The Role of Knowledge-Based Information on BIM for Built Heritage

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C. K. Cogima, P. V. V. Paiva, E. Dezen-Kempter, M. A. G. Carvalho, and Lucio Soibelman

Abstract

Information about historic buildings is extensive and fundamental for maintenance, preservation, and restoration purposes. However, a common problem is lack of standardization and documentation updating. This work aims to gather 3D BIM model of historic buildings with their knowledge-base through a formal ontology. A terrestrial laser scanner was used to collect geometrical data. The resulted point cloud was delimited by Regions of Interest (ROI) then downsized and segmented. The selected case study is the Ballroom, part of the Pampulha Architectural Ensemble designed by the renowned architect Oscar Niemeyer. This building, located in Belo Horizonte, Brazil, has a unique, sinuous and irregular shape, recently listed as World Heritage site by UNESCO, rising its documentation importance both locally and worldwide. The CIDOC-CRM (International Committee for Documentation—Conceptual Reference Model) and FRBRoo (Functional Requirements for Bibliographic Records—object oriented) is the source for create the building ontology, later connected to the model. The proposed methodology shows that linking geometric and semantic database into a BIM environment can improve heritage documentation.

Keywords

Reality-based surveying • Ontology-based system • Computer vision

4.1 Introduction

The undergoing massive growth of digital technology is affecting all areas of Architecture, Engineering, and Construction (AEC), enabling unprecedented efficiency on all fronts, from design to construction. In recent years, there has been an increasing amount of research focused on the use of these technologies also in the stock of existing buildings, mainly in the maintenance and operation. The computational development in AEC, among them the Building Information modeling (BIM), allowed the integration of information about the whole system with the elements of the 3D model. According to [1],

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in addition to BIM, the semantic web technologies allow describing the information behind the artifact, namely all documentation about the complete context of the artifact, including all kinds of relations, types, properties, and links. For the heritage conservation purpose, linking BIM and semantic web technologies is valuable to gather and document all relevant information of the historic building, which is mandatory for renovation and maintenance works.

As demonstrated in other studies (e.g. [2–4]), the accurate data recording into BIM components allows the creation of a database where the interested party can filter specific information, providing an efficient documentation system able to memorize data for future interventions. Concerning BIM database, [5] pointed out the importance of the ontological model for built heritage representation. Ontology is described by [6] as "an explicit specification of a conceptualization" this means that when the universe of knowledge is precisely defined, a set of objects with relationships can represent it, creating a knowledge-base readable through programs. Therefore, an ontology-based system is based on the formalization of all knowledge related to each artifact through semantic networks, regarding entities, properties, and relationships. In order to support information management during the investigation and restoration activities, this paper presents an ongoing research that aims to develop a framework to integrate optical measuring surveys (material properties, geometrical data) and knowledge base (historical analysis, e.g. information models within its context) in a BIM Model. Our approach relies on an ontology-based system to represent the knowledge related to the historical events of each technological components of the building.

This paper is organized as follow: the state of art section addresses the scientific achievements in the field of BIM for heritage, integration of BIM and ontology by semantic web technologies, and computer vision applied to 3D data. Section 4.3 describes the methodological workflow applied to the case study. The results obtained and their potential application for the heritage conservation domain are discussed in Sect. 4.4. Section 4.5 outlines the limitations and future works offered by our approach.

4.2 State of Art

Some authors like [7] developed a conservation process model that aimed to be more than a data repository on existing architecture but also supporting heritage conservation process, which could be reached by means of ontologies. So, its approach is based on a double scope, capturing and representing the semantic contents of cultural heritage conservation process and suggesting a model that may achieve integration, mediation and interchange of information in the cultural heritage conservation field.

The International Committee for Documentation (CIDOC) developed a Conceptual Reference Model (CRM) to categorize and represent the semantic data of cultural heritage [8], the ISO 21127:2006 standard for cultural heritage documentation; it is an attempt by the Committee of the International Council of Museums (ICOM) to achieve semantic interoperability of cultural heritage data. CRM is an ontology which primary role is "to serve as a basis for mediation of cultural heritage information and thereby provide the semantic 'glue' needed to transform today's disparate, localized information sources into a coherent and valuable global resource" [9]. In addition, the CIDOC group has been working on documents to create specific ontologies such as FRBRoo, its objective is represent the bibliographic information and interchange it with museum data. Some works have explored this focused on cultural heritage [7, 10]; others for cultural information for tourism purposes [11]; software engineering [12]; compare bibliographic metadata [13]; and others.

Transpose geometric data to enriched models is not a direct operation demanding computational techniques able to convert early survey into workable information. Treatments like noise reduction through statistical tools or point cloud processing [14], filter outlier and small regions. Large point collections also compromise modeling tasks causing computational cost increment. A usual solution is point cloud downsizing [15] when recursive structures reduce cloud density. Additionally, segmentation provide easily convertible regions to models. A standard method to separate defined form is RANSAC common used to recognize regular elements such wall, ceil, floor, etc. [16].

4.3 Overview of the Approach

The methodological framework adopted for the proposed Knowledge-based BIM modeling consists in four steps as follow:

(1) Gathering Non-Geometrical Data: historical survey to track record of the different stages of the building (use changes, relocations, historical stratification, and degradations);

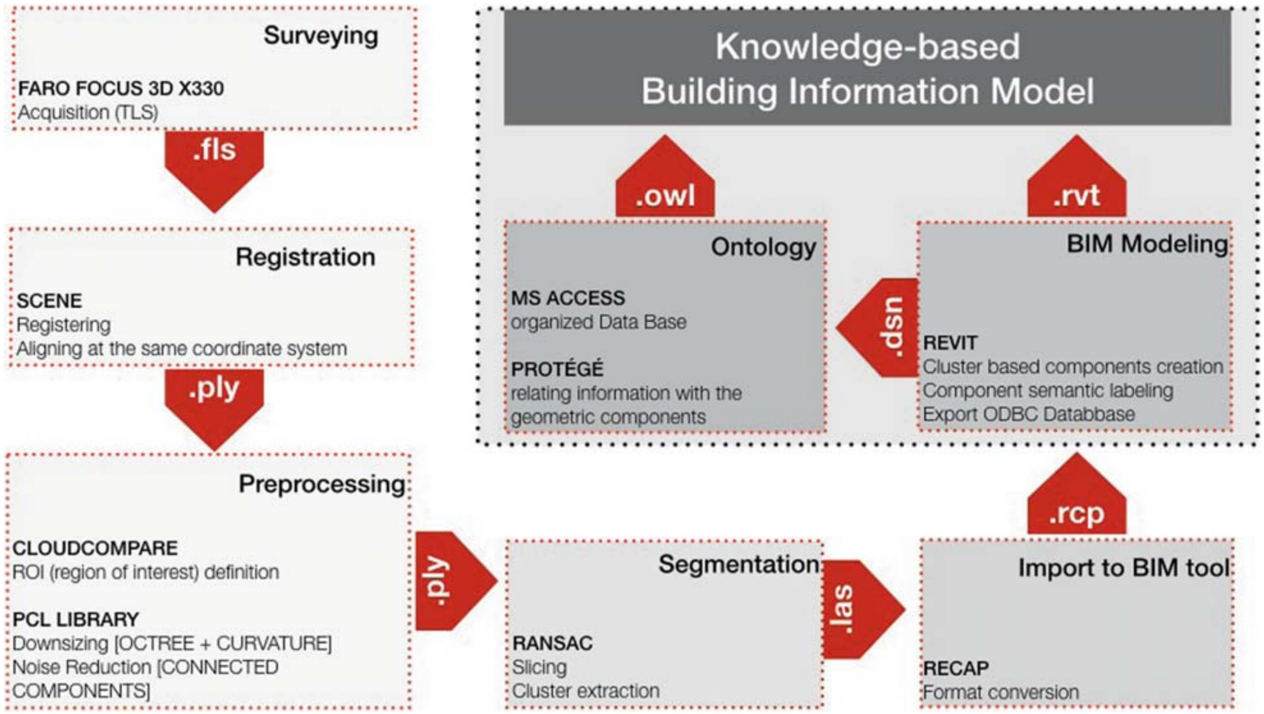

Fig. 4.1 Workflow for knowledge-based BIM

(2) Gathering Geometrical Data: measurement survey using laser scanning; point cloud registration; processing of the raw data and segmentation;
(3) Modeling building components in a BIM environment: defining identifiable classes in order to associate the non-geometrical data with them;
(4) Developing the Knowledge-based Information integrated with the BIM model. We adopted the CIDOC-CRM as the core ontology in this study to map heritage information in an extensible semantic framework.

Figure 4.1 summarizes these steps, starting from the laser scanner surveying, showing the software and format file for interoperability of each step.

4.4 Building the Knowledge-Based Information Model

4.4.1 Case Study: The Oscar Niemeyer's Ballroom in the Pampulha Modern Ensemble

A case study was selected to demonstrate the creation of a knowledge-based digital built heritage model. The presented case study is the Ballroom designed by Oscar Niemeyer in 1940 (Fig. 4.2). The Ballroom is one of the four buildings planned by Niemeyer surrounding an artificial urban lake that shapes the Pampulha Modern Ensemble (PME), located in the city of Belo Horizonte, in Brazil. The UNESCO's World Heritage Convention listed the PME for its outstanding universal value as a Cultural Landscape in 2016. Niemeyer's works in Pampulha establish a synthesis between local and regional practices and the principles of modern architecture language focused on new experiments in reinforced concrete.

The Ballroom is located in an artificial island and is composed of the main building, whose spatial organization is defined by two internally secant circles, with a free span exceeding the 19 m supported by a 40 cm high concrete grid. The horizontal interior roof plane flows on the outside to become a winding marquee supported by slender round columns, connecting the main building with the dressing room, a small outdoor stage, and a lily pond. In 2003, Niemeyer, at the age of 93 years, was responsible for the directives of intervention inside the building, constructing an auditorium and adapting the service rooms and sanitary, justified by the use change of the place. The modeling and comparison between the current state

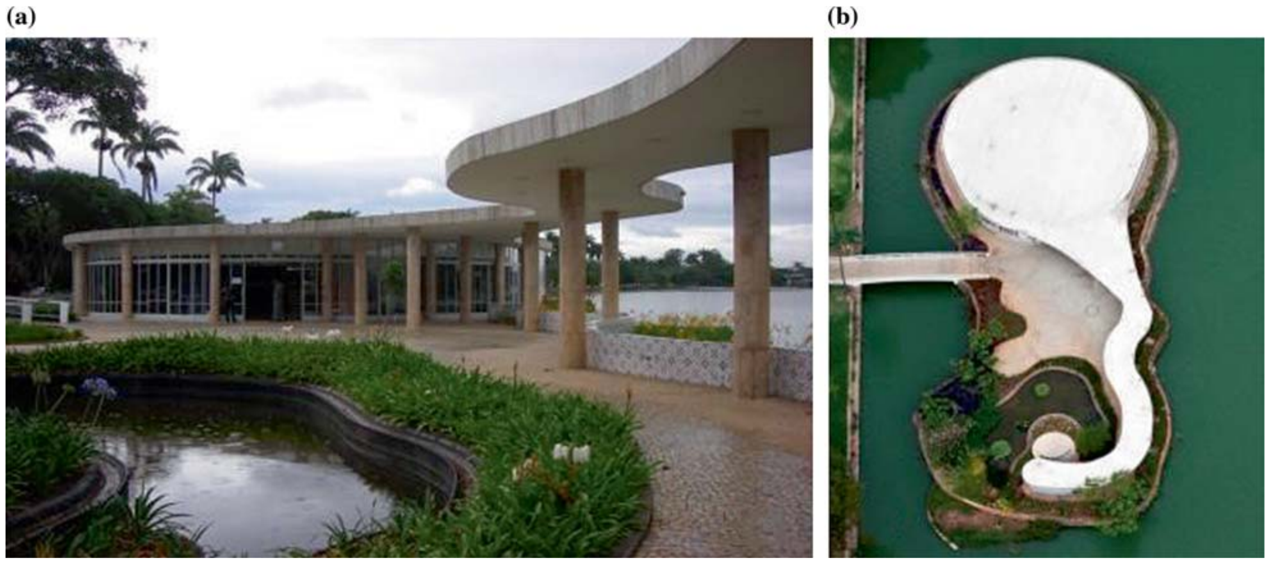

Fig. 4.2 Images of the Ballroom **a** view from the garden; **b** aerial view

of the building and its projected situation are fundamental to the understanding of the process of use change and documentation of these historical events. In the future, the building can undergo a new alteration if the use of the building changes again, but now as World Heritage any modifications must be strictly controlled to preserve its original features.

4.4.2 Non-geometric Data

A historical building, even with high quality data raised, still needs information related to its history to compose the model and make it semantically complete [17]. To do this, it is necessary to search in responsible public bodies official documents that bring important data such as their initial design, construction elements, materials, interventions suffered over time, their incorporated legal and social aspects and their impacts (environmental or anthropological).

For this work, the IPHAN (Institute of Historical and Artistic Heritage), a governmental institute responsible for preserving and disseminating the country's material and non-material assets, provided all documental information data. For this purpose, IPHAN produces an historic survey of each asset listed as cultural heritage, gathering documental information, photos, sketches, web references and other kind of media.

4.4.3 Geometric Data

The Ballroom location and its unique architecture reduces geometric data acquisition to few options. The building is inside a restricted air space due its proximity to Pampulha Regional Airport, excluding UAV survey. Another limitation is Ballroom position surround by Pampulha's Lake. Those factors associated with curved aspect on mainly construction elements demand a particular approach, described on next sections.

Data Acquisition. Due site restrictions, building singularity and accuracy required, TSL became the only alternative to geometry acquisition. Faro Focus 3D X330 was used covering both inside and outside areas of the building, including the roof (see Fig. 4.3). Ballroom rounded aspect and the lake were overcame positioning the scanner at different ranges. Point cloud density deteriorate as TSL and object surface distances increase. This and other issues are treated on preprocessing phase.

Preprocessing. Challenges imposed by the Ballroom architecture and the limited available areas for TLS arrange elevated the number of scanning position. Registration creates a dense point cloud containing around 370 million points. Although many points been required to represent a complex structure, the initial survey infeasible its analysis. Restrict the raw point cloud to region of interest (ROI) is primordial to exclude unnecessary data. Even been intuitive, this simple step

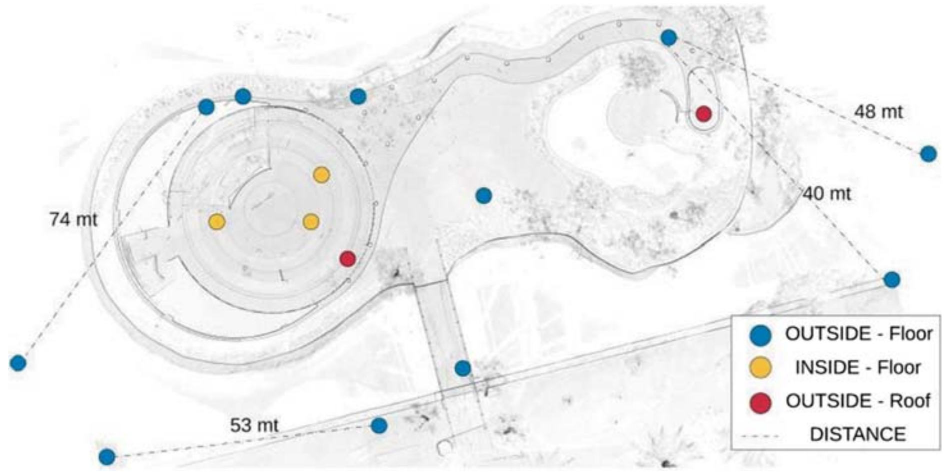

Fig. 4.3 Scanner position over Ballroom area (colors for distinct situations and measures in lines for distant positions)

lower the cloud to 90% of its original size. Density normalization is possible by octree downsizing, method able to recursively reduce point clouds defining a fix cubic structure and maintaining only center points [18]. At this stage, data decrease reaches 75% forcing even more withdrawing. Keep wiping out points after the previous methods probably compromises objects forms, invalidating the cloud for modeling. An appropriate policy to lower cloud avoiding impairments is point exclusion weighting by its curvature. Computing normal and estimating local curvature [19] enables choose regions better describable with few points. Maintaining higher density where curvature also increase is desirable (blue vs. red areas at Fig. 4.4) a simple algorithm minimize the cloud to 56 million points (15% of raw size).

Small clusters, usually noise, possibly remain but a well know method easily exclude those groups applying connected components strategies [20].

Segmentation. A wide spread technique for point cloud segmentation on as-built state of art is RANdom SAmple Consensus (RANSAC) [21]. In brief, its operation tries to find a defined form (e.g. planes, spheres, and cylinder) estimating how well random sets of points fits the model. Floor and roof are basically planes what makes RANSAC capable to recognize it precisely just adjusting inliers. The same applies to columns assuming cylinders as model for detection. For non-regular forms, a model is not possible turning hard to segment these structures. Alternatives for RANSAC are available but horizontally slicing the prepressing cloud was already enough for Ballroom case.

4.4.4 Modeling Through the Point Clouds

The Dense surface models resulted from the 3D point cloud has non-structured features as lack of topology and semantic discretization. This makes the building information modeling an essential step to provide intelligence for these data. Due to the rounded building shape, automatic feature extraction was not effective. We used EdgeWise Software for automation but it failed to deliver satisfactory results.

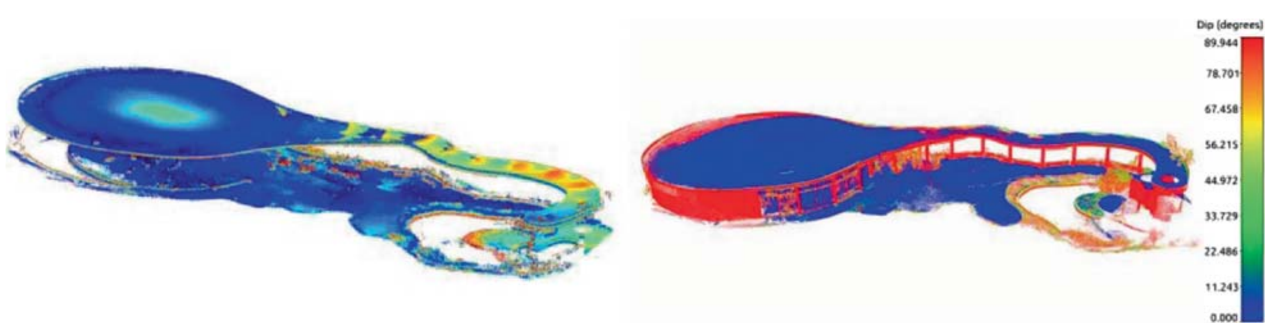

Fig. 4.4 Curvature analysis of downsized Ballroom scanning from lowest to highest [blue to red]

Fig. 4.5 Model of Ballroom: **a** point cloud section of interior; **b** rendered interior view of BIM model; **c** rendered exterior view of BIM model

The Ballroom was modeled in a BIM environment using Autodesk Revit 2018 tool. We performed the modeling approach directly on the imported point clouds from Autodesk ReCap tool, using the native systems families (walls, columns, floors, roofs, curtain walls), model in-place components (ceilings) and hosted in system elements (windows, doors).

In addition, the slices were used for the modeling of the other components in BIM environment. The greatest difficulty of this particular building is in its non-regular form, which requires more time to finish the job.

Each BIM component was labeled using the OminiClass element, which is primitive of Revit and shared parameters were used to the CIDOC_CRM ontological system. Figure 4.5 depicts the final model of The Ballroom and a section in the aligned point cloud.

4.4.5 Knowledge-Based

In the Historical Building conservation process thousands of facts and documents are collected to shed light on the past contextualizing the object in study, but nevertheless it is difficult to integrated and connect all evidential data in a relationship to the physical substance of the building.

The goal of connect all kind of documents, including digital measurements acquisition and 3D Models is to provide the means to the historical data in such a way that the following functionality is supported:

1. Maximize interpretation capability over the documents and facts contextualizing their spatiality;
2. Possibility of the knowledge revision in the building life cycle;
3. Comparing all intervention on the building;
4. All kinds of comprehensive material and historical studies.

Some software are being developed to sketch out this ontological process so that structure the information in classes and subclasses and connect them to the instances through relationships. In this way, it is possible to visualize all the non-geometric relations this artifact has. In this research, the Protégé software was used to create the ontological basis.

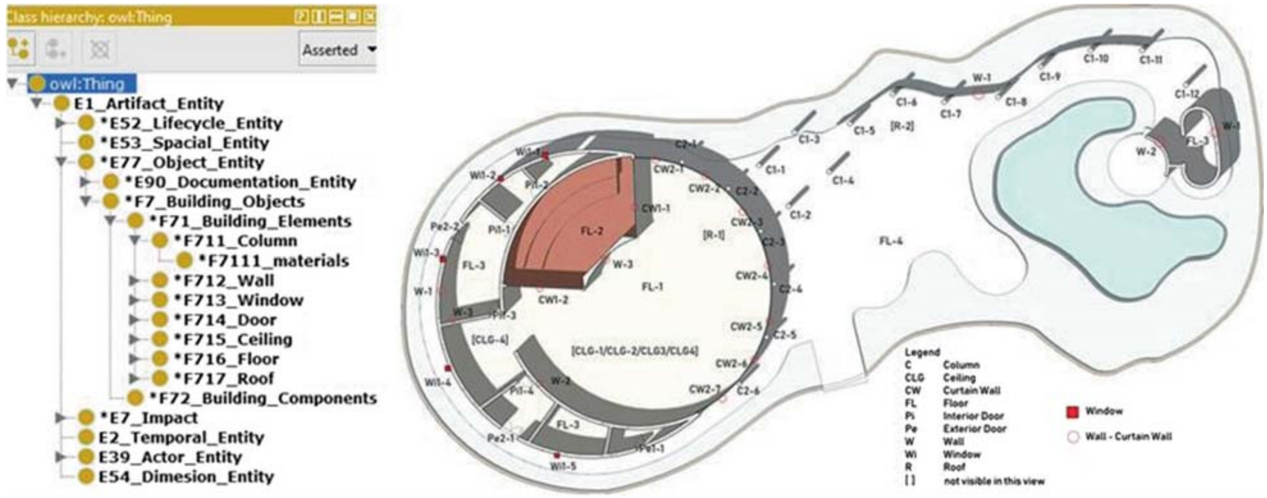

Fig. 4.6 Knowledge-base created in Protégé and element markings

The artifact was defined as the main class coded as E1 (CRM Entity), according to the CIDOC-CRM, being followed by entities (subclasses): temporal, spatial, object, impact, actors, dimension and life cycle. The subclasses with the letter F were taken from FRBRoo. In each of them was inserted the information, in subclasses and instances. Some ad hoc adjustments to the codes were necessary to follow a logical sequence and to detail the information; they are shown with an asterisk. The graph result is shown in Fig. 4.6.

After creating the ontology, this was connected with 3D model based on [22]. The elements were named according to the proposed ontology and DBLink Plugin formalized the integration between the BIM environment and knowledge base. The steps for integrating the ontology with the BIM model are described in four steps, according to [22]:

- Export the BIM model information in Access format, containing its properties and objects, throught DBLink plug-in;
- Conversion of the ontology file in MySQL format, for OWL connection of Protégé software;
- It is necessary to name the objects and properties in the ontological software according to the BIM model, and;
- Mapping and identification of the semantic structure in the two databases (Revit and Protégé).

4.5 Conclusions and Future Works

In this paper, we proposed and detailed a methodological framework to improve the BIM model for heritage, including non-graphical information. Contribution especially needed when the modeling environment is created for existing buildings starting from scratch.

This work aimed to collaborate to overcome the drawback the low level of semantics in use of BIM for heritage, as cited by [1]. Corroborating with said by [23], the exploitation of point cloud, the BIM environment could produce fully detailed graphics documentation, for the conservation of historic structure, in 2D and 3D representation. The aggregation of semantic information in the model enhances the digital documentation, as shown in our approach.

This study demonstrated the possibilities to linking non-structured data into BIM to create a comprehensive environment for built heritage knowledge management. Ontology-based Systems allows the integration of the building's components with knowledge representation and management, fostering a useful bundling of geometrical and non-geometrical data. BIM proved to be a tool capable of managing information collected and modeled, improving its availability and accessibility.

Working semantics into BIM is not trivial work. For this reason, we envisage for next research the development of a tool based on dataset for IFC model structure, enabling easily visualization of the BIM model components and their linked semantics.

References

1. Acierno, M., Cursi, S., Simeone, D., Fiorani, D.: Architectural heritage knowledge modelling: an ontology-based framework for conservation process. J. Cult. Heritage **24**, 124–133 (2017)
2. Pauwels, P., Bod, R., Di Mascio, D., De Meyer, R.: Integrating building information modelling and semantic web technologies for the management of built heritage information. In Digital Heritage International Congress (Digital Heritage), vol. 1, pp. 481–488. IEEE (2013)
3. Fai, S., Graham, K., Duckworth, T., Wood, N., Attar, R.: Building information modelling and heritage documentation. In: Proceedings of the 23rd International Symposium, International Scientific Committee for Documentation of Cultural Heritage (CIPA), Prague, Czech Republic. pp. 12–16 (2011)
4. Dore, C., Murphy, M.: Integration of historic building information modeling (HBIM) and 3D GIS for recording and managing cultural heritage sites. In: 18th International Conference on Virtual Systems and Multimedia (VSMM), pp. 369–376. IEEE (2012)
5. Garagnani, S., Manferdini, A.M.: Parametric accuracy: building information modeling process applied to the cultural heritage preservation. Int. Arch. Photogrammetry Remote Sens. Spat. Inf. Sci. **5**(1) (2013)
6. Gruber, T.R.: A translation approach to portable ontology specifications. Knowl. Acquisition **5**(2), 199–220. ISSN 1042-8143, https://doi.org/10.1006/knac.1993.1008 (1993)
7. Fiorani, D., Acierno, M.: Conservation process model (CPM): a twofold scientific research scope in the information modelling for cultural heritage. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **XLII-5/W1**, 283–290. https://doi.org/10.5194/isprs-archives-XLII-5-W1-283-2017 (2017)
8. CIDOC CRM Homepage, http://www.cidoc-crm.org/. Last accessed 2018/05/02
9. Doerr, M et al.: Realizing lessons of the last 20 years: A manifesto for data provisioning & aggregation services for the digital humanities (a position paper). D-lib Mag. **20**(7/8) (2014)
10. Guillem, A., Bruseker, G., Ronzino, P.: Process, concept or thing? Some initial considerations in the ontological modelling of architecture. Int. J. Digit. Libr. **18**(4), 289–299 (2017)
11. Di Giorgio, S., Felicetti, A., Martini, P., & Masci, E.: Dati. Cultura Italia: a use case of publishing linked open data based on CIDOC-CRM. In EMF-CRM@TPDL, pp. 44–54 (2015)
12. Aalberg, T., Vennesland, A., Farrokhnia, M.: A pattern-based framework for best practice implementation of CRM/FRBRoo. In: East European Conference on Advances in Databases and Information Systems, pp. 438–447. Springer, Cham (2015)
13. Nurmikko-Fuller, T., Jett, J., Cole, T., Maden, C., Page, K.R., Downie, J.S.: A compara- tive analysis of bibliographic ontologies: implications for digital humanities. Digit. Humanit. 639–642 (2016)
14. Han, X.F., Jin, J.S., Wang, M.J., Jiang, W., Gao, L., Xiao, L.: A review of algorithms for filtering the 3D point cloud. Sig. Process. Image Commun. **57**, 103–112 (2017)
15. Wang, C., Yong, K.C., Changwan, K.: Automatic BIM component extraction from point clouds of existing buildings for sustainability applications. Autom. Constr. **56**, 1–13 (2015)
16. Jaehoon, J., et al.: Productive modeling for development of as-built BIM of existing indoor structures. Autom. Constr. **42**, 68–77 (2014)
17. Simeone, D., Cursi, S., Toldo, I., Carrara, G.: BIM and knowledge management for building heritage. In Acadia, vol. 2014, pp. 681–690 (2014)
18. Trevor, A. J. B. et al.: Efficient organized point cloud segmentation with connected components. Semant. Percept. Mapp. Explor. (SPME) (2013)
19. Meek, D.S., Walton, D.J.: On surface normal and Gaussian curvature approximations given data sampled from a smooth surface. Comput. Aided Geom. Des. **17**(6), 521–543 (2000)
20. Elseberg, J., Borrmann, D., Nüchter, A.: Efficient processing of large 3d point clouds. In: XXIII International Symposium on Information, Communication and Automation Technologies (ICAT). IEEE 2011
21. Lu, Qiuchen, Lee, Sanghoon: Image-based technologies for constructing as-is building information models for existing buildings. J. Comput. Civil Eng. **31**(4), 04017005 (2017)
22. Cursi, S., Simeone, D., & Coraglia, U. M. An ontology-based platform for BIM semantic enrichment
23. Quattrini, R., Malinverni, E.S., Clini, P., Nespeca, R., Orlietti, E.: From TLS to HBIM. High quality semantically-aware 3D modeling of complex architecture. The international archives of photogrammetry. Remote Sens. Spat. Inf. Sci. **40**(5), 367 (2015)