Challenges of District Information Modeling (DIM) Applied for Heritage Preservation

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Abstract. The urbanization is a complex and continuous process requiring updated data over time. Information and Communication Technologies (ICT) are essential to assist in the planning process. However, distinct computational environments are necessary to use all available data. Faced with these challenges and aiming to generate technical inputs to foster a better understanding and management of urban spaces, this paper seeks to analyze the potentiality of the District Information Modeling (DIM) applied to a distinguished historical urban scenario. In this paper, we show that the Scan2-BIM2GIS process represents an essential technology for management at the city level. We reported the results of a study developed by postgraduate students in a course on Special Topics on Computer Graphics. The scope was to understand the steps for creating the DIM model of the Monte Alegre District, a former industrial area located in the city of Piracicaba, state of São Paulo. The starting point of the proposed approach was the District 3D geometric reconstruction obtained from an image-based surveying campaign with a Unmanned Aerial System (UAS), allowing to make a point cloud with excellent accuracy from the distinctive buildings, the roofs, the street system, and the open spaces. Building Information Modeling (BIM) tools permitted the creation of component-based structured 3D semantic models of the buildings with the desired Levels of Detail (LOD), and the Geographic Information System (GIS) environment enables indexing quantitative and qualitative attributes to these buildings. Furthermore, interoperability between software becomes a crucial factor, and improvement of data sharing will be relevant for future developments.

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1 Introduction

The non-existence and inadequacy of cartographic documentation tools at the scale of cities with a multidisciplinary approach have been impediments to the strengthening of the concept of urban heritage in the last century.

In Brazil, there is a patrimonial vision focused on the individual monument and not on the group of the historic built environment. The institutions of heritage protection lack instruments for a global understanding of the issues related to heritage in addressing historic cities and districts, such as the resulting cultural landscape, land uses, the scale of buildings, states of conservation, build changing of the style, and materiality, among others.

Regarding Urban Heritage, a wide-ranging updated and reliable geo-referenced multidisciplinary and multiscale data (e.g., from building to the entire district) is a critical pillar for its management improvement, including monitoring, conservation, and restoration process.

Scanning, BIM, GIS, and City Information Modeling (CIM) are among the technologies developed in the context of buildings, sites, and city management over the last decades. All of these ICTs linked with Information aim at structuring and organizing the data. What differentiates them, in a simplified way, are the scales of application and users' interests. [1] pointed out that in the CIM scenario, the ICTs application addresses the search for the most appropriate model to capture the objects' semantics and geometric representation relevant to the scope of a city. Semantic is a relevant part, as it allows the application of the model to different types of analysis and simulations.

However, issues related to integration and interoperability between these different ICTs still exist. This particular lead to combining content associated with different scales of representation, generalizing them and establishing processes, without any continuity solution, from an information system at the regional level (GIS) to the urban scale until reaching the building scale (BIM) [2]. Overcoming issues related to the integration of semantics and geometries without significant loss of content is the great challenge of researchers and software developers in recent years. The AEC industry has recognized the need to integrate BIM and GIS, and design software companies are looking forward to further collaboration to help simplify workflows and improve outcomes for both GIS and BIM users [3].

Our approach aims to investigate the integration of 3D data from geographical information about assets and districts, and information-rich building models. This integration can subsidize decision making based on knowledge and management of the cultural landscape, on the micro (building), mid (historical sets), and macro (district/city) scales. Thus, this work focuses on the potential application of BIM and GIS to the documentation and maintenance of historical sites. This article reports an academic experience for the integration of different computational tools for data processing and modeling, including digital scanning technologies, applied to the Monte Alegre District, located in Piracicaba, SP, Brazil. The contribution of this work refers to the integration of GIS and Historic BIM (HBIM) towards an innovative and more efficient way for the management of historical sites: the Historic District Information Model (HDIM). Certainly, the obtained results can contribute to leverage the process of documentation and management of large areas of historical and cultural interest by municipal bodies.

2 Background

According to [4], the integration of GIS and BIM deals with numerous challenges. The authors cite some efforts developed by [5], such as a CityGML extension, to get semantic IFC data into a GIS context. Other applications included conversion, translation, and extension of existing Standards that works as a bridge between BIM and GIS, such as InfraGML, IndoorGML, model-Unified Building Model-UBM, QUASY Project with QuVariants [6]. The authors [4] also stated that in previous works, [7] classified the integration methods into three different levels: **data**, **process**, and **application**. Based on these levels, [4] defined parameter criteria named EEEF (effectiveness, extensibility, effort, and flexibility), which list the pros and cons of each integration solution (see Table 1).

Table 1. Comparison of integration solution by EEEF criteria.

Level	Integration methods	Effectiveness	Extensibility	Effort	Flexibility
Data	New standards and models	Case-by-case	Case-by-case	Case-by-case	Case-by-case
	Conversion, translation and extension of existing standards (manual)	Medium	High	High	Medium
	Conversion, translation and extension of existing standards (semi-automatic)	Medium	Medium	Medium	Medium
Process	Semantic web technologies	High	High	High	Medium
	Services-based methods	High	Low	High	Low
Application	Application focused methods	Case-by-case	Low	Low	Low

The **effectiveness** means less information loss, while **extensibility** relates to the high degree of openness. The **effort** reflects the time, labor, and money cost involved in the method, and **flexibility** represents the possibility of one result be applied by other studies [4].

The application focused methods are implemented to work a specific use and can employ various tools for such integration of information between the two systems as a customized plug-in available for BIM software and a central database [8]. Another option used by [9] is a schema to work as an integration medium adopting an intermediate data format between GIS and BIM. In this case, the gbXML file was converted to KML and COLLADA. The advantage of this type of method is that it is not costly in terms of time, labor, and money.

Applications of GIS and BIM Integration in Heritage Management according to [6], included efficient information management in three dimensions: (a) segmentation; (b) structuring the hierarchical relationships; and (c) semantic enrichment (Fig. 1).

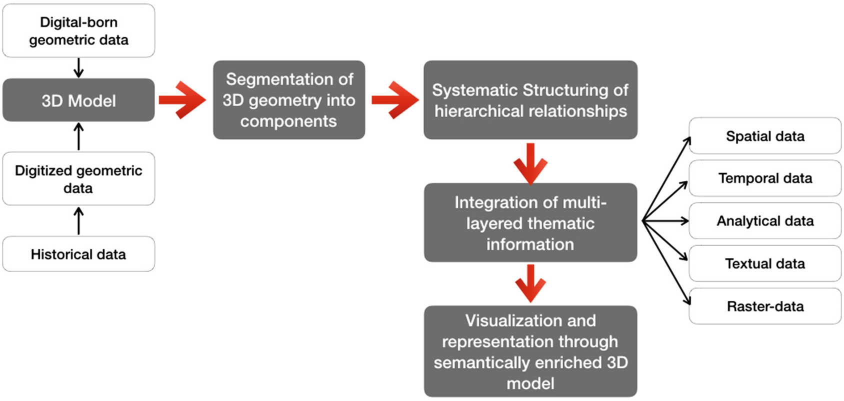

Fig. 1. The workflow diagram for semantically enriched 3D heritage models

GIS is the most common approach to managing multi-layered thematic information on a larger scale (city or district), including land use, construction typology, transportation, vegetation data. The main functions of GIS are to capture, store, manipulate, analyze, manage, and present all types of spatial or geographic data. This capability has facilitated its use in various applications, including heritage documentation.

Historic Building Information Modeling (HBIM) focuses on the integration of digitized geometric and historical data [10]. Accurate surveys data gathered by laser scanning or photogrammetry will result in segmented point clouds assisting in 3D modeling in BIM and also in the acquisition of orthophotos for data records in GIS.

Applied to urban heritage management, the GIS enables the storage, documentation and analysis of data assigned to preservation objects and surrounding spaces. It allows the construction of visualization products of spatial characteristics and topological relations - digital models and thematic cartographies - with varied levels of information and details linked to simple and complex geometries in 2D and/or 3D. It also makes possible the approximation between documental heritage GIS, other urban GIS and those with complex parametric urban models in BIM logic expanding the possibilities of documentation, modeling, understanding and simulation of the real world in digital environment [e.g. 11, 12]. For this effective and collaborative purpose, it is important that all information on an urban site is stored together, including data on territories and individual buildings on the site of interest.

Thus, 3D urban models approximate the real world, where features are modeled to a certain degree, and certain elements are simplified or omitted. The amount of detail in a 3D urban model, both in terms of geometry and attributes, constitutes its level of detail (LOD), indicating how thoroughly a spatial extension was modeled. For [13], the quantity and combination of contents (geometry and attributes) are driven by several factors, such as the intended use of the model, source of the primary data, acquisition techniques, spatial scale, financial, and human resources invested.

3 The Monte Alegre District

The Monte Alegre District (Fig. 2) was chosen as a test site for the proposed Scan2GIS2BIM-approach. The Municipal Preservation Body listed the District as a heritage site, and the protected-area perimeter covers 650 thousand square meters. Despite its historical and cultural importance for the state of São Paulo, the lack of adequate and comprehensive documentation that is required to carry out further preservation, conservation, and rebuilt actions, has led to a process of deconfiguration and even ruination of significant buildings in the complex.

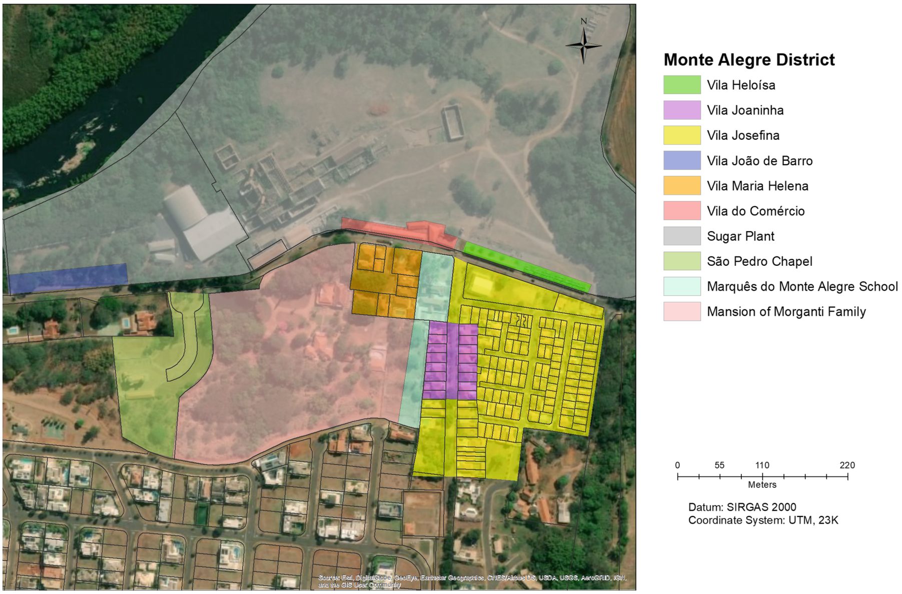

Fig. 2. The sectors of Monte Alegre District

The Case Study is a former industrial area located in the city of Piracicaba, state of São Paulo. The District has regional historical relevance, and represents one of the largest manufacturing centers in the State, formed from the culture of sugarcane and the sugar and alcohol production of the Monte Alegre Sugar Mill. Located on the banks of the Piracicaba River, the Monte Alegre District was built to meet the workers' demands of the Sugar Mill in the early twentieth century. The District development was becoming a relevant historical, architectural, and socio-cultural urban scenario for the city.

The Sugar Mill Assembly, which drove the emergence of the District, is the closest building to the Piracicaba River, and its construction started in the 19th century, together with the construction of the employer area where the Mansion of Morganti Family is located. The Sugar Mill operated until the 1980s, passing through some changes during its life cycle.

The 906 dwellings grouped in Vilas were organized according to various criteria, such as implantation dates, construction characteristics, morphology, scale, and the function of the worker at the plant. Vila Heloísa, the oldest and most modest, was implanted in 1920, followed by Vila Maria Helena and Vila Josefina between 1920 and 1930. Eight different houses arranged to form a square inside the court composed the Vila Maria Helena, intended for higher-ranking employees. Vila Marisa and Vila Joaninha were built between 1940 and 1950 and, finally, Vila Renata, established in 1950.

The Monte Alegre District contains reasonably well-preserved buildings types, like the old school inaugurated in 1927, and the Chapel of São Pedro built-in 1937. The Chapel stands out for its 600 m^2 of frescoes painted by Alfredo Volpi. All of these assets are under analysis for registration by the Council for the Defense of the Historical, Archaeological, Artistic, and Tourist Heritage of the State of São Paulo (CONDEPHAAT).

4 Overview of the Approach

The methodology was outlined in four steps: (i) aerial **survey** by UAS, aiming at the creation of a Digital Surface Model (DSM) and the orthophoto of the district; (ii) **historical and cadastral survey** in the archives of the city of Piracicaba to aggregate data as attributes in the **GIS model**; (iii) **BIM** modeling of significant community structures at different levels of detail (**LOD**); (iv) **GIS and BIM integration** for the development of HDIM.

4.1 Surveying

The reality-based digital model, generated through UAS, had a double purpose. The first one is to enable accurate 3D documentation of the district as-is condition, framing an accurate source of information for interpreting the urban structure of Monte Alegre District. The second one is to allow the creation of other mapping products such as the site orthophoto, the start point from the digital interpretation in a GIS environment.

For the district DSM, 2294 images were acquired in two survey campaigns, completed on different days (Fig. 3). On the first day, the UAV survey was performed with an amateur UAS model DJI Mavic Pro with a 12.7 MP camera. Three flights were performed in a double grid at 70 m from the lowest point of the area, the first at nadir, and the second with the camera at 60° to capture the facades. These flights generated 645 images. On the second day, two flights in a double grid were performed with a professional UAS model DJI Inspire 2 with a 20 MP camera.

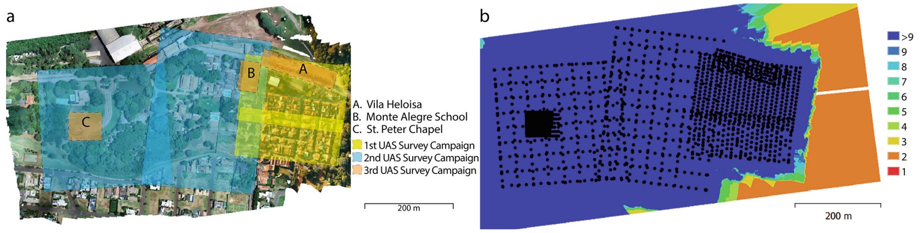

Fig. 3. (a) UAS Survey campaigns and (b) double grid of each flight in the area, the color schema represents pictures overlap

For this survey campaign, the UAS flight at 120 m from the site lowest point with the camera at nadir, generating 1649 images. On the third day specific flights were carried out for the buildings of interest (Chapel, School), in which, in addition to the double grid, a circular flight was made over the building with the camera at 45° (see Fig. 4c). For the Phototriangulation process, 8 control points were captured by Ashtec Geodetic GNSS receivers.

All 2294 photographs of the different surveys were processed in the same batch using Agisoft's Metashape software. Due to the high number of pictures, the process was set in low alignment parameters resulting in a dense point cloud with 23.5 million points and a point density of 31.9 points/m^2 (see Fig. 4a).

Fig. 4. (a) DEM of the total area, (b) DEM of the first UAS campaign, and (c) DEM of the School showing the grid of capture

Interior surveying in the São Pedro Chapel was driven using three types of cameras: a DSLR (Digital Single Lens Reflex) with a fixed super zoom lens (Nikon Coolpix P1000); a compact Mirrorless (Sony ILCE 6000); and cell phones (SM-A750G). The capture process with the DSLR equipment took place with the aid of a tripod and programmed shooting. With the other ones, the process was manual. All 498 photographs of these cameras were processed in the same batch using Agisoft's Metashape software, resulting in a dense point cloud (54.5 million points) and with high texture quality (see Fig. 5). The Baptistery section was captured with the Sony ILCE 6000 camera, and the 49 photos were processed separately, generating a TIN (Triangulated Irregular Network) mesh to be published on the Sketchfab platform[1].

Fig. 5. (a) Negative point cloud from interior of St. Peter Chapel, and (b) TIN mesh of the Baptistery

4.2 GIS

The data were incorporated into the software ArcMAP from the platform ArcGIS (ESRI) based on a SHP digital file of the neighborhood cartography obtained from municipal administration of Piracicaba-SP. The orthophoto was imported in a matrix format for the software environment, being kept in a data layer parallel to the vector concerning the geometry of the lots, blocks, and streets. From the layers overlapping, attributes such as area and perimeter were subsequently indexed, as well as other attributes defined as singular and measurable for the characterization of the study area such as construction year (Historical Evolution), buildings conservation status, characterization degree, and land use (see Fig. 6). Once the database constituted from in the lots related geometry, buildings projection, streets, blocks, and attributes, it was possible to obtain cartographic visualizations of the isolated and combined information, considered relevant for the understanding of this landscape and its management as a site of historical and cultural interest.

[1] Avaiable in https://sketchfab.com/3d-models/igreja-de-sao-pedro-f932c6c7d283435d8ac63bf447b2e765.

Fig. 6. Monte Alegre Cartography developed in ArcGIS Pro

4.3 HBIM

It is well-known the importance and revolution that BIM brought for the building's design and construction processes. In the last decade, efforts have been made to extend the BIM benefits (knowledge database), combined with scanning and computer vision, for the historic buildings. It is due, mainly, to the potential of this technology for the conservation of historic structures and sites (e.g., point-to-BIM, tangible and intangible information, building conditions assessment, ontology-based semantic information organization).

A different dimension of object characterization, regarding not only its geometric accuracy but also reliable information, defines the scope, purpose, and complexity of a 3D knowledge-based Model. The geometric and semantic specialization that this model can achieve requires the definition of the level of complexity to be reached. Around this general idea, different denominations have been created: Level of Detail (GIS environment) and Level of Development (BIM environment).

The geometric and semantic specialization, as well as the information and Knowledge enhancement that each model in different levels should be present, is depicted in Fig. 7.

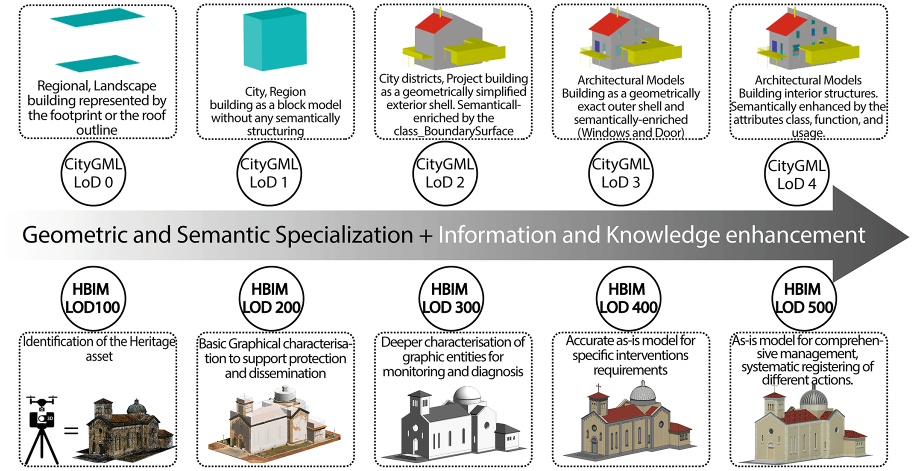

Fig. 7. Correlation between different Levels of Geometric and semantic specialization, and information and knowledge enhancement in different technologies that use a 3D knowledge-based models as database.

Based on CityGML LoD 1, the geometric model of the District was developed from the vector maps and the point cloud. The Models of the most significant buildings, such as the Chapel, Vila Heloisa, Vila Josefina and the School was created in LoD 3 (detailed only the exterior) and LoD4 (detailed exterior and interior) (see Fig. 8). The software Revit (Autodesk) and Archicad (Graphisoft) were used for modeling, and the point cloud was the basis for creating the parametric components and details, also defining the height reference of the buildings.

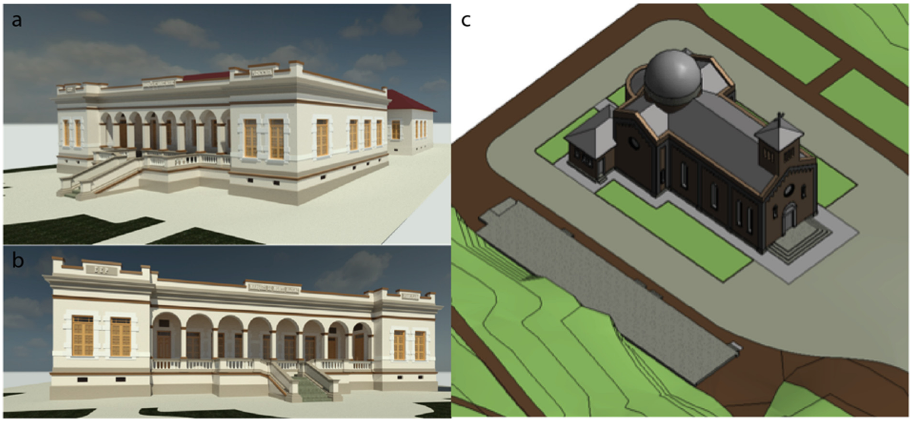

Fig. 8. (a) and (b) Render views from BIM model of Monte Alegre School in LoD 4, (c) BIM Model of St. Peter Chapel in LoD 3.

The other buildings were modeled in LoD 1 with a mass creation tool. Shared parameters tools in the Revit environment were created to define the building´s degree of characterization, state of conservation, and classes of use (see Fig. 9).

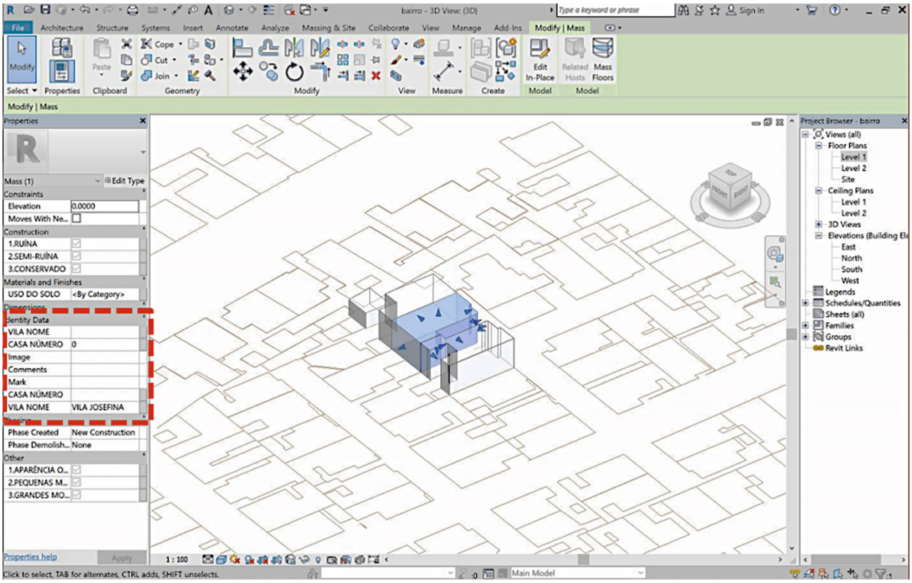

Fig. 9. Defined shared parameters in Revit environment for the mass representing the buildings in LoD1.

4.4 HDIM: GIS and BIM Integration

The integration method used in this study was the Application Focused Method defined by [4]. This method presents low extensibility; therefore, a small effort is required, employing the tools already known by the authors (e.g., Revit, Archicad, ArcMAP, ArcScene).

The point cloud, 2D technical drawings made in AutoCAD software, and the shapes produced in ArcGIS software were linked in the Revit software. In the Revit environment, shapes were converted into masses representing the heights of the buildings. Subsequently, materials created with the attribute's parameters (preservation degree and occupancy types) were applied to each building. An attempt to integrate the BIM models in the GIS does not show a satisfactory result due to the difficulty in integrating the IFC or RVT data into ArcScene. As this case study was developed in a time-limited discipline, it was not possible to explore the software to define a data integration workflow.

The Fig. 10 shows the LoD 1 model of the macroscale according to the classes of use show the microscale models (buildings) with LoD 3 and 4, Vila Heloisa, Vila Josefina, School respectively, inserted in the urban model.

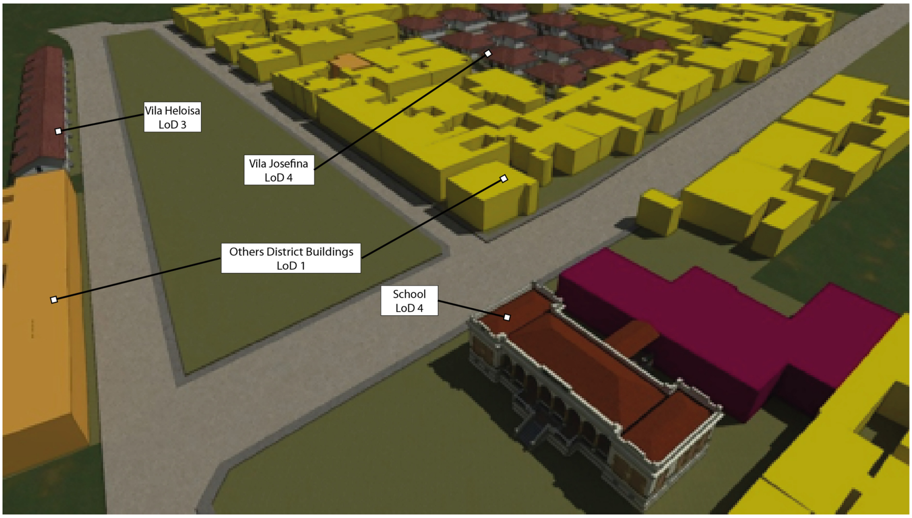

Fig. 10. Different levels of detail represented in the urban model

5 Conclusions

In this paper, we proposed and detailed a methodological workflow to implement a scan2GIS2BIM-approach to a Historical District Management.

The use of photogrammetry enabled the creation of an unstructured 3D geometric reconstruction of the district, also orthophotos, which were used in the GIS platform, and in the BIM environment for the data spatialization. BIM tools allowed the creation of component-based structured 3D semantic models of artifacts and buildings with the desired levels of detail (LOD).

The proposed workflow demonstrates that a 3D cadaster for Historical sites can benefit from the information that is maintained by the public administration and the Heritage Preservation Council and in other databases, creating an easily accessed and shared single information repository. In this case, the low cost of UAS-based context capture allows the continuous updating of the actual situation of the study area.

Despite the quality of the products generated, the proposed workflow encountered some difficulties, highlighting the lack of interoperability between software, which made it impossible to connect the BIM and GIS platforms more closely. The interoperability between the software, the definition of the attributes, and which LOD are the most suitable are some of the challenges found in this research.

The manipulation of acquired data is a method that requires higher human effort, especially when feeding the GIS system for the generation of Thematic Cartography and BIM modeling based on the point cloud. The use of GIS for applications in historical sites allows the characterization of the territory, generating information to understand how the district is inserted in its surroundings. Thus, interventions would not be limited only to the scale of the building but would extrapolate to the local scale.

Exporting the georeferenced mapping from the GIS platform to the DXF format to work it in Revit and Archicad environments (there is not a direct and simultaneous link between the software), only the georeferencing coordinates were maintained, losing all other attributes previously indexed in GIS software. Another challenge is to understand the modeling on each platform so that information is not lost in interoperability.

Thus, the integration of BIM and GIS semantics and instances in a single platform was complex and unsatisfactory, and it is part of future work to seek solutions to this problem.

References

1. Corrêa F.R., Santos E.T.: Na direção de uma modelagem da informação da cidade (CIM). In: VII Encontro de Tecnologia de Informação e Comunicação na Construção (TIC 2015), pp. 344–357. Blucher Engineering Proceedings, Recife (2015)
2. Ruffino, P.A., Bocconcino, M.M., Del Giudice, M., Osello, A.: From the elaboration process of point cloud to information systems both for planning and design management of cultural heritage. In: 2nd International Conference of Geomatics and Restoration. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XLII-2/W11, pp. 1031–1038 Italy (2019)
3. Andrews, C.: GIS and BIM Integration Leads to Smart Communities. ArcUser Newsroom (2018)
4. Liu, X., Wang, X., Wright, G., Cheng, J.C.P., Li, X., Liu, R.: A State-of-the-art review on the integration of building information modeling (BIM) and geographic information system (GIS). ISPRS Int. J. Geo-Inf. **6**(2), 1–21 (2017)
5. De Laat, R., van Berlo, L.: Integration of BIM and GIS: the development of the citygml GeoBIM extension. In: Advances in 3D Geo-Information Sciences. Springer, New York (2011)
6. Saygi, G., Remondino, F.: Management of architectural heritage information in BIM and GIS: State-of-the-art and future perspectives. Int. J. Herit. Digit. Era **2**, 695–714 (2013)
7. Amirebrahimi, S., Rajabifard, A., Mendis, P., Ngo, T.: A data model for integrating GIS and BIM for assessment and 3D visualisation of flood damage to building. Locate **15**, 10–12 (2015)
8. Irizarry, J., Karan, E.P., Jalaei, F.: Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. Autom. Constr. **31**, 241–254 (2013)
9. Niu, S., Pan, W., Zhao, Y.: A BIM-GIS integrated web-based visualization system for low energy building design. Procedia Eng. **121**, 2184–2192 (2015)
10. Murphy, M., Mcgovern, E., Pavia, S.: Historic building information modelling – adding intelligence to laser and image-based surveys of European classical architecture. ISPRS J. Photogram. Remote Sens. **76**, 89–102 (2013)
11. Dore, C., Murphy, M.: Integration of HBIM and 3D GIS for digital heritage modelling. In: Digital Documentation, Edinburgh, Scotland, pp. 1–5 (2012)
12. Vacca, G., Quaquero, E., Pili, D., Brandolini, M.: GIS-HBIM integration for the management of historical buildings. Int. Arch. Photogram. Remote Sens. Spat. Inf. Sci. **42** (2), 1129–1135 (2018)
13. Biljecki, F.: Level of Detail in 3D City Models. TU Delft, Delft (2017)