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Refurbishment and School Buildings Management in a Smart Building Environment

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Abstract. Building Information Modelling is a methodology, which is able to take into account many data, both geometrical and non-geometrical, in order to evaluate at the actual condition of the asset. The project has the scope of evaluating the conditions of different school buildings, in order to develop a way to choose the best-tailored management solution to the owner. A further step is the management and planning of design solutions during the life cycle customized on monitored buildings' conditions. The research work focuses on providing a support decisions concerning the gap between the present building state laws and the current state of the existing buildings. The process will be developed in an expanded BIM environment, using sensors, which will give back the state of the consistency of the actual conditions to enable the buildings to adapt themselves in the best way into their specific constraints and boundaries. The results of the study are (i) a complete workflow to make decision and the possibility to shape the decision process on an objective through a scientific approach, (ii) evaluate the current state of the asset and (iii) manage maintenance in the lifespan. Further development will take in consideration all the aspects related to management of big data environment generated by a smart buildings system.

INTRODUCTION

Building Information Modeling (BIM) is one of the most promising field of development in AEC industries and it can be defined as a Project Management methodology (Peterson et al. 2011). BIM allows a coherent and all-embracing view of the project; its application to existing building needs to start from a deep study of the documents concerning building fact-finding. The allocation of information in the model gives many benefits to the building maintenance phase, since all documents are available and well organized in the same location and wherever accessible. In this new IoT era (Zanella et al. 2014), data are crucial in order to support decision processes (Castellani et al. 2010) and the partial autonomization of these processes is a key feature of the Industry 4.0 concept. Through the application of BIM to refurbishment interventions, the research addresses the description of a path that can promote a traditional asset manager to an expert one who could understand and support his/her decisions on a computational approach. Current Laws impose a wisely evaluation of building management and in particular European Directive 24/2014 (European Union 2014) suggests an evaluation of building lifetime cost instead of an based-on-construction evaluation. At national level the Government is discussing about the introduction of BIM in the public contract and scheduled introduction phases and references are under review and debate. The main statement is that the transition to BIM is necessary however; a phase on soft landing introduction should be triggered for a twofold reason. As first, to allow the contracting authority to get in touch with BIM methodology and approach which primarily could enable them to ask for BIM in an appropriate and aware manner; secondly to lead the construction enterprises to a mature stage to propose complete BIM approaches and not only Bimifications of

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traditional processes. Nowadays there is a strong polarization of BIM methodology and Bimification of projects. The government invested on existing school building stock to increase the quality of buildings with focused policies to enhance the health and beauty of the more than 42,000 schools in Italy. The Government action is oriented to promote energy efficiency (Governo Italiano 2015) as one of the main challenges of the future. The goal is not only to control the energy running costs, but also improving pupils' health conditions by means of innovative learning environments (Governo Italiano 2015), and, last but not least, the growth of awareness on environmental issues of the younger generation (Di Giuda et al. 2016). The government programme promoted the introduction of BIM into design contests to gather new project for schools nevertheless many proposed projects started from traditional design process and introduced the digitalization as the last step to present and visualize data. This kind of approach can be defined as Bimification and it can be seen as a required step on implementation towards a mature state of BIM into design and construction process at national level. The proposed methodology aims at promoting a comprehensive approach to digitalization of assets to enable the connection of databases and enable life cycle management in a "kaizen" (Imai 1986) vision of progressive improvement on a real-time controlled environment enabled the framework of the digitalization.

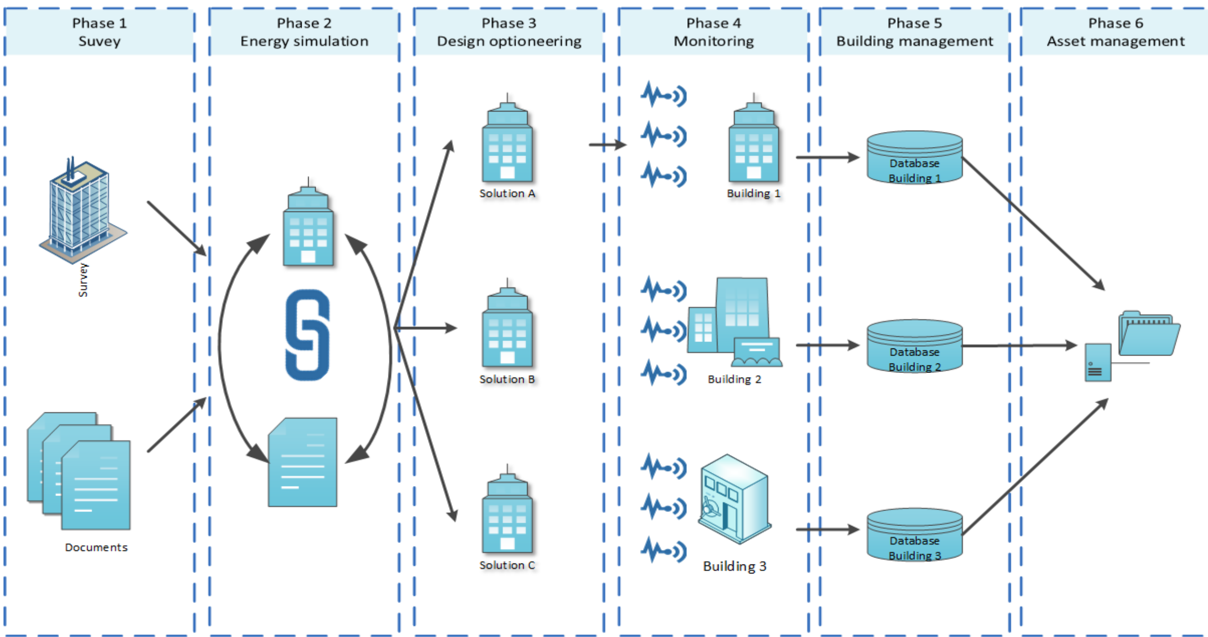

FIGURE 1. Methodology workflow to frame the smart city by digital twins of the assets, which enable the real-time control and maintenance of the buildings.

Smart buildings should constitute the future city and a digital framework will be the structure of the path to reach a networked control of the management flows and processes in the life cycle. Six steps establish the path to reach the objective; in particular, the former consists in a survey of the on-site situation and the collection of all documents concerning the building. After this first analysis effort, a BIM model enables further considerations such as energy assessment, structural analysis, quantities computation, etc. Energy retrofit is a driver for further implementations and could be the key factor to adopt specific solutions in consideration of technical and economic constraints. A comparison between requirements by law and building performances provides a first estimation of the gap to be filled; from this result, through Design Optioneering method and a structured multi-criteria analysis, design choices are figured out to achieve a compliant with legal standards building scenario or going a step further towards a Net Zero Energy Building. Moving on to the subsequent phase for each building the most suitable technological solution is promoted and realized and a monitoring plan is developed and actuated to gather data from each asset of the networked city. The digital twin of the building is used as a database of geometrical and alphanumerical data which are the computable and machine readable information about the building and the indoor conditions to enhance users' wellbeing and promote a healthy lifestyle. The main use of data collected through sensors inside the building can be listed as the following (Ciribini et al. 2017):

- Inform and visualize data to increase awareness and communication;

- Check and verify the indoor conditions to adjust the parameters according with the users' preferences or energy targets;
- Analyze parameters and condition in order to achieve standard or improved comfort conditions, getting better experience for the users and providing information to the energy manager;
- Control and report to check constantly the conditions, prevent faults, and operate with a predictive maintenance procedure.

The asset management is based on data collection, data mining and predictive models developed on data. The AI that can be applied to computational information allows filtering and defining scenarios based on real-time data gathered by sensors and promoting the autonomization of such a process that can be activated on machine-readable criteria. In this way it is eased to focus the attention and detailed simulation on critical factors which need a more specific framework of analysis. In the smart city context, it is not possible to hypnotize to promote manual processes and custom adjustment of the conditions but it is reasonable to reduce the user active behavior on that kind of processes needing tailored procedures. The more the process is autonomous the less inconsistencies should be faced and users' preferences could shape the scheduled behavior of a responsive building. Frequently the performance gap that is retrieved derives by interrupted information chains and approximation in modelling the energy behavior of the building and users' fluctuation introduces a harsh factor to be included into the analysis. The building digitalization introduced a further possibility to experience crowd simulation and predict people flows and behavior through automated feedback analysis. The behavioral design (Cecconi et al. 2017) introduces the occupancy variable to reduce the referred gap (Tagliabue et al. 2016) and also studies about how to include the users into the information loop (Rinaldi et al. 2016) through IoT (Internet of Things) could be implemented into the workflow (Ciribini et al. 2017).

ENERGY SIMULATION BASED FOR PREDICTIVE MODELS

The energy performance of an existing building can be evaluated referred to the energy bill and consumption of the actual construction however some specific aspects of the thermal or electric behavior could be lost in the fixed number provided by the public utility. Building Energy Modelling (BEM) are used to analyze the performance and provide a reliable predictive model of the energy behavior in different configurations providing a powerful tool to analyze technological and economic scenarios. The possibility to link a BIM model to a BEM model, i.e. to use the same information stored into the BIM model directly translated into the energy model could assure a congruity in forecasted results which will be strongly beneficial, decreasing time consuming manually implemented dynamic energy models. The national law since 2005 (Governo Italiano 2005) a mandatory certification of the building in order to make the assets comparable in the real estate market. The energy simulation has been defined through significant parameters for energy simulation in steady-state regime and without using a geometrical model (i.e. the geometrical information should be included by dimensions extrapolated data but no 3D model is required or base on). This kind of calculation is a standard use simulation, which is not fitted or tuned on the real performance and can be useful for a standard comparable value, as ones used for photovoltaic modules, to introduce a threshold quality value for new buildings. In case of new buildings the energy performance, defined through the standard value calculated into steady-state regime as required by the regulations (Governo Italiano 2015) can be enriched with dynamic simulation to better estimate the energy behavior taking into account the transient thermal flows and the effect of the thermal mass. This kind of simulation provides a more reliable value of the building performance however, the performance gap should be reduced through a tuning process fitted on actual, real-time monitored data. For that reason, the new efficient buildings trying to achieve significant results in energy saving during the life cycle are analyzed by dynamic model and BEM is a further document to link to the digital model of the building. To use the BIM data into the BEM model is a first step for congruity and robustness of the model and transferring sensor data to BIM model is the second step. For existing buildings, the survey procedure harvests data for different models. Each of them includes all the information related to specific discipline (i.e. structural, architectural and MEP); in this way, it is possible to perform further analyses providing the teamwork with results and data that could figure out how to make an effective refurbishment plan, maintenance schedule, or specific improving works. BIM models are a repository of information from which is possible to extrapolate assumptions. This process allows verifying the result related to different analyses (e.g. energetic, acoustic and structural); otherwise, the benefits of connecting all the building aspects in the same database would be lost. Analyzing the consequences of each scenario of the design optioneering, an optimized solution in terms of cost, global performances and construction schedule is one of the key advantages of the application of the BIM methodology.

DESIGN OPTIONEERING

An additional consideration is related to the use of the BIM model to make supplementary evaluations on the suggested operational proposals. Complexity is an essential topic in AEC industry and Building Information Modelling allows an all-embracing view and control of the project. The parameters, which should be taken into consideration, make design choices difficult, because they are not based on the best solution, but on what fits better that particular project. The strategies, defined each time, take into consideration the European directive 23, 24 and 25/2014 were issued (Italian Parliament 2016; Italian Parliament 2017; European Union 2014). They aimed at increase freedom in the choice of the authorities, but in the meanwhile asking them more empowering skills. In this way, the owner will define the criteria on which evaluate the design choices, based on punctually defined need. Multicriteria decision analysis (MCDA) (Franco & Montibeller 2009) is a methodology for supporting decision making (phase 3), when multiple objectives have to be pursued (i.e. performances, cost target), has been extensively used to support complex decision problems in many field (i.e marketing, research and development evaluation, financial planning and medicine). In this way, a solution is not chosen by making the decision on a single aspect but on a multicriteria analysis.

We can assume that it is possible to evaluate in the same way a public tender and an internal choice for refurbishing a building. The principle that constitute Most Economical Advantageous Tender (MEAT) is suggested by the UK cabinet (UK Cabinet Office 2014; Lenferink et al. 2013) and Italian government (Di Giuda et al. 2015) as the correct way to evaluate a project.

This change of mind allows a different approach, namely it is possible to base a series of consideration, which usually are just based on an economical point of view, with this method are performance based. This methodology has the ability to provide a solution, which is not the best in absolute terms, but will be the one that fits better the owner needs. In particular, criteria are split in three categories: (i) technical, (ii) temporal and (iii) economic. It is possible with ponderation to evaluate each solution in a quantitative and mathematical way. According to Pardalos (Pardalos & Horst 1995), this perspective change allow an alignment the initial objective to the final result. Only through a methodology that allow an all-embracing view of the project is possible to achieve the optimal solution, hence BIM evaluation method allow an automatically evaluation of buildings.

REFURBISHMENT THROUGH SMART CITIES AND ASSET MANAGEMENT

Nowadays, life conditions are evolving and, on the same way, the interaction between men and buildings changed. According to BIM strategy, after BIM Level 3 (Zong et al. 2017), the next step that will bring people in a completely connected word is the link between men and buildings in a cloud-base system. That possibility can allow producing a huge amount of data and they could provide analytics possibly to produce statistics on the real performance of the envelope.

Enhanced Facilities Management and derivative services associate design layout views with real-time status information. Through the system and the interaction evolution, we can obtain a smart building, which adapts itself related to the context conditions. This kind of building could choose the best way to configure themselves to obtain best performances.

The integration of sensors (phase 4) in the whole building allows monitoring the rooms' thermal performance, testing design solutions, and the indoor comfort levels. All the data collected will be processed, elaborated and shared to continue promoting a sustainable model, applicable to improve the users' condition or future asset development.

Sensors record space condition continuously and they provide a huge amount of data and their analysis is related to the four Vs that are commonly used to define the complexity of Big Data phenomenon: (i) volume, (ii) variety, (iii) veracity and (iv) velocity (Chen et al. 2014; Gudivada et al. 2015). One of their main problem is the sensor reliability, because they have to be set to properly provide data and they could not be well calibrated, this fact could affect further considerations.

Owner advantages could be individuated in the continuous monitoring of the building. These Cognitive Buildings have the ability to monitor and acquire data in order to calibrate automatically the system. Hence, users could be able to choose, for example, the configuration of the shading to minimize solar gain in summer or the way to produce energy (Zong et al. 2017). Those benefits could be obtained only if we collect data in an automatic way. Sensors are able to mix data from different sources; this process, otherwise, was not able to be process by a human being in real time. All data collected from sensors are stored in a unique database that allow managers to check and validate building condition at any time.

One of the main aspect related to BIM is the correlation and coherence between graphical and non-graphical information. This link allows having information related to each elements and always updated. This relation is based on the fact that sensor could be collected and stored in DB linked to the model (phase 5). This way of manage a big amount of data allow to have an historical data storage, which is a repository for all the information collected and they can be used to (i) check how the buildings is acting, (ii) compare to the design hypothesis of the model and (iii) make further evaluation on future maintenance measure (Eastman et al. 2011). As past experiment suggested by Jung (Jung & Joo 2011), this methodology allows an all-encompassing management view of the asset. According to Liu (Liu & Issa 2012), BIM models are wasted, especially for large owners (Kensek 2015), if models do not provide correct e reliable information on the as-built status to the facility manager. Facility management benefits from the integration of sensors and buildings, because cognitive buildings could provide them a series of information (i.e. energetic, MEP, comfort) to well understand building problems, before they cause damages and intervene fixing.

CASE STUDY

The school building, designed for 500 alumni, is site in Melzo (Italy), it was developed as a research project in collaboration with the working group led by Prof. Giuseppe M. Di Giuda of the Politecnico di Milano. The building is divided into three functional and technologically separate parts: (i) the first of which is a central reinforced concrete spin that connects all rooms with administrative function (teaching, library and auditorium) by the central corridor; (ii) the second body is linked to the former and it is composed by three blocks with a wooden structure, they contain teaching classrooms and workshops; (iii) the third part is a double height body made of precast concrete elements and it contains gymnasiums, canteens and technical rooms.

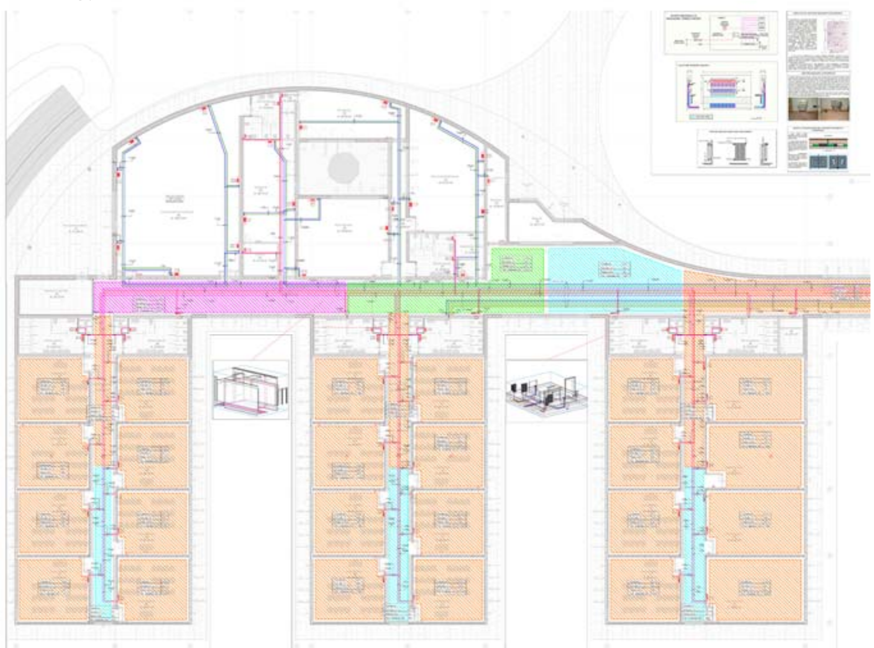

FIGURE 2. Melzo Primary School, plants distribution and sensors location

This case study was developed to evaluate performances, consumption and use model of a school complex. These reasons led researchers to place different sensors (as shown in Table 1). Fig. 2, instead, shows their location.

Now the building construction is finished on schedules and without extra costs due to the BIM process adopted allowed a high level of coherence of the project which removed unpredicted problems and issues that often affect complex buildings.

TABLE 1. Melzo Primary School, plants distribution and sensors location.

Symbol	Description
TP	DDC 4200: Automation Station with Color Touch Screen TFT Touch Screen (5.7 "), BACnet IP Protocol, Integrated Web Browser, has 56 Universal I / O, RJ45 Interface, 2 Ports for Expansion Modules, One RS232 and a Bacnet MS / TP, alim. 24VAC.
MS	Ultrasonic luminaire: Wireless internal, EnOcean communication protocol, 0.1024 Lux range, 12Vdc power supply or batteries, ceiling mount
RP	Wireless bidirectional gateway: EnOcean radio protocol, including 2.5m cable, BACnet / IP ethernet interface, DIN rail mount, 15..24 Vdc (± 10%) or 24 Vac (± 10%) power, IP20 protection
SO	CO_2 probe, humidity and ambient temperature: output signal 0.10Vcc, humidity range 0 ÷100% UR, CO_2 (0 - 5000ppm) 0 - 50 ° C, wall mounting, 24Vac power supply / 24Vdc, IP30 protection.
T.A.	Ambient temperature probe: with set point variator, range 0..50 ° C, accuracy +/- 0.15 ° C (Class A EN60751), active measuring system, sensing element 2.73V / 0 ° C, 10mV / K, IP30 protection.
CTR	More Ambient Controller: LON FTT10 interface, 6 analog inputs, 3 outputs for 24Vdc or 0.10V servo thermic outputs, 1 relay output for electric battery, 230Vdc power supply.

(a) (b)

FIGURE 3. Melzo Primary School, (a) main building with the classroom blocks, (b) photovoltaic plant installed on the rooftop to provide electricity for the energy consumption of the building.

Now the building construction is finished on schedules and without extra costs due to the BIM process adopted allowed a high level of coherence of the project which removed unpredicted problems and issues that often affect complex buildings.

The building will be an example of public contracts where the control of the project should be performed automatically. Sensors and actuators have been installed and planned, they will provide data for the monitoring phase. Based on them, important information regarding the retrofit and condition of use of the building will be acquired and studied. This is a first step to organize a holistic approach of the entire asset of the municipality. In the smart city, the buildings are part of a system of systems where resources are properly used and optimized. The information given by the sensors could be also be integrated by user' information, preferences and feedbacks which will be crucial to involve the user and implement the operating phase. In this case the administration, the technologies and the citizens are a functional structure able to develop the basis of the smart city environment. "A Smart Community is a community that has made a conscious effort to use information technology to transform life and work within its region in significant and fundamental, rather than incremental, ways."

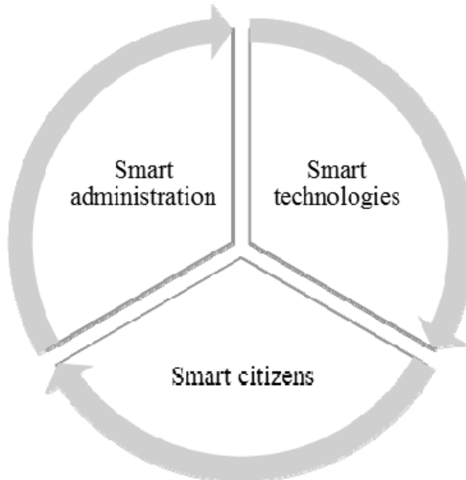

FIGURE 4. Melzo Primary School, plants distribution and sensors location.

CONCLUSION

Through building, users and owners could benefit from a complete management system, both in terms of historical data, as action made on the building, and in term of actual condition to check and make consideration on its behaviour. This is the way to control and help the facility management phase, because technicians have a complete view of the situation of all the building in the asset. In this way it is possible to check water consumption, shading system, heating and cooling system, safety system, control of inside air quality and asset's behavior upkeep. This work allows to have a consistent state of performance improvement at any time. The research objective is a complete workflow to make decision and the possibility decision with an objective and scientific approach.

At the beginning the process start from the evaluation of the law deficiency based on the schools' conditions, hence create criteria on which decide how proceed. These parameters are tailored on the owner needs. They are created as set weight parameter (i.e. time, costs, impact). The combination of the criteria through an algorithm allow the owner to reach its main objective. Further development consists on the control of the actual improvement managing the MEP system on the external condition (UK Ministry of Justice 2015; Washburn & Sindhu 2009). Through an uninterrupted control of the asset is possible to manage maintenance phase. Further development will take in consideration all the aspect related to management (Doukas et al. 2007) of data in a big data environment as a smart building is, due to the fact that data, from smart building, represent the only way to understand and make the building self-adaptable and energetically eco-friendly (Europen Commission 2011).

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