

SEMANTIC APPROACH TO 3D HISTORICAL RECONSTRUCTION

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ABSTRACT:

Our work deals with the semantic 3D reconstruction of some rooms of Forte San Giorgio on Capraia Island (Livorno, Italy) excavated by the University of Pisa during the last summer. Data acquisition was achieved by total station and processed in order to generate a simple 3D dxf file for the schematic representation of the building; dxf is an “open format” and has a complete integration with xml language. Furthermore, dxf is readable by the major 3D data model software.

To construct the model, we then imported the dxf into Blender, the most important and powerful 3D modelling open source software. First of all, by using Blender, we created a layer on which we put the real archaeological data gathered on field. Then, on another layer, we drew the hypothetical reconstruction. It was thus possible to export the file into SGJ-3D software and organize the layers according to the classes of CityGML, which is a profile application of GML designed for the semantic management of 3D features (buildings and its components like windows, roofs, walls, doors, etc.). The semantic structure is based on the relationship “is part of”; for each spatial element it is possible to assign an attribute in order to distinguish the feature’s reliability in the reconstruction process.

SGJ-3D-software uses a database model and thus allows detailed description of object-oriented geographic data as well as mapping these data on the data scheme. All geographic data, attribute data and metadata are GML-structured. They are stored in object-relational databases, that provide the basis for SGJ-3D.

GML is based on XML, therefore all the spatial features are encoded in XML. It is possible to visualize the file by using specific software (Aristoles or LandeXplorer) and keeping the layer distinctions. Further, through XML-based web it is possible to perform queries in order to extract all required information concerning the model and its layers.

1. INTRODUCTION

1.1 Forte San Giorgio

In the last years, 3D technology applied to archaeological research has been the scope of intense experimentation by different scientific groups. The activity has mainly been concentrated on the use of 3D technologies for the acquisition of 3D geometries and the reconstruction of hypothetical ancient monuments or sites. The interest of the researchers has been addressed to exploit the potential of virtual reality for the visualization and the navigation of 3D archaeological environment. Often the reconstruction targets prevailed over the scientific purposes; therefore we have lots of good models, but we don’t have the chance to understand the real part from the reconstructed one. In other domains, like scientific restoration, international charters providing information about the carrying out of restoration of ancient works of art have been defined; all charters highlight the importance of distinguishing the ancient part of the object from the new one. This scientific approach doesn’t seem to animate the 3D research field; on the contrary it is characterized by the idea that the final reconstruction show realistic texture without any distinction.

In order to try to implement a more scientific model we started a new approach which includes the possibility to manage all hypothetical reconstructions by semantics.

Our proposal concerns an integration of open formats, like GML and DXF, managed by open source software for 3D

modelling (Blender). SGJ-3D-software uses a database model, thus allowing a detailed description of object-oriented geographic data, as well as mapping these data on the data scheme. All geographic data, attribute data and metadata are GML-structured and are stored in object-relational databases that provide the basis for SGJ-3D. The database solution supports international standards of ISO/OGC and thus allows the storage of arbitrary XML/GML-structured 2D/3D-data schemes, e.g. CityGML, etc.

1.2 Geographical and historical context

Forte Sang Giorgio is located on Capraia Island on Tyrrhenian Sea, at 64 km in a southerly direction from Livorno.

The archaeological evidence of an ancient civilization from the Neolithic to late Roman age (IV/V sec. B.C) makes us suppose that the area of Forte San Giorgio was already occupied before the construction of the fortress.

The actual structure dates back to 1540 when, after the bombardments of the pirate Dragout and his fleet, it was completely razed to the ground. The “Banco of San Giorgio”^{*} couldn’t allow to leave the island militarily unarmed so, on the 27th of October 1540, they began the reconstruction of the new fortress. The documents of the epoch point out that the fortress was rebuilt by the commissioner Genesio Da Quarto according

^{*} Local savings bank

to a sketch by a Genoese engineer (probably Giovanni Maria Olgiati), between 1540 and 1542.

By comparing the reconstruction to the old map of the fortress, we noticed that the preceding structure had some boundaries, two meters in height and one meter in width, set today above the plinth at the base of the present building among the two ramparts. Inside the fortress walls were 33 houses and a church. Work on the new structure began on October 27th 1540 from the southern ramparts and were completed in 1541 with the realization of part of the north ramparts.

The vertical alignment on the masonry of the northern rampart marks the passage between the first construction and the second one and the successive expansions occurred to it in 1559.

The population of the island began to increase and the new fortress assumed predominantly military functions. Comparing the documentation and the structure (a project of the 1580), it seems that fortress was designed in such way as to receive the entire population within its walls in case of an attack, but not to hold them in in time of peace.

This aspect marks the military character of the building.

The first available cartographic document pertaining to the fortress of S. Giorgio dates to the 21st of December 1580. It consists of a plan drawn by Carona Battista, sent to Genoa by the governor of Corsica, Pier Baptist Cattaneo, and composed of two sketches showing some work to be carried out by the Genoese government in the fortress in order to modify one of the buildings.

In 1624 the commissioner Alessandro Sforza converted the central building of the fortress into a public building to be used as a center and as lodgings for the commissioner himself.

1.3 The archaeological context

The archaeological dig was undertaken last summer by the University of Pisa in accordance with the Archaeological Bureau of Tuscany, while the job of restoring the old fortress was finalized to convert the military building into a residential area.

The excavation area interested the entire historical complex. The archaeological assistance during the excavation of the structures of the fortress aimed at creating stratigraphical documentation of the site and at the conservation of the architectural evidence of the building. The last task was accomplished with the aid of a team of architects.

2. METHOD

2.1 Data acquisition and managing

In order to acquire a digital model of the building we have used the following devices:

1. Total Station *Leica TCR 307*
2. Digital camera with calibrated parameters (Canon EOS 400).
3. A personal computer (PC) for the elaboration of raw data from the total station and 3D software (Blender) to develop the model.

The methodology used during the topographical relief phases was characterized by the individualization of a tri-orthogonal theme of faces to which we reported the coordinates of the points measured by the single stations.

To establish the workflow of the relief job, we have carried out some surveys, in which we annotated the most articulated details of the building and its apparatus. During the inspection phase we elaborated a first sketch of all the elements of the

building.

The measurements were achieved with a total station *Leica TCR 307*. This tool has the peculiarity to be able to operate without the necessity to position a reflecting prism on the coincided point, since it is endowed with a coaxial laser measurement.

In the coincidence of a point we measured the azimuthal, zenith and the tilted angles. The tool is endowed with an integrated computer for the determination of the coordinates of the point.

At the end of the topographical relief, the data was unloaded onto a PC, introduced and elaborated by the *Leica SurveyOffice* program.

Subsequently with the *Leica Win Drive* the data are exported in *.dxf and *.xyz formats to make them compatible for subsequent elaborations. This program allows to read and layout the book of the measures and that some coordinates of all the beaten points. Subsequently with *Leica Win Drive* the data are exported in formed *.dxf to be able to elaborate them.

In the image acquisition phase we took some photos at a distance of 10 meters and then we elaborated them to get a single photoplane by making the points of passage coincide with the coordinates X, Y, Z.

For a correct representation of the model, we imported the 3D .dxf file of the fortress in *Blender* software, the most important and powerful 3D modelling software. (Figure 1)

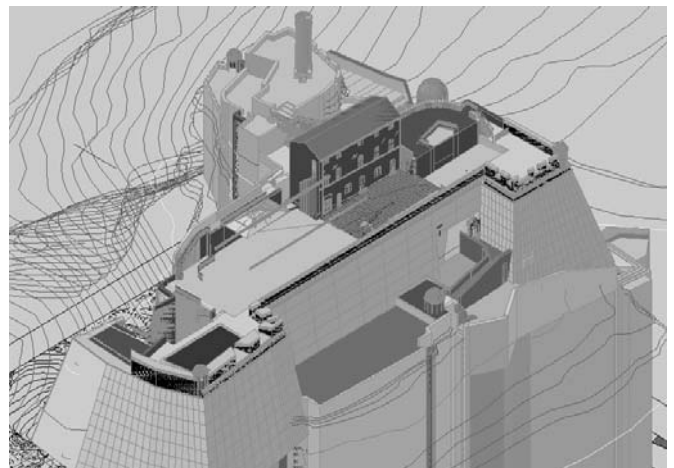


Figure 1 3D dxf model of Forte San Giorgio

3. THE PROJECT

3.1 CityGML ontology

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the Geography Markup Language 3 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC2. The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model. This is especially important with respect to the cost-effective sustainable maintenance of 3D city models, allowing the reuse of the same data in different application fields.

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is realised as an application schema for GML3, the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC). The main idea is 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 (Gröger et al., 2006). This is important for cost-effective sustainable maintenance, allowing the reuse of the same dataset in different application domains.

The modelling principle is based on a feature class taxonomy and a decomposition both on the semantic and spatial side (from the whole city over the city objects like buildings down to smaller components like a balcony). The semantic model of CityGML consists of class definitions for the most important features within virtual 3D city models, including buildings, DTMs, water bodies, transportation, vegetation, and city furniture. Figure 1 shows a small part of the semantic model used to describe buildings. 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. Features comprise spatial as well as non-spatial attributes which are mapped to GML3 feature properties with corresponding data types.

Spatial properties of CityGML features are represented by objects of GML3's geometry model, which is based on the standard ISO 19107 "Spatial Schema" (Herring, 2001), representing 3D geometry according to the well-known Boundary Representation (B-Rep, Foley et al., 1995). CityGML actually uses only a subset of the GML3 geometry package.

The geometry model of GML3 consists of primitives. For each dimension, they may be combined to form (among others) aggregate or composite geometries, meeting different connectivity requirements. Whereas aggregate geometries are arbitrary collections of primitives, composite geometries only represent primitives topologically connected along their boundaries.

In CityGML, topology can be represented explicitly. Every part of space may be modelled only once and then referenced by all features which include the same geometry. Thereby redundancy can be avoided and explicit topological relations between parts are maintained.

Furthermore, the concept of Levels of Detail (LoD) is supported. In one dataset, the same object may be represented in up to 5 discrete and well-defined LoDs simultaneously, ranging from pure DTMs to architectural models with interior structures. This is achieved by feature classes being only valid for a specific range of LoDs. For example the building feature class is valid for LoDs 1 to 4 whereas the boundary surface feature class is valid for LoDs 2 to 4 only.

Thus, CityGML is capable of representing 3D city models at various degrees of complexity with respect to geometry as well as semantics. This allows flexible use of CityGML as exchange format both in terms of representable data and applications.

3.2 CityGML ontologies

Every class of CityGML is represented by an xsd schema (Figure 2) like building, vegetation, external_object etc.; each xsd is composed of a subset of attributes.

```

<!-- ..... -->
<xsd:complexType name="BuildingInstallationType">
  <xsd:annotation>
    <xsd:documentation>A BuildingInstallation (German translation is 'Gebäudecharakteristik') is a part of a Building which
    has not the significance of a BuildingPart. Examples are stairs, antennas, balconies or small roofs. As subclass
    of CityObject, a BuildingInstallation inherits all attributes and relations, in particular an id, names, external
    references, generic attributes and generalization relations. </xsd:documentation>
  </xsd:annotation>
  <xsd:complexContent>
    <xsd:extension base="core_CityObjectType">
      <xsd:sequence>
        <xsd:element name="class" type="BuildingInstallationClassType" minOccurs="0"/>
        <xsd:element name="function" type="BuildingInstallationFunctionType" minOccurs="0" maxOccurs="unbounded"/>
        <xsd:element name="usage" type="BuildingInstallationUsageType" minOccurs="0" maxOccurs="unbounded"/>
        <xsd:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0"/>
        <xsd:element name="lod3Geometry" type="gml:GeometryPropertyType" minOccurs="0"/>
        <xsd:element name="lod4Geometry" type="gml:GeometryPropertyType" minOccurs="0"/>
        <xsd:element ref="GenericApplicationPropertyOfBuildingInstallation" minOccurs="0" maxOccurs="unbounded"/>
      </xsd:sequence>
    </xsd:extension>
  </xsd:complexContent>
</xsd:complexType>
<!-- ..... -->

```

Figure 2 XSD schema BuildingInstallationType of CityGML

For example, The abstract class *_AbstractBuilding* (Figure 3) contains properties for building attributes, purely geometric representations and geometric/semantic representations of the building or building part on different levels of detail. The attributes describe:

1. The classification of the building or building part (*class*), the different functions (*function*), and the usage (*usage*). The permitted values for these property types are specified in a separate XML file, using the dictionary concept of GML3.
2. The year of construction (*yearOfConstruction*) and the year of demolition (*yearOfDemolition*) of the building or building part. These attributes can be used to describe the chronology of the building development within a city model. The points of time refer to real world time.
3. The roof type of the building or building part (*roofType*). The permitted values for the *RoofTypeType* are specified in a separate XML-File, using the dictionary concept of GML.
4. The measured relative height (*measuredHeight*) of the building or building part ridge line (highest point).
5. The number of storeys above (*storeyAboveGround*) and below (*storeyBelowGround*) ground level.
6. The list of storey heights above (*storeyHeightsAboveGround*) and below (*storeyHeightsBelowGround*) ground level. The first value in a list denotes the height of the nearest storey wrt. to the ground level and last value the height of the farthest.

3.3 Our proposal

All geographic data, attribute data and metadata are GML-structured. GML (Geography Markup Language), an XML-based grammar for the modelling, exchange, and storage of geographic information.

GML grammar specified in one or more XML Schemas, is able to describe spatial objects using a variety of coordinate reference systems, geometry, topology, time, units of measure and generalized values to build a set of geographic features that can be considered a digital representation of the real world. Nowadays, GML format is the most important and useful international standards of ISO/OGC series.

3.3.1 Architecture of the system

Our proposal consist of using of an integrated system composed by:

1. Blender, to develop the 3D model from the raw data of the total station. We create a layer on which we put the real archaeological data gathered on the field. Then, on another layer, we draw the hypothetical reconstruction of the building with textures.
2. PostgreSQL with its geographical extension PostGIS to manage spatial data and which provides the basis for SGJ-3D software.
3. SGJ-3D developed by Support GIS is a modern 3D Information system, powered by an object relational database. The software is based on the standards of ISO and OGC – especially CityGML. It is suitable for high performance visualization of very large 2D/3D datasets.

During the development of the 3D model in Blender, we have followed the structure of building.xsd schema and we made one layer for each architectural element and for each action of restoration. Finally, the model was saved with .dxf extension. We created a database called “CityGML” in PostgreSQL server and we compiled it with a PostGIS extension. Then we connected geo database to SGJ-3D software and we imported CityGML *building.xsd* schema in “CityGML” database; during

the import process, the system will create a scheme where the entities of the database will correspond to the entities of *building.xsd* schema.

SGJ-3D besides allows to edit and see the GML and XML file created directly into the software.

3.3.2 Semantic Model

The semantic structure is based on the relationship “is part of”; for each spatial element it is possible to assign an attribute in order to distinguish the feature’s reliability in the reconstruction process.

Our model was developed following a hierarchical scheme according to CityGML proposal (Figure 4), in which we start from the feature *Building*, a subclass of root class *_CityObject*, that contains every geometrical element of the complex represented by other features “*_AbstractBuilding*”; in that feature there are different elements that compose it, like “*class*”, “*function*”, “*usage*”, “*roof_type*”, “*years_of_construction*”, “*years_of_demolition*” etc. The feature *_AbstractBuilding* is more specialized than *Building* or *Building Part*

In order to define the other components of the building we can define some features for windows and doors “*_Opening*”, for *floor surface*, *wall surface* etc.

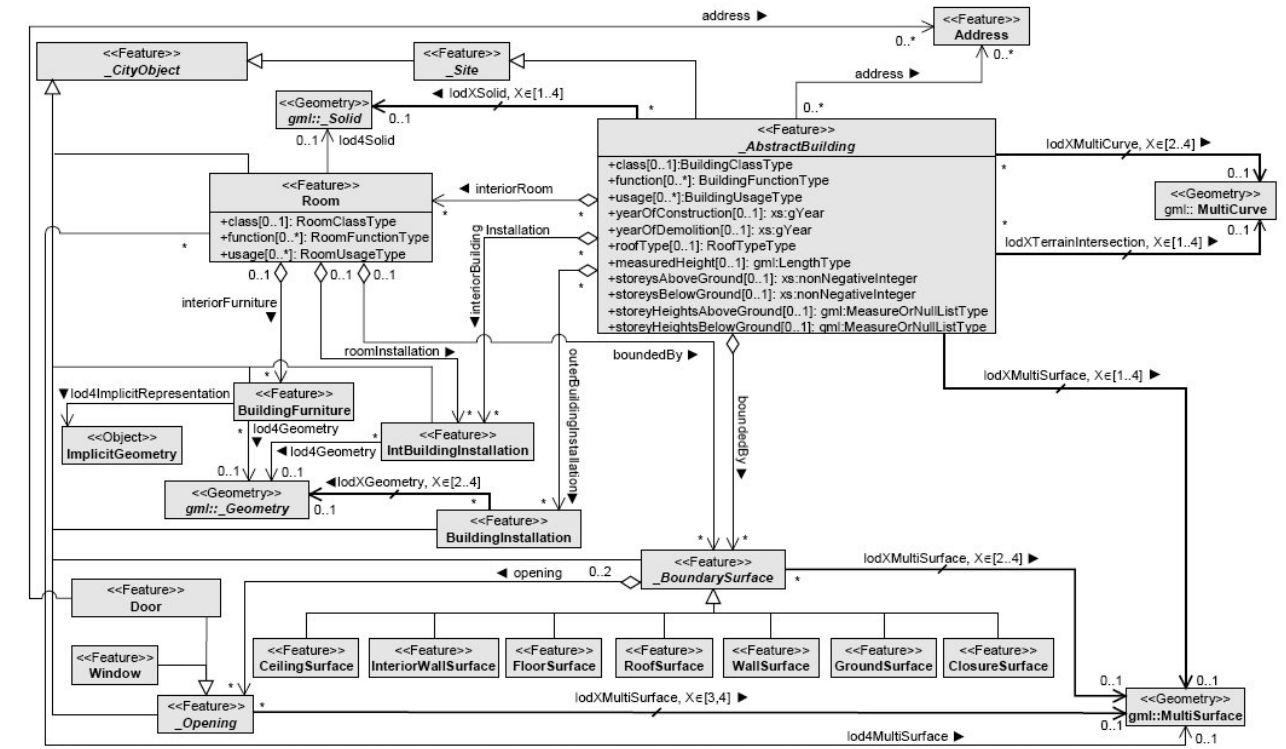


Figure 3: UML diagram of CityGML’s building model

Each feature is connected to the other by the relation “is part of”. In fact *_openings*, *walls* etc. is part of a *_AbstractBuilding* and *building* is part of *CityObjectGroup*.

By utilizing this structure we can attribute one feature for each layer classified in Blender to distinguish the original element

from restored one; it is also possible to import the model in SGJ-3D and ask the model to show the restored element instead of the original one or to see a special phase of the fortress in a particular historical period.

4. CONCLUSIONS

Our work introduces it as an applicable standard method of data management on any monument.

In archaeological research it's very important to contextualize different elements from different periods, in order to obtain a homogeneous vision of the site in a particular context.

Moreover a semantical mapping by ISO/OGC standard allows a homogeneous definition of the data in the scientific community.

Nowadays we are able to map only architectural or restored elements but, in the future, we hope to be able to define also the single actions or USM typical of the archaeology of the architecture.

```
<!-- ===== -->
<!-- =====CityGML Building module ===== -->
<!-- ===== -->
<xs:complexType name="Forte San Giorgio" abstract="true">
  <xs:annotation>
    <xs:documentation>Type describing the thematic and geometric attributes and the associations of buildings. It is an
    abstract type, only its subclasses Building and BuildingPart can be instantiated. An AbstractBuilding may consist
    of BuildingParts, which are again AbstractBuildings by inheritance. Thus an aggregation hierarchy between
    AbstractBuildings of arbitrary depth may be specified. In such an hierarchy, top elements are Buildings, while
    all other elements are BuildingParts. Each element of such a hierarchy may have all attributes and geometries of
    AbstractBuildings. It must, however, be assured that no inconsistencies occur (for example, if the geometry of a
    Building does not correspond to the geometries of its parts, or if the roof type of a Building is saddle roof,
    while its parts have an hip roof). </xs:documentation>
  </xs:annotation>
  <xs:complexContent>
    <xs:extension base="core:_SiteType">
      <xs:sequence>
        <xs:annotation>
          <xs:documentation>The name will be represented by gml:name (inherited from GML) list order for
          storeyHeightsAboveground: first floor, second floor,... list order for storeyHeightsBelowground: first
          floor below ground, second floor below ground,... The lodXMultiSurface must be used, if the geometry
          of a building is just a collection of surfaces bounding a solid, but not a topologically clean solid
          boundary necessary for GML3 solid boundaries. </xs:documentation>
        </xs:annotation>
        <xs:element name="Fabbricato_A" type="BuildingClassType" minOccurs="0"/>
        <xs:element name="military" type="BuildingFunctionType" minOccurs="0" maxOccurs="unbounded"/>
        <xs:element name="defensive" type="BuildingUsageType" minOccurs="0" maxOccurs="unbounded"/>
        <xs:element name="1540" type="xs:gYear" minOccurs="0"/>
        <xs:element name="1624" type="xs:gYear" minOccurs="0"/>
        <xs:element name="1020" type="RoofTypeType" minOccurs="0"/>
        <xs:element ref="Nel 1624 l'edificio viene convertito da corpo di guardia a palazzo del commissario" minOccurs="0" maxOccurs="unbounded"/>
      </xs:sequence>
    </xs:extension>
  </xs:complexContent>
</xs:complexType>
<!-- ===== -->
```

Figure 4 example of semantic building schema in accord to CityGML specifications.

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