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BRIDGING THE GAP: AN OPEN-SOURCE GIS+BIM SYSTEM FOR ARCHAEOLOGICAL DATA. THE CASE STUDY OF ALTINUM, ITALY

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ABSTRACT:

GIS tools in archaeology have become fundamental for professionals and researchers around the world. In recent years, the "3D revolution" has drastically changed archaeological practices and methods, including the use of GIS. This paper presents the results of a project aimed at building an integrated system for the management and study of archaeological data in 2D and 3D, connecting GIS to BIM. Building Information Modeling (BIM) is an innovative technology developed for architectural design and planning, and later adapted for cultural heritage and historic buildings (HBIM). More recently, it has been tested on archaeological sites. Some attempts have been made to connect landscape scale GIS projects with BIM models of individual buildings. However, these have not been applied specifically to archaeology thus far. Through the use of open-source software, a seamless workflow from data collection in GIS to 3D visualization and modeling in a native OpenBIM environment has been created. The paper illustrates this methodology with a case study about Altinum, a Roman city in northeastern Italy near Venice. The GIS component of the project manages the archaeological map of the city, while the OpenBIM application allows the virtual reconstruction of the sites. For the latter, the case of the ancient city-gate of Altinum is considered and explained.

1. INTRODUCTION

The fortune of GIS in archaeology can be largely attributed to its effectiveness in collecting and organizing different types of data, but also to its ability to perform complex analyses on them. In recent years, the "3D revolution" has drastically changed archaeological practice and methods. With regard specifically to GIS, recent trends in the discipline are pushing for further integration of the third dimension into visualization techniques and analytical processes related to geospatial data, in conjunction with the widespread use of 3D spatial recording techniques (Dell'Unto and Landeschi, 2022).

This paper presents the results of a project aimed at building an integrated system for the management and exploration of archaeological data in 2D and 3D, combining GIS with an innovative technology such as BIM, in order to incorporate the aforementioned third dimension into archaeological processes.

The site chosen as a case study is the Roman city of Altinum (Venice), particularly interesting for to the fact that it was abandoned in the Late Antiquity and since then there has been no significant urban development in the area. The main objective of the project was to create a comprehensive information system for managing and studying spatial and 3D archaeological data about the ancient city, available to all stakeholders.

2. METHODOLOGY

While GIS tools are a well-established component of the archaeological method, BIM applications in Cultural Heritage sector are still in an experimental phase.

Building Information Modeling (BIM) was developed for architectural design and planning, in response to the needs of the AEC (Architecture, Engineering and Construction) industry. The acronym denotes a process for creating digital representations of the physical and functional characteristics of facilities through semantically enriched 3D models, with the aim of managing this information throughout its life cycle.

As BIM has proven to be a fundamental innovation for AEC processes, this approach has also been applied to built architecture, in particular to historic heritage. The term HBIM refers to the reverse engineering process that uses 3D survey data to create a semantically enriched 3D model composed of parametric elements realized specifically for the building in question (Murphy, McGovern and Pavia 2009; Murphy, McGovern and Pavia 2013).

According to the distinction proposed in (Saygi and Remondino, 2013), the first and primary use of BIM is related to 3D models derived from design data, such as new buildings and structures (*as-designed BIM*), while *as-built BIM* defines buildings and contexts described in their current state, such as HBIM models. The needs and requirements differ significantly between the two categories, as do the final outputs of the processes.

2.1 BIM in archaeology

Experimental applications of BIM methodology to archaeological sites are still remarkably limited. The results of a recent survey of scientific publications show that about fifteen projects have been carried out to date, all with very different approaches to the subject (Yajing and Cong, 2011; Scianna, Gristina and Paliaga, 2014; Achille, Lombardini and Tommasi, 2015; Garagnani, Gaucci and Govi, 2016; Cera, 2017; Trizio, Savini and Giannangeli, 2018; Bosco et al. 2019; Banfi 2020; Diara and Rinaudo, 2020; Moyano et al., 2020; Bosco et al., 2021; Diara, Rinaudo, 2021; Guerrero Vega and Pizzo, 2021; Banfi et al., 2022; Saricaoglu and Saygi, 2022).

In the scientific discussion on BIM, archaeological case studies have often fallen under the HBIM label. In the aforementioned paper (Saygi and Remondino, 2013), these cases are considered *as-built BIM* when archaeological remains are the subject of the

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modeling process, while *as-designed BIM* is used for virtual reconstructions of ancient buildings and/or architectural elements.
However, the review of recent scientific literature on this subject has necessitated the introduction of a third distinction, specific to reconstructed buildings (Figure 1). This classification is intended to be broad enough to include any type of hypothetical reconstruction of a lost building or context, based on historical and archaeological data. *As-reconstructed BIM* development cannot be included in either of the other two categories, as the 3D models differ significantly in terms of processes, goals, and semantic structures.

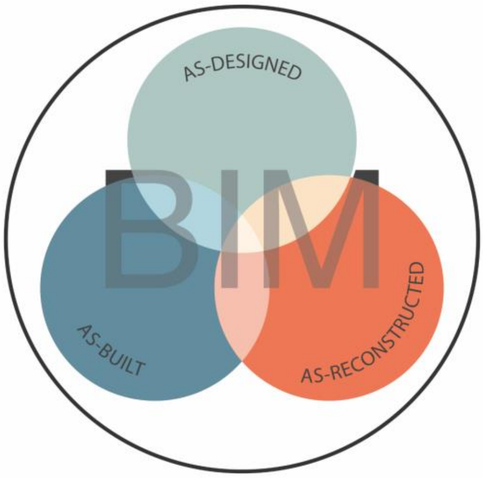

Figure 1. Proposed classification system for BIM applications, based on (Saygi and Remondino, 2013).

With regard to archaeological sites, the majority of the case studies considered could be classified as *as-built BIM*, as they aim to represent the actual state of the remains with a BIM semantic structure. However, this requires a considerable degree of adaptation of the BIM methodology.
On the software side, BIM models today are mostly produced with proprietary tools, such as Autodesk's Revit and Graphisoft's ArchiCAD (NBS' 10th Annual Report). FOSS solutions are rare: FreeCAD has implemented a BIM workbench (Diara and Rinaudo, 2020), while Blender has a dedicated add-on. An open-source approach in this field has several advantages. First, it allows you to work in a native OpenBIM environment, develop projects in a vendor-neutral process, and ensure digital sustainability. It also enables the development of workflows based on open standards such as IFC (Industry Foundation Classes), which is now the most common format for sharing information throughout the lifecycle of a building or an asset.

2.2 GIS+BIM integration

With the increasing popularity of BIM in the AEC sector and in Cultural Heritage practice, there has been a growing demand for integration between BIM and GIS. Attempts in this direction date back to the early days of BIM (Dore and Murphy, 2012).
An integrated information system addresses administration and maintenance needs of CH buildings and areas in general, bringing together large amounts of different types of data. Considering the nature of these objects, 3D models represent the optimal solution for their representation and management. Moreover, it is crucial that this system also takes into account the fourth dimension in order to keep track of changes over time (Tobiáš, 2016).

In recent years, the connection between GIS and BIM has been partially incorporated into the development of both software, but relevant interoperability issues remain. In particular, most of the case studies related to the integration of GIS and HBIM focus on the compatibility of geometry and information (De Laat and Van Berlo, 2011; Centofanti et al., 2012; Dore and Murphy, 2012; Baik, Yaagoubi and Boehm, 2015; Matrone et al., 2019; Colucci et al., 2020.). The strategy adopted required importing HBIM models and data into a GIS environment capable of representing and managing these data. However, the two systems use different exchange formats (CityGML for 3D virtual city models and IFC for buildings), based on different semantic structures and data modeling languages. In the last few years, the standards have been adapted in order to "communicate" more efficiently with each other.
Some case studies use different strategies than the one presented, such as collecting data in a 2D GIS and then migrating to a 3D HBIM model (Tsilimantou et al., 2020).
Archaeological sites and buildings have distinctive characteristics that are difficult to standardize through rigid semantic structures. This may be one of the reasons why archaeological examples of BIM models are so rare, and why an integrated GIS+BIM system on an archaeological site has never been attempted.

3. AN OPEN-SOURCE GIS+BIM SYSTEM FOR ARCHAEOLOGY

The project aimed to implement digital tools in the archaeological research of the ancient city of Altinum. For this purpose, a new operational framework has been elaborated, integrating GIS and BIM to obtain a comprehensive system for the storage, visualization, and processing of three-dimensional spatial data. This environment has been developed taking into account the requirements and procedures specific to archaeological research and conservation. The final users of this platform are expected to be different professionals and scholars, therefore a modular structure has been implemented in order to ensure usability at any level of technical expertise.

3.1 Conceptual framework

An archaeological map of the site has been developed in GIS using a data collection methodology established by the Italian Ministry of Culture for the new Archaeological Geoportal (GNA). In addition, a specific data module was added to map the archaeological features at a higher level of detail. The BIM environment allows efficient visualization of 3D data and development of 3D models in native OpenBIM. Modeling using directly IFC classes has made it possible to address the issues of BIM adaptability in archaeology without further levels of interpretation present in other BIM software. In this case, the decision was made to focus on the *as-reconstructed BIM*, modeling a hypothetical building based on GIS data and archaeological interpretation.
The results of an extensive multidisciplinary data collection campaign were then imported into the related system (Figure 2).

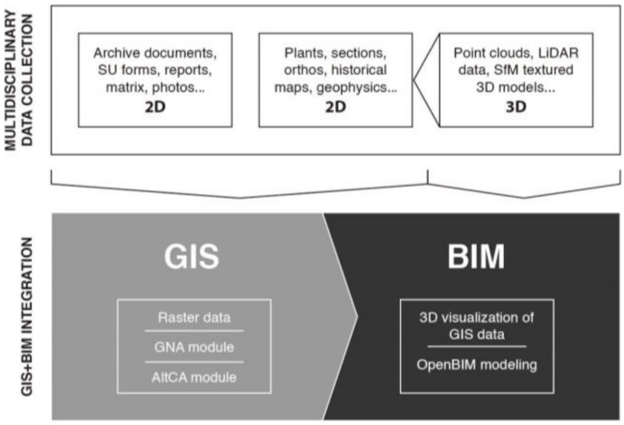

Figure 2. Conceptual data model of the GIS+BIM system for archaeology.

3.2 Software framework

As mentioned above, an open source solution was implemented to create a collaborative platform that could be used by everyone involved in the project.
On the GIS side, QGIS was chosen, because it is by far the most developed open-source software in this sector and is widely used by archaeologists. Open-source BIM modeling tools, on the other hand, are not as widespread. For this project it was decided to use an experimental add-on of Blender, BlenderBIM (BlenderBIM Development Team, 2023).
QGIS and Blender were connected through another Blender add-on, BlenderGIS, which was used to import GIS data into the 3D modeling software (BlenderGIS Development Team, 2022). This add-on allows to visualize not only 2D and 3D spatial data in Blender, but also the related information stored in GIS attribute tables. After setting the correct geographic coordinate system of the data, the import process is straightforward, although it is necessary to convert the Geopackage into a Shapefile in order for it to read the geometry correctly.

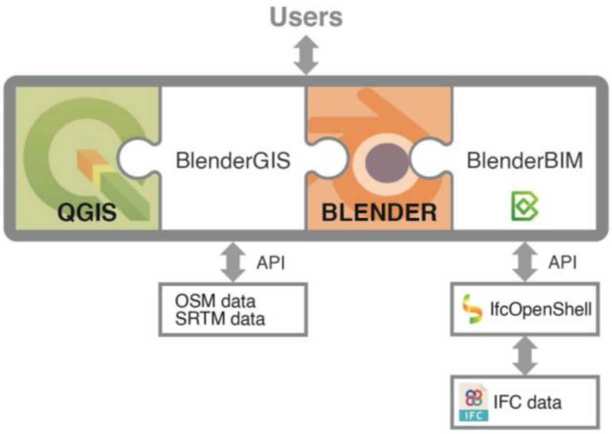

Figure 3. Software framework of the GIS+BIM system.

4. CASE STUDY: THE ROMAN CITY OF ALTINUM

The proposed workflow has been tested on the site of Altinum, near Venice, which presents traces of a long occupation, from Prehistory to Late Antiquity. This first part of the project has focused exclusively on the Roman period of the settlement, while other side projects are currently underway.

4.1 History and topography of the site

Altinum is located in the municipality of Quarto d'Altino (province of Venice), close to the margin of the Venice Lagoon. A complex network of rivers and canals and a few central mounds, formed by archaeological deposits, define its landscape (Mozzi et al., 2016).
Archaeological finds in the area date back to the Mesolithic period. The first permanent settlement began in the eight century BCE, and prospered thereafter, becoming an important trading center for the Veneti, the indigenous population of the area (Gambacurta, 2011).
At the beginning of the second century BCE, the Roman expansion in the Italian peninsula started the process known as "Romanization". Altinum was consequently integrated into a larger network of roads and sea routes, in particular the Via Annia, which connected the main northern Adriatic cities from Adria to Aquileia, at the eastern border (Tirelli, 1999).
During the first century BCE, the city underwent a systematic reorganization of its natural and hydraulic framework, along with an extensive monumentalization of the urban center. Altinum maintained its key role as a port city (*emporium*), as evidenced by numerous archaeological finds related to trade and commerce dating from this period (Cresci and Tirelli, 2003).
The municipium flourished during the Roman Empire, but it was abandoned around the seventh century CE, when various factors caused the population to migrate from the interior to the nearby lagoon islands (Tirelli, 2011).
The region remained uninhabited for centuries and was not reclaimed until the 19th century. To this day open fields and farms are the main features of the landscape. This means that most of the archaeological deposits are still buried and "frozen" at the time of the abandonment. During the 20th century Archaeological research focused mainly on the necropolises located along the main roads connecting the city with other centers of the region. Only a few extensive excavations have shed light on the urban center, revealing a conspicuous part of the new neighborhood expanded during the Augustan period, consisting of several houses and a section of the *decumanus*, as well as the city gate, which marked the northern boundary of the city and was also used as a landing place (Scarfì and Tombolani, 1985).
A major breakthrough in research occurred in 2007, when a remote sensing campaign by the University of Padua produced a series of visible and near-infrared aerial photographs of the Altinum area, revealing conspicuous and detailed cropmarks in relation to the underground urban structures (Figure 4). Thanks to these images and further research, it was possible to identify the monumental sector of the city, including the central *forum*, its shops, the theater, an *odeion*, the amphitheater, large buildings with apses, walls, gates, roads and canals (Ninfo et al., 2009; Mozzi et al., 2016).
After this pivotal moment, there has been a renewed interest in research on urbanization and urban development, aimed at better understanding the complex set of data provided by the aerial photographs. In particular, since 2012, a research group at Ca' Foscari University has been studying the dynamics related to a residential sector of the city (Sperti et al., 2017; Sperti et al., 2018).

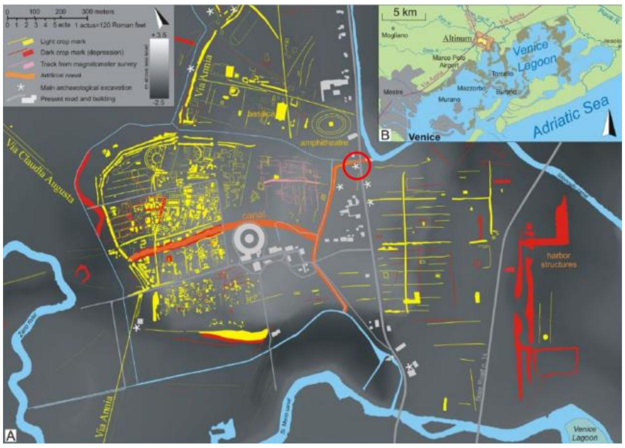

Figure 4. Map of Altinum based on the aerial photos; the red circle shows the location of the city gate (Ninfo et al., 2009; modified by the authors).

4.2 AltCA3D: the GIS+BIM system of Altinum

Once the system was designed, the project AltCA3D (Archaeological Map of Altinum 3D) was ready for implementation.
The first step was the data collection, which involved the National Archaeological Museum of Altinum and included various sources of information. The main task was the digitization of the museum’s archive, where all the data from old excavations and researches are stored. These include reports, drawings, photographs, historical maps, previous aerial photographs, and results of geophysical campaigns.
Other data were obtained through web services or specific requests, such as the DTM data from the Italian Ministry of the Environment.
The two archaeological areas of the *decumanus* and the city-gate are currently the only sites of the ancient Altinum that can be visited. Since their structures are well preserved, we carried out a 3D digital acquisition campaign, using an integration of different survey’s methods that have proven particularly effective in archaeological contexts, including UAV photogrammetry and laser scanners (Balletti et al., 2015).
Once this data was collected and processed, the information was entered into the GIS, mapping all excavations and finds from the Roman period (Figure 5).

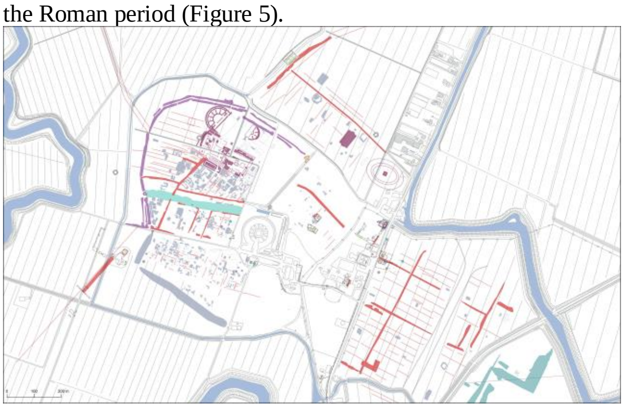

Figure 5. The archaeological map of Altinum in GIS.

The GIS gathers raster data organized into categories. Vector layers are distributed in two modules, as mentioned.
The system has been designed to manage information from the area of the excavation down to the level of detail of stratigraphic units, the smallest recognizable evidence of an individual activity (Harris, 1989). This provides an accurate and scalable 2D representation which is linked to a complex set of alphanumeric attributes, presented in forms (Figure 6).

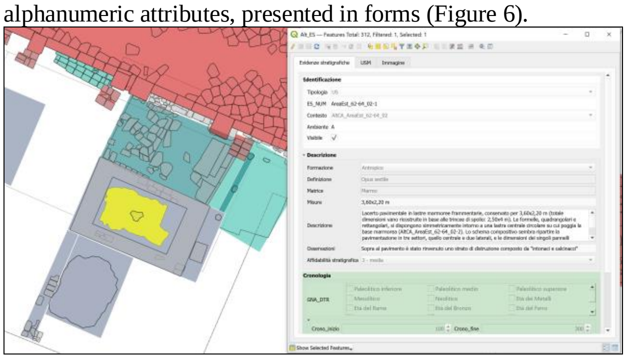

Figure 6. The attributes of the stratigraphic unit of a Roman marble floor.

After the data entry phase, the GIS project was already a complete tool that could be used for research and conservation purposes. In particular, the system makes it possible to collect and analyze different types of data, allowing a comprehensive approach to the study of the ancient Altinum, bringing together all the information related to the finds, even those recovered in the smallest excavations.
A selection of relevant data has been extracted from the entire GIS dataset for processing and import into the 3D environment.
The BlenderGIS add-on adapt Blender 3D space adding in the Custom Properties of the scene the information regarding its Coordinate Reference System (CRS). Once the CRS of the project is defined, BlenderGIS is able to manage the coordinates of the scene’s origin and update the corresponding longitude/latitude, simplifying the long string of coordinates into a single precision number (float32), that Blender can read.
The add-on currently supports import of the following formats: Shapefile (.shp); georeferenced raster (.tif .jpg .jp2 .png); Open Street Map XML (.osm); ESRI ASCII Grid (.asc). For this reason, it was necessary to add an additional step to the import process, since all the vector layers of the GIS were stored in a GeoPackage. This conversion had also to take into account the fact that BlenderGIS does not support multi-geometry Shapefiles. The steps of this procedure were: selecting the data, converting it to a single polygon geometry, assigning the Z-value to each polygon (extracted from the DEM using the QGIS “Drape” process), exporting the resulting layer as a shapefile. During the import of this file through BlenderGIS it was possible to use the elevation data extracted to position every feature in the correct location in the 3D space (Figure 7).

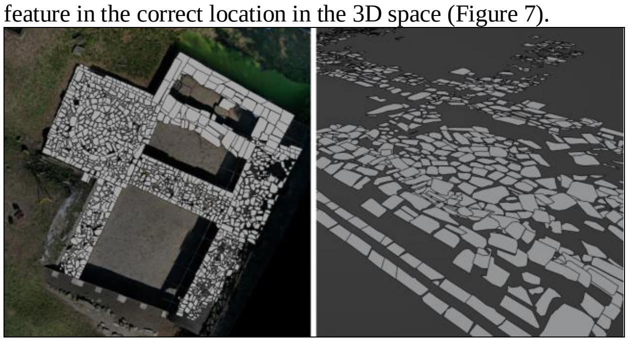

Figure 7. GIS data in Blender (orthophoto and polygons); detail of the polygons distributed in the three-dimensional space.

The city-gate case study presented here determined the selection of imported files. The first element to be imported was the ortho image of the entire area of the ancient city. Thanks to a feature of the add-on, this was then visualized using the DEM as a displacement texture to display the surface of the landscape in 3D. A set of raster and vector layers describing the city gate was

then imported into the scene. Lastly, point clouds of the city-gate from laser scanning and photogrammetry were inserted.
The BIM process in Blender, through BlenderBIM, makes it possible to create and author native IFC files. This means that in addition to the Blender project itself, the add-on creates an .ifc file that contains the BIM models and it is saved separately.

4.3 The city-gate: an example of *as-reconstructed BIM*

The city-gate was chosen as test subject for the development of the BIM part of the project, because it is one of the few well-documented and preserved sites in the ancient city (Balletti and Delpozzo, 2021).

4.3.1 Archaeological description

Excavations in the area began in 1972, continued between 1980 and 1985, and resumed between 1991 and 1994 to complete the work necessary to include this sector in the archaeological itinerary for tourists.
The architectural structure, dating back to the first half of the 1st century BCE, consists of two square-plan towers, round inside, and a central *cavedium*, with foundations made of sandstone blocks resting on massive timber piles, which were needed to assure the building stability (Figure 8). The western tower is completely preserved and measures 7.40 m on each side. The walls, which have not been preserved, were probably made of brick and the architectural decorations were made of terracotta elements.
In the northern part of the building, the archaeologists identified the foundations of an *avant-corps*, later added to the structure and slightly offset to the northeast, interpreted as the southern sector of a bridge. This side of the city gate overlooked a canal and therefore had the additional function of a landing place. On the opposite side, south of the building, a paved road (*cardo*) was found (Scarfi and Tombolani, 1985; Tombolani, 1987; Gambacurta, 1992; Tirelli, 1999; Cipriano, 1999).
In the stratigraphic units attributed to the construction phase, the archaeologists recovered a ritual deposit related to the foundation of the building, consisting of animal bones, bronzes, and pottery shards, some bore dedicatory inscriptions in Venetic, Greek, and Latin (Tirelli, 2011).
It seems that the city-gate had not only a defensive function, but was also an important landmark, as a symbol of the *pomerium*, the border between the city and the suburbs. (Tombolani, 1987).

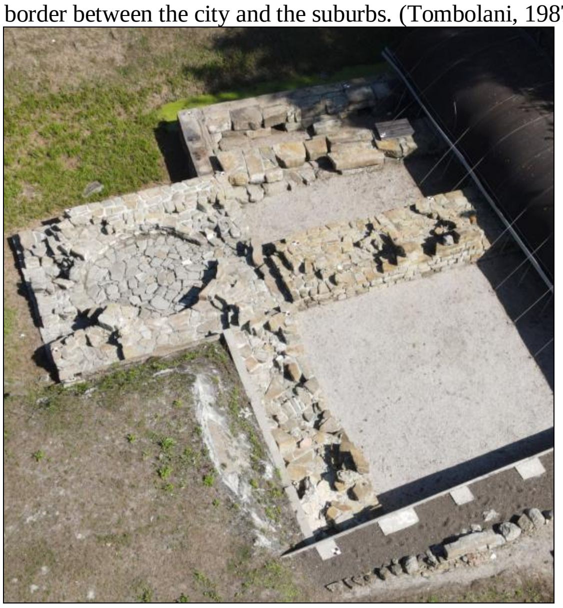

Figure 8. The archaeological area of Altinum's city-gate.

4.3.2 The BIM model

For the case study considered, an *as-reconstructed BIM* model of the first building phase of city-gate is proposed. The idea was to test the adaptability of the IFC schema for archaeological reconstructions, and to use the BIM model to test the hypotheses of the scholars about the original aspect of the building.
The BIM model of the city-gate was developed following the IFC4 version of the standard and using most of the classes already present. For this specific case, the classification system was not expanded in any way and architectural elements which are not classified in IFC were designated as IfcBuildingElement (an example of another approach in Diara and Rinaudo, 2020).
Since *as-reconstructed* models are based on hypothesis, a custom Property Set was created in order to give information regarding the reconstruction process of every individual element (wall, window, etc.). This set (AltCA3DPSetTransparency) can be applied to the class IfcObject and its hereditary entities. The properties arranged here are:

- **Reliability**, on a scale of 1 (low) to 4 (high);
- **SUNumber**, stratigraphic unit number corresponding to the one in the GIS system;
- **BuildingPhase**, to identify additions and changes in the architectural structure and their relative chronology;
- **ObjectVersion**, to distinguish hypothetical different versions of the same building element;
- **Notes**, textual field to add generic information about the modeling process.

In order to assure the transparency of the reconstruction, the IFC system to connect external resources was exploited (IfcExternalReference – IfcDocumentReference), creating an archive of documents about the comparisons and references used to model the city-gate. For example, pdfs of papers and drawings of the Porta Leoni in Verona were attached, as this is the closest example of a Roman city-gate with the same design as Altinum's (Cavalieri Manasse, 1986). These documents were associated principally to the entity IfcBuilding and can be open directly from the Blender interface. If necessary, they can also be associated to object entities (IfcObject) or their types (IfcObjectType).
After the creation of a new IfcProject, the IfcBuilding of the city-gate was generated, divided in six storeys (IfcBuildingStorey). This entity is defined as "a (nearly) horizontal aggregation of spaces that are vertically bound" (IFC4 documentation), so it was used to separate objects coherently, such as foundations, walls of the first floors, roofs, etc. Using this class assured the definition of corrected spatial relations between the different parts, as defined in the IFC schema.
The next step was the creation of typologies of building elements sharing common features (IfcObjectType), such as walls of different width and materials. The modeling was done using the ancient Roman measuring system (1 foot = 29,64 cm).
For the foundations, two types were created: IfcPileType to represent the timber piles, and IfcFootingType for the foundations of the two towers. At this point, the question arose as to the foundation of the south wall, which was not made of stone as the others but was composed of various layers of soil and debris. This particular foundation type is common in the region during the Roman period, but could not be easily assigned to an IFC class. For this reason the association was made with IfcElementAssembly, which "represents complex element assemblies aggregated from several elements" (IFC4 documentation).
Starting from this, the modelling was carried out using the point clouds of the site, imported in PLY format, which provided correct measures and representation of the features (Figure 9).

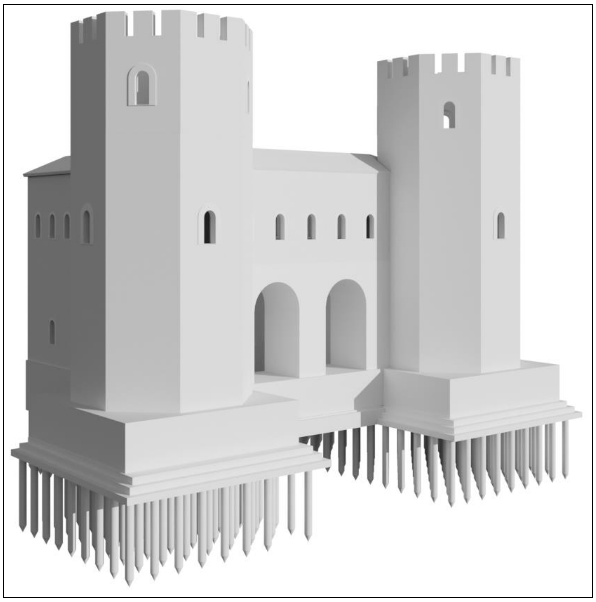

Figure 9. The BIM model of the city-gate.

Similar to HBIM, the other problem encountered during the modeling phase involved objects with complex geometry that had to be manually modeled.
Finally, each building element was enriched with the metadata of the property set AltCA3DPSetTransparency (Figure 10).

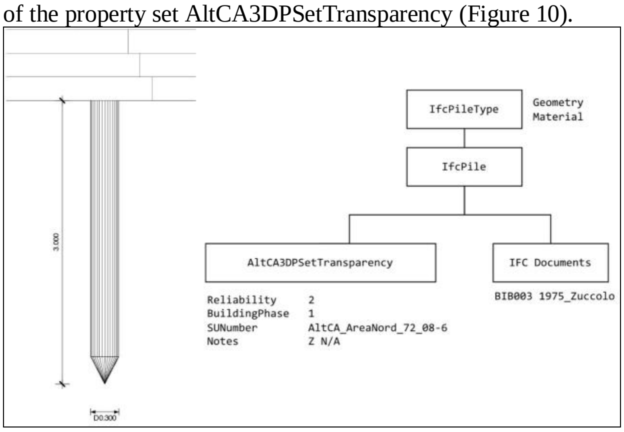

Figure 10. Example of properties attributed to the element IfcPile.

The resulting model is a knowledge base for research, as mentioned, but it can also be used for dissemination purposes, particularly by the museum.

5. CONCLUSIONS

The application of BIM in archaeology is still in an experimental phase. The process presented here, which brings together GIS and BIM, represents an innovative proposal to improve the digital method in archaeology, starting from GIS to collect and analyze data going to the 3D space to visualize and formulate hypotheses on the contexts studied.
In this respect, BIM is an effective tool for realizing "smart" virtual reconstructions, where each element is semantically linked to others and associated with the related data, including those about the reconstruction process itself. *As-reconstructed BIM* models could be an efficient way to apply BIM methodology in archaeology, as they would represent buildings with structural integrity, as opposed to *as-built BIM*.

As with HBIM, the problem of geometries and architectural elements that are difficult to standardize remains. In general terms, the IFC schema can be applied to most elements, but specific architectural features need to be manually modeled and semantically associated to generic classes. One of the possible future developments could be the implementation of IFC (or a another standard based on it) for built heritage and ancient architecture, and the creation of shared object libraries as promoted by HBIM specialists (Murphy et al. 2021).
The case study of the city-gate of Altinum is only partially representative of the complexity of Roman construction techniques and examples. Nevertheless, the proposed methodology could be a starting point to advance the discipline of virtual archaeology. In this framework, the virtual environment is not limited to visualization, but it becomes a "digital research laboratory" to analyze data, run simulations, test hypotheses, etc.
In order for it to be a collaborative and effective research tool, this had to be an open system, hence the decision to develop it using open-source software. This entails some limitations, for example the mentioned add-ons are still experimental and may cause some problems in everyday use. On the other hand, open-source tools are editable and customizable, and the online community can help overcome these problems and tailor solutions to the users' needs.
Ultimately, the bridge built between GIS and BIM represented an effective development in the research. From this moment on, the GIS project will be implemented with more data from the excavation history of Altinum and will become the knowledge base for all stakeholders in the area. The BIM system, for its innovative potential, would be used for dissemination purposes and could contribute to the research of this site and the Venetian territory in general.

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