Interoperable integration of high precision 3D laser data and large scale geoanalysis in a SDI for Sutra inscriptions in Sichuan (China)

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Abstract. Over the entire province of Sichuan (China) there exist Buddhist stone inscriptions – so called Stone Sutras – dating from 8th to 12th century. So far, the documentation and reproduction of the surface texture of these historic inscriptions took place via simple manual tracing on paper (rubbing). Innovative Terrestrial Laser Scanning (TLS) methods make it possible to capture these artifacts both digitally and in 3D and to derive high-resolution 3D models. This paper presents a concept for the integration of the Buddhist inscriptions into a Spatial Data Infrastructure (SDI) using Open Geospatial Consortium (OGC) Web Service (OWS) standards in archaeological, art-historical and linguistic contexts. The aim is to link existing humanistic data to an interdisciplinary Web-based Geographical Information System (GIS) with appropriate time and space reference. Special emphasis is put on SOA-based geo-processing (OGC WPS) and 3D visualization (OGC W3DS). The whole SDI is enriched with additional historic metadata of the inscription sites and finally joined in a Web Atlas for Stone Sutras in China.

Keywords. *SDI, Geo-processing, 3D Visualization, Stone Sutras, Web Atlas*

Introduction

On the Asian continent the Buddhism was based on both the inscribed words (*Sutra*) and the statues or pictures of the Buddha originally. Chinese Buddhist monks started writing the holy Scriptures into rock faces in the second half of the 6th century [10]. Over the entire province of Sichuan (China) around 80 Sutras dating from 8th to 12th century can be found [8]. In particular in the Chinese area it throws a new light on the history of the Chinese Buddhism and on its adjustment to the Chinese culture. More than 1,500 years the preservation, documentation and reproduction of the surface texture of the Buddhist inscriptions were made via so-called *rubbings* [6]. A copy of the original text was made by simply pressing thin, wet pieces of paper on the inscriptions written in stone and carefully dyeing the paper by manually tracing the surface. By means of these rubbings the teachings of the Buddha could be easily transported and distributed.

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However, due to the progressive weathering of the rock inscriptions and the abrasion with the production of the rubbings this archiving method can be used only conditionally for the protection of this information treasure. Hence, the objective of the research project *"3D-Sutras"* is to investigate and document the stone inscriptions with different scientific approaches and from different viewpoints, including archeological, art historical, linguistically and geographical. New innovative capturing methods are necessary for a permanent preservation of the stone Sutras. A possibility for a contactless archiving of the Sutra text is offered by *Terrestrial Laser Scanning* (TLS) techniques which record the data digitally as 3D point clouds. In the course of several measuring campaigns the stone inscriptions were scanned by precise measuring procedures and processed to 3D models by our project partners at the University of Applied Sciences Mainz (i3mainz, Germany). The point density of the laser scan data depends on the size of the Sutra characters. A typical character covers about 1 cm^2 and a complete Buddhist stone inscription enclosure approximately 3x4 meter. Therefore, the scan has been carried out with a lateral resolution of 0.25 mm, which results in a data set of about 1,500 to 2,500 points per character. The size of the laser data set of an original 3D model of $4m^2$ is about 4.32 GB [8].

Sharing all the historic and spatial information as Web services is a fundamental key aspect of our study. In order to make all historic geographical information available in different scales in a sustainable way, all data is integrated into a *Spatial Data Infrastructure* (SDI). The visualization component based on standardized spatial Web services includes an interactive 2D map to geographically browse the available information about the archaeological inscription sites, the historical infrastructure which connected the sites, time dependent information about the development of the area of power of the Tang-Dynasty from to 669 to 820 AD and time dependent information about the itineraries of Buddhist monks involved with the sutras and the province at the specified time [2]. In the research project, conventional SDI was enriched with additional services. Besides the classical SDI for the management and visualization of the spatio-temporal datasets acquired by historical text investigation and interpretation, the proposed Web-Atlas component provides a sophisticated spatial information infrastructure. Important implemented functionality are e.g. the textual description of all inscription sites, an inscription catalog with metadata about the texts, a reading tool to explore the inscriptions and a search module to query the inscription database. Furthermore, a multimedia map combines geographic 2D/3D visualization with 360°-panoramas, annotated photographic pictures and GIS functionality for measuring, searching and analyzing. This study goes even one step further and investigates (3D) geo-processing functionality based on the OGC *Web Processing Service* (WPS) interface specification [9] and 3D visualization component based on the OGC *Portrayal Service* like the *OGC Web 3D Service* (W3DS) [7] in order to give enable realistic 3D exploration of the archaeological sites by means of a virtual 3D model derived by laser scanning and other modeling techniques. This paper focuses on the geo-processing aspects in different scales from region wide spatial analysis to only few millimeter long Sutra inscription character based on TLS data as well as 3D visualization techniques in spatio-temporal and art-historic context.

The objective of the research work is: first to preserve the stone inscriptions with innovative capturing methods based on TLS and improve the readability; second detect spatial relationships associated with historical information of the Buddhist inscriptions between sites; third introduce a new concept for a Web-based SDI covering different scientific approaches from different domains and scales for this purpose.

1. Geospatial Infrastructure for Art History

Within the context of art history, geographical data has been considered only negligibly and not consistently, usually as scanned ancient maps or rubbings, not georeferenced in open formats. In order to make these precious assets accessible in a sustainable and flexible way and usable in a geo-spatial context, we pursued the integration into a SDI. From a technical viewpoint, an SDI is usually based on standardized Web services as specified by the OGC. The Web-Atlas utilizes several standardized OGC Web services for distributing and maintaining vector (*Web Feature Service*, WFS) and raster data (*Web Coverage Service*, WCS), for data analysis (*Web Processing Service*, WPS), and for the portrayal of 2D (*Web Map Service*, WMS) and 3D data (*Web 3D Service*, W3DS).

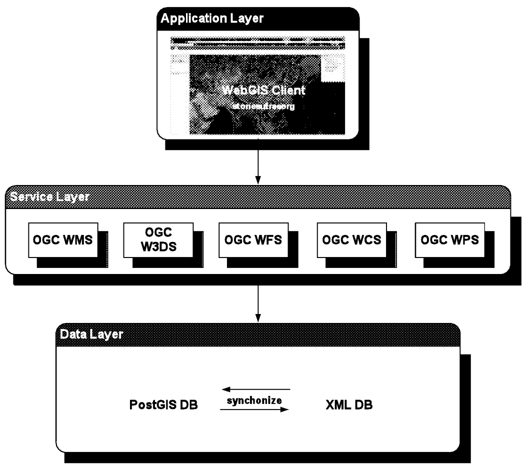

Figure 1. Overview of the 3D Sutra SDI architecture

A challenge is to develop a sustainable and interoperable concept for the integration of existing digital data of historical Buddhist inscriptions, which are held in a previously set up XML data base, into an SDI. This XML data base originated from a previous research project and is designed for electronic encoding, structuring, and exchange of documents within the domains of social science and art by using metadata standards. The historic data is stored in an open source XML database called eXist (exist-db.org). Industry standards such as XQuery, XPath, and XSLT are used for complex queries and processing of the content. Import of data can be easily accomplished by using a WebDAV compliant editor or an online form [1]. The content of this database comprises textual scientific documents, transcriptions, catalog meta data of inscriptions, context data about inscriptions of sites and caves etc. Each XML document is referenced with a geographic coordinate which enables to utilize geospatial query and analysis methods as well as to directly integrate content in a map application. However, the technological gap must be bridged. Since these documents are not available in a common geo-standard, they cannot be used by OGC services directly. This has been solved by implementing a connector which synchronizes the XML data base with the geo database which is implemented in PostgreSQL/PostGIS. As soon as changes in the XML database occur, events are triggered, which synchronize the geospatial database by creating, deleting or updating Simple Feature geo-objects with respective attributes (Fig. 1). The Web client can then easily access the combined geospatial data and information on Buddhist inscriptions through a WFS. Alternatively, map overlays can be created using a WMS/WCS based on the same content. This geo-visualization pipeline has been implemented using open source software *Geoserver* and *OpenLayers*.

2. **Web-based Geo-processing Toolbox for Historians**

The WPS interface standard as specified by the OGC [9] describes an interface in order to provide Web-enabled distributed processing and analysis capabilities for geodata. A WPS process defines the implemented algorithm logic that run the calculation. The rather generic WPS specification provides spatial and non-spatial processes in arbitrary complexity. Thus, it is possible developing services in a wide range of complexity.

In order to analyze both high-resolution laser scanning data as well as large scale spatial relationships between historic sites and monasteries, WPS processes were implemented. Multiple WPS frameworks were used for this task. By utilizing terrestrial laser scanners for capturing Sutras a very high volume of data (point clouds) is produced in a short time. Standalone or classical desktop GIS software can hardly cope with this massive amount of 3D raw data. It is therefore preferred to move the CPU intensive task of processing TLS data to a high performance server accessible through a standardized WPS. The purpose of TLS processing of Buddhist inscriptions is to improve the readability and thus interpretability by applying morphological, geometrical, and image based pattern analysis. As an example for image based processing, phong normals and relief shading maps have been computed from 3D stone inscriptions. They allow a better recognition of the heavily weathered carved characters. The process has been developed using the WPS 1.0.0 interface implementation based on the Java deegree framework [4].

Until now, inscriptions are not examined on spatial relationships. In a first step, we evaluate the available spatial data for potential archaeological analyses in historic-geographical context. Classical questions for historians are for example: Which monasteries are visible from a certain point of view? How far did a monk walk by foot within one hour? Which routes have the monks in dependence of the historical route network and the geographical conditions (e.g. slope inclination, river barriers etc) possibly selected? Which path would be a cost-effective path and which were selected? What distance and how many meters of altitude were covered? Which further monasteries lie in a periphery of 300km? From this, typical geographical analysis are identified. An interactive analysis toolbox for historians is implemented based on the historical information of the migration of a monk. Apart from simple measuring functions on the 2D map, regional analyses like the creation of a buffer or a surface profile, the investigation of sight relationship (line-of-sight and viewshed analysis) or accessibility and distance cost analyses are implemented, based on the pyWPS implementation. This WPS implementation offers the possibility to use all GRASS GIS analysis functionalities by a Python implemented WPS interface [3].

3. **Interactive Web 3D Service**

In contrast to other comparable portals within the domains of art history or archeology, 3D content is not just added as multimedia component for displaying single artifacts within this project. Instead, terrain and object information within the extent of the site is embedded as independent component (*OGC Web 3D Service*, W3DS) into the SDI. The advantage is on the one hand, that efficient streaming of complex landscapes can be utilized; on the other hand the persistent geo-referencing which allows a straightforward overlay with other geo data. The W3DS is designed as *3D Portrayal Service*, meaning that spatial subsets of 3D data sets for the display in Web GIS or online portals (as in this case) are served. Several information layers can be switched on and off separately. The data exchange with the 3D Web client relies on industry standards (X3D/VRML). Similar to the WMS, the W3DS also provides the capability to retrieve further information on selected objects. Upon a position query (mouse click) and transmitting the coordinates, the server generates a list of available attributes which can then be displayed by the client. Furthermore, the geo-referencing enables superimposing arbitrary 3D models with aerial and satellite imagery. For this project a satellite image has been integrated and is served by a WMS. By spatial tiling as described earlier, the satellite image can be mapped as color texture on the 3D terrain. For each tile served by the W3DS, a WMS GetMap request with matching coordinates is generated and attached as texture URL. A 3D scene viewer is embedded in the atlas system visualizing both the inscriptions in the caves and the 3D surface model.

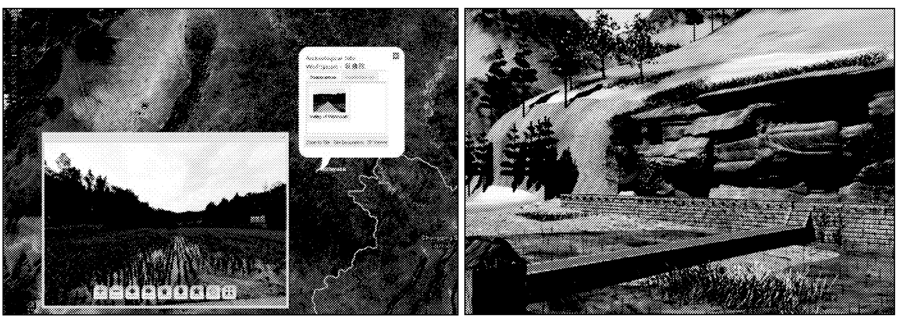

Figure 2. Parts of the Web-Atlas Interface. Left: Spatial access to meta data and site information, right: detailed 3D view of one site.

4. **Conclusion & Outlook**

The research collaboration between social science, humanities and geoscience creates new views on technical aspects of SDIs as well as on spatial questions related to archeological and historical research fields. An important aspect of the interdisciplinary research is the integration of existing non-spatial data repositories (e.g. Stone Sutra XML database) into a standardized SDI using Web services. A sustainable and interoperable integration of systems of different domains has been accomplished by locating and geo-referencing Buddhist stone inscriptions. Data on cultural heritage can be collected and maintained using already established user interfaces without the requirement of GIS expert knowledge. At the same time all this data is automatically synchronized and made accessible to map clients through standardized geo services. This study developed a combined 2D and 3D map framework as entry point for all available data. Detailed models of stone Buddha created from TLS data along with multimedia content such as 360°-Panoramas provide realistic impressions of the historically significant sites. Furthermore, the implemented geoprocessing toolbox can be used, in order to offer different analysis functionalities over the Web client. Altogether the Atlas platform offers an integration of GIS components into classical text-based analysis techniques of the traditional historic art science.

Concluding, this approach has a large potential for future social and historical studies with spatial context. However, there is a need to extend OGC service based SDIs beyond the access and visualization of geo data and to include analytical tasks that support archeological studies. For example, it is possible to develop domain specific OGC WPS Application Profiles taking semantic descriptions and even ontologies into account. Another important research area is processing high volume raw 3D spatial data such as point clouds from laser scans within an SDI [5]. Due to limited processing power and bandwidth, it is preferable to use dedicated powerful servers providing WPS interfaces. Further processing performance could be gained by connecting cloud computing and grid computer clusters to OGC components to achieve (near) real time workflows. It is important to agree on generic concepts that can be applied to a wide range of application domains, and to develop WPS processing profiles, otherwise the flexibility of SDI will get lost.

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