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ÍNDICE DE COMUNICACIONES Y PONENCIAS

1. FORMACIÓN E INVESTIGACIÓN EN BIM

2. DISEÑO Y CONSTRUCCIÓN CON BIM

3. EXPERIENCIAS REALES CON BIM

A DIGITAL WORKFLOW FOR BUILDING ASSESSMENT AND RENOVATION

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Abstract

This paper presents a methodology for digitalization and assessment of existing building stocks. This research is developed for the municipality of Melzo, as part of a research programme that regards the digitalization of the municipality's buildings, to evaluate their performance, state of conservation, and to provide cost-related analyses of potential interventions. The proposed approach is structured on BIM models created from building surveys, followed by a simplified energy behaviors assessment, and an evaluation of potential improvements, both on building envelope, and energy building systems.

Compliance to regulatory requirements in terms of fire safety, energy performance, indoor comfort, accessibility layout is verified in a semi-automated way based on BIM models. The analyses of costs in a Life Cycle perspective helps building owners to establish a hierarchy of interventions on building asset. The proposed workflow can be adapted to different building types.

Keywords: *Building renovation, Life Cycle Cost, digital twin, building asset management.*

Resumen

Este documento presenta una metodología para la digitalización y evaluación de edificios existentes. Esta investigación se desarrolla para el municipio de Melzo, en el marco de un programa de investigación sobre la digitalización de los edificios del municipio, para evaluar su eficiencia, estado de conservación y proporcionar análisis de costes de las posibles intervenciones. El enfoque propuesto está estructurado en modelos BIM creados a partir de encuestas de construcción, seguidas de una evaluación simplificada de los comportamientos energéticos y de una evaluación de las posibles mejoras, tanto en la envolvente del edificio como en los sistemas de construcción de energía.

El cumplimiento de los requisitos reglamentarios en materia de seguridad contra incendios, eficiencia energética, confort interior y accesibilidad se verifica de forma semiautomática en base a los modelos BIM. El análisis de los costes desde la perspectiva del ciclo de vida ayuda a los propietarios de edificios a establecer una jerarquía de intervenciones sobre los activos del edificio. El flujo de trabajo propuesto puede adaptarse a diferentes tipos de edificios.

Palabras clave: *Renovación de edificios, coste del ciclo de vida, gemelo digital, gestión de patrimonio inmobiliario.*

Introduction

Existing buildings stocks play a fundamental role in current research nowadays, as they account for the most part of energy consumptions and CO_2 production (Ravetz 2008), and as the Operation & Maintenance phase is the one that has a stronger impact in economic terms on the overall service life of a building (Cabeza, Rincón, Vilariño, Pérez, & Castell 2014). The theme of building renovation plays a primary role in European and national agenda, due to its relevance to reach the goals of decarbonisation.

When considering existing buildings, literature is mainly focusing on building renovations, including energy performance evaluations (REF), prototypes and materials for building retrofit (Sanhudo et al. 2018), or cost/benefits approaches. A methodology for the evaluation of large building stocks that includes not only building renovation, but also facility management is lacking. The goal of the research here presented is the setting of a BIM-based methodology to evaluate and manage existing building stocks.

1. **State of the Art**

The main research area related to the use of BIM for existing building regards building renovation and sustainability. Some explorations regarding the application of collaborative methodologies to asset and facility management can be found (Ayman, Alwan, & McIntyre 2020; Boje, Guerriero, Kubicki, & Rezgui 2020; Lu, Xie, Heaton, Parlikad, & Schooling 2020), underlining that research interest is rising.

Research lines regarding the application of BIM for existing building can be divided in:

- BIM for operation and maintenance; data-driven methods to plan and manage maintenance operations of buildings, building systems and equipment (Pärn, Edwards, & Sing 2017; Volk, Stengel, & Schultmann 2014);
- BIM for energy retrofitting, integrating BIM workflows with energy simulation tools and exploring alternatives (Habibi 2017; Sanhudo et al. 2018);
- BIM for post-occupancy evaluation and monitoring, providing evaluations of internal comfort and quality (Coates, Arayici, & Ozturk 2012; Roberts, Edwards, Hosseini, Mateo-Garcia, & Owusu-Manu 2019).

This multiplicity of research lines follows the complexity of asset management (Becerik-Gerber, Jazizadeh, Li, & Calis 2012); though providing a wide and detailed starting point, the lack of resources exploring strategies for asset management based on digital methods (including BIM) can be underlined (Munir, Kiviniemi, Jones, & Finnegan 2020).

Evaluation methods based on BIM regard energy-related aspects linked to existing green building tools, and are addressing specific case-study buildings (Ilter & Ergen 2015). A wider application that refers to building stocks and that does not limit the evaluation to energy retrofitting could provide interesting developments. Furthermore, the collaborative process undelaying research activities should be detailed and clarified in order to facilitate the handover of information and procedures, especially in public sector.

Both Public administrations and private owners of large building stocks needs to develop tools and procedures for the management of their assets. Public administrations have in this sense very strict budget limitations, resulting in a stronger need of planning and managing their facilities (Carbonari, Corneli, Di Giuda, Ridolfi, & Villa 2019). The use of BIM could represent a crucial improvement, helping to structure and define an enhanced asset management.

Currently, the most part of building documentation (related to construction, maintenance, facility management, and other aspects) is still paper-based and not integrated in digital asset management tools or procedures. The digitalization of public building asset is encouraged by current legislative frameworks, and could result in an optimization of asset facility operations.

Public Administrations (PAs) have wide building assets, but in many cases, they do not have proper tools to optimize its management. Digitalization mainly appears as a cost- and time-consuming activity that would require deep changes in consolidated processes of Administrations. Nonetheless, the shift to digitalization would provide relevant advantages, shown in the following table.

Table 1. Main barriers and drivers to digitalization of building assets for PAs

Barriers	Drivers
Cost onerousness	Progressive decrease of cost and time investments
Time consuming activity	Increase in quality of building management
Lack of tools to properly manage digital processes	Reduction of costs of maintenance of existing buildings
Lack of expertise of Public Administrators	Legislative requirements

The scope of this research is the setting of a methodology for building assets digitalization and management. This paper presents the general approach, with first applications to case study buildings of the Municipality of Melzo, a medium-size town in Lombardy near Milan. Based on an evaluation of buildings conditions, the goal of the work is the setting of an evaluation method to understand the current state of buildings, to establish renovation needs and priorities, and to explore alternatives for building retrofitting.

2. **Methodology**

The provided process is under development in accordance with the Municipality of Melzo, and is therefore based on its needs and requests, as it is part of a research project for the digitalization of Public Administrations. It has been applied to a first set of buildings to prove its reliability and to balance between usability and robustness. This approach has been tailored on the Municipality requests, but can be replied on different Clients, modifying the evaluations and the weight of the scores.

The Municipality has expressed the need of a simplified approach to evaluate potential interventions on its building stock. The requirements of the Municipality included (i) the evaluation of current state of the buildings, in terms of energy performance, fire safety, and compliance to legislative requirements, (ii) the development of BIM models to be used as base for these evaluations, and (iii) as repository for building documents, and (iv) a cost/benefit evaluation of potential renovations on the building.

The method does not provide an exact evaluation of energy behavior, as this approach is intended to be applied in early stages. In this sense, the usability of the approach has been preferred to avoid overburdening the model. The energy evaluation provided is useful to define in early steps potential renovations, and to compare energy performances of different buildings of the analyzed stock (Chaves, Tzortzopoulos, Formoso, & Biotto 2017).

In accordance with the Municipality, the methodology's phases are presented in Table 2, together with techniques and tools that can be used to reach each phase's objective.

Table 2. Research phases

1. Building survey and documents collecting	This first phase is necessary to provide the complete state of the building. Building survey can be carried out by means of basic tools, or through more sophisticated methods, e.g. laser scanning (Cabeza, Rincón, Vilariño, Pérez, Castell, et al. 2014). Documents collected about the building include authorizations and permits, reports, projects drawings…,

2.	BIM modelling	A BIM model based on the guidelines should be carried out (DI GIUDA, Giana, Schievano, & Paleari 2020). The model should include all the relevant information in terms of architecture, building systems, and structures.
3.	Legislative requirements evaluation	Depending on the building use, different requirements should be satisfied, including fire regulations, space layouts, use of specific materials, etc.(Choi, Choi, & Kim 2014)
4.	Creation of a database	A database including all the collected documents is associated with the BIM model of the building. This operation can be carried out through simple tools (e.g. Excel), or through the creation of a proper Document Management System (DI GIUDA, Giana, Schievano, & Paleari 2019).
5.	Energy evaluation	An evaluation of the building current energy performance is provided, including the envelope and the building systems. Depending on the administration requirements, basic evaluations or refined simulations can be carried out (Chong, Lee, & Wang 2017) .
6.	Evaluation of the building conditions	Through the analysis of legislative compliance, and energy behavior, it is possible to set a multi-criteria grid to evaluate the building asset, in order to establish priority of interventions (Nielsen, Jensen, Larsen, & Nissen 2016).

The first step of the proposed approach is the definition of BIM guidelines for the creation of models. This aspect is relevant for different reasons: firstly, as the building models are created by the research group, but will be managed and then created by the administration, it is particularly relevant to set a standard. In addition, it is vital that PAs are able to cope with their models, to interact with them, interrogate them, and manage them, as the future processes of maintenance will be set on digital building models. This is particularly true considering that, in accordance to legislative framework, the use of BIM is progressively becoming compulsory.

The first activity for the creation of BIM models is the survey of the building. Building survey can be carried out manually, or through laser scanning, depending on building typology, available budget, and time constraints. In the proposed cases, building survey has been carried out manually, but more sophisticated survey techniques will be explored for the following case study buildings.

BIM models are then created, based on the guidelines; relevant information and a An energy evaluation tool, based on simplified models, is set to evaluate the current performance of the building stock.

Building validation is based on semi-automated verification of legislative requirements, entirely based on BIM models previously created: this step is necessary as it provides an evaluation of the quality and the compliance of buildings to current legislative framework, depending on their use.

The creation of a grid allows to give each building a score that express its need for refurbishment, depending on the non-compliance of requirements and therefore the urge for intervention. These scores combined with weights chosen by the Client allows to establish a multi-criteria methodology to evaluate the building asset and the priority of intervention.

Outputs deriving from the proposed method are presented in Table 3.

Table 3. Outputs of the proposed method

Phase	Output
1. Building survey and documents collecting	-
2. BIM modelling	BIM guidelines
3. Legislative requirements evaluation	Evaluation reports
4. Creation of a database	Building digital dossier
5. Energy evaluation	Simplified energy model
6. Evaluation of the building conditions	Building score

3. **Model creation and guidelines definition**

Advanced BIM clients have developed their own standards for data management and information modelling. In this sense, the creation of proprietary guidelines is useful for clients to guarantee that project information requirements are driven by specific organizational requirement, as for ISO 19650.

BIM guidelines facilitate the implementation of BIM methodologies in projects and processes of institutions. The definition of requirements of the Municipality is the first step to create guidelines for BIM; in this phase, the inclusion in the process of facility managers is crucial, as they can help in properly define requirements for Operations & Maintenance phases (Pärn et al. 2017).

Three guidelines have been developed for Melzo Municipality, for new buildings, for interventions on existing buildings, and for maintenance operations. These guidelines had as starting point the analysis of procedures and data workflows of the municipality; a first analysis of the building asset was conducted to identify general features to be included in the guidelines. A detailed building survey is then performed, following the rules set in the guidelines. Once the guidelines were set, BIM models of the building were developed, based on a Product Breakdown Structure (PBS) to identify all objects and components; the codification of objects has been developed based on existing procedures and standards. A BIM Library is created for architecture, structures and building systems.

The first phase of the research project involves seven buildings of the Municipality, with different uses and different ages (a canteen, the city hall, a primary school, a kindergarten, a bocce court, a cultural center hosted in an historical building, and a secondary school).

These models are used as a base for documents collection, energy data extraction, and further potential analyses (e.g., Post-Occupancy Evaluations).

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4. Building evaluation

The building evaluation of the asset is carried out through a grid that includes six main aspects, divided in sub-criteria, summarized in the following table and in following paragraphs. Sub-criteria are furtherly divided in more specific aspects.

Table 4. Evaluation criteria

Criteria	Subcriteria	Evaluation method
State of conservation	1. Building envelope conservation 2. Internal elements conservation 3. Building services conservation	Qualitative
Structural stability	4. Vertical structures 5. Horizontal structures	Qualitative
Energy efficiency	6. Envelope 7. Building services	Quantitative
Fire safety	8. Building site 9. Construction features 10. Specific risk areas 11. Evacuation routes 12. Active protection systems	Quantitative
Accessibility	13. General layout and distributions 14. Rooms 15. General requirements	Quantitative
Documentation availability	16. General data (cadastral information) 17. Construction permits 18. Reports 19. Certifications (e.g, materials and products certifications, energy certification, building services declarations of conformity) 20. Maintenance 21. Drawings	Quantitative

For each criterion, a qualitative or quantitative evaluation should be provided, based on the BIM models. The only exception is the state of conservation, which has been evaluated through direct observation of the existing elements.

The complete evaluation of structural stability should be based on the survey of all structural elements, through specimens and materials analyses. In this case, considering the application of this method to early stages of design, this aspect is limited to the evaluation of the state of conservation of structural elements (columns, walls, slabs, beams).

Once all the schemes have been completed, it will be possible to give each building a “score” depending on its performance in all the defined criteria.

All documents related to the building (building permits, certifications, drawings) have been collected from the archives of the Municipality, digitalized, collected in a database through Microsoft Access, and connected through the plugin DBLink to the BIM models.

4.1 Energy efficiency diagnosis

As previously stated, a complete evaluation of the energy performance of buildings is out of scope of this research; nonetheless, a detailed energy analysis can be included in the proposed methodology when required. The approach can be described as a deductive method, based on consumptions, surface/volume ratio, and energy needs. Building services are evaluated as a black-box meaning that only their efficiency η, based on production, distribution, control, and emission is taken into account (Evangelisti, Battista, Guattari, Basilicata, & Vollaro 2014).

This allows a description of the real building energy behavior. Based on this, it is possible to evaluate the potential improvements in energy behavior related to renovation interventions. Energy consumption of the building, obtained from documents and bills, is the starting point to define its losses, and therefore potential improvements in both the building features (passive approach), and in building services use (active approach). Ventilation losses are evaluated based on the use of the buildings and air change requirements. The part of consumptions deriving from the envelope (transmission loss) can be approximately defined subtracting ventilation losses from energy consumptions. Transmission loss are necessary to define current features of the building envelope. The proposed approach can be described as an energy diagnosis, rather than an energy modelling, due to two main reasons: in first place, this approach keeps into account the actual use of building services, and on the other hand, allows some primary considerations in terms of retrofit interventions, that should be detailed in following steps.

For each building, based on energy diagnosis a hierarchy of actions to be carried out is defined, including:

- Change in the use of the building services;
- Interventions on the envelope (external insulation, roof insulation);
- Windows replacement;
- Internal insulation.

At current state of development of the research, the energy diagnosis model has been defined and tested on three building.

4.2 **Fire safety and accessibility**

Fire safety is a complex issue, that regards several features of the building; usually, the intervention and the interpretation of a human being is required to check fire safety compliance (Strug & Ślusarczyk 2017)(Choi et al. 2014)(Choi et al. 2014)(Choi et al. 2014)(Choi et al. 2014). Furthermore, the legislative framework is wide and complex, and depends on the use of the building. For this reason, a specific chart for each building typology has been set, taking into account general features of the building, technological features of its components (fire resistance, geometrical layout, etc.).

For each of the features, a score has been defined in terms of compliance with the existing legislation.

Accessibility involves the absence of architectural barriers; similarly to fire safety, it is a complex context, including several legislative references and taking into account different features of the building and of its surroundings.

To provide an evaluation of fire safety and accessibility compliance, legislative requirements have been translated into machine-readable rules, incorporated in a Dynamo node, that combines information from the model and from the excel grid. The node automatically fills the excel grid with the results of the comparison between the requirement and the building features contained in the BIM model.

4.3 **Further steps**

The setting of a structured approach based on BIM models increases the quality of the evaluation, and its reliability. Data are extracted from the model to perform the evaluations required, and can be stored and managed in a proper way through the entire Life Cycle of the building.

If the evaluated building does not comply with legislative requirements (e.g., fire escape routes have an inadequate dimension), it is possible to simulate the intervention in the BIM model and to see its efficiency.

Considering the score obtained for the buildings, it is possible to define a hierarchy of intervention, based on the weight given to each criteria. Costs are being included in the process, in order to evaluate potential intervention strategies and their effect on the building evaluation.

5. **Outcomes**

The digitalization of building stock is a complex and long-term operation that could result in relevant improvements in terms of cost-efficiency, quality, and asset management efficiency of the assets. This path should be carefully defined in order to properly incorporate the requirements of the client. BIM models will provide a valuable context to structure analysis and explore interventions on the existing building stock. The workflow here presented is an example of an ongoing process of digitalization of a Municipality's building stock. The setting of a collaborative workflow helped in better understanding the requests and needs of the client, and the careful management of information during the whole process will help the handover. The client has constantly been updated during the work, through dossiers and presentations, and training meetings have been planned to facilitate the proper understanding of all the steps.

The use of BIM as a base for all the activities is proving to be particularly valuable as it result in better communication among the multiplicity of actors involved in renovation activities. The constant collaboration with the Municipality has stimulated their engagement in the process, as benefits deriving from a digital approach are immediately visible.

Efforts have been made to balance the reliability of the method and its robustness; some simplifications avoid its overburdening. The proposed process provides a useful evaluation tool to be used to support early stage of design decisions; considering the relevance of information, decisions can be based on data rather than on previous experience, and measurement of the effectiveness of intervention is immediately available.. This strategy can help Public Administration with large building stock to properly allocate their resources. As previously stated, this process is being developed with a specific Municipality, and is therefore tailored on its requirements. Nonetheless, this approach can be extended to other Public clients and can fit their goals and needs, as evaluation criteria are flexible and can be modified. Also, their weights can change to better fit the needs of the client. In addition to the evaluation of the building asset and of renovation interventions, the creation and constant updating of BIM models of the Municipality's building assets allows the performing of FM performance measurement tools, that will be part of successive research phases.

The shift to digitalization of building asset requires long-term strategies and planned processes, but results in valuable and countable benefits. BIM methods allow digital handover of information, overcoming the limits of paper-based, non-collaborative activities, and making data accessible and increasing the efficiency of the entire process.

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