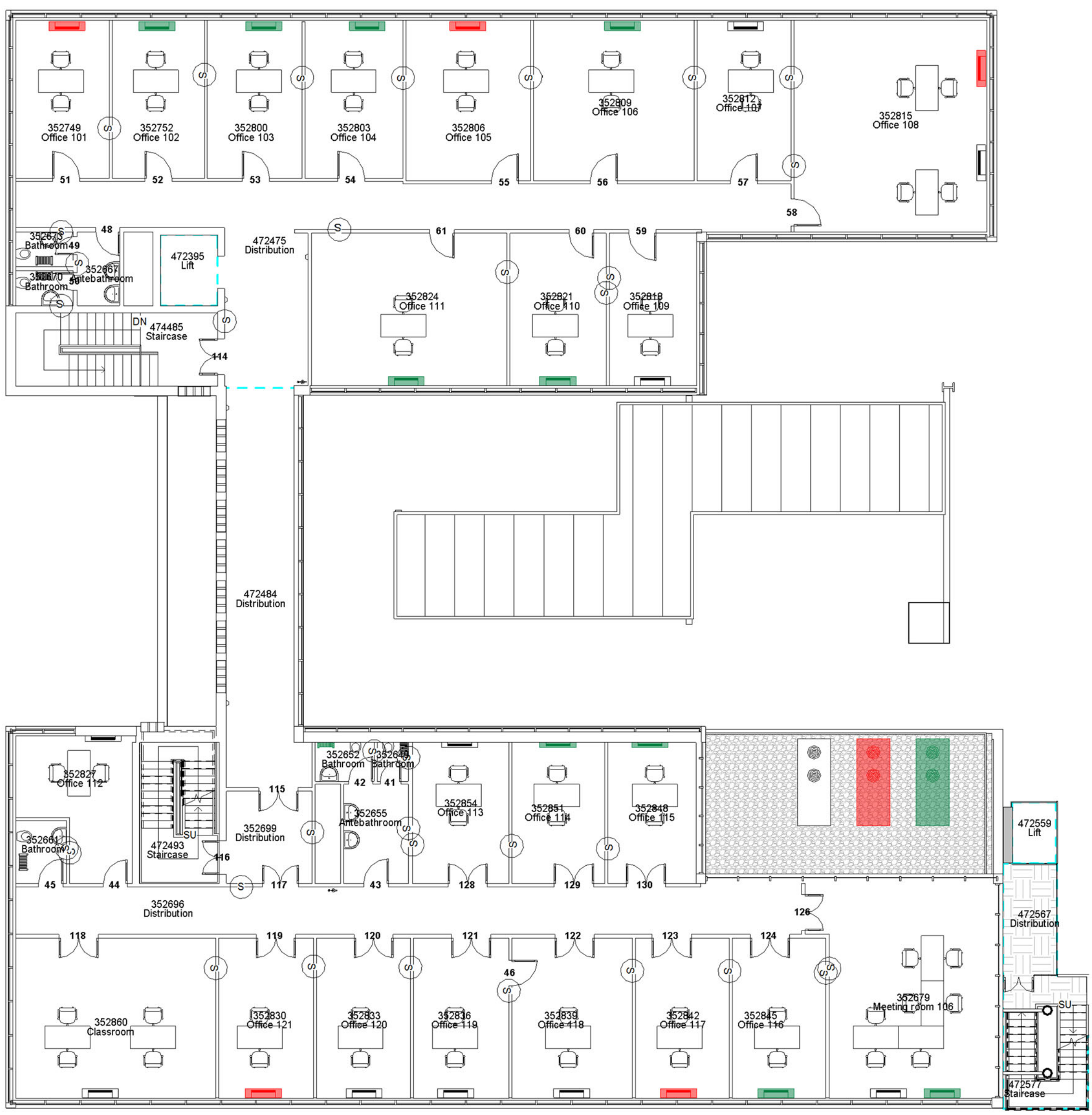


Fig. 11 Thematic plan of the mechanical equipment tool

Fig. 12 Web interface of the BCA (main KPIs)

of checking the data in a 3D view of the model (Fig. 15, right). Data can be also listed in a schedule, for a more detailed analysis.

Discussion and conclusions

Building Information Modeling is an emerging innovative methodology that can be used to improve performance and productivity in any phase of an asset lifecycle: design, construction, operation, and maintenance [57, 58]. In addition, in refurbishment projects, a form of BIM may provide greater value as it can provide improved visibility of existing physical asset sizes/condition and clearly shows any remodeling changes—leading to a better final project information result [59].

This research proved that "starting with the end in mind" is not only a statement strongly advocated for all projects but a must for BIM adoption in asset management and that enhancement in asset management can be obtained from the use of BIM models only if new procedures and tools are adopted to cope with BIM opportunities and limitations.

The huge amounts of information that a BIM model can store and the reliability of data makes the adoption of BIM in an asset management process economically feasible only if it is planned from the early stages and if client's BIM implementation strategy is properly communicated to the suppliers [59]. Even if planned, a complete BIM model for an existing asset can be too expensive to be made; thus, a lot of effort should be put in defining type and quantity of data needed. Another hurdle that prevents BIM adoption in asset management is the accessibility of data by people that do not use BIM authoring tools. Stakeholders have the need to access data in an easy way, without using complex instruments and focusing only on the relevant data.

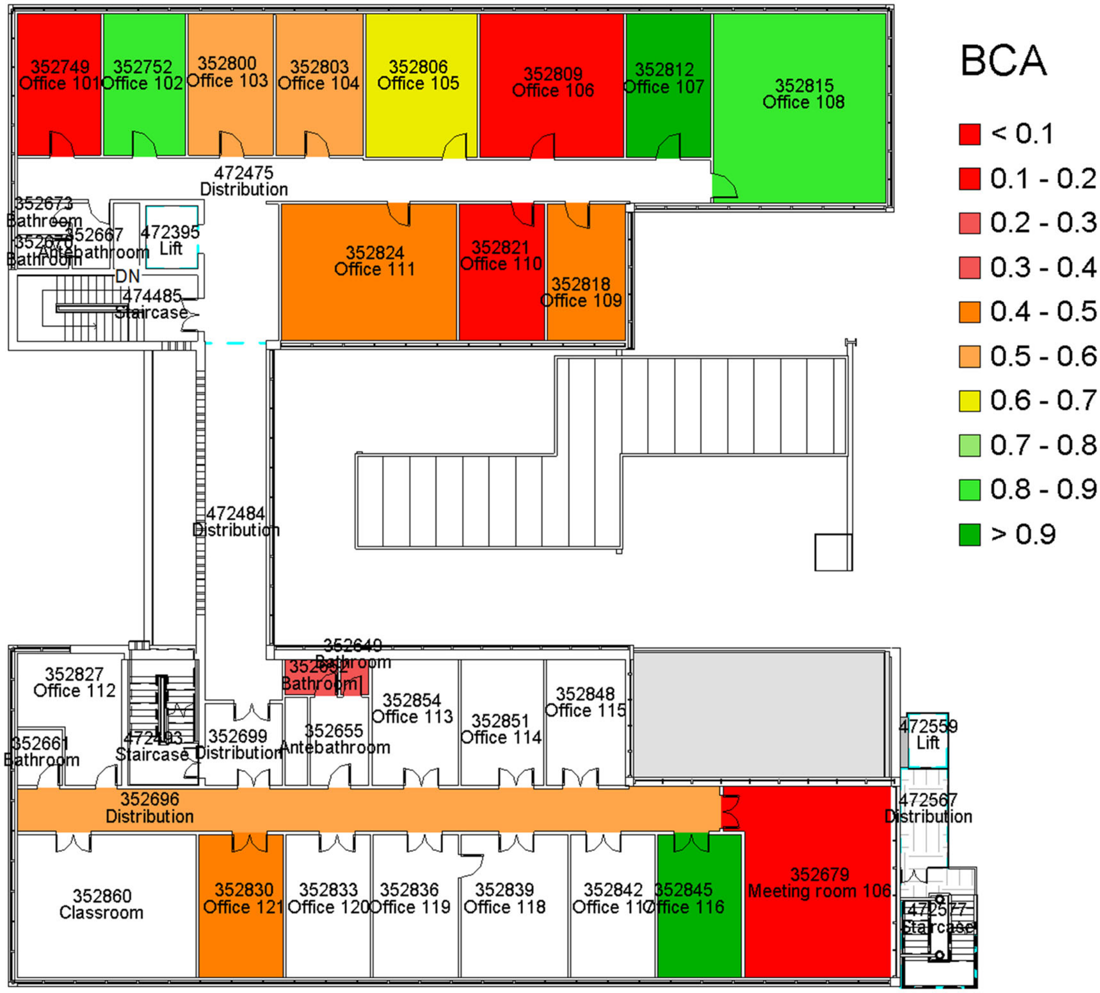


Fig. 13 Thematic plan of the BCA tool

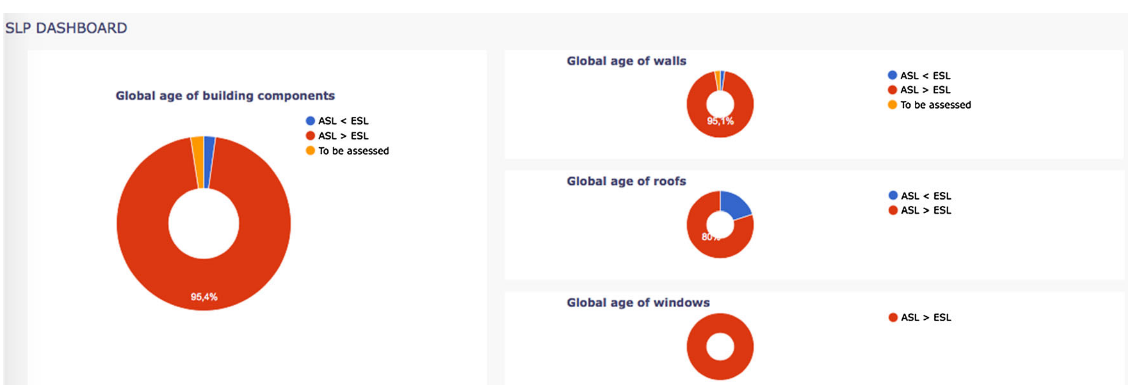
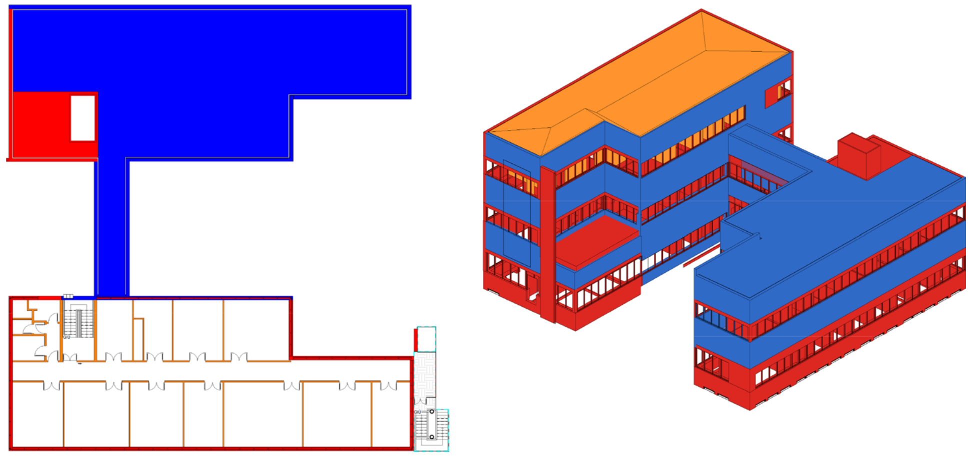


Fig. 14 Web interface of the service life planning tool (graphs)

The property of the data in a BIM environment, as well as in cloud services, is an actual and important topic [60]: many users are hesitant in exploiting BIM in their companies and organizations for the fear of losing their data. The tools developed are meant to demonstrate the possibility of transposing asset management procedures into a BIM environment; as this possibility is confirmed, there is the need to develop a fully working software, but also precise procedures to share and elaborate data. These procedures are contained in BIM guidelines that authors

Fig. 15 3D view of the BIM model for service life planning



are currently developing. Moreover, the tools developed help the client in keeping the data, as they are stored in the model, while the user of the tools can access and interact only with the Web pages defined by the client, as instance the ones to input data and not to calculate KPIs; nevertheless, this topic should be investigated further.

The research proved that a BIM model with low level of detail and high level of information can be profitably used in asset management if specific procedures and tools are developed. The transition from a traditional asset management system to a BIM one has of course significant starting costs (mainly related to training of personnel and internal workflows re-organization), but it surely leads to results, both in terms of savings and quality of the results. The tools and the connected procedures developed help in dealing with the real estate, improving the knowledge about the asset and storing the data in the Asset Information Model (AIM), intended as the digital representation of the physical asset; in this way, data are readily available to every stakeholder, who can update and manage them according to his needs.

This research, even if with a preliminary case study, demonstrated that the transition to BIM technologies is not only feasible, but also profitable in terms of savings and precision of the output.

Eventually, there is a lot of space for improvements and expansions towards other topics related to asset and portfolio management, which will be investigated during the next months. Among them, there is a strong need to develop guidelines and procedures to store, access, and share data from/to CAFM software, creating a Common Data Environment that enables stakeholders to interact in an efficient way, especially during building operation. Another interesting research topic to deepen is the interaction of building users with some simplified data contained in the model, as instance for energy monitoring and space management. Eventually, to enhance tools interoperability, there is the need to investigate the possibility of using IFC attributes instead of custom parameters.

References

1. Aziz ND, Nawawi AH, Ariff NRM (2016) ICT evolution in facilities management (FM): building information modelling (BIM) as the latest technology. Procedia Soc Behav Sci 234:363–371
2. Kensek K (2015) BIM guidelines inform facilities management databases: a case study over time. Buildings 5(3):899–916
3. British Standards Institution (PAS 1192-3) (2014) Specification for information management for the operational phase of assets using building information modelling. British Standards Institution, London
4. Cagle RF (2003) Infrastructure asset management: an emerging direction. In: AACE international transactions, PM21
5. Fazli A, Fathi S, Enferadi MH, Fazli M, Fathi B (2014) Appraising effectiveness of building information management (BIM). Proj Manag Procedia Technol 16:1116–1125. doi:10.1016/j.protcy.2014.10.126
6. International Organization for Standardization (ISO 55000) (2013) Asset management—overview, principles and terminology. ISO, Geneva
7. BBC Bitesize (2015) Decision-making in business. http://goo.gl/35UyRY. Accessed 17 July 2015
8. Ente Italiano di Unificazione, UNI EN 15221-1 (2007) Facility management—Part 1: Terms and definitions. Ente Italiano di Unificazione, Milano
9. International Organization for Standardization (ISO 21504) (2015) Project and programme portfolio management. ISO, Geneva
10. Gallaher MP, O'Connor AC, Dettbarn Jr JL, Gilday LT (2004) Cost analysis of inadequate interoperability in the U.S. Capital Facilities Industry (NIST GCR 04-867). U.S. Department of Commerce Technology Administration, Washington, DC
11. Teicholz P (2013) BIM for facility managers. IFMA Foundations, Houston
12. Jung J, Hong S, Jeong S, Kim S, Cho H, Hong S, Heo J (2014) Productive modeling for development of as-built BIM of existing indoor structures. Autom Constr 42:68–77
13. Wang C, Cho YK, Kim C (2015) Automatic BIM component extraction from point clouds of existing buildings for sustainability applications. Autom Constr 56:1–13
14. Sabol L (2008) Building information modeling and facility management. Des Construction Strat 1:13
15. Liu DL, Zhu XB, Xu KL, Fang DM (2014) Design and development of as-built document management system based on BIM. Appl Mech Mater 513–517:2492–2495

16. Wang S (2013) Integrated digital building delivery system based on BIM and VR technology. Appl Mech Mater 380–384:3193–3197
17. Kazi AS, Aouad G, Baldwin A (2009) Lifecycle management of facilities components using radio frequency identification and building information model. J Inf Technol Constr 14:238–262
18. East B (2014 Construction-Operations Building Information exchange (COBie). https://www.wbdg.org/resources/cobie.php. Accessed 8 Sept 2015
19. M-six (2015) VEO—connecting designer, builders and owners. http://www.m-six.com. Accessed 13 Sept 2015
20. AR-media (2015) Augmented reality media. http://www.armedia.it. Accessed 13 Sept 2015
21. Technical Research Centre of Finland—VTT (2015) Mobile augmented reality for building maintenance. https://www.youtube.com/watch?v=uYFtYbqvoq0&feature=youtu.be. Accessed 13 Sept 2015
22. Behzadan AH, Dong S, Kamat VR (2015) Augmented reality visualization: a review of civil infrastructure system applications. J Adv Eng Inf 29:252–267
23. Meza S, Turk Z, Dolenc M (2015) Measuring the potential of augmented reality in civil engineering. Adv Eng Softw 90:1–10
24. Koch C, Neges M, König M, Abramovici M (2014) Natural markers for augmented reality-based indoor navigation and facility maintenance. Autom Constr 48:18–30
25. Gu N, London K (2010) Understanding and facilitating BIM adoption in the AEC industry. Autom Constr 19(8):988–999. doi:10.1016/j.autcon.2010.09.002
26. Jung Y, Joo M (2011) Building information modelling (BIM) framework for practical implementation. Autom Constr 20(2):126–133. doi:10.1016/j.autcon.2010.09.010
27. Parsanezhad P, Dimyadi J (2014) Effective facility management and operations via a BIM-based integrated information system. In: CIB facilities management conference. Technical University of Denmark, Copenhagen, pp 1–12
28. Uzarski DR, Grussing MN, Clayton JB (2007) Knowledge-based condition survey inspection concepts. J Infrastruct Syst 13(1):72–79
29. Percy DF, Kobbacy AH (2000) Determining economical maintenance intervals. Int J Prod Econ 67(1):87–94
30. Ahluwalia SS (2008) A framework for efficient condition assessment of the building infrastructure. University of Waterloo, Waterloo
31. ASTM, E2018-08 (2008) Standard guide for property condition assessment: baseline property condition assessment process. ASTM, West Conshohocken
32. Royal Institute of Chartered Surveyors (RICS) (2002) Stock condition surveys—RICS guidance note, 2nd edn. RICS, London
33. Standard & Poor's (1995) Property condition assessment criteria. Structured Finance Ratings Real Estate Finance, New York
34. Department of Infrastructure Australia (1996) Asset and building policy, information sheet 14—condition assessment, a strategic look at your constructed assets. Department of Infrastructure Australia, Canberra
35. Baird G, Gray J, Isaacs N, Kernohan D, McIndoe D (1996) Building evaluation techniques. McGraw-Hill, New York
36. Shohet IM (2003) Building evaluation methodology for setting maintenance priorities in hospital buildings. J Constr Manag Econ 21(7):681–692
37. Johnston DR, McFallan SL, Tiley PA (2002) Implementation of a property standard index. Facilities 20(3/4):136–144
38. Rodrigues MFS, Teixeira JCM, Cardoso JCP (2010) Building envelope anomalies: a visual survey methodology. Constr Build Mater J 25(5):2741–2750
39. RILEM 166-RMS, CIB W083 (2003) Condition assessment of roofs—final report of the condition assessment task group. CIB General Secretariat, Delft
40. Flores-Colen I, De Brito J, De Freitas V (2011) On-site performance assessment of rendering façades for predictive maintenance. Struct Surv 29(2):13–146
41. Ximenes S, De Brito J, Gaspar PL, Silva A (2015) Modelling the degradation and service life of ETICS in external walls. Mater Struct 48(7):2235–2249
42. American Society of Civil Engineers (2014) ASCE/SEI 30-14—guideline for condition assessment of the building envelope. American Society of Civil Engineers, Reston
43. Roulet C-A, Flourentzou F, Labben HH, Santamouris M, Koronaki I, Dascalaki E, Richalet V (2002) ORME: a multicriteria rating methodology for buildings. Build Environ J 37(6):579–586
44. Salim NAA, Zahari NF (2011) Developing integrated building indicator system (IBIS) (a method of formulating the building condition rating). Procedia Eng 20:256–261
45. International Organization for Standardization (ISO 15686–1) (2011) Buildings and constructed assets—service life planning—Part 1: General principles and framework. ISO, Geneva
46. Hovde PJ, Moser K (2004) Performance based methods for service life prediction. CIB report: publication 294. CIB, Rotterdam
47. Hovde PJ (2005) The factor method—a simple tool to service life estimation. In: Proceedings of 10th DBMC durability of building materials and components, Lyon, France
48. Moser K (1999) Towards: the practical evaluation of service life—Illustrative application of the probabilistic approach. In: Lacasse MA, Vanier DJ (eds) Proceedings of the 8th DBMC durability of building materials and components 8. Vancouver, NRC Research Press, Ottawa, pp 1319–1329
49. Re Cecconi F (2004) Engineering method for service life planning: the evolved factor method. In: Proceedings of building for the future: the 16th CIB world building congress, Toronto, Canada
50. Emídio F, De Brito J, Gaspar P, Silva A (2014) Application of the factor method to the estimation of the service life of natural stone cladding. Constr Build Mater 66:481–493
51. Silva A, De Brito J, Gaspar P (2016) Methodologies for service life prediction of buildings: with a focus on façade claddings. Springer, Cham
52. International Organizarion for Standardization (ISO 15686–4) (2014) Building construction—service life planning—Part 4: Service life planning using building information modelling. ISO, Geneva
53. International Organizarion for Standardization (ISO 16739) (2013) Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. ISO, Geneva
54. Becerik-Gerber B, Jazizadeh F (2012) Application areas and data requirements for BIM-enabled facilities management. J Constr Eng Manag 138(March):431–442. doi:10.1061/(ASCE)CO.1943-7862.0000433
55. International Organization for Standardization (ISO 15686–8) (2008) Buildings and constructed assets—service-life planning—reference service life and service-life estimation. ISO, Geneva
56. British Standards Institution (PAS 1192-2) (2013) Specification for information management for the capital/delivery phase of construction projects using building information modelling. British Standards Institution, London
57. Love PED, Simpson I, Hill A, Standing C (2013) From justification to evaluation: building information modeling for asset owners. Autom Constr 35:208–216
58. Succar B, Kassem M (2015) Macro-BIM adoption: conceptual structures. Autom Constr 57:64–79
59. UK Ministry of Justice (2016) STD/BIM/P001.1 BIM2AIM Quick Start Guide, version v1.5
60. Alreshidi E, Mourshed M, Rezgui Y (2017) Factors for effective BIM governance. J Build Eng 10:89–101