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Building Information Modeling for Cultural Heritage: Beyond Asset Modeling. A pragmatic comparison of literature case studies

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***Abstract* – The Building Information Modeling is an innovative approach based on two main pillars: new technologies and a collaborative work environment. It includes the creation of a digital container where all the information about the building and its lifecycle are dynamically allocated. Whilst the use of BIM in the management phase represents a unexpressed potentiality, the exploitation of the 3D virtual model could give a multiplicity of benefits, above all as regards big and historical buildings that are complex to manage. This paper wants to give a contribution to clarify what happens after modeling the cultural heritage with the principles of HBIM –Historical BIM- and managing its documentation. The authors analysed, with a pragmatic approach, a series of case studies documented in literature. The analysis led to highlight strengths and weakness of current approaches and a possible framework to overcome them.**

I. INTRODUCTION

Heritage buildings need specific systematic management processes to look after them [1], and also structured 3D models in order to handle conservation, restoration, modification or reconstruction projects and to support their management [2]. With new technologies available, this can mean the creation of a knowledge base, planning actions and operations over time, organizing information to be accessible and long term preserved. HBIM is used as "a state of the art tool for the efficient documentation of information of historic buildings" and as the enabler for stakeholders to remotely and collaboratively access this information [1].

As HBIM model is not created at the beginning of the lifecycle of a structure, it can be included in the vast topic of "As-Built" BIM model [2].

Nowadays no tool supports the direct conversion of raw data collected in the survey phase (e.g. point clouds) into a BIM model, this step becomes a sub-process of three tasks: the acquisition, the segmentation, and the enriched 3D modeling [2]. The survey of an historic structure, even if now involves laser scanning technology, georeferencing and advanced photogrammetry, is usually complex, long and time consuming. BIM based software are not flexible enough to describe complex and deformed geometry [3]. This forces to make choices that reduce the amount of information reported by the informative model resulting in loss of data. Survey metadata (devices names, accuracy, ..), that may come in handy on later stages, are missing as well.

This first stage of creating the base of knowledge and the 3D informative model is just the foundation for reaching the full aim of BIM, i.e. managing information for the full lifecycle of a structure. With literature still looking for a standard process to create the model, it should be kept in mind that an historical building will need constant decay monitoring and conservation operations over time, as this means updating information multiple times by different stakeholders at once.

This research starts from the hypothesis that the informative model of heritage structures should be created for these purposes and that standards should be applied to application format, models and notations in order to assure interoperability and allowing the creation of a full HBIM model useful for the whole lifecycle.

The BIM model of an existing building is created necessarily through a metric survey with the available technology of our time: digital photogrammetry, laser scanning, total stations, etc..

How the survey has been carried out is part of the knowledge that should be attached to or expressed by the model. A building could need additional surveys at different points in time, with the aim of monitoring and managing maintenance management and operations, supporting decision making and cost cutting.

After an overview of current state of the art, the methodology of the research is described in section III. Section IV illustrates a summary of the analysis carried out on the literature. Early results and future research are exposed in section V. Conclusions follow in Section VI.

II. STATE OF THE ART

A consistent part of literature is focused on the application of BIM methodology to heritage structures and to the preservation of the information related to historical and archeological sites. [4] describes Historical-BIM (HBIM) as "a data structure based on existing historical elements: "as-built models" including quantitative (parametric) and qualitative (attributes) information. Unlike traditional laser scanner or photogrammetric data (point cloud or mesh), HBIM has the ability to describe by variables our, incorporating the concepts of management in the lifecycle of the built environment and making feasible the adaptability of content to a wide range of scenarios".

Many scholars agree that BIM methodology and the standard already formalized for existing buildings do not suit the needs of cultural heritage or, in general, when the informative model is generated in the middle of the lifecycle of a structure. [5], for example, points out that "Digitalization of a historical building and interventions on it, after the survey and consequential considerations on the "singularity" of each element, does not allow any standard step and asks for more flexible operations to model them; The model is often composed of ad hoc elements or families, which causes an increase in file size and difficulties related to interoperability (and data loss) between different software".

[5] highlights two different trends in literature: one dealing with accuracy solved either by enriching the 3d model in a semantic way comparing survey data and information from historical documents, creating a historical library [6] of building object models that currently do not exist, or adapting as much as possible available building objects models to data from the metric survey; the second trend, calibrates the model as a function of a design scope (e.g. energy analysis, structural analysis or FM simulation). In this trend, before proceeding with the modelling phase in detail, it is necessary to establish a level of accuracy or level of detail according with the design scope.

There is no agreement on one single formally specified methodology.

It is also emphasized that the current approaches cause an important loss of the data generated during the survey and the processing phases, both resources and time consuming [7] [5].

These themes are strictly linked to the constant monitoring of decay (material pathologies and structural performance). Moreover, from an accurate study of these information would be possible to organize restoration and maintenance operations in a timely manner, optimizing costs [8] [9].

[10] includes in the "Durable Architectural Knowledge" both voluminous point cloud data and semantically consistent descriptions of building products, pointing out the value to practitioners of the possibility to re-use this captured knowledge. It also describes the use case, in the prospective of long-term archival of 3d laser scanning information, where practitioners and authorities "will want to compare the current state of a building through a scan with the one described in the storage". [11] proposes a framework for HBIM data management that includes among other things: accurately surveyed data, facilities management, Internet of Sensors and "a structure and standards that support continual retrieval and reuse for decades if not for centuries".

III. METHODOLOGY

The first stage of the present research work was a literature study in order to understand which methods are currently used, to link relevant information to the BIM model and if metadata and non-manipulated data are stored in the virtual informative model.

To this end, the quantitative and qualitative research was addressed to the papers concerning the cultural heritage management over time. Firstly, a set of key words were chosen:

- HBIM operation management;
- HBIM management;
- HBIM operation;
- Historical BIM management;
- Heritage BIM management;
- HBIM monitoring management;
- HBIM monitoring;
- Historical BIM monitoring;
- Heritage BIM monitoring;
- HBIM data representation;
- HBIM metric survey.

These key words were then used to search papers in Web of Science and Scopus bibliographic databases and 54 papers were found (full list available at: https://cpdmlab.unisalento.it/MetroarchaeoHBIMliterature.html).

In the second stage, after an analysis of papers content, a selection of papers has been carried out and those papers that weren't relevant to the research, i.e. papers which were non concerning the cultural heritage management, were eliminated. The 45 papers selected were read and the recurring workflows and/or operations used to create the BIM model were recorded.

The final step was to elaborate and propose a framework aiming at associating relevant information to a twofold digital model over time, based on the literature study results, starting from the assumption that "the ability to view, edit, compare and represent strategic decisions is an enormous advantage for solving critical operating situations, such as the delay of construction phases, cost increase and the risks involved during work phases [5]".

IV. SUMMARY OF THE ANALYSIS

After a deep analysis of all papers found and selected in literature, a first classification was referred to the level of detail that each paper gives to the description of the survey (fig.1) as a symptom of the importance given by the paper to data and metadata produced during this phase: instruments, settings, precision, software, pre-processing and post-processing etc.. Only 28 papers could have been classified and among them 12 gave a high level or medium level description of the survey phase.

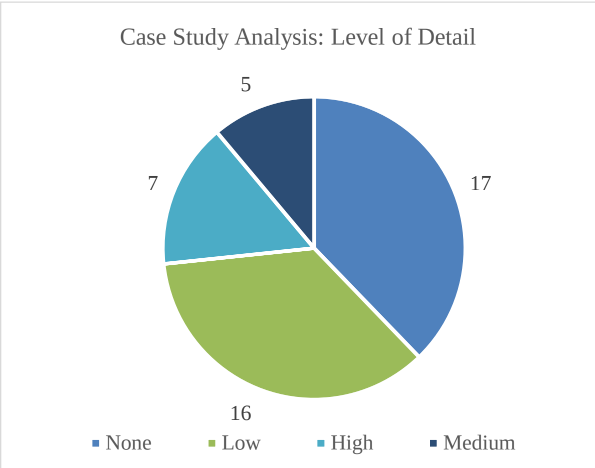

Fig. 1 Classification of papers level of detail

Fig. 2 shows which survey technologies were explicitly mentioned by the papers. The majority of papers focuses on data acquisition via new technologies (laser scanner, photogrammetry, UAV-Drone). In some cases a combination of different techniques is applied. The fact that GPS and Total Station are less mentioned could derive from a focus shift of research to new technologies, even if this two instruments are still applied in almost every survey.

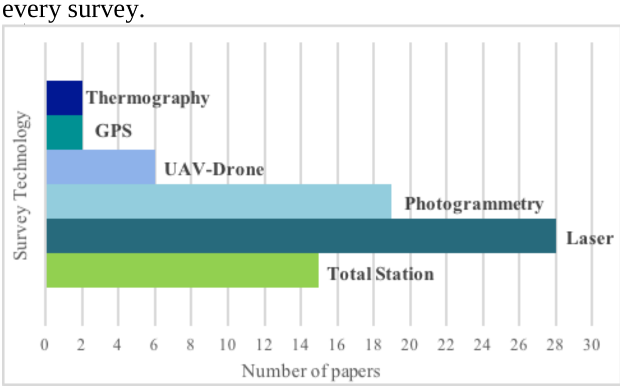

Fig. 2 Survey technologies

The following histogram (fig.3) illustrates which application software tools have been cited (and applied) in the papers read. Most of them were used in order to process data deriving for example from a point cloud (Cloudworks, Cloud Compare, Autodesk ReCap, Leica Cyclone) or from traditional and UAV-Drone photogrammetry (Agisoft PhotoScan, Photogrammetric Studio, Autodesk ReCap). CAD and 3D Modelling software as Autodesk Revit, AutoCad and ArchiCad were often not sufficient to model accurately the architectural elements and decorations of historical buildings, making many authors forced to use others tools as ad hoc Nurbs algorithms, Rhino, Unity 3D and Arena4D for advanced modeling or visualization purposes. PgAdmin has been adopted as an interface for managing an external DataBase associated to the model. In 2 cases a web platform (Autodesk 360) has been used to share information among actors involved in the project.

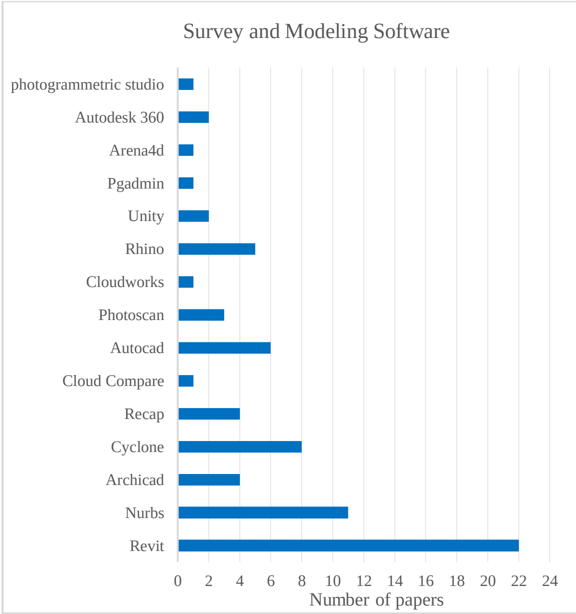

Fig. 3- Software tools used

Some papers proposed methodologies that enriched the Building Information Modeling (fig. 4). The most recurring proposal is the introduction of a semantic data model or ontology to represent data in a specific logical way. The conceptual model includes semantic information that adds a basic meaning to the data, their attributes and their relationships. This data modeling and data organization approach facilitates the development of application programs and also the maintenance of data consistency when data is updated. Ontologies are said to be at the "semantic" level, whereas database schema are models of data at the "logical" or "physical" level. They are used for integrating heterogeneous databases, because of their independence from lower level data models, enabling interoperability among varied systems. Many papers reveal also the need of a link to a database (in 2 cases via url) capable of containing both the model, and consequently its parametric objects, and all information and additional file related to each object. A central database will enable the sharing and synchronization of project changes in real-time if accessible via web. In addition to that, the model can also be easily shared over the web for visualization and used for tourism applications. Another proposal is the integration with a Geographical Information System (GIS) to give a geospatial perspective of the HBIM model, adding a further analysis tool as support for many location-enabled services that rely on analysis and visualization.

Standardization is a path encouraged by many scientific exponents in construction field, and also in Cultural Heritage, as fig. 5 shows, several authors proposed the use of a standard language. The most cited is the Industry Foundation Classes (IFC) promoted by BuildingSmart, an international association that aims to spread the adoption of Open BIM in the Construction Industry sector. The HBIM library is also often cited, as a collection of digital editable objects managed by a public entity and available to designers for modeling purposes.

It is worth noticing that many standards are related to the IT and ontology world: owl, ifd, rdl, sparql.

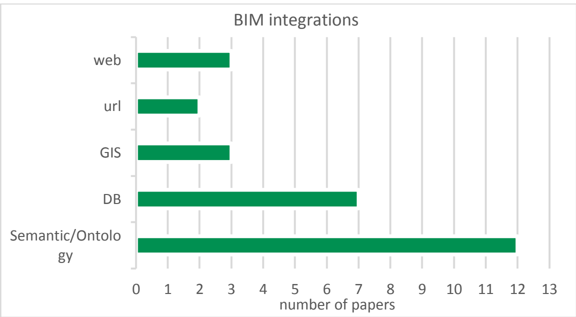

Fig. 4 BIM integration proposed

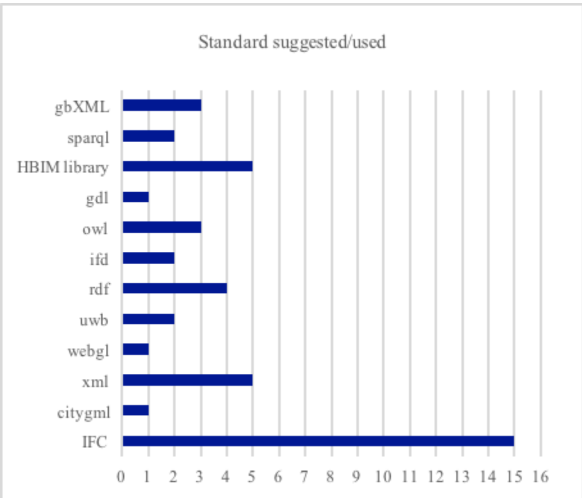

Fig. 5 Standard suggested/used

In the view of the objective of the paper, authors investigated the perception of the need of the HBIM model management over time and, as fig. 6 shows, the majority of the papers doesn't study the long term model management aspect.

Only 20 papers propose a workflow about operations discussed (surveys, modelling or model management): 11 workflows are implicit in the papers and 9 are structured workflows, but not expressed in a standard language.

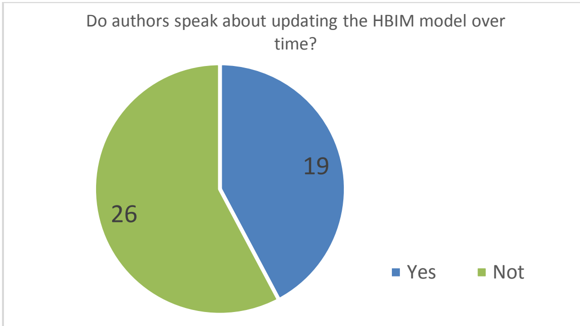

Fig. 6 Long term model management

V. EARLY RESULTS AND FUTURE RESEARCH

Two different insights have been detected among the papers examined. One is the need of keeping as much knowledge as possible from metric surveys, the second is the need of having a model suited for certain type of analysis: energetic, structural, bill of quantity etc, usually of a lower level of detail in order to reduce file size and computational time.

The first one is well exposed by [10] namely the Advanced 3D model or LIM (Lidar Information Model); the second is ascribable to the one described by [6] as HBIM model made of solid, parametric objects from a specific HBIM library semantically enriched with the help of H-IFD (Historical International Framework for Dictionary).

These models, if taken individually, present limits in fully representing the nature of knowledge linked to cultural heritage.

The first is optimal to not loose detail on historical architectural shapes and artifacts (including deformation and decay), to compare different sets of raw data coming from surveys carried out in different points in time and to enhance the virtual cultural fruition of a structure.

The latter is indicated when a parametric lighter solid model is needed.

This research proposes a framework for Cultural Heritage management where these two models coexist, in order to benefit from both insights. The two models should be linked in a bidirectional way to be updated simultaneously if needed and to give a full overview of models attributes to the user.

In order to allow collaborative and geographically distributed access to the twofold model the framework is thought as web service enabled, representable via Web Ontology Language (OWL), as suggested by project DURAARK [11] in order to provide also "a sound basis for very long term archiving, retrieval and reuse of architectural information".

Steps for future research will be firstly modelling the proposed framework into an agnostic system with UML (Unified Modelling Language) and OWL-S. The second step will be prototyping a software architecture based on the model produced and then test it on one or more use cases from Cultural Heritage.

VI. CONCLUSIONS

Preventive conservation, thus, regular maintenance, is a real necessity for Cultural Heritage. The HBIM model is not considered sufficient to cover and manage the whole lifecycle of a historical building because of the huge quantity of historical information, survey data, geospatial data, administrative documentation that should be linked to the digital model. To overcome this issue it is necessary to identify the proper ontology in order to structure data in an integrated knowledge-base, dynamically updatable and accessible by users involved in the process.

Many papers propose a workflow or a framework of activities on short pieces of a more wide full process from survey to the operation phase. From the management point of view a whole complete flow of activities should be proposed and formalized in a standard notation like BPMN to be immediately interoperable and uploaded in a software. This study reveals the lack, and contextually the need, of a standard and open HBIM library that allows to customize elements in order to represent local peculiarities. In fact, among the analyzed papers, there is not a common notation language or a common methodology. Standardization is not merely the answer to the need of a unique language, understandable by all the stakeholders, but it is a tool that could give a fully representation of processes, avoiding project errors, reducing risks, costs and waste of time, and facilitate automation of phases and the development of application programs.

In Cultural Heritage field, where conservation over time is the main scope of all restoration processes, maintenance and decay preservation become crucial concepts. H-BIM based processes, with appropriate enrichment as OWL standard framework and an open H-BIM library, where digital objects could be downloaded, edited and customized by including local materials or constructive techniques, and eventually re-uploaded in order to make them available to other users, could be a good knowledge base to innovate this sector.

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