



Palazzo degli Studi in Macerata. Photo by the authors.

HBIM tools for knowledge, maintenance and conservation of concrete built heritage

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Abstract: In the 20th century, reinforced concrete was one of the most popular building materials. It was formerly regarded as a material of outstanding durability and resilience, but over the past 50 years, it has revealed severe fundamental flaws. Main weaknesses of concrete include susceptibility to chemical agents and degradation brought on by poor design and construction. As a result, restoration interventions, recovery efforts, and re-functionalization of these artifacts have progressively grown in recent decades. Only when these improvements are combined with ongoing maintenance are they effective in extending the life of the structure. The most accurate knowledge of the building and all of its components can improve the efficiency of maintenance and recovery actions.

Recently, the use of BIM tools for reinforced concrete buildings is spreading more and more, going beyond new construction to include built heritage. A BIM model of an existing asset may be used to assess the building's condition of conservation, pinpoint any issues, and assess the alternatives available for repair and conservation while projecting the impact of the adjustments on the structure. This data may be used to plan maintenance and restoration activities, track the building's condition of conservation through time, and assess the effects of any alterations on the structure.

In this work, a workflow for "reverse engineering", enabling the creation of an HBIM model of an existing building, is proposed and then applied to a case study building.

This technique may be regarded as a watershed moment in the management of reinforced concrete structures since it simplifies and organizes all of the information needed to preserve the existing architectural heritage while utilizing available resources.

Keywords: HBIM, built heritage, maintenance, reinforced concrete.

1. Introduction

The reinforced concrete, thanks to its “malleability”, has been one of the most used building materials in the 20th century. Designers have used it to build wondrous architectural works such as, for example, the Millard House by F.L.Wright, the Chandigarh Parliament by Le Corbusier, the Cathedral of Our Lady of Fatima by O.Niemeyer, the Pirelli Skyscraper by G. Ponti and P.L. Nervi, the Gatti Wool Mill of P.L. Nervi; the list could go on and on. Along with these structures, which unquestionably represent one of the most significant examples of 20th-century architectural culture, reinforced concrete was also used in the construction of a sizable portion of the common heritage. For example, over 50% of the Italian building stock has a structure made of reinforced concrete (Vona et al., 2004). The majority of these structures, have been constructed between the Second World War and the end of the 1960s, particularly in large urban areas. Concrete was thought to have extraordinary qualities in terms of durability and resistance up until the 1950s, but it has since revealed several fundamental flaws. Buildings in particular have demonstrated over time a high susceptibility to the effects of environmental chemical agents (carbon dioxide, chlorides, sulphates, etc.), but they have also continuously deteriorated as a result of poor design and construction (attention to construction details, workmanship, etc.) (Coppola et al., 2015). These factors have led to a rise in the restoration, recovery, and re-functionalization of these objects, especially monumental ones, since the turn of the 20th century. If not supported by ongoing maintenance work, these interventions - in which significant economic and sociocultural resources are annually invested - appears to have a limited impact (López et al., 2018).

It is generally recognized that understanding the product and its construction history is the foundation for proper maintenance. Equipping the building with a complete, flexible, and simple information system that, evolving with the building, makes available all the necessary information for both preventive (or ordinary) and reactive (or extraordinary) maintenance is therefore one of the key challenges in recovery and re-functionalization projects (Nummelin et al., 2011). The use of BIM-oriented processes in building management, which also includes maintenance, enables us to understand the locations and connections between the different components of the 3D model, including the architectural, technological, structural, and MEP engineering. This type of modelling (6D modelling) (UNI 11337, 2017) makes the data and information entered in the model usable over the useful life of the building (design, construction, etc.) in order to ensure proper management over time and careful maintenance. It allows for the storage and consequent

updating of all the data relating to the activities, the state of the components, the specifications, the maintenance manuals, the guarantees, etc. (Altohami et al., 2021).

2. Sustainable maintenance of historic buildings using HBIM

Building Information Modeling (BIM) provides spatial and functional representations of the building elements using parametric objects (UNI 11337:1 - Modelli, elaborati e oggetti informativi per prodotti e processi, 2017). Using this methodology is required for project planning, design, and management of public projects in many Countries (e.g., Italy, DM 560/2017; United Kingdom, Government Construction Strategy, May 2011: Requires Fully Collaborative 3D BIM Approach to Be Adopted in All Public Funded Projects, as a Minimum by 2016, 2011). In the past ten years, Heritage Building Information Modelling (HBIM) has been developed to adapt BIM techniques for the built heritage (Murphy et al., 2009). HBIM modelling, reversing the traditional design process based on decision, modelling, and realization, starts from historical research and on-site surveys for collecting geometrical and non-geometrical building data, to create the building model as a final step (Agliata, Bortone, & Mollo, 2022). These models add to the typical BIM advantages (visualization, data management, error correction in the early-design stage, shared knowledge resources, data sharing and coordination, cost calculation, interoperability, etc.) the possibility of implementing tailored interventions in heritage constructions, thanks to 3D modelling (Attenni et al. 2019). Also, they allow data storing and updating (e.g., historical information, photographs, drawings), evaluation of changes, planning of retrofit interventions, including past, current and potential forthcoming modifications (Ramírez Eudave & Ferreira, 2021). An HBIM model, including historical information, intervention, and preservation analysis, can serve as a database for all kind of future interventions, also enabling different stakeholders to work together exchanging all building information in real-time (e.g., architects, structural, electrical and energy engineers, consultant, etc.). Despite these benefits, creating an HBIM model is still a challenging task because of two key issues: (i) completeness of survey operations and data collection; and (ii) the lack of parametric libraries for historical and existing architecture or the difficulty in creating them (Dore & Murphy, 2012; 2014; Quattrini et al., 2015; 2016). The first aspect has a direct impact on the representation's accuracy, whilst the second has an influence on the representation's quality and consistency of the gathered data.

With reference to the national legislation (UNI 11337, 2017), the Level Of Detail (LOD) in BIM modeling refers

to the level of in-depth representation of a building model or an architectural element. It applies to graphical (LOG – Level Of Geometry) as well as to informative (LOI – Level Of Information) aspects (LOG + LOI = LOD). Although its definition and levels vary in different Countries, the rating system is similar in all standards (ISO 19650 - Organization and Digitization of Information about Buildings and Civil Engineering Works, Including Building Information Modelling (BIM). Information Management Using Building Information Modelling, 2018). For example, a built object has a LOD “F”; the highest LOD is “G” and is retained by a refurbished building element (corresponding to an updated object in BIM environment). This means that, level F of in-depth analysis, also known as “as built”, calls for the archiving and virtualization of the building object as it was built. This entails that any project modifications made throughout the construction phase are documented, as well as all the specific quantitative and qualitative characteristics of each technological element installed or set out are detailed. In this phase, for each technological element or system, the interventions, including maintenance to be performed during the asset’s life cycle, are also defined. Level G instead, virtualizes the building historicization process and allows for the model to be updated on a regular basis to reflect all the changes that have occurred since the testing date. This updates also includes performance and degradation data as well as information needed for further management and maintenance (Daniotti et al., 2020). Ultimately, the as-built model of the building (LOD F) must be routinely updated in order to always guarantee its correspondence to the real situation (LOD G), not only for the geometric-representative features but also for the technological aspects (Deng et al., 2021).

LODs in an HBIM model are influenced by a wide range of variables, including the model’s intended use, the size of the representation, and various inherent uncertainties related to both the investigation and rendering stages. The first source of uncertainty is the fragmented information generated by an achievable low accuracy of the field investigation (e.g., the impossibility of accurately inspect the detailed stratigraphy of slabs and walls). The uncertainty in the rendering phase is related to the available HBIM objects included in the libraries, which can mismatch the real ones, preventing an adequate modelling. In this case, the building element should be modelled from scratch, or modifying an existing object. The designer is entrusted dealing with these aspects, hence the resulting HBIM model is influenced by its interpretation and sensitivity. Because of the aforementioned uncertainties, an HBIM model’s LOD may change for various items inside the model itself. The LOD of an HBIM model may change for various items inside the model due to the stated uncertainties. The Italian standard UNI

11337:4 (Evoluzione e sviluppo informativo di modelli, elaborati e oggetti, 2017) specifies a LOD not less than F for restoration works.

For what has been said so far, although HBIM for maintenance is a current research topic (Cernaro et al., 2023), professionals (engineers, architects, restorers, etc.) still hardly ever use this methodology in their daily work (Brumana et al., 2021).

The methodology proposed in this piece of research follows three steps: (i) collection of the available design materials (e.g., design documentations, floor plans, etc.), (ii) parametric survey on site, and (iii) modelling of the building using the acquired knowledge. In the section 3 basics of reverse engineering are given; while in section 4 a sample application is presented, concerning the BIM modeling of a multi-storey reinforced concrete building designed at the end of the last century and completed in the early 2000s.

3. Reverse engineering

The method used is “reverse engineering”. It is commonly recognized that the purpose of this type of analysis and methodology is to comprehend how an object was designed, constructed, and how it works. In civil engineering, it is applied to understand the technologies used for the construction of a building. Reverse engineering is basically the process of gathering all the data necessary to comprehend how a structure or one of its technical components functions in order to adapt it to new demands, maintain it properly, rebuild it, or replace it (Biancardo et al., 2021). In building industry, reverse engineering is often applied to *black boxes*, i.e., it means without being able to observe the system or the sub-system in its internal structure. Think of the load-bearing structure of a reinforced concrete building or an electrical system, of which we only have knowledge about the performance and the location of the terminals. More rarely, for some sub-systems, it is possible to operate in a *white box*, that means by inspecting the internal functioning of the system.

The difficulty with using reverse engineering method in construction sector lies in the complexity of the process that calls for highly skilled technicians and sophisticated survey equipment. Therefore, in order for its application to be feasible on a large scale, it is necessary to find sustainable solutions, i.e., not very dependent on complex systems and high human skills (Saiga et al., 2021). The application described here is based on this concept.

4. Application example

The chosen asset is a small building constructed around the turn of the century. It is located in the residential expansion area (P.E.E.P.) of Frattaminore, a municipality of about 16.000 residents that is part of Naples' metropolitan area (Figure 1).



Figure 1 | Site layout.

It is a reinforced concrete building with five levels above ground; warehouses and garages are housed in the basement floor, businesses operate on the ground floor and homes are located on the above four floors. There are eight different-sized flats in all (Figure 2).



Figure 2 | Building view.

Being a relatively recent building, the design documentation (floor plans, elevations and sections) was available. After a preliminary study of the mentioned documents aimed at understanding the structure of the building (bearing structure, symmetries, position of the stairwells, etc.), field survey was carried out, to ascertain any discrepancies between the project and the actual condition. (Figure 3).

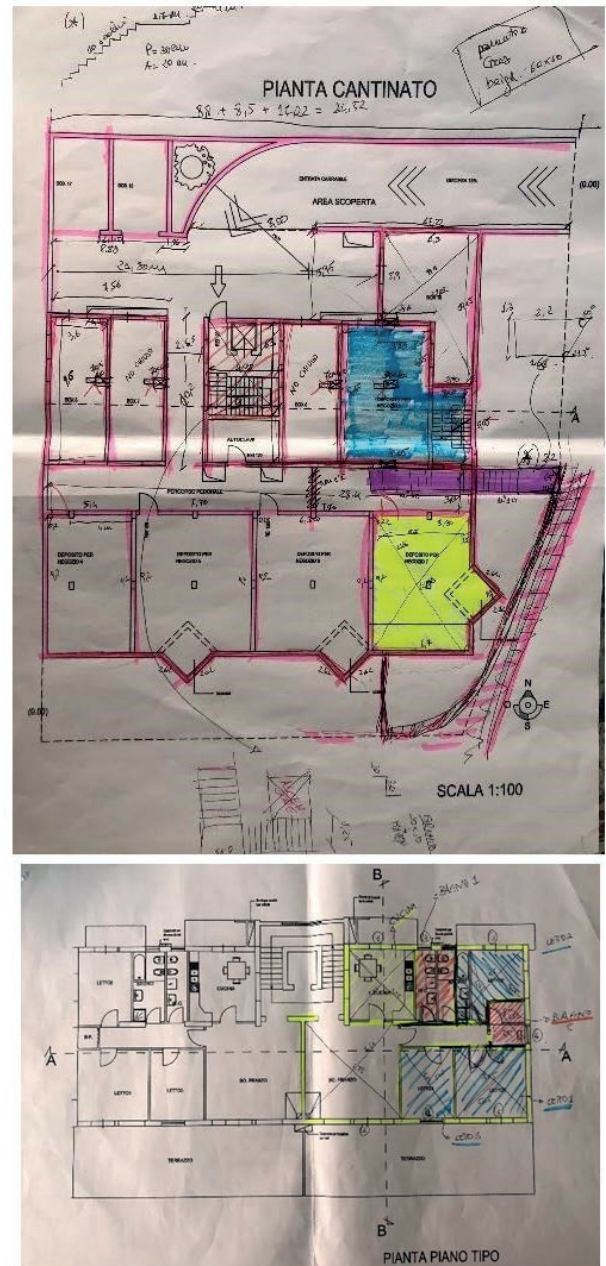


Figure 3 | Sketches of the floor plans showing the modifications detected in the survey phase.

A traditional, direct survey was performed using only a laser measure. A photographic survey of all the formal and technological elements of the building was also carried out. The photographic survey is very significant and serves as an indispensable tool for the return operations as well as for a better understanding of the survey documents: in many circumstances, the photo itself serves as a helpful record for restitution since, if it was shot carefully, it may contain information that may be used to identify

the various components. The technological component were examined by means of specifically designed survey sheets (materials, geometry, etc.). Particular attention was paid to the survey of the structural system (pillars, beams and floors), of the plant sub-system and of the vertical closures. As an example, Figure 4 shows the “clean copy” of the survey sheet used to examine windows. It is a straightforward and comprehensive form that enables you to visually inspect the object’s geometrical and material properties while adding a few measurements.

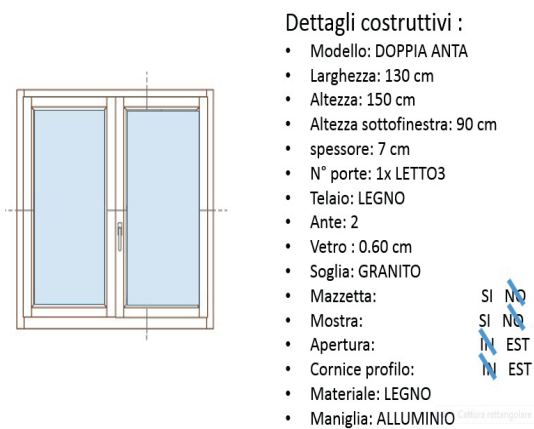


Figure 4 | Example of survey sheet (window).

A freehand sketch was used to create the image on the inspection sheet. Similar steps were used for the survey of other technological components, altering the data to be gathered in accordance with the technological component to be surveyed (Figure 5 displays the radiator survey sheet).

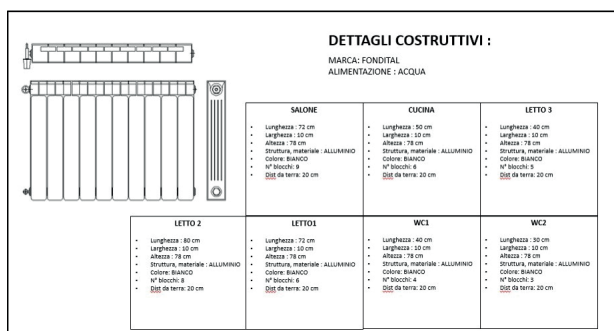


Figure 5 | Radiator survey sheet.

This procedure proved to be more difficult for the structure because only a partial direct survey may be

used to move on with the structural parts. We had to rely on the construction company’s project records (Figure 6), yet verifying the geometric dimensions and orientation of the pillars on site.

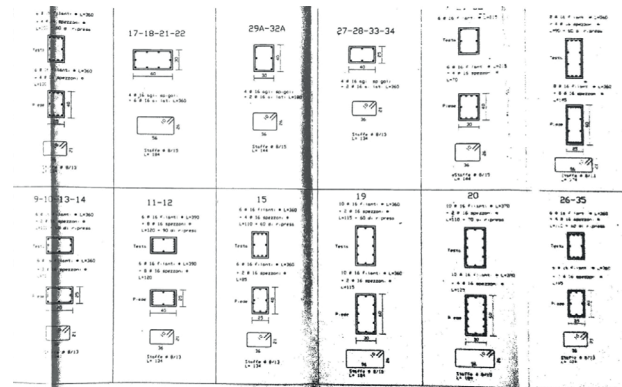


Figure 6 | Pillars.

All of the data gathered following the meticulous, in-depth, and collaborative archival work (municipality, civil engineering, construction company, etc.) and the field survey were returned as metadata during the creation of the HBIM model, for which the software Edificius® by ACCA Software was used (Figures 7 to 9).

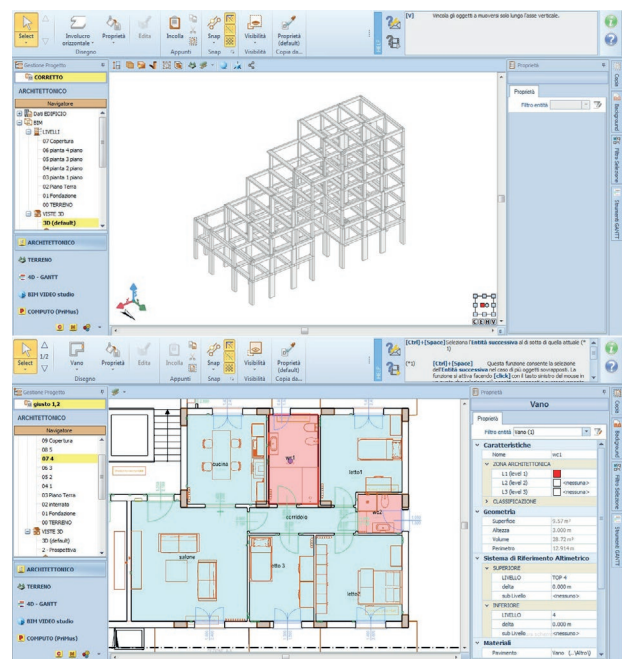


Figure 7 | Structural model and floor plan in BIM environment.

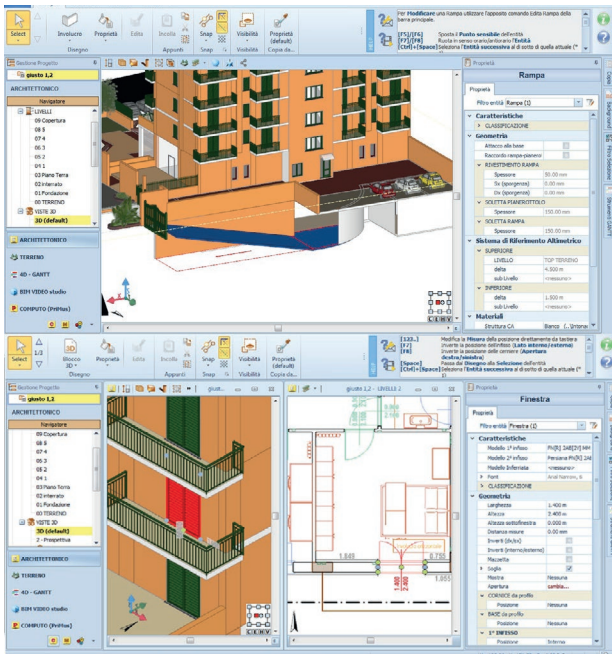


Figure 8 | Modelling of the technological elements.



Figure 9 | 3D model and photorealistic rendering.

4. Conclusions

The data gathered over time in an HBIM model (and in its accompanying database) can help the critical evaluation of the changes, especially on complex buildings, supporting virtuous and conscious multidisciplinary investigations.

HBIM appears to be the most appropriate methodology for virtualizing the historical stratification of the built environment, in order to promote, support, and improve a deeper understanding of the built heritage of the 20th century and plan its maintenance, conservation, and enhancement.

The main objective of the application was to demonstrate that a high quality of the 3D model can be achieved

when the latter combines efficient representational approaches with deep levels of detail.

The work showed that the more detailed the parametric survey operations, the greater the support that BIM would be able to provide for the historical record and the management of the built heritage.

The research is now evaluating the application of this methodology to a historic building with the purpose of an energy requalification involving photovoltaic energy.

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