Architectural heritage information in 3D geospatial models: developing opportunities and challenges

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ABSTRACT: The relationship between the cultural value of architectural heritage and its spatial features is straightforward. Digital 3D models are very effective to store such information, which can be further enhanced through the management in 3D information systems. Mainly two approaches are proposed by literature, notwithstanding the still existing challenges: the Heritage Building Information Models (HBIMs) or the archiving of the information in 3D city models. They are both extensions of systems and tools adopted in other fields (construction for BIMs and city management for 3D city models). They use different methodologies and technical solutions (e.g. different kinds of geometries; different reference standards foreseeing interoperability, etc.). However, some work is on-going for integrating them. A review of HBIM and 3D city models including heritage is described, in connection with the respective supported applications, as a starting point towards their integration for a more comprehensive 3D geospatial information for architectural heritage.

1 INTRODUCTION

Spatial values are intrinsically connected to the cultural value of architectural heritage, since, most of times, they embody the most valuable characteristics of the involved objects in many levels of detail: from the smallest objects to the widest landscape compositions.

It is essential to consider their effective representation (of multiscale shapes and spatial relationships), also in connection with non-spatial properties, because those values are critical when dealing with heritage management and preservation. Recent European projects have highlighted this need, like the Virtual Multimodal Museum project and its Manifesto, which stresses the importance of the inclusion of a richer information in documentation systems. Therefore, the spatial documentation of architectural heritage is of extreme importance, and it can be more and more accurate and complete, by means of the possibilities offered by the new advanced tools for 3D survey and spatial data management.

In this paper, the support given by the (3D) spatial documentation to the architectural heritage preservation and management is described. Moreover, a short review of recent research about some interesting solutions for the management of the heritage information using 3D spatial information systems (Heritage Building Information Models and 3D city models including heritage) will be used as base to draw some preliminary considerations towards the adoption of integration solutions, under development, for architectural heritage.

2 ARCHITECTURAL HERITAGE SPATIAL DOCUMENTATION

A great step towards a better understanding of architectural heritage and its preservation was even the 2D graphical representation, better if supported by survey measurements (Fasolo, 1954). However, many architectures have very complex shapes and require instead a 3D approach. For this reason, the 3D representation methodologies had a wide success in recent times, aided by the great advancement of survey instruments and digital representation tools (e.g. Centofanti et al., 2014; Scopigno et al., 2011). 3D models are used effectively for communication and education (Paladini et al., 2019). As examples, Rua, Alvito (2011) employed 3D models in archaeological gaming applications; some 3D inventories, like the Cyark inventory are built as support for education aims (https://www.cyark.org); the 3D reconstruction of Pompei is used in a 3D movie reproducing the tragedy (http://www.pompeii3d.eu).

Also great support can be given by 3D models to preservation: for example, they make the accurate computation of surfaces possible for restoration projects and can be used for improved structural analysis (e.g. Bertolini-Cestari et al., 2015, Riveiro et al., 2011).

However, plain 3D data are not sufficient yet to archive the complexity of heritage: many data are connected to one single architecture (from different sources, representing different states in time, stored in various formats), and functional and spatial relationships must be considered to underline and understand complex (multi-dimensional) systems. For example, the semantic relationships (the meaning of objects) have to be considered through wide pieces of land (including the ones which build up as, or connected to intangible heritage). Moreover, the relations to risk and vulnerability elements are important to support preservation. Furthermore, a multi-scale representation is needed, since sometimes the small details are the ones that embody the proper cultural value, in elements distributed on the landscape, or as the product of traditional skills and know-hows. Finally, some administrative information, like the ownership relationship of buildings are important for their understanding and management (e.g. common properties of buildings, common managements, specific constraints, etc.). This are only examples of a very high richness and complexity characterizing heritage and related dynamics. It is therefore essential to consider this complexity in a system for improving knowledge, preservation and supporting sustainable and effective enhancement and promotion, by structuring the data in effective information. And this can be done through spatial information systems.

3 SPATIAL INFORMATION SYSTEMS AND 3D SPATIAL INFORMATION SYSTEMS

Spatial information systems can give great support to heritage understanding and preservation even when managing 2D data (e.g. Salonia, Negri, 2003; Donadio, Spanò, 2015; Noardo, Spanò, 2015; Melòn et al., 2019, Lu et al., 2019). However, even more powerful tools are given by the management of heritage in 3D information systems, namely Building Information Models (BIM) and 3D Geographical Information Systems (3D GIS).

They are usually considered as opposed, but actually they have a lot in common at a conceptual level, if considered for the architectural heritage application: they are both developed by other fields then cultural heritage: architecture engineering and construction field for BIM and cartography, geomatics and city management for 3D GIS, or 3D city models.

They both can archive 'enriched' 3D models, joining the geometric representation, in many levels of approximation, with the semantics of the models, by associating the objects to concepts, usually hierarchically organized, with attributes and reciprocal relationships. They can be georeferenced, even if it is still challenging for BIM. Finally, they are not only archives, but also include a wider framework and methods for managing processes and tools.

The key condition for information to be universally understood, used, re-used, and exchanged is interoperability. For this reason, open standards are being developed with a wide consensus among stakeholders, academics and developers, within international organizations.

The most widespread open standards in BIM and 3D city models domains are, respectively, Industry Foundation Classes (IFC) by buildingSMART and CityGML by the Open Geospatial Consortium (OGC). In the following subsections, the main characteristics of BIM and 3D city models, their standards and their use in the heritage field is summarized.

3.1 *Building Information Models and Heritage Building Information Models*

Building Information Modelling derives from the evolutions of Computer-Aided Drawing software, used in the field of building design, and implies not only 3D models, but more complex systems including procedures and tools for managing the project and the modelled object, being mainly buildings and infrastructures (Historic England, 2017).

Many tasks can be assisted by them: e.g. design options assessment; quantities and cost estimation; construction simulation; energy modelling; manufacture and off-site construction; project management (efficient collaboration, multi- disciplinary project team); facilities and asset management; design and construction coordination.

In building information modelling, levels of approximations are used, which are called 'Levels Of Development' (LOD), and give an indication about the progress in the design definition (from a general draft in LOD100 to the inclusion of fabrication details of each single small element in LOD400; LOD500 is for as-built BIMs) (BIMFORUM, 2019).

For BIM, IFC is the reference open standard (ISO 16739). It is part of a more complex standard including processes and further tools. It defines rules, structures and encodings for the management of interoperable, exchangeable and reusable BIM data. Moreover, the IFC data model defines a standardized semantics, which is strictly related to new constructions.

The field of architectural heritage has also understood the potential that such tool could develop for supporting preservation and management of historical constructions. Therefore, many researches are on-going about the topic: e.g. for supporting heritage interpretation (e.g. Attico et al., 2019), structural analysis and testing preservation and intervention scenarios (e.g. Malinverni et al., 2019; Chiabrando et al., 2017), as a framework for collaborative processes and sharing of coordinated datasets in multi-disciplinary environments; for architectural heritage energy-related management and retrofitting (e.g. Khodeir et al., 2016; Gigliarelli et al., 2017) and more.

The specific functionalities that can be usefully applied to heritage are also described by some official documents (e.g. Historic England 2017): decision-making support; heritage management, as work programming (conservation, repair, maintenance and reuse), visitor management, condition monitoring; project management; security, fire safety, visitor safety and health and safety planning; disaster preparedness.

However, some challenges have still to be tackled for BIM to be completely suitable for heritage. BIMs were born for reusing highly standardized components (like industry-fabricated elements), but it is not always possible to apply the same criteria with architectural heritage elements, which were often handcraft produced. As a consequence, the parametrically modelled geometries can be little consistent with the actual ones (which are often irregular) (e.g. Visintini et al., 2019). Furthermore, the available tools in software are conceived and designed for the needs of new-designed buildings, which do not always apply also to heritage, whilst others, potentially useful, can be missing.

3.2 *3D Geographical Information Systems / 3D city models including Heritage*

The other very powerful 3D spatial information systems to be considered are 3D GIS, or 3D city models. They are the more natural evolution of traditional GISs, and they are usually oriented to the representation of medium levels of detail objects (e.g. the city, or portions of the city). In 3D city models, usually a boundary representation (storing coordinates) is used, georeferencing is straightforward and the semantics concern the city or land objects.

In this case the levels of detail represent the generalization from the most accurate and detailed data, taken as reference (for example the survey data). Officially 5 LoDs are used (Gröger Plümer, 2012), but some recent research gave a more granular definition of them, resulting in more effective 16 (Biljecki et al., 2016).

Use cases of 3D city models are many (Biljecki et al., 2015): e.g. energy simulations, noise modelling, shadow analysis, navigation, flood simulations, multivariate analysis, risk analysis, 3D cadaster, multitemporal analysis, flows analysis and so on.

Also heritage can have advantage of 3D city models and 3D GIS (Campanaro et al., 2016), supporting the documentation management in a unique and structured framework, permitting complex landscape analysis and cross-boundary investigations, coordinate wide preservation strategies, and, especially, they could be used as base for extracting new knowledge from the existing patterns, through using for example inferences from ontologies technologies (e.g. Lin et al., 2008, Acierno et al., 2017), data mining, machine learning (Llamas et al., 2016) and so on.

However, also in this case, some challenges are still present: for example, an LoD specification specific for heritage would be useful, much more data are needed, and some technical issues linked to software (and hardware) and data formats can make the use of such tools by current users difficult.

The OGC CityGML, is the most used open standard for 3D city models. It defines rules, structures and encodings for the management of interoperable, exchangeable and reusable 3D city models, with a semantics related to city object representations. An important feature of CityGML is the coded possibility to extend the model with application-related classes, attributes and relationships, through the CityGML Application Domain Extensions (ADEs).

In literature, CityGML ADEs have been developed also to manage the architectural heritage. For example, some studies developed a CityGML extension to manage architectural heritage in connection with energy-related information for historical centers retrofitting (Prieto el al., 2012; Egusquiza et al., 2018). Noardo (2018) developed a Cultural Heritage ADE to improve the flexibility of the model, in order to adapt it also to the detailed representation of such complex and unique buildings. In that study, the attribute ‘level of specialization’ was introduced, in order to represent one further dimension of the model information, that deals with the level of the semantic segmentation hierarchy even when considering one only geometric level of detail (e.g. the objects involved in part-of or subclasses relationships). Moreover, a tentative connection to external approved conceptualizations was proposed, for example reusing code-lists from existing vocabularies (e.g. the Getty Institute vocabularies). The extension also describes the entities regarding connected information, whose management is also relevant for architectural heritage, with the needed complexity (e.g. patron, usage, author, and so on). One last issue addressed in the study is the possibility to customize the segmentation criteria in order to allow different kinds of representation in an explicit way, through an attribute ‘DescriptionAim’ that permits the existence of different overlapping representation of the same object (according to different use cases and aims) avoiding inconsistencies.

Other studies (Fernández-Freire et al., 2013; McKeague et al., 2012) extended instead the INSPIRE data model, which is given by the European Directive for building an ‘INfrastructure of Spatial Information in Europe’ (INSPIRE), with the aim of a common environmental management. One of those was specifically intended to represent heritage in connection to the natural hazard, for the ResCult project (Chiabrando et al., 2018; Colucci et al., 2018).

4 GEOBIM

Both BIMs and 3D city models can offer great support to architectural heritage, and it is not possible to choose only one of the models. It is therefore necessary to integrate them. On-going research (e.g. Sani et al., 2018, Wang et al., 2019) about the integration of geoinformation and BIMs (‘GeoBIM’) can be the reference for the concepts to be applied also to heritage.

The topic ‘GeoBIM’ means multiple concepts, which have to be all addressed to reach an actual integration. First of all, the integration of the data (as produced) must be addressed, intended as the achievement of harmonizable and explicit characteristics, so that they can actually fit together once that more technical integration are performed. Secondly, the data must have an interoperable format, towards which the definition and use of open standard is a first step. However, it is still necessary to work for the standardized data to be suitably supported by software and correctly coded and exchanged. A third challenge is the definition of suitable procedures able to make completely consistent conversions between the two kinds of data. A study funded by the International Society for Photogrammetry and Remote Sensing (ISPRS) and the European association for Spatial Data Research (EuroSDR) is being addressing those last two issues (GeoBIM benchmark 2019). Finally, it is also necessary to integrate and harmonize the involved procedures implied in BIM and GIS-related tools and methods, for them to be used in seamless workflows.

The advantages that can be given by the integration are many for both sides (Arroyo Ohori et al., 2018). The geo-world can obtain information for high-level-of-detail 3D cadaster, avoiding duplication of tasks related to the 3D data collection, efficiently updating 3D maps databases without additional financial costs, effective data exchange with professionals (architects, engineers, environmental scientists, etc.). Moreover, they can obtain a stronger information for lifecycle asset management and enhanced infrastructure and network management, with an enhanced level of detail, also enabling enhanced city analysis.

On the other hand, the BIM world could more easily obtain a correct, accurate and useful description of the context for design reference, perform improved analysis about the designed building into its context and exploit GIS analysis for testing the impact of the building on the city or landscape.

However, at present, the differences of the two models, explained in section 3 are not completely overcome yet. Moreover, when considering data produced by professional practice, even more challenges arise, since they are usually not fully compliant with the theoretical assumptions from academy. In addition, those technology have only recently begun to be applied, and not many data are available yet. The lack of data is moreover increased due to the implied privacy issues concerned with BIMs.

To overcome the inhomogeneity of the data in order to enable the integration, an agreement is needed between stakeholders and data producers about the requirements the data should respect (e.g. levels of details, needed entities and semantic information, need for georeferencing, specific information needed in specific use cases, etc.).

5 GEOBIM FOR ARCHITECTURAL HERITAGE

As a result of the initial literature review and initial tests on data, it is possible to envision the advantages that the use of GeoBIM, in a seamless flow of information, would allow for the heritage field, which is external to both geo and BIM.

Some of those advantages are: the archive of heritage information from dense survey and other sources in detailed semantic 3D models; the heritage analysis in connection to the context and other distant heritage; the support to heritage management and risk prevention (e.g. Kilsedar et al., 2019, Matrone et al., 2019); no duplication of data collection and representation efforts; processes optimization.

Some work will be still needed to reach those ambitious aims. However, the next steps to be addressed are already clear, which are, however, not straightforward, since an agreement among a number of interdisciplinary experts needs to be found for overcoming the present discontinuities and problems preventing a suitable integration.

Notwithstanding the integration of 3D GIS and BIM systems for heritage representation has the advantage that the source of the data for modelling is the same, that is, the existing architecture, it is anyway necessary to find agreements between data producers even within the same branch, since the existing data present differences in geometry, semantic, level of implementation of the followed data models and standards. More specific rules and guidelines are therefore needed first of all to enable a suitable harmonization between different 'geo' data, different 'BIM' data; then, to permit their integration.

With respect to geometry, guidelines are needed for overcoming the differences due to the various kinds of metric data that can be used: different kinds of survey (instruments, precision, methods, reached accuracies); different processing methods of the measurements, and so on.

Moreover, it is necessary to consider the differences due to different adopted modelling methodologies: in the data used as source (2D/3D, density, accuracy, etc.), in the modelling and interpolation methods and algorithms (manual or automatic) in the kinds of geometry storage.

Additionally, with respect to semantics, we need to agree on terms, hierarchies, semantic rules, better if using already shared and affirmed ontologies, such as the Conceptual Reference Model of the Documentation Committee (CIDOC) of the International Committee of Museums (ICOM), i.e. the 'CIDOC CRM' (Doerr, 2003) and the vocabularies published by the Getty Institute (http://vocab.getty.edu).

Requirements have to be defined for the needed results and best practices should be proposed as reference to achieve them. One fundamental need for the reuse and understanding of data is the archiving of suitable metadata, clearly explicating the data properties as listed before, preferably compliant with the existing standards (e.g. for geographic information, ISO 19115, Labetski et al., 2018).

6 CONCLUSONS

As a conclusion, it is possible to state that first of all, institutional challenges and inter-sectorial preconceptions have to be overcome in order to find agreements to fruitfully collaborate. The representation and archiving of architectural heritage in 3D city models must improve, by applying extensions systematically, to consider the heritage as special also in common city analysis and management. Moreover, the archiving of 'geo' heritage models in connection to HBIM for having advantage of both systems. As a preliminary condition, both should follow common parameters and criteria in the representation, explicated in standardized metadata, to be suitable for enabling conversions and following specific use case requirements in connected fields (e.g. history, restoration, construction, structural engineering).

Great opportunities are given by the management of architectural heritage information in HBIM and 3D city models, and their integration. Multidimensional integrated and interoperable information for architectural heritage is not yet straightforward, but initial foundations are being laid.

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