Historic Building Information Modeling towards building diagnostic data management. 
A case study

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Highlights

Material-constructive characterization and building condition assessment supported by on-site diagnostic tests is a topic insufficiently investigated in Historic Building Information Modeling (HBIM) methodology. An approach for integrating diagnostic activities in HBIM methodology, for refurbishment of historic buildings, is proposed.

Abstract

The article proposes a methodology for acquisition and management of integrated knowledge for refurbishment of architectural heritage, belonging to the Apulian construction tradition. The acquisition phase is based on historical-archival analysis and visual inspections, to proceed with the subsequent planning and execution of diagnostic surveys. Successively, the handling of information collation and archiving follows criteria of Historic Building Information Modeling (HBIM), an innovative approach for coordinating refurbishment process, which, in the specific study, contributes to the systematization of knowledge about materials, constructive techniques and residual performance levels about architectural components, limiting uncertainty of interpretation.

Keywords

HBIM, Historic buildings, Non-destructive tests, Wooden and wattle vaults, Wooden slabs

1. INTRODUCTION

The design of appropriate refurbishment succeeds on the basis of an accurate knowledge about the building, and its transformations over time [1][2]. Firstly, assessment activity includes the execution of complementary sub-activities for gaining information, and subsequently, diagnosis for identifying causes of detected anomalies, by objectifying the criteria of information analysis, comparison and interpretation. However, being data and information contained in independent documents, their correlation often makes critical the diagnosis phase. On this point, an integrated information management approach is required. A new paradigm, already validated for new buildings, demonstrates its potentialities in managing knowledge; it consists in Building Information Modeling (BIM), which becomes Historic Building Information Modeling (HBIM) for structured knowledge exchange about existing artefacts.
Knowledge, once acquired through analytical studies, and diagnostic and monitoring tests, is made entirely consultable during refurbishment design and execution, extending its effective availability over the entire building life cycle [3][4].

In addition, progressive developments in Information & Communication Technology (ICT) move BIM in the direction of streamlining and automating workflows. Indeed, nowadays, the insertion and use of data is performed at different levels of digitization. The first one, which we call Object Information Level (Ob-IL), occurs through the creation of attributes in parametric objects within the digital model [5]. The second method allows real-time data acquisition, archiving and management into databases or web-based platforms linked to the model, for a continuous monitoring and updating of information [6]. The name Real-Time Monitoring Information Level (RTM-IL) is assigned to this level.

Recent research aims to integrate Internet of Things (IoT) into BIM methodology in order to eliminate informal controls and reduce uncertainties [7]. The actual use of information ensues through methods and tools for the Operational Information Level (Op-IL), such as the navigation of BIM model, or Virtual Reality (VR) and Augmented Reality (AR), for rapid and user-friendly consultation [8][9].

Therefore, the diagnosis phase of historic buildings can be effectively managed through HBIM and information digitization. In that scenario, this research work initiates with the state of the art that highlights limited studies in literature about protocols for including diagnostic information and building condition assessment in an integrated HBIM-aided refurbishment project. In the next section, a structured framework about diagnostic data management, employing currently available software tools, is shown. The validation of this proposed procedure has been performed on a representative case study, the eighteenth-century Palazzo Palmieri in Monopoli (Bari, Southern Italy). In particular, the study focuses on wooden slabs and vaults, located on the noble floor, for selected limitation of scopes.

2. STATE OF THE ART

The concept of HBIM originates with Murphy’s research [10], which includes the creation of a library of architectural components modeled in parametric objects, after geometric surveys carried out with photogrammetric and laser scanning techniques. Acquired point clouds and raster images are processed with reverse engineering algorithms for three-dimensional or orthophoto
reconstructions that accurately capture shapes, geometries and textures in “as damaged” conditions. The next step is converting three-dimensional reconstructions into parametric objects, process called “scan-to-BIM” or “point-to-BIM” [11], a still open research topic because of the required definition of algorithms for segmentation and automatic recognition of each single components [12][13]. The recognition methods have been implemented in applications for direct conversion of such building and technical components characterized by regular geometries. Whereas, this operation is difficult for modelling existing buildings characterized by complex and irregular shapes; for instance, limestone masonry buildings present non-constant cross sections and out-of-plumbs (for limiting loads and moving the center of gravity to the lowest level), and vaults of complex geometry [14].

Although the photo-reconstructions contain geometric data and information about degradation conditions, such as cracks and humidity patterns, their direct re-use into simulation software products is incompatible, limiting their usage as consultable sources for design and programming (times and costs) of energy retrofitting, structural consolidations, seismic improvements and functional transformations. This is because data is visible but not computable within controlled, automated and bidirectional import/export operations, objectives of BIM approach. For this last detail, in spite of the complexity of accurate parametric reconstruction, creating a BIM model of existing building is worth because it should provide greater control of design decisions in terms of performance, cost and time, thanks to capabilities of quantifying the extension of decay patterns, calculating costs of intervention alternatives and managing performance parameters (thermal, mechanical, etc.).

Subsequently, BIM model is populated with attributes inherent materials, structural properties, and considerations about the state of conservation, activity belonged to the first digitization level (Ob-IL), which falls under the HBIM process called semantic enrichment. Nevertheless, a limited number of studies have dealt with the structuring of such data within the model [11][4], in order to contribute to the definition of guidelines for the information exchange and to widespread the adoption of this new paradigm in refurbishment. In this perspective, Bruno and Fatiguso, 2017 [4] formalized the information requirements for non-destructive diagnostic tests to be included into the model, in the specific, metadata and measurements generated with the application of GPR tests on limestone masonry, for assessing degradation conditions and monitoring the effects of former consolidation interventions.

Equally, continuous performance monitoring supports design and execution of refurbishment. Some monitoring applications, integrated in BIM for
existing buildings, concern Building Automation and Building Energy Management for managing thermal and energy performance of mechanical systems, controlling temperature, humidity and energy consumption and simulating energy retrofits [15]. Nonetheless, the identification of decays and risk situations, controlling cracks or dynamical behavior, could be likewise useful in calibrating structural simulative BIM models.

3. METHODOLOGY

The organization of BIM workflow observes well-defined rules. In the United States context, these are defined in the National BIM Standard - United States® Version 3 [16], while the English BIM Task Group established the BIM Protocol [17] and PAS 1192-2 [18]. In Italy, UNI 11137:2017 is the guideline for the digital management of information processes, in BIM optics [19]. In this article, a systematic framework of HBIM approach is suggested, with particular interest in material-construction characterization and building condition assessment. According to American regulations, before launching a project, the BIM Execution Plan (BEP) is required for defining the uses of BIM and information exchanges within the process phases, in this case related to refurbishment. A BEP planning category is the BIM Process Design, consisting in business process mapping and information exchange definition with the specification Business Process Management and Notation (BPMN). The specific methodology involves integration, management and use of diagnostic information (Fig.1).

Preliminary design activity in BIM optics is the ontological structuration of knowledge (Ontology Knowledge Structuration [OKS]), specifically the definition of required data and information, their encoding, ontological relationships, fundamental aspects for structuring Industry Foundation Classes (IFCs) schemas contained in the Model View Definition (MVD), specification employed for tool-to-tool information exchange [5]. This structuration generates effects on team organizations (1.1_Work Organization [WO]) and process breakdown structure.

Before constructing the model, the retrieval of knowledge is carried out in archivistic and bibliographic documents in order to have preliminary information on architectural typology and construction techniques, materials and distribution of rooms (2_Preliminary Knowledge Collection [PKC]). Then, correlating this preliminary knowledge with measurements gathered via geometric and photographic sensing. If geometric survey is performed with innovative contactless techniques, such as photogrammetry or laser scanning, the next step concerns reverse engineering (3_Reverse engineering
Figure 1. BPMN structuration about knowledge acquisition and refurbishment in HBIM process.
[RE]). In the case study, the BIM model is built with reference of CAD drawings, elaborated in previous studies. Therefore, in this HBIM process, the “Scan-to-BIM” or “Point-to-BIM” phase (4_Sc2BIM) is absent for generating the parametric model from three-dimensional meshes. However, the selection and creation of parametric families for modelling walls, decorative elements, doors, windows and slabs are mandatory steps. The core of the illustrated methodology is the execution of diagnostic tests for confirming or re-evaluating preliminary assumptions about material-constructional characterization and building condition assessment (BCA). The inclusion of diagnostic data within BIM model takes place in form of attributes and descriptions about equipment, execution methodology, results and observations, upstream elaborated comparing preliminary analysis [4].

The workflow, thus set, is developed for assessing technical-constructional characteristics and the state of conservation of horizontal slabs and vaults on the noble floor of Palazzo Palmieri, a residential complex of the eighteenth century. The planning and execution of non-destructive in-situ investigations provided detailed analysis of preliminary investigations, with the scope of creating a comprehensive knowledge framework.

4. RESULTS

Palazzo Palmieri is a noble residence of the eighteenth century, located in Monopoli, southern Italy (Fig.2). Expanded between 1769 and 1772 with the aggregation of some contiguous dwellings, the building acquired the character of an 18th century house, in Late-Baroque style, with influences of Neapolitan architecture. Palmieri family owned the building until 1921, when it was ceded to a charity congregation for becoming a school of arts and crafts. In 1926 and 1928, the building underwent consolidation and transformation works into a public school, in accordance with regulations of that era, with significant impacts on the last level, above the noble floor, where cracks and moisture infiltration had heavily compromised the wooden slabs, partially replaced, and partially recovered. Further works, on the last level, were carried out on several occasions in the years 1950-1960, such as the construction of hollow-core concrete roofs. The illustrative technical documentation also refers to interventions on the horizontal wooden slabs, in terms of increasing the resistance section, in order to adapt the structures to public and school buildings. Nevertheless, the consolidation techniques, adopted for this purpose, are not completely described.
After planning in-situ tests based on archival information, wooden slabs and vaults on the noble floor, most of which adorned with fine decorative motifs (Fig.3), have been investigated with an integrated system of investigation, including metric and photographic survey, mapping of cracks patterns and superficial alterations.

In addition, instrumental tests have been performed, such as thermographic acquisition of intrados and georadar of extrados of floors, with the aim of evaluating characteristics and conditions of components. In particular, two aspects have emerged as particularly interesting.

The first, as detected by radar scanners (IDD DAD Fastwave Control Unit and 2GHz Antenna) relates the presence of a structural system, consisting of discontinuous elements, above the wooden beams of slabs, installed with interaxis of about 80 cm, deep 10 cm from the upper floor surface. These overlapped components are offset of 40 cm, from the original ones, and immediately below the pavements. These elements are reasonably attributable to reinforcing metal profiles, interpreting distance and amplitude of hyperbolas where electromagnetic signal is reflected (Fig.4).

The second concerns the comparability of the radar response, in correspondence of both wooden slabs and vaults. Such comparability suggests non-bearing functionalities of vaults, indeed installed to the consolidated wooden slabs, similar to those not covered.

The hypothesis is proved by the results of thermography (FLIR T430sc thermocamera) taken from the vault intrados. The tests evidence the structure of wooden and wattle vaults (Fig.5), confirmed by the analysis of cracks patterns, not developed along the generative lines of a pavilion vault, but configured as widespread and random micro-cracks (Fig.5), effect of degradation of covering support.
Figure 5. Vault and eighteenth-century wooden slab on the noble floor.

Figure 4. Response type of radar survey on wooden slabs.

Figure 5. Thermography of a vault.
This information has been structured before being inserted as parameter-attributes related to BIM objects, defining its denomination, properties group and data type (numeric value, property and relative unit of measurement, image, URL, etc.). In the case of study, the BIM model was constructed from the available CAD drawings and it consists on the aggregation of parametric objects that model vaults (finishing and wood structure), wooden floor, moldings and decorative structures, windows and doors (Fig.6).

The attributes inherent the GPR investigations are organized within the group “Data” of instances about longitudinal profile type “GPR_ProfileX_L0n” and transversal profile “GPR_ProfileX_L0n” generated as a custom family, starting from an adaptive generic model (Fig.7).

5. CONCLUSIONS

The planning and execution of preliminary and diagnostic surveys, such as radar and thermography, about historical buildings affect uncertainty and interpretative reliability of material-constructive characterization and building condition assessment. In addition, methods of archiving and re-using the acquired information contribute to successful completion of diagnosis. Therefore, this research work has implemented BIM methodology for a
case study, highlighting the potential for knowledge management before proceeding with decisions about refurbishment interventions. Specifically, this article introduces the building condition assessment (BCA) phase within HBIM, starting from its first configurations analyzed in literature.

In this article, activities for integrating diagnostic knowledge were validated according to the criteria defined for the first digitization level, namely the

Figure 7. Management and sharing methods of attributes with BIM.
insertion of diagnostic information, in form of attributes, within modeled parametric objects (Ob-IL). This information is used navigating model and properties within instances, or reading reports and tables generated with BIM tools (Fig.7). Nevertheless, knowledge sharing is more effective if supported by bi-directional link among BIM model and databases or web-based platforms, methods and tools that require further research in the field of refurbishment.

As well, it is evident the importance of switching to RTM-IL level, for real-time data updating, and to Op-IL level, in order to ease model consultation through Virtual Reality and Augmented Reality, allowing proactive decisions, even in case of emergencies.

6. REFERENCES


