

# Semantic Enrichment of Geographic Data and 3D Models for the Management of Archaeological Features

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## Abstract

*The present paper describes various technologies to link semantic information to 3D models during the process of management of 3D data and geometries used by the archaeologists for the reconstruction of ancient monuments or sites. This is an important requirement for the purposes of modern research since, although we have a lot of good 3D models of topographic objects, it is often difficult to make computers aware of the nature of the related real object (buildings, sites or landscapes) or parts of them (e.g. a column capitel and its various elements). The same difficulties occur when it is necessary to link geographic information to 3D models or to deal with metadata and annotations concerning the same elements, for which semantic technologies are required. We propose a possible way to integrate 3D data in a geographic environment and in addition to enrich 3D models by providing a set of semantic descriptions for each geometrical component of a given object, extended with semantic annotations of the model as a whole or of specific parts of it. The proposed technology is based on the use of various standards, including GML and one of its application schema, CityGML, specifically designed for the representation of 3D urban objects, and CIDOC-CRM, the cultural heritage ontology suitable for every non-structural description of each topographic object or building, including temporal entities (events).*

Categories and Subject Descriptors (according to ACM CCS): H.3.7 [INFORMATION STORAGE AND RETRIEVAL]: Digital Libraries—Standards

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## 1. Introduction

The use of 3D technologies and methodologies is becoming very useful and widespread in many areas of archaeological research and this is due in particular to the 3D models' ability to be extremely powerful tools, intended not only to be used for general presentation but also for scientific analysis. 3D modelling comprises nowadays a wide range of applications for every aspect of the archaeological work, from the big scale activities of landscape analysis and excavation area documentation, down to the creation of digital representations of monuments and artefacts intended not only for general public use, but also for research, restoration and preservation purposes.

In recent years archaeologists have become aware of the possibilities offered by new 3D technologies, and they are getting more and more interested in using them not only during the final steps of the documentation process and for

the presentation of the final results, but also during the excavation activities. 3D technologies offer great benefits, especially if we consider that often archaeological excavations are destructive activities and that a lack in the documentation at this stage could cause the loss of important (and sometimes vital) information forever [D'A06b].

In the past the systematic use of 3D models in archaeology did not set in so quickly, if compared with the use of other information technologies. GIS tools and relational databases have always been the archaeologist's best friends during the process of encoding excavation information, while 3D has been often seen in turn as a beautiful toy to play with (but just a toy) or, on the contrary, as a very powerful, but too sophisticated mate to deal with. This can surely be ascribed in most part to the high costs of the 3D and to the difficulties of using 3D tools properly. Even at present, the expensive tools required to create valuable 3D models are rarely easy to use

and very often they do not provide user-friendly interfaces with the related software. There are also other issues to be considered and in our opinion one of the most relevant are the difficulties encountered in 3D data integration.

For a very long time, proprietary data formats have created barriers to the integration among 3D data and the other 2D digital information. The war of the “closed formats” is far from being concluded and at present, formats like *DWG* and *3D Shape* are still considered *de facto* standards, although they frustrate any possibility of efficient data sharing and exchange.

Besides this, other more flexible and open formats (e.g. *X3D* [X3D] and *COLLADA* [COL]) and many powerful and open (and very often free) tools, have appeared on the scene. The openness of the formats relies very often on their XML nature, which guarantees the necessary portability and interoperability of information between different systems and over the Web: what makes XML really amazing is the capability to provide many layers of standardization between archives, since its open nature makes it ideal to be used by different applications.

Many 3D applications able to read, create and exchange XML data are now Open Source, meaning not only that they are cost free, but mainly that they have no master to obey other than the user him/herself. Relevant examples of this new generation of software are MeshLab [MES] and Blender [BLE]; both are worthy sons of the Open Source philosophy and, while being totally free, are priceless for the infinite possibilities of personalization offered by their modular systems to the developers, which have the freedom to adapt and extend their features and interface for every specific need of the user.

XML and Open Source are of course great allies of users and developers in overcoming the tyranny of the proprietary formats. But standardization of the formats and availability of open tools are not enough to guarantee real data integration. The third corner of the triangle is *semantics*, i.e. the intelligent and meaningful use of metadata and the other huge set of information that usually accompanies (or should accompany) the data itself. Semantics is the way to establish a direct relationship between digital data and real objects in the real world. And once every element is described with the words of the real world, integration will naturally follow, as we live in a relational reality.

In recent years we have already oriented our research towards the integration of geographic data and archaeological excavation records stored in relational databases by “enriching” them with semantic information [DFLP09] [FL07]. We have widely investigated and tested the various possibilities offered by XML-based technologies and by ontologies to enhance standardization and we verified that semantic enrichment for spatial and non-spatial information was the real key for integration [DMZ06] [EFOH08]. The problem seems to be very topical also for 3D, since semantic data management

of 3D models has become one of the big issues of many important European projects [FK3] [I3D]. The 3D-COFORM project [3DC], specifically focused on the use of 3D for the documentation of physical cultural heritage, for instance, has an eye on the metadata topic and a lot of its effort will be devoted to the creation and exchange of valuable semantic information for the 3D digital artefacts.

In this paper we present the preliminary results of our research and some general consideration on the different possibilities offered by the present day technologies and standards for the management of 3D models in geographic contexts and for the enrichment of 3D models by attaching coherent and meaningful layers of semantic metadata to them. This would allow the establishment of semantic communication within 3D tools and other traditional documentation systems (GIS and databases) and to implement data integration based on semantics.

At this very early stage of our research we have chosen CityGML [CIT], an XML-based standard language, derived from the Geographic Markup Language (GML) [GMLa], to describe archaeological 3D contexts regarding different structural and architectural objects. We performed our tests using only 3D models of archaeological topographic objects by using an adapted subset of the CityGML model.

Blender and other Open Source GIS software (i.e. GRASS GIS [GRA] and its user-friendly incarnation, QuantumGIS [QGI]), suitably modified and extended for our purposes, have been chosen to setup the “software environment” for GIS and 3D integration and for metadata creation. CIDOC-CRM [CRM] was the chosen ontology and the RDF language [RDF] has been used for the encoding of the semantic layers linked to GIS and 3D models. Finally, a semantic container (the SAD/MAD Framework [Fel06]), able to perform semantic query and operations and intended to be the real “place” for semantic integration, has been set up for the semantic management of RDF information. All the mentioned technologies were tested using the information taken from the archaeological excavation of *Uchi Maius*, in Tunisia.

## 2. 3D Models, GIS and Semantics

In technical terms, a 3D model is a just a piece of alphanumeric information stored in a file or in a database. When this digital object is rendered by a specific application, the user can see, understand and possibly recognize what is shown in three dimensions, but no information is provided to the computer, which is not aware of what the 3D model represents unless some metadata or semantic descriptions are provided along with the model itself.

If, for instance, we visualize the 3D model of an ancient Doric temple, our brain easily distinguishes the different elements composing the scene (e.g. the walls, the columns, the roof and so on), to recognize the relations between them (e.g. the roof resting on top of walls and columns) or to deduce

stylistic information from the type of the structure or from decorations (e.g. the specific architectural style, the *Doric* in this example). Usually no “explanation” is attached to the model to “tell” the machine how the scene is built, which features link the elements among each other, and other such information.

Without the semantics, without a formal machine-understandable description of the scene or object represented, the 3D model is destined to remain what it actually is: a piece of alphanumeric code; and a query like “show me all the 3D models of temples having eight doric columns on the front” would be impossible to perform in a non-semantic environment. On the contrary, a semantic-enabled system would very easily execute this query and possibly provide a set of 3D models matching the required criteria, among which you would see, for instance, the 3D model of the Parthenon of Athens.

But how it is possible to make 3D and, in general, other digital data more semantic? One of the possible ways to accomplish this is to encode information by using one of the standard languages developed to describe specific relations: the GML language, for example, perfectly meets all the needs of the spatial information description, by providing a hierarchical structure able to capture every geographical relationships between features.

The CityGML language, on the other hand, uses the same mechanisms as GML to underline the structural relationships among the different components of a topographic 3D model. That’s a very interesting aspect of this language which would allow, on a geographical scale, to use geo-referenced 3D information within a GIS platform, as already implemented by the Google Maps/Google Earth platform, in which 3D models of specific buildings can be visualized on top of the geographic feature representing them on a map (and, actually the KML code generated by Google applications is itself a subset of GML).

However we noticed that, even when using formal languages like the ones based on GML, a lot of useful information (e.g. the “non-spatial” and the “non-structural” one) is still missing and that something different is needed to create information regarding, for instance, the temporal entities, the events.

We also discovered that non-spatial and non-structural data can easily be captured by using *annotations*, that is by creating a meaningful link between a piece of semantic information and a specific “point” or “area” of a given digital object. This process is what we called *semantic enrichment* of digital data and will be described in detail in the following sections.

### 3. The Integration Environment

#### 3.1. GML and Semantics in Spatial Data

The GML language stands at the very core of our research, since a relevant part of the integration process relies on the use of this powerful XML technology. One of the interesting aspects of GML is that it is a language aimed at objects, in which every entity contains both geographic and also some semantic information: in GML, for example, every *entity* is a class apart and every *object* is defined by the class it belongs to.

The GML structure is very flexible and the objects are grouped according to logical criteria. Moreover, an object may contain other objects: spatial and dimensional data may be added to cartographic data and structured according to the ISO 19107 and ISO 19111 standards; this avoids the need to recall them from external files.

What really makes GML an extremely valuable format is the ubiquitous use that has granted it the status of *de facto* standard: every GIS application today, whether proprietary or Open Source, is able to handle the GML format for data exchange. The latest release of GML (3.0) [GMLb] is even more powerful, as it allows the handling of a wider bunch of information, including:

- complex, non-linear, three-dimensional geometries
- topology for bi-dimensional elements
- ability to visualize elements having temporal and/or dynamic components
- use of referencing and/or unit of measurement systems
- conformity to other prescriptive standards

in addition, it allows the definition of the most appropriate data structure for every single application.

Encoding spatial data using GML3, as already pointed out, gives the spatial data a basic level of semantics. Additionally, we’ve set up a mechanism to enrich the GML code with CIDOC-CRM entities (especially “temporal” entities) to create aggregated pieces of XML code (*aggregated objects*) carrying both spatial and non-spatial information. To implement the semantic functionalities we have developed a CIDOC-CRM *Python* plugin for the GRASS/QuantumGIS open source software that can be activated directly from the graphic user interface and makes the entities and properties of the chosen ontology (in our case CIDOC-CRM) immediately available.

With them the user has the possibility to express some of the most common relationships among spatial objects (e.g. the *is\_contained\_in* spatial relationship) using CIDOC-CRM properties (e.g. the *P89F.falls\_within* property) or to create brand new semantic annotations. This way it is possible to define semantic relationships directly from the GIS software and to semantically extend the GML description of spatial features with RDF code. An example of XML aggregated object, describing a temple both

semantically (as a CIDOC-CRM Place) and geographically (as a GML polygon) is shown below:

```
<crm:E53.Place rdf:about="Temple_B">
  <crm:P67B.is_referred_to_by>
    <crm:E73.Information_Object>
      <gml:Polygon>
        <gml:outerBoundaryIs>
          <gml:LinearRing>
            <gml:coordinates>
              168534.100,247424.700
              ...
            </gml:coordinates>
          </gml:LinearRing>
        </gml:outerBoundaryIs>
      </gml:Polygon>
    </crm:E73.Information_Object>
  </crm:P67B.is_referred_to_by>
</crm:E53.Place>
```

Another feature of the CIDOC-CRM plugin allows user to export/send the whole set of XML-based information on the web towards a WebGIS or towards a semantic container to be queried and integrated with other similar information (see Figure 1)

### 3.2. The CityGML Application Profile

The other GML based language we used in our work is CityGML, an open data schema originally designed to store and exchange virtual 3D city models. CityGML is not an independent language, but just an *application schema* (i.e. a domain specialization) of the most generic GML format, designed to achieve a common definition of the basic feature classes, attributes, and relations in the sense of an ontology for 3D city models with respect to geometric, topological, semantic, and appearance properties.

The modelling principle is based on a taxonomy definition and on a decomposition both on the semantic and spatial side of the topographic elements from the whole city (defined as a composition of *buildings*) down to smaller components, such as a balcony, windows or doors. CityGML also provides a basic semantic model for the topographical objects which consists of class definitions for the most important features within virtual 3D city models, including *buildings, water bodies, transportation, vegetation, and city furniture* [Lor09b]. All classes shown are derived from the basic class *Feature*, defined in ISO 19109 and GML3 for the representation of spatial objects and their aggregations. Spatial properties of CityGML features are represented by objects of GML3's geometry model, based on the standard ISO 19107 *Spatial Schema* representing 3D geometry according to the well-known Boundary Representation (*B-Rep* [Str06]).

CityGML actually uses only a subset of the GML3 geometry package. One interesting aspect of CityGML is the full support for multiple *Levels of Detail (LoD)*. This means that in one dataset, the same object may be represented by a

maximum of five discrete and well-defined *LoDs* simultaneously, ranging from pure DTMs to architectural models with interior structures. Thus, CityGML is capable of representing 3D city models at various degrees of complexity with respect both to geometry as well as semantics. This allows flexible use of CityGML as exchange format both in terms of representable data and applications.

Since CityGML has the same XML syntax of GML, semantic annotations of non-structural data (e.g. information on who is the builder of a certain temple, where the materials came from, when and why the temple was built/destroyed/rebuilt, and other relevant events) can be put directly into the code in order to document the whole model or only certain parts of it. This is quite an easy task, as each component of the model is described by a fragment of XML/GML code and it is very straightforward to enrich it by stating semantic RDF-like relations.

From the technical point of view we have adopted the same principles successfully employed for GIS data in QuantumGIS: also for CityGML the enrichment operations are performed taking advantage of another very popular Open Source tool, Blender, and of its plugin mechanism. We have developed a semantic plugin able to attach CIDOC-CRM entities and relationships to the CityGML code. The plugin, written in Python and perfectly integrated within the Blender's User Interface, allows the user to perform many operations, and specifically:

1. *To give the user the possibility to import the entities and the relationships of the CIDOC-CRM ontology* (or of another chosen one) to be used for the semantic enrichment.
2. *To create one or more annotation:* once the user has selected one or more 3D elements on the scene (or the full scene) he/she can create a *semantic annotation* using the entities and properties of the loaded ontology, to be linked to the chosen part of the model. Once created, the annotation(s) will be directly attached to the CityGML code and will enrich it with semantic information to create an aggregated CityGML/RDF object. With this technique it is possible, for instance, to assign the non-structural descriptions (e.g. the style, the provenance and temporal information) to the CityGML structural description of a *ionic capital*. Additionally it is possible, for every 3D object selected and/or annotated in the Blender Viewer, to see the related CityGML code and check where the semantic RDF annotations (if any) have been placed. This "advanced option" (requiring particular user skills) would allow the direct editing of the code to match specific user needs.
3. *To send the entire XML code (containing X3D, CityGML, GML and CIDOC-CRM information) to the semantic container* that will store it and make it available for semantic queries. The semantic container is the place where geographic, 3D and semantic integration is actually per-



formed and where aggregated objects could be also created as result of semantic queries.

The semantic container used in our tests is SAD, yet another Open Source tool developed by us.

#### 4. SAD, a Semantic Container

SAD is a featured data archive capable to store semantic, geographic and 3D information in XML format, to reply to simple and complex queries, and to generate on-the-fly XML aggregated objects. The first release of SAD (called MAD) was developed at PIN during the EPOCH European Project [MAD]. Improved with a lot of features, it has proved to be an efficient and flexible tool, easy to integrate into different frameworks. The current version of SAD comes with a web-oriented container written in PHP and powered by a MySQL database. The semantic layer is based on the ARC2 RDF classes, an open source set of PHP libraries specifically oriented towards the management of semantic information [ARC]. SAD also has native support for many popular protocols, such as REST [RES] and SOAP [SOA] for network communication, and provides a SPARQL [SPA] end point for semantic queries.

The current release of the SAD also implements a basic set of semantic interfaces and a basic reasoner able to compare structural, spatial and semantic relations to check for data consistency. For the next release of SAD we are planning to extend it with a reasoner able to check for the coherence of the DB by comparing, for instance, the semantic and structural statements of the annotations defined in Blender and the geographic statements inferred from the spatial information in GRASS. SAD comes with a set of query interfaces which provides, in addition to the traditional “keyword” query (which looks for a certain string or expression in the whole archive and returns results accordingly), the following features:

- *Faceted Browser Semantic Navigator*. A panel based on the faceted browser paradigm allowing users to navigate and slice the RDF graphs stored in the semantic container by defining *starting points* (just clicking on the entity which the user is looking for) and proceeds by restricting the search portion of the RDF data by selecting the related properties.
- *Semantic Query Builder*: a panel from where it is possible to specify entities and relationships for the query using all the classes and properties provided by the CIDOC-CRM or by other ontologies. Additionally, the query can be refined by adding a string for domain or range entities. This is intended to be the interface from which user can perform the “*eight column temples*” semantic query as described above and to get relevant results in the form of aggregated object, i.e. a set of RDF triples containing all the semantic (RDF), geographic (GML) and structural (CityGML) information concerning the searched objects.

After the query has been performed, the aggregated object can be sent to any CityGML-enabled tool for the models visualization (e.g. Blender), to any GML-enabled GIS software for geographic visualization on maps or used as a starting point for additional faceted navigation of RDF graphs and semantic queries.

Future features will include the possibility to convert geographic and structural information in other formats to create, for instance X3D or COLLADA code from CityGML or KML code from GML and CityGML information, to be used in Google Earth and Google Maps and Google SketchUp applications. This is a very straightforward operation since the KML format was developed by Google as an application schema of GML itself.

### 5. The Uchi Maius Case Study

#### 5.1. The Archaeological Area

To test our tools we have used the digital archive of the Uchi Maius archaeological excavation. Uchi Maius is a place located about 100 Km south of Tunis in a hilly region; the site is in the lowland of Mejerda in the area called Hencir ed Douamis on the left bank of the Oued Arkou river. The archaeological area was discovered by a French soldier in 1882 and was identified with the city of Uchi Maius quoted by Pliny the Elder (*Nat. Hist.* 5,29).

The site was founded by the Numidians in the V century B.C.; after the *Bellum Iugurtinum* the veterans of Mario were installed in this area. In 230 A.D., Uchi Maius obtained the autonomy and the status of *Roman Colony*. During the V century the city was still flourishing; material evidence shows that in this period many manufactures typically devoted to the reuse and trade of objects of the Roman period still existed. The archaeological investigation of the site was carried out by the Universities of Pisa and the University of Sassari starting from 1995 [Lor09a]; the excavation area includes three close connected elements: an Islamic oppidum, a Roman forum and an oil mill as shown in *Figure 2*.

#### 5.2. The CityGML Subset and Extensions

The core CityGML is a general schema representing only descriptions of urban objects within a modern settlement. However, being a general model, it does not provide specific classes for archaeology. Before commencing the CityGML encoding operations, we defined a subset of CityGML entities suitable for the description of archaeological features [D’A06c] [D’A06a]. Actually the hierarchic structure of CityGML allows the definition of subclasses inheriting all the properties and relationships of the ancestor classes without compromising the internal coherence of the core schema. For this reason the core model is very easy to extend with detailed definitions describing each element in a more specific way.

The archaeological schema for Uchi Maius was developed by importing the core schema of CityGML into the Protégé editor. First of all, we selected a subset of the CityGML general schema containing only those classes suitable for the description of an archaeological site, afterwards we proceeded with the definition of the new subclasses for the description of archaeological and historical objects (e.g. temple, basin, oil mill, sarcophagus, mortar and so on). The top class of the new schema is the abstract Building class, a subclass of root class Thing containing every geometrical element of a complex of buildings. The Building class also provides different properties like function, usage, type, year\_of\_construction, year\_of\_demolition and so on. Each new class was then explicitly joined with its superclass using the *is-a* and the *is-part-of* relationships. This domain-specific schema, designed to be used specifically for the Uchi Maius case study, is also suitable to be employed in other archaeological contexts and is intended to be the first step towards a definition of a more general schema able to describe the 3D features of every structural archaeological element.

### 5.3. Uchi Maius 3D Models and Spatial Information

To create the 3D representation of the Uchi Maius archaeological site, we started from the information gathered in 2002, when the entire area was surveyed using a total station. We collected the resulting .dxf files and imported them into Blender to be used for the 3D modelling operations. Taking advantage of the *Procad* Blender plugin, it was possible to work with the 3D model as if in a CAD-like environment, browsing both the planimetry and the elevation of the various elements (see *Figure 3*). Afterwards we assigned specific CityGML structural classes and relationships to the different layers and objects of the 3D model in order to create a CityGML representation of the whole scene and visualize it with the *Hypergraph* module, installed by default in Blender, very useful to graphically show structural relationships between components of a scene and to interact with them [AD10].

After that, the Blender semantic plugin was used to attach CIDOC-CRM annotations (mainly temporal entities) to the whole model (e.g. information concerning the year of foundation of the city by the Numidians, the event consisting in the assignment of the status of Roman Colony and so on) and to specific parts of it (e.g. the artistic style of a certain decorative element or the interpretation given for it by the archaeologists). Eventually, the CityGML model was then exported by using the export features of Blender and reimported into GRASS/QuantumGIS for geo-referencing and for the creation of GML spatial features. At this stage it was possible to add CIDOC-CRM annotations to the geographic information by using the related QuantumGIS plugin.

At the end of the process the aggregated objects created

during the various operations were sent to the SAD container for the semantic storage and the semantic retrieval operations. An example of aggregated object, showing structural, geographical and semantic information related to the Uchi Maius oil mill, is shown below:

```
<blgd:Building gml:id="Oil Mill">
  <gml:is_part_of>
    <gml:Envelopes rsDimension="3" ... >
      <gml:lowerCorner>
        3450014.23977 5429996.20351 0.0
      </gml:lowerCorner>
      <gml:upperCorner>
        3450021.23977 5430003.20351
        4.73881527191149
      </gml:upperCorner>
    </gml:Envelope>
  </gml:is_part_of>
  <crm:P116F.starts>
    <crm:E63.Beginnig_Of_Existence
      rdf:about="IV Century a.D.">
  </crm:P116F.starts>
</blgd:Building>
```

## 6. Conclusions and Further Work

This project is the fruit of the collaboration between PIN, University of Florence and the Italian Ministry for Cultural Heritage. The Uchi Maius dataset was kindly provided by the archaeologists of the Department of History of the University of Sassari.

The performance of the various tools and technologies tested and the promising results obtained from the case study have shown that Open Source tools combined with well accepted standards offer a wide range of possibilities even in the complex and multiform universe of 3D. The ability to describe spatial, structural and semantic data using standard languages based on XML will facilitate the creation of more efficient archives enhancing the exchange of information and the interoperability between different environments. The indispensable prerequisite to match this goal is the availability of good standards and ontologies matching the specific needs of the archaeology and of the cultural heritage in general [ND06]. The definition of the CityGML extension for the Uchi Maius 3D models and the HST Domain Ontology [HST] (developed for the Hala Sultan Tekke documentation project as a specialization of the CIDOC-CRM core [NFS\*10]) can be considered as relevant methodological examples on the path of the standardization.

While the integration of spatial data and 3D data has already been implemented in many ways and many tools already exist which easily accomplish this task (Google SketchUp is one of the best known examples), the idea of describing a 3D model semantically is quite new and not yet investigated nor fully applied to exploit its full potential. Our approach is of course not the only possible one, but it envisages some interesting scenarios. The possibility to annotate

the CityGML description of a 3D model instead of embedding annotations in the 3D model itself, for instance, seems to be a very promising technique for adding meaningful information without compromising the integrity of the original binary data that will remain untouched.

The various technologies we tested, as already said, are currently valid only for 3D representations of buildings and other topographic objects described with CityGML, but in the future we are planning to extend the mechanism to any other kind of 3D objects and to other XML-encoded formats for 3D, such as X3D and COLLADA.

Further additional activities will focus on the fine tuning of the semantic query interfaces of SAD and on the creation of more user friendly and better integrated encoding interfaces assisting, archaeologists (and cultural heritage experts in general) throughout the entire process of semantic enrichment of geographic and 3dimensional data, eventually providing them with a complete toolset to easily perform encoding operations.

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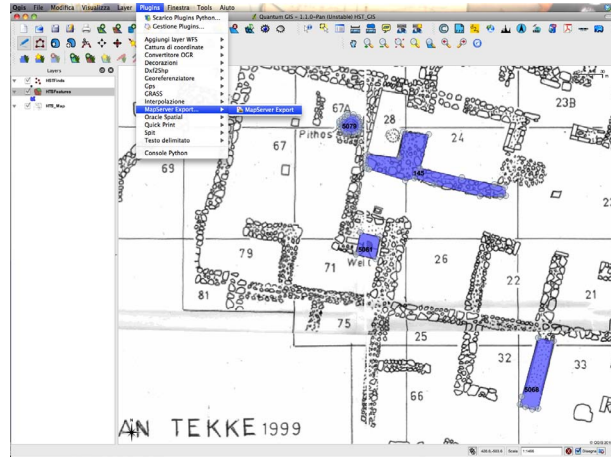


Figure 1: The Semantic Plugin in the QuantumGIS



Figure 2: The Uchi Maius Archaeological Site

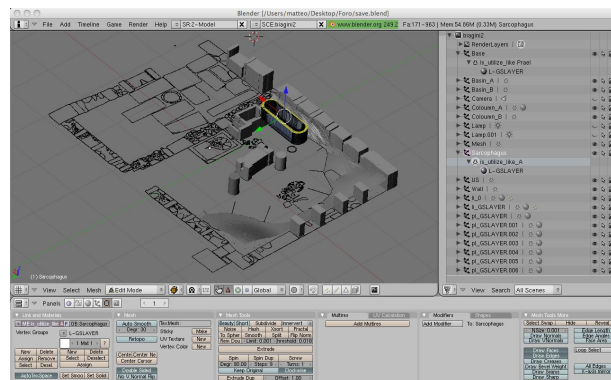


Figure 3: CityGML 3D model in Blender