BEITRÄGE ZUR SUDANFORSCHUNG. BEIHEFT 9

THE KUSHITE WORLD

PROCEEDINGS OF THE 11TH INTERNATIONAL CONFERENCE FOR MEROITIC STUDIES
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Edited by Michael H. Zach

Vienna 2015

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Publisher:	Verein der Förderer der Sudanforschung c/o Department of African Studies University of Vienna Spitalgasse 2, Court 5.1 1090 Vienna Austria
Printing House:	Citypress Neutorgasse 9 1010 Vienna Austria

ISSN: 1015-4124

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3D RECONSTRUCTION OF THE LION TEMPLE AT MUSAWWARAT ES SUFRA: 3D MODEL AND DOMAIN ONTOLOGIES

Gilda Ferrandino and Matteo Lorenzini

Abstract
The management of huge amounts of data requires new methods, particularly in the field of information technologies. This paper describes the 3D reconstruction of the Lion Temple at Musawwarat es Sufra in Sudan. The monument was erected in the third century B.C. A 3D reconstruction of the temple has already been made in the 1990s starting from the excavation data. Our project is addressed at testing a new approach based on the integration of the open source software BLENDER for the processing of 3D data, with the CityGML for the management of geographical data. In order to manage and organize the architectonical, iconographical and geographical data we used an ontological formalization for the sharing of our archive. So it is possible on the one hand to visualize the 3d model and all information, and the other hand to perform any possible queries on geographical and descriptive data. The standardization of the software and its interoperability could guarantee the fruition and exchange of data among different users; in this way it will be possible check and update the reconstruction.

Introduction

Monuments are unique and unrepeatable "documents", expression of art, of able material culture and of the flow of time. They are testimony of the existence of a human group and its culture. These material testimonies are an important source for an historical reconstruction of a particular culture. The study of monuments through the archaeological investigations is followed by a program of management of the data and improvement of the historical "document".

Computer Science in Archaeology has become a fundamental tool for archaeological research. Its use to share the data in a scientific community has modified the approach to archaeological study and excavation report. If it offers to archaeology the possibility to make practical and systematic storage and management of the data, it offers also the possibility to try new systems for scientific data processing. For our project we considered two major problems in the use of the Artificial Intelligence in Cultural Heritage.

The first problem is the increase of the quantity and quality of information requiring interoperability of digital archives that guarantee the sharing and use of data among different users/ archaeologists. Therefore, Computer Science has moved towards the standardization of the resources through the creation of dictionaries and thesauri. In the meantime open source systems were developed to avoid limits in data sharing originated by the formats of the owners' software. Therefore, nowadays the implementation of standardized procedures through the use of open source systems is one of the most important questions dealt with in Cultural Heritage.

The second problem is the improvement of Cultural Heritage and the spread of knowledge. Recently a 3D analysis system has been tested and adopted in different fields of Cultural Heritage, both as a research tool, in particular in restoration field, and as a tool for knowledge, in museums.

In this perspective our project is oriented to test a new approach based on the achievement of a 3D model of the Lion Temple using open source software for the processing of 3D data, and considering a possible integration with an ontological model for the management of geographical, architectural and iconographical data. The importance of this project is the use of 3D open source software and the procedures representing the model, which can be easily exported, operated with other 3D platforms.

We have considered the Lion Temple of Musawwarat es Sufra as our case study because we relied on published materials, and the publication of this structure is characterized by new high standards both in terms of metric data and graphic illustrations for allowing a 3D reconstruction.

The Lion Temple of Musawwarat es Sufra

The site of Musawwarat es Sufra is situated in the Kebara ca. 160 km north to Khartoum and ca. 40 km east of the river Nile. Within a circular valley there are two major monumental complexes, the Great and Small Enclosures, as well as the Apedemak or Lion Temple, smaller shrines and two hafirs. The site's ancient name was *Ỉpbr-ʿnḫ* that appears in Apedemak's epithet *nb Ỉpbr-ʿnḫ* in the Lion Temple.

Fig. 1: Geographical Map

Archaeological fieldwork at Musawwarat es Sufra was conducted by Fritz Hintze (Humboldt University/Berlin) from 1960 until 1968. The first years of work were dedicated to excavate the Small Enclosure (IB), the Great Hafir (IIG), other small buildings as e.g. IIA, IIB, IID, ID, but in particular the Lion Temple (IIC) that in this paper we analyse and describe in a virtual way.

The Lion temple was built during the reign of king Arnekhamani whom Hintze was able to date to the third quarter of the third century B.C. The king dedicated it to the indigenous god Apedemak. This temple is an example of the one-roomed shrines built in the third century B.C. and thanks to the work of Hintze it was rebuilt in the years 1969-1970, and now it is visible to visitors.

The German project was based on the reconstruction of the temple by Arnekhamani after the collapse of the pylon that implied also the crash of the roof. It is built in the form of a rectangular temple with a single columned hall, 14.21 m in length, 9.13 m in width and 4.7 m in height. The entrance to the temple is located southeast and characterized by a pylon and a lintel above the door with an uraei frieze. Inside, there are six columns. Originally there were four of them, but after the collapse another two were erected. This long columned room led to the throne at its northwest. As regards the roof, Priese suggested the presence of joists that carried palm-ribs with mats, and a thick coating of mud plaster.

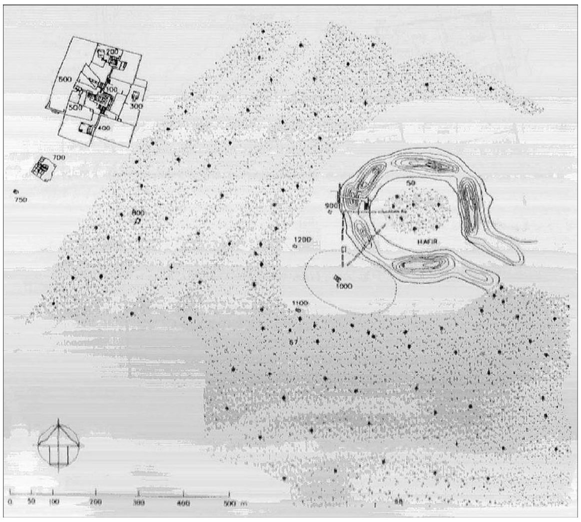

Fig. 2: Musawwarat es Sufra

The Lion Temple is one of the main sources of knowledge of Meroitic architecture, art and rituals represented on the reliefs covering the interior and exterior walls as well as the columns. They reveal a synthesis of Kushite and Ptolemaic Egyptian religious and political concepts expressed through the iconographical conventions and symbols that belong to both cultural environments. The reliefs also include inscriptions accompanying the images. In general, these inscriptions comprise invocations, eulogy, and royal titulary expressing the relationship between deities and the royal family, therefore playing a key role for the reconstruction of the iconographical program. The temple appears as a document that throws light on religion with its rituals and its pantheon characterized by deities which are the syncretistic products of indigenous and Egyptian gods, on royal ideology as well as political propaganda.

The project

The studies on the Lion Temple have produced a great quantity of published material and the publication of this structure is characterized by a new high standard both in terms of metric data and graphic illustrations. For this reason it appears necessary to analyse and manage the data for appropriate documentation of the monument. So we considered management of the architectural and iconographical data using an ontological model for the formalization of knowledge, starting with the realization of a three dimensional view of the temple as base to apply our new approach.

The new methodology that we propose is based on the integration of open source software for the processing of 3D data and ontologies for the management of architectural and iconographical data.

used by each. In contrast to open formats, proprietary formats are controlled and defined by private interests. Open formats are a subset of open standards.

The primary goal of open formats is to guarantee long-term access to data without current or future uncertainty with regard to legal rights or technical specification. A common secondary goal of open formats is to enable competition, instead of allowing a vendor's control over a proprietary format to inhibit use of competing products. The most important open format language is represented by XML family developed by W3C consortium.

XML provides a basic syntax that can be used to share information between different kinds of computers, different applications, and different organizations. XML data is stored in plain text format. This software- and hardware-

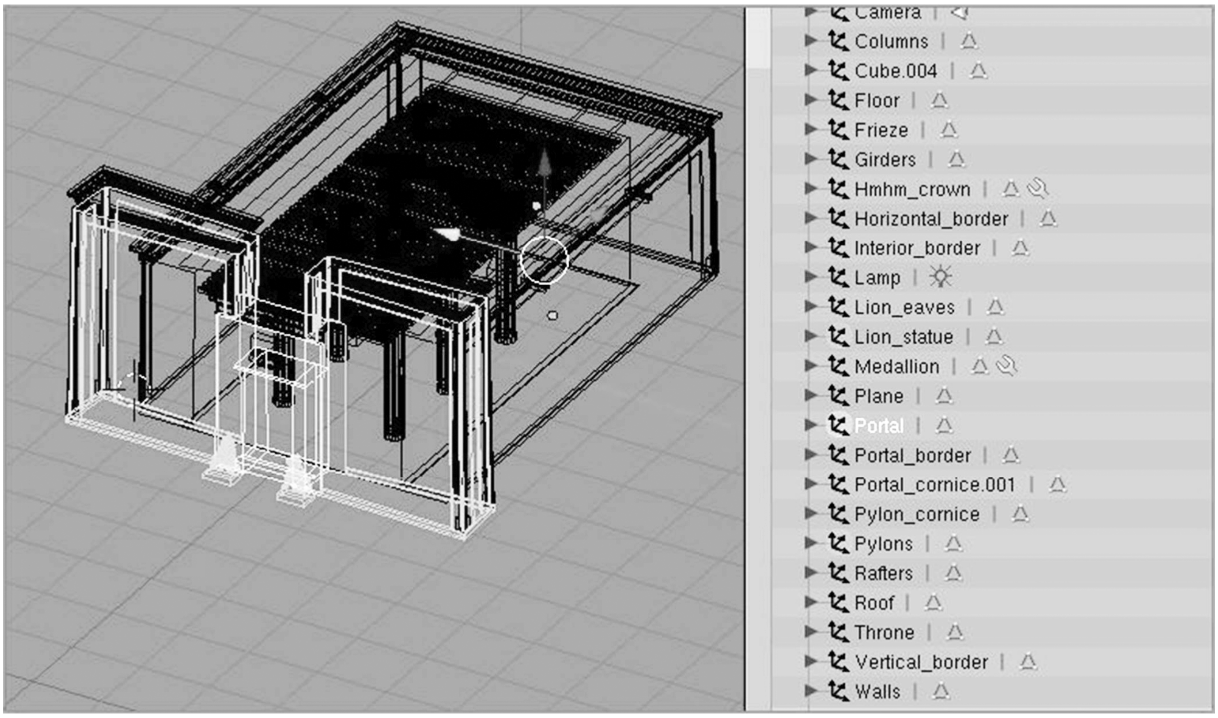

Fig. 3: 3D reconstruction and database with Blender

A 3D model with Blender

For the 3D modelling we used the open software Blender, which manages the open format orientation. An open format is a published specification for storing digital data, usually maintained by a non-proprietary standards organization, and free of legal restrictions on use. For example, an open format must be implementable by both proprietary and free/ open source software, using the typical licenses independent way of storing data allows different incompatible systems to share data without needing to pass them through many layers of conversion. This also makes it easier to expand or upgrade to new operating systems, new applications, or new browsers, without losing any data.

Blender is a 3D graphics application released as free software under the GNU General Public License. It can be used for modelling, UV unwrapping, texturing, rigging, water simulations, skinning, animating, rendering, particle and other simulations, non-linear editing, compositing, and creating interactive 3D applications. It is also an open source software developed with C++ language program. Also it is a multiplatform software and we have a stable version for Windows, Mac OS X, Linux and Solaris thanks to his open “core”. With blender, finally, we can import and export a lot of formats and files developed by the other 3D programs like 3D studio max, Maya etc. in XML grammar language.


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                                        <instance_geometry url="#colonna-Geometry"/>
                                </shape>
                        </technique_common>
                </rigid_body>
        </physics_model>
</library_physics_models>
```


Fig. 4: XML representation of a Lion Temple’s column with its information

For us, Blender is the best way to share 3D data in a scientific community. During the achievement of the 3D model we have given a name for all architectural elements of the structure. This passage is very important because we have the possibility to create an internal database connected directly with our 3D model. When we export the 3D model in XML format the data of the architectural structure represented are recorded and they can be managed through the CityGML semantic model. This model is useful to organize all architectural and geometrical information of the Lion Temple.

CityGML semantic model

CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application scheme 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 realised as an application scheme for GML3, the extendible international standard for spatial data exchange also 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 the feature class taxonomy and decomposition both on the semantic and spatial sides (from the whole city over the city structures 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.

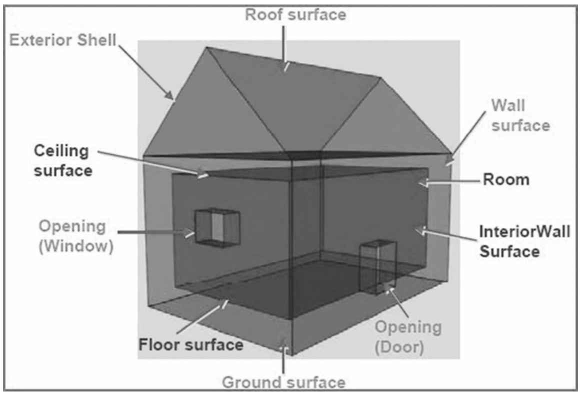

Fig. 5: Classification of BoundarySurface

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.

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

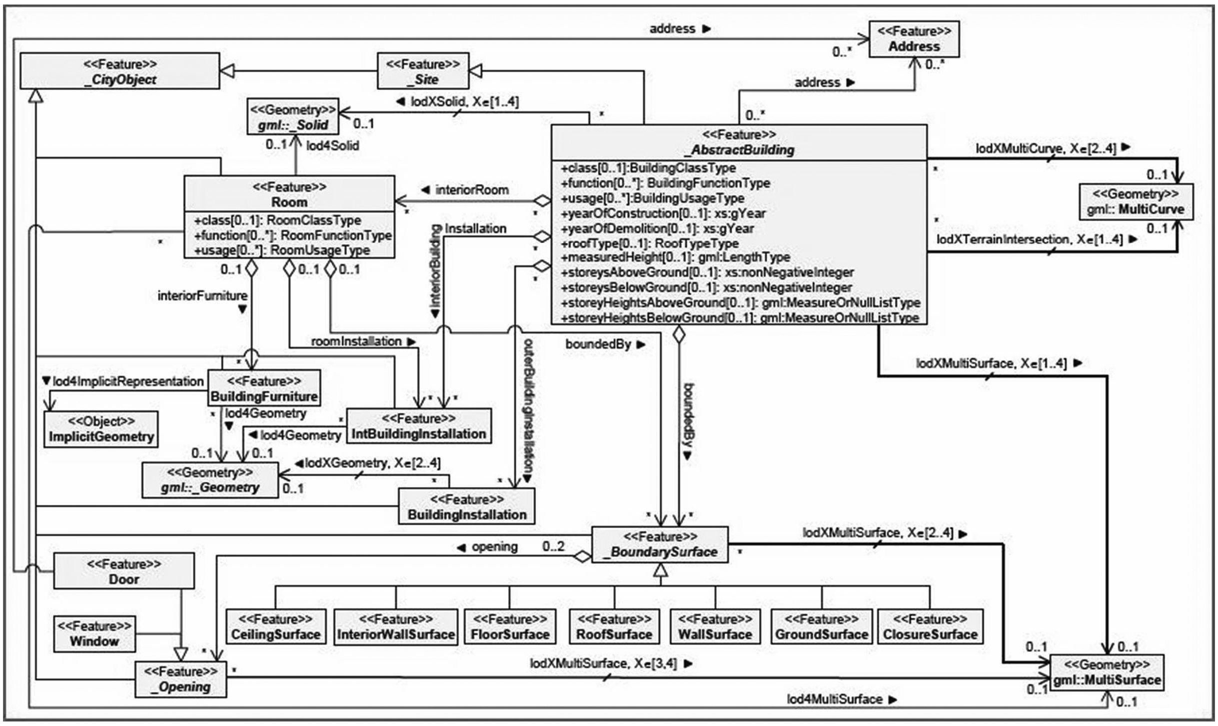

Fig. 6: CityGML diagram

Spatial properties of CityGML features are represented by objects of GML3’s geometry model, which is based on the standard ISO 19107 “Spatial Scheme” (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

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 semantic. This allows flexible use of CityGML as exchange format both in terms of representable data and applications.

Every class of CityGML is represented by an xsd scheme like building, vegetation, external_object etc.; each xsd is composed of a subset of attributes. For example, the abstract class *_AbstractBuilding* contains properties for building attributes, purely geometric representations as well as geometric/semantic representations of the building or building parts 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 (*storeyAbove Ground*) and below (*storeyBelowGround*) ground level.

6. The list of storey heights above (*storeyHeights AboveGround*) and below (*storeyHeightsBelow Ground*) ground level. The first value in a list denotes the height of the nearest storey to the ground level and last value the height of the farthest.

```
Abstract_Building
+name                      >  LionTemple
+BuildingClassType         >1180     (function)
+BuildingFunctionType      >2280     (temple)
+BuildingUsageType         >2280
+YearOfConstruction        >3rd century B.C.
+RoofType                  >1000     (flat roof)
+MeasuredType              >m 4.7
+StoreyAboveGround         >1
                           outerBuildingInstallation
                                     BuildingInstallation
                                     +name       >Pylon
                                     +class      >1000     (outer characteristic)
                                     +function   >1070     (other)
                           interiorRoom
                                     Room
                                     +class      >1150     (function)
                                     +function   >1030     (hall)
                                                 roomInstallation
                                                           InteriorBuildingInstallation
                                                           +class          >6000  (statics)
                                                           +function       >7020  (columns)
                                                 interiorFurniture
                                                           BuildingFurniture
                                                           +class          >1180  (function)
                                                           +function       >1310  bench
```

Conclusion

In this project we have described the Lion Temple through a graphic and semantic representation. The semantic aspect regards the geographical and architectural data, but we know the temple presents a lot of reliefs that must be represented not only in graphical but also in semantic way. So our next step will be to describe the iconographical data using a specific semantic model, Cidoc-CRM. The Cidoc-CRM is an ontology used in Cultural Heritage. Combining the two ontological models it will be possible to manage architectural, geographical and iconographical information.

So, according to CIDOC-CRM and GML grammar, it is possible to manage a coordinate reference system and alphanumerical data in the same file. By this way, our 3D model is able to be imported inside a GIS system in order to place the temple in a geo-referenced cartography of the archaeological site.

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The EPOCH European Network of Excellence in Open Cultural Heritage: http://www.epoch.eu/
3D Modell des Löwentempels: http://www.vordenker.de/tempelvr/tempelvr.htm
XML Path Language (XPath) Version 1.0.:http://www.w3.org/TR/xpath/