DEVELOPMENT AND USE OF A 4D GIS TO SUPPORT THE CONSERVATION OF THE CALAKMUL SITE (MEXICO, WORLD HERITAGE PROGRAMME)

M. van Ruymbeke [a]*, V. Tigny [b], E. De Badts [b], R. Garcia-Moreno [a], R. Billen [a, c].

[a] University of Liège, European Centre of Archaeometry, Allée du 6-Août 17, B 4000 Liège, (mvanruymbeke, RG.moreno)@ulg.ac.be
[b] GIM , Researchpark Haasrode, Interleuvenlaan 5, B 3001 Heverlee, (vincent, erik)@gim.be
[c] University of Liège, Geomatic Unit, Allée du 6-Août 17, B 4000 Liège, (rbillen)@ulg.ac.be

KEY WORDS: ICT, GIS, World Heritage, Archaeology, Remote Sensing

ABSTRACT:

The present project proposes to develop and implement an information management system for the conservation authorities of the Biosphere Reserve and Archaeological Urban Centre of Calakmul. This online system will allow Mexican managers and scientists to store, share and create interaction between their data, in order to coordinate various actions of conservation, management, planning, monitoring and research undertaken in the reserve. It will benefit from new developments in the GeoICT, Archaeomatic and Spatio-temporal Analysis, Computer Vision and Earth Observation fields and will integrate 2D GIS layers, 3D objects and time. An innovative scientific protocol is proposed to incorporate in a GIS complex archaeological data.

1. INTRODUCTION

1.1 Aims

Formed at the beginning of the twentieth century, the name “Calakmul” refers nowadays to three different entities: an ancient Maya city, an ecological reserve and a municipality. The described project concerns the two former entities. The study zone lies in the South East of the Campeche State, in the middle of the Yucatan peninsula (Mexico).

The Calakmul biosphere reserve was created in 1989. It covers an area of almost 7.300 square kilometres and constitutes one of the largest protected forests of the tropical zones. It shelters rare species of flora and fauna. It also includes many archaeological sites, Calakmul being the most important one. This pre-Colombian city has been registered on the World Heritage List (cultural part) in 2002.

Within recent years, settlement pressure, farming and new extraction of commercial timber caused threats to this natural and cultural heritage. In order to help the Mexican authorities INAH (Instituto Nacional de Antropologia e Historia) and CONANP (Comision Nacional de Areas Naturales Protegidas) to preserve it, UNESCO – World Heritage Programme proposed to make use of Belgian expertise to assist the preservation and conservation management of the area. Accordingly, four research teams (3 University laboratories, 1 private company) were selected and funded by the Belgian Science Policy Office (BELSPO) and formed a consortium in charge of the project.

1.2 Description

The so called “Development and use of a 4D GIS to support the conservation of the Calakmul site (Mexico, WHP)” project started in December 2007. Following UNESCO requirements, the consortium proposes to develop and implement an information management system for the conservation authorities of the Biosphere Reserve and Archaeological Urban Centre of Calakmul. This system will allow Mexican managers and scientists to store, share and create interaction between their data, in order to coordinate various actions of conservation, management, planning, monitoring and research undertaken in the reserve. It will also assist them in their reporting activities and to apply for a nomination (“mixed site”) at UNESCO in the framework of the World Heritage Convention. Within this scope, the 4D aforesaid system means: handling of usual 2D, plus time, plus 3D models for some specific works of art like stelae or small buildings.

2. 4D GIS ?

2.1 Concept

The present project is based on the use of new technology and scientific developments for the conservation of natural and cultural heritage. Thus it will benefit from new developments in the GeoICT, Archaeomatic and Spatio-temporal Analysis, Computer Vision and Earth Observation fields.

The information management system will indeed be an online tool with integration of:

- 2D GIS layers and 3D objects,
- large and small scales layers,
- time.

To do so it will use recent advancements and emerging open standards, but also innovative method and data models to integrate archaeological data and carry out spatio-temporal analysis. It will combine new computer vision techniques to produce 3D models of buildings and works of art from digital photograph sequences.

Finally, it will use newly available Formosat 2 satellite images to investigate the possibilities to document Maya ruins: buildings or evidences of man-made structures.

The information management system will be used as the main data repository to store all data referring to the archaeological inventory, the individual cartography for Calakmul and the cartography of the large nature protection area. This tool will have the following capabilities:

- Manage and visualise data, small and large scale at the time, in 2D and 3D.
- Monitor processes, like eg. the restoration of the site and the land use changes in the surroundings.
- Perform spatial analysis, for the purpose of regional and local planning.
- Facilitate reporting (at national level and towards UNESCO (WHP/MAB...))

The project is divided into three main phases, which are:

- the data procurement,
- the software development, preceded by a requirements analysis and a service description, and
- the capacity training of the Mexican partners.

Each of the three phases is subdivided into a cultural and an ecological aspect due to the different user-groups and scales.

However, as the project has just started, technical choices concerning the system and open standards to be used (eg 2D Map Viewer with time slider coupled with a Content Management System; information models and data formats for 3D GIS: Collada, X3D, CityGML, etc. and OGC WebServices) have still to be taken based on the user requirements analysis. After this short description of the whole project, we will thus basically focus hereafter on the Cultural Heritage data modelling question and on the use of Earth Observation data for documenting archaeological evidences.

2.2 GIS, Remote Sensing and Cultural Heritage

Remote Sensing offers many useful and sometimes indispensable data that can be integrated in a GIS for the mapping, monitoring and management of World Heritage sites, either natural (parks, landscapes...) or cultural (monuments, archaeological sites...). GIS and Remote Sensing are thus excellent tools to support the monitoring process that is required for the good conservation of World Heritage sites (BELSPO, 2002).

With respect to Cultural Heritage and archaeology, as far back as the middle of the eighties, Anglo-Saxon archaeologists were the firsts to take advantage of Geographical Information Systems (GIS), especially in a predictive modelling perspective. During the nineties, professionals involved in inventories of Sites and Monuments found in GIS a particularly attractive technology offering a map–based representation of sites' locations. Then came interest for spatial analysis dedicated to archaeological questions (Wheatley & Gillings, 2002).

Having overtook the technological appropriation phase, scientists are henceforth debating about theoretical concepts subtended their researches on GIS. Indeed, initial 2D representation gives way to an increasing involvement of volume and time dimensions, although current GIS vendor solution do not allow such variety of dimensions (Lefebvre, 2006).

On the other hand, it is more and more admitted that, in speaking of the Cultural Heritage domain, the principal challenge lies, not so much in collection or geo-localization or even modelling of the data, but in the manner of processing related non spatial information (Blaise & Dudek, 2006).

With respect to Remote Sensing, very high resolution satellite images can be used to monitor archaeological remains or to map large sites not covered by vegetation thus providing valuable information for Cultural Heritage management as well.

Consequently the advantages of GIS and Remote Sensing for World Heritage Conservation are numerous (BELSPO, 2002):

- They become a valuable tool to assist conservation activities.
- All information is exactly localised and gathered in one tool.
- Information can be continuously updated.
- Better decision making by spatial analysis.
- Possibility of direct extraction of thematic maps for terrain use.
- Digital handling of data.

3. DATA

3.1 Archaeological data

3.1.1 History of discoveries: Inhabited for more than 1500 years, left and even forgotten since the end of the ninth century, the Maya archaeological site of Calakmul was rediscovered in 1931 by an explorer: Cyrus L. Longworth. Longworth was employed by a chicle exploitation firm and informed of the existence of archaeological evidences by two chicle workers. Inspired by the two high pyramids emerging from the forest, he called the city, by using the still common Maya language: Ca (two), Lak (nearby), Mul (mound). However, epigraphers are now almost sure that the old name of the city was "Kaa Nal", the (head) snake (Marcus, 1973).

The first cycle of real archaeological records took place in 1932, under the supervision of Sylvanus G. Morely, sponsored by the Carnegie Institute. Subsequent researches have been done by several teams. First of them directed their attention to topographical and mapping survey. Excavation operations really began in 1984, with William J. Folan (Universidad Autonoma de Campeche - UACAM), and since 1994 by Ramon V. Carrasco (INAH). To add to this, international teams are nowadays cooperating with Mexican scientists on some specific spots. (Giorgi & alii, 2006; Niccolucci, 2006; Šprajc, 2008).

The results of their works, combined with epigraphic studies, historical analysis and other knowledge domains, shows that we are in front of a very important place. Indeed, during its apogee at the early classic period, Calakmul was the largest city of the Maya region and had to assure its hegemony by any means, peaceful or not. It was a feared jungle chieftain until the end of the seventh century A.D. when Jaguar Paw, king of Calakmul, was defeated after a bloody battle against Tikal, the rival city. From that moment on, began the slow decline of the head snake kingdom (Folan & alii, 2001; Vidal-Angles & Domínguez-Turizza , 2003).

3.1.2 Figure 1) Spread over an area of 30 square kilometres, with more than six thousands archaeological structures, most of them only faintly drawn on a plan but not excavated, the city appears like a vanished urban centre now covered with vegetation. The core of the town has been built upon a great natural flat-topped hill, partially lain out to base platforms of pyramids, palaces and other temples. Those buildings are split up into several poles: a central place and smaller groups placed in spokes. (Folan & alii, 2001; Vidal-Angles & Domínguez-Turizza, 2003).

As it is now, the site remains like it was before its disuse, during the Late Classic period. But the most surprising thing lies under the facades: each monument hides - and fortunately protects - one or more earlier building phases, often magnificently well preserved. On account of this, Calakmul is seen as an unrepeatable testimony of the daily life of a gone civilization: wall paintings, low reliefs, decorated ceramics depict unexpected scenic aspects like, for example, the funerary rituals.

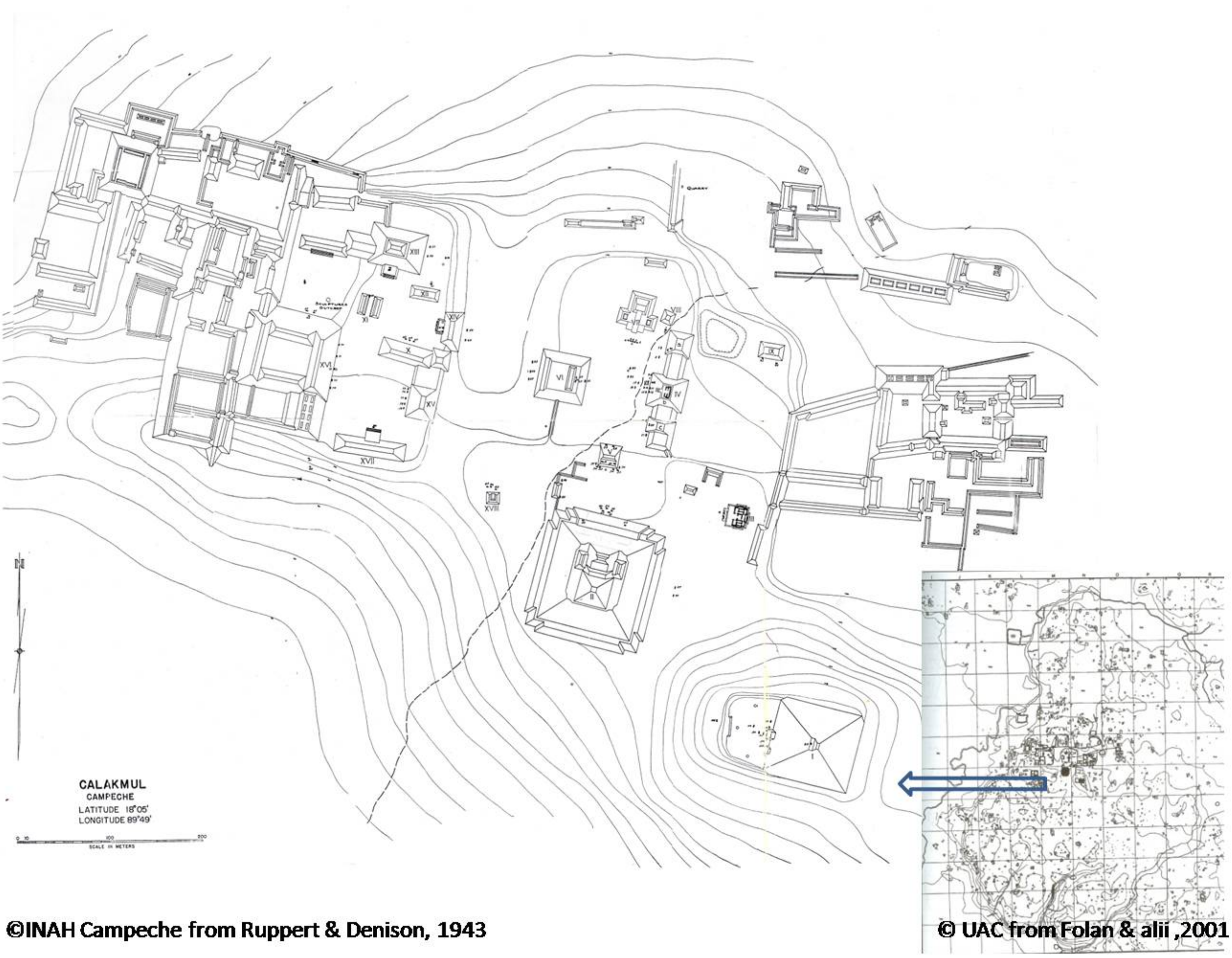

Figure 1: The main place in the urban centre

3.1.3 Complex data: To incorporate in a GIS such an intricate reality, it is necessary to find a way to build an efficient data model. This model will enable to handle architectural buildings, with their geometrical component (in 2D), but above all to link them with quintessence of scientific cognitions collected about them. This knowledge concerns mainly questions of function, time, agent, influences, technical observations, contextual data and documentation.

Another difficulty resides in the fact that more than one of these aspects may be applicable for one object: the function may be major, minor, incidental or symbolic. The time may be the construction one, the use or disuse one, it can be a date or a duration, it can be absolute or relative. Agents embedded in this model will be gods, kings, priests, artists, archaeologists, epigraphers, while the influences bring together notions like cultural traditions, technical advancement, religious or political currents and historical events.

The technical observations will manage the question of material, making process, preservation condition and damage description. The contextual data refer to relations supported by objects towards other objects, archaeological or not. At least, documentation part comprises things like bibliography, iconography, excavations' evolution and so on.

Moreover, two specificities characterize archaeological data: the inherent uncertainty level and the coexistence of contradictory and sometimes conflictive scientific interpretations.

All this information can't simply be stored in an attribute table of a GIS, because then it is possible that the data could not be useful for ulterior requests. It is thus necessary to find a best way to incorporate it.

3.2 Remote Sensing data

Thanks to BELSPO financial support, new Formosat 2 images are currently being acquired. Formosat 2 sensor is a new Taiwanese satellite launched in 2004 that offers 24X24 km images with 2m resolution (PAN – 8m MS). This will allow us to obtain the first very high resolution satellite mosaic over the entire reserve.

4. METHODS

4.1 Models for archaeological data

To model archaeological data, we have planned to put into practice the scientific protocol recently proposed by H. Galinié, X. Rodier and L. Saligny (Galinié & Rodier, 2002; Galinié, Rodier & Saligny, 2004; Rodier & Saligny, 2007). Based on the F. Bouillé's Hypergraph Based Data Structure method (Bouillé, 1977) and the Peuquet's triad (Peuquet, 1994), it requires, using a rigorously formalism, the transformation of heterogeneous data into robust entities (urban objects) delimited by three domains: the spatial, social and temporal features. This method aims at studying urban archaeological contexts, especially to get their dynamics of change: Indeed, archaeologists wish to work on heritages, inertias, trajectories, or process. We hope to obtain an horizontal and vertical vision of phenomena: what does occur at a given time? or which is the evolution of such a place? at least how such a thing did happen ?

On that goal, the scientific protocol notably suggests avoiding information redundancies: functional interpretation of an urban object is made by choosing an instance of a hierarchical thesaurus. That choice is reasoned by chronological and spatial contexts of that object. Secondly, spatial entity localises the identified urban object and finally, temporal entity dates it. To avoid redundancies, space and time are deconstructed in small fragments, reusable as often as necessary.

On the other hand, research about ontology undertaken by computer science and geomatics specialists (Zlatanova, 2000; Billen & Zlatanova, 2003) shows promising results and potential solutions with concepts like juridical, fictional and abstract objects. They should be useful to model data without or with incomplete spatial components. For example, we could imagine to use that concept for modelling reigns, periods, territories etc...

At last, new triangular model (Van De Weghe & alii, 2007) for time representation will also be tested. Its main characteristic is to conceptualize time like a 2D plane. Consequently, instants and time intervals may be represented and analysed in 2D too.

4.2 Image processing technique

The innovative method chosen here to extract information from satellite imagery is the object-oriented image processing technique. In contrast to traditional image processing methods, the basic processing units of object-based image analysis are image objects or segments, and not single pixels. The classification to produce the land use maps is thus not done on the basis of imagery pixels but on the basis of image objects detected during the segmentation process. This will increase the time-efficiency as well as the potential for products updating since segmentation and classification procedures can be transformed into standardized protocol and stored to be applied to other datasets.

5. CONCLUSIONS

If the main goal of this project consists in elaborating a whole and efficient integrated system combining various data, its major scope concerns Cultural Heritage in all its complexity: Incomplete knowledge, uncertainty, contradictory data will feed a tool supposed to manage more standardized questions. To take them into consideration, we will have to customise a number of scientific issues *a priori* dedicated for other fields of research. To do so, cooperation between Belgian and Mexican partners, know-how and knowledge transfer, flexibility and cleverness will be necessary. By bringing to fruition all those challenges, this project will produce results reusable for other Cultural Heritage sites.

6. REFERENCES

BELSPO, 2002. Remote Sensing and GIS in support of World Heritage Conservation.
http://telsat.belspo.be/whp/remotesensing.html

Billen R., Zlatanova S., 2003. 3D spatial relationships model: a useful concept for 3D cadastre ? *Computers, Environment and Urban Systems* 27, pp. 411- 425.

Blaise J.-Y., Dudek Y., 2006. Modélisation informationnelle: un cadre méthodologique pour représenter des connaissances évolutives spatialisables. *Extraction et Gestion des Connaissances 2006*, vol. 1, *Revue des Nouvelles Technologies de l'Information* E-6, Lille, pp. 347-358.

Bouille F., 1977. *Un modèle universel de banque de données simultanément partageable, portable, répartie*. Thèse d'Etat es Science, Université de Paris VI, Paris.

Folan W.-J., Fletcher L., May Hau J., Florey-Folan L. (coord.), 2001. *Las Ruinas de Calakmul, Campeche, Mexico : Un lugar central y su paisaje cultural*, UAC, CIHS.

Galinié H., Rodier X., 2000. TOTOPI Topographie de Tours Pré-Industriel, un outil d'analyse urbaine. *Les petits cahiers d'Anatole11*.
http://citeres.univ-tours.fr/doc/lat/pecada/F2_4.pdf

Galinié H., Rodier X., Saligny L., 2004. Entités fonctionnelles, entités spatiales et dynamique urbaine dans la longue durée. *Systèmes d'information géographique, archéologie et histoire, Histoire et Mesure* XIX, 3/4, p. 223-242.

Giorgi R., Chelazzi D., Carrasco R., Colon M., Desprat A., Baglioni P., 2006. The Maya site of Calakmul : « in situ » preservation of wall paintings and limestone by using nanotechnologies. *IIc congress 2006: proceedings*.

Lefebvre B., 2006. Construction et déconstruction de l'espace urbain : une modélisation en volume du bâti ancien. *MIA journal* 2, VII.
http://www.map.archi.fr/mia/journal/.

Marcus J., 1973. Territorial Organisation of the lowland Classic Maya. *Science* 180, pp. 911-916.

Niccolucci F., 2006. On-Site ICT Applications in Archaeology. The Calakmul case. *Proceedings of the EVA London conference*.

Peuquet D.-J., 1994. It's about time: a conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of the American Geographers* 3, pp. 441-461.

Rodier X., Saligny L., 2007. Modélisation des objets urbains pour l'étude des dynamiques urbaines dans la longue durée. *SAGEO 2007, Rencontres internationales Géomatique et territoire*, CdRom. Série : Aménagement du territoire, AgroParisTech-ENGREF Clermont-Ferrand.

Ruppert K., Denison J.-H. Jr., 1943. *Archaeological Reconnaissance in Campeche, Quintana Roo and Peten*. Carnegie Institution of Washington, Publication 543, Washington D.C.

Šprajc I. (ed.), 2008. *Reconocimiento arqueológico en el sureste del estado de Campeche: 1996-2005*. *BAR International Series* 1742, Paris Monographs in American Archaeology 19, Oxford, Archaeopress.

Van De Weghe N., Docter R., De Maeyer P., Bechtold B., Ryckbosch K., 2007. The triangular model as an instrument for visualising and analysing residuality. *Journal of Archaeological Science* 34, pp. 649-655.

Vidal Angles C., Domínguez Turizza M. (coord.), 2003. *Calakmul Anthologia*, Conaculta – INAH, Campeche, Mexico.

Wheatley D., Gillings M., 2002. *Spatial Technology and Archaeology, the Archaeological Applications of GIS*, Londres et New York, Taylor & Francis.

Zlatanova S., 2000. 3D GIS for Urban Development. *Technical Sciences*. Graz Austria, Graz Austria of technology, p. 222.

7. ACKNOWLEDGEMENTS

The research presented in this paper is carried out in the framework of the "Development and use of a 4D Geographic Information System to support the conservation of the Calakmul site (Mexico)" project which is funded by the international actions program of the Belgian Science Policy Office and supported by UNESCO, INAH, CONANP and UACAM. In addition to ULg and GIM, authors of this publication, this project is carried out in partnership with the Universiteit Gent and the Katholieke Universiteit Leuven.