Applications of GIS and Remote Sensing in Cultural Heritage Management

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Summary

Cultural heritage defines pre-historical and historical objects, buildings, and social complexes that show evidence of human manipulation of the environment. The field of cultural heritage management strives to identify, interpret, and protect these artifacts and sites. GIS and remote sensing technologies have made important contributions to the field of cultural heritage management in the last few decades. GIS technologies allow managers to predict the location of new sites through overlay analysis, while novel combinations of remote sensors are allowing archaeologists to find subterranean features and determine the historical extent of known sites. Once these sites have been identified, GIS and remote sensing technologies can help detect biodeteriogens and other hazards or analyze the spatial uses of the site.

While aerial photographs have been helpful in identifying archaeological features and sites, different remote sensing technologies have recently been applied to this pursuit. Remote sensors can detect features through thick foliage and sometimes through thin layers of surface sedimentation. Chase et al. used LiDAR to locate Mayan structures in the Belizean jungle that were otherwise invisible through thick vegetation (2011). Similarly, Evans et al. used LiDAR to map areas surrounding the medieval urban center of Angkor Wat in Cambodia and discovered evidence of human manipulation of the environment that indicated that the city was much larger, more populous, and more developed than previously understood (2013). Rowlands and Sarris used multi- and hyper-spectral sensors to detect shallow subterranean chemical and physical anomalies to indicate ideal areas archaeological excavations (2007). In these cases, remote sensing changed the understanding of site extent, which can impact how historians and archaeologists interpret past civilizations.

While remote sensing can identify archaeological remains through energy patterns, GIS overlay analysis can compare site qualities to help predict where archaeological sites may be. In Southeastern Norway, Fry et al. combined digital elevation data with information on the soil, aspect angle, land use, and other features of known grave sites to generate a model to predict where other grave sites were most likely to be located (2004). In their work in Northern Italy, Campana and Francovich were able to greatly enhance the archaeological record of the area by digitizing Ikonos-2 images, performing overlay analysis in GIS, and georeferencing these locations with GPS. While these technologies have contributed to archaeological finds, data quality and quantity can limit predictive location modeling, especially in rural or rugged areas (Fry et al., 2004).

Once cultural heritage sites have been located, if the management plan calls for preservation of these sites, remote sensing and GIS also have applications in management
practices. Remote sensing can be used to monitor erosion and degradation to outdoor cultural sites. Using the medieval French castle of Haut-Andlau castle, Grussenmeyer et al. supported the point maps generated by the laser scanner with to those collected with cameras and other sensors (2008). In this analysis, they found that the use of laser scanners in terrestrial heritage sites has some limitations. However, other methods also have limitations and the overlap of interdisciplinary methods represents one solution. Another laser technique for the preservation of structures is fluorescence LiDAR. Fluorescence LiDAR measures the chlorophyll presence on the surface of an artifact and compares the chlorophyll fluorescence profile with known microorganisms to determine what biologic deterioration processes might be acting on the artifact. Repeated fluorescence measurements of the same monument overtime would allow for continued monitoring and an understanding of the conservation status and needs (Raimondi et al., 2009).

GIS can also be used to protect cultural heritage sites through spatial planning and hazard mapping. By mapping where sites are particularly vulnerable to human-caused or environmental erosion or degradation, managers can balance these concerns with where tourist interpretive aids, pathways, and facilities are located. Branching into the field of hazard mapping, Canuti et al. used aerial surveys to identify geomorphological anomalies and runoff patterns (2000). By overlaying this information with soil data around known archaeological sites, the authors were able to determine which parts of the sites were at the most risk from landslide and flooding events. This type of information could contribute to site preservation or evacuation planning. While archaeological monuments or buildings may be easy for passers-by to visually identify, larger sites with less visible features such as ancient farming terraces may be harder to spot. As such these sites may be affected by urban or agricultural encroachment (Rowlands and Sarris, 2007). The use of spatial data analysis through GIS in management plans may help to prevent this type of encroachment or lead to different uses of space that will not harm the site.

Once heritage sites have been identified and a management plan has been established, spatial technologies can contribute to site interpretation and the dissemination of information. Global cultural heritage can provide information about the human past and is knowledge about this information is considered public property. Researchers are working to develop open and available online platforms where people can learn about the extent, condition, artifacts, and history of cultural heritage sites remotely (Meyer et al., 2007). This type of information will also contribute to analyses and researchers will be able to look for patterns and better understand pre-historical and historical human landscapes. However, from a management standpoint, the presentation of detailed spatial data for research has to be balanced by considerations of how looters might be able to use this data (Chase et al., 2011).

Spatial analysis tools and technologies have contributed to the ongoing paradigm shift in the field of cultural heritage management from object-based study to landscape analysis by detecting agricultural, canal, or other features that indicate more extensive human presence at known urban centers than previously understood. Similarly, spatial data and technologies can show how pre-historic and historic people used different features of the landscape and contribute
to anthropological theories of human existence. Using predictors for how people historically interacted with the landscape to identify cultural features allows for the consideration and testing of patterns of human activity, supporting the recent paradigm shift in cultural resource management towards a landscape rather than object-based interpretation of the past (Fry et al., 2004).

As remote sensing technologies continue to improve and GIS systems become more specialized, many authors writing about the use of these technologies in the field of cultural heritage management discuss how continuing improvements will enhance the information that can be derived from these sites. In the last few decades, multi-spectral sensors have improved to include bands that are helpful for archaeologists and LiDAR has proven very helpful in determining site extent and locating archaeological remains through vegetation. As GIS technologies become more widely used, managers will be better equipped to consider spatial dimensions in management and monitoring plans. Similarly, as web platforms are developed and become more widespread, researchers will be able to share information and consider other management techniques. GIS and remote sensing allow archaeologists and resource managers to use new techniques to locate, monitor, and understand sites, as well as provide a means of disseminating information to enhance the work of scholars around the world.
Annotated Bibliography


Early applications of aerial photography and remote survey in the field of archaeology were plagued by precision problems with locating the sites and boundaries in the field. In their article outlining the application of remote survey and geographic information systems (GIS) techniques to the analysis of archaeological landscapes in Northern Italy, Campana and Francovich argue that the progress made in remote sensing and GIS technologies in the last decade has made these technologies much more applicable to fields such as archaeology where researchers need to be able to associate remotely sensed discrepancies with particular, small locations on the ground. In a 470 square-kilometer search area in Tuscany, the authors identified over 1800 archaeological features by manipulating Ikonos-2 data. The red and near infrared bands were most useful in defining soil and crop marks that could indicate archaeological features. By then combining this data with GIS overlay information on likely feature locations and use GPS to identify field locations, the authors were able to greatly increase the archaeological record of the area through remote sensing technologies.


Using guidelines established by the United Nations Education, Scientific, and Cultural Organization (UNESCO) and GIS technologies, Canuti et al. evaluate the risk posed by natural processes to two Italian historical sites at Latium and Sardinia. Using information from field surveys and aerial photographs, the authors mapped soil type, geomorphological hazard risks, runoff patterns, and the location of known archaeological sites or excavations. These factors were then ranked to establish a intensity and hazard scale or level, to produce a map showing archaeological situations with the highest risk potential. This information is valuable to inform hazard mapping and planning, as well as in a cultural heritage management context to inform preservation decisions and trade-offs.


With the ability to penetrate vegetation, Light Detection and Ranging (LiDAR) point cloud data has the potential to revolutionize archaeology as a field both in terms of site detection and protection. Using an airplane-mounted Optech GEMINI Airborne Later Terrain Mapper (ALTM), researchers obtained 4.28 billion measurements and were able to generate a bare earth Digital Elevation Model (DEM) at a resolution of 1 meter. By applying a hillshade model to this 2-D data, Chase et al. were able to distinguish topographical from built features. In order to test the effectiveness of LiDAR data, these rendered images were compared with IKONOS imagery. This comparison revealed that LiDAR data detected manmade features in areas that were preciously understood to be vacant of human alteration. While traditional archaeological methods use survey techniques to excavate small areas, LiDAR can provide data about site
extent. In this study, LiDAR data revealed that agricultural terracing in Caracol, Belize was much more extensive than previously known, suggesting connections between urban areas and much higher historic populations, adjusting commonly accepted sociopolitical models of Maya civilization.


Although settlements at Angkor Wat, Cambodia, represents one of the most extensive preindustrial urban centers in the world, the full extent of human occupation and landscape alteration was, until recently, unknown. Because the structures at Angkor Wat were made of perishable materials, the site extent indicators consist of man-made topographical features such as raised roads, canals, ponds, walls, and agricultural networks. LiDAR has made the discovery of these features through dense vegetation possible. Using an airplane mounted Leica ALS60 laser system and a 40 megapixel Leica RCD105 camera as well as a GPS unit, Evans et al. gathered LiDAR data at 4 or 5 points per square meter and took photographs with 8 centimeter resolution. These data were compiled and processed to generate high-precision digital elevation models. The discovery of the extent of this civilization, complexity of built structures, and spatial arrangement of the city has informed and substantially altered the historical interpretation of class structure, trade, and urban organization in the region.


Using kriging to generate a digital elevation model (DEM) from 10 meter square pixel size data, Fry et al. layered known Bronze and Iron Age grave mound sites and soil quality information with GIS. At the study site of Ski in southeast Norway, Fry et al. then created a model that considered the aspect angle, viewshed (based on the height of the observer and pre-erosion mound height), and soil qualities of the locations of known grave mounds to create a map of locations with higher likelihoods of containing cultural heritage remains. Both by testing their model predictions on known sites and by looking for cultural heritage remains in sites identified by the model, Fry et al. found their model to make predictions with 94% accuracy.


Although there are many technologies and methods to document cultural heritage sites from an object-based approach, in this article the authors evaluate terrestrial laser scanning (TLS) as a technique for capturing the architectural features of the medieval Haut-Andlau castle in Alsace, France. Although the authors were hopeful about the application of this technology, TLS did not provide data that was compatible with georeferencing technologies and was not able to gather data about the structure through thick vegetation. In order to support TLS, the authors took and digitized photographs and tacheometric measurements in order to accurately draw the castle structure. By comparing these methods, the authors found that TLS was highly accurate on flat
and regularly shaped surfaces. Photogrammetry and conventional survey techniques also have limitations; however, as technologies develop these methods may become more practical and more accurate.


Although archaeologists have incorporated new information systems including GIS into their work, these systems are not typically designed for archaeological data. GIS and other systems can be adapted to incorporate and analyze the heterogeneous data gathered from archaeological research. This type of analysis can be very helpful in cultural heritage work because GIS can combine information from very different types of surveys to synthesize historical and environmental features, create visualizations, and can potentially overlay text-based and object-based information. However, in order for these technologies to be useful, they need to be multi-lingual, widely and publically accessible, and compatible with different analysis platforms. In order to illustrate their framework, the authors created a relational database of cultural heritage features in Luxembourg with temporal, spatial, archaeological, and text information on each object. In the Luxembourg platform, the supporting textual information can be used to create 3D images of structures in less eroded and weathered conditions. The eventual product uses GIS to create a virtual research environment to enhance the historical and archaeological information available to researchers and managers.


In this paper, Raimondi et al. discuss the use of fluorescence LiDAR in classifying the chlorophyll *a* pigments and determine what type of biodeteriogens may be present on the surface of historic and cultural monuments. This active remote sensing technique uses a particular wavelength of laser radiation to excite fluorescent molecules in the organisms. This technique can be carried out from substantial distances and can take collect data on monuments *in situ*. Different photoautotrophic bacteria fluoresce at different wave lengths and by removing the input from the metal ions, minerals, and elements that characterize the stone used in the monument, the type of biodeteriogen may be identified.


While ground penetrating radar and magnetic prospection are commonly used in detecting subsurface archaeological features, multi- and hyper-spectral aerial sensing have yet to be commonly applied in this field. Rowlands and Sarris discuss the benefits and detriments of the application of multi- and hyper-spectral imaging in the detection and delineation of surface and subsurface archaeological remains. Using the extensively documented Itanos area of eastern Crete as a case study, Rowlands and Sarris gathered airborne imagery with Compact Airborne Spectrographic Imager (CASI), Airborne Thematic Mapper (ATM), and LiDAR systems and processed these data using ground-based measurements for correction. With an object-oriented
approach, the authors were able to detect, classify, and map surface features; however, subsurface features presented different challenges. Subsurface archaeological features can be detected through changes in the runoff patterns and chemical characteristics of surrounding soils, but these qualities are obscured by vegetation interference with soil characteristic identification. However, the authors were able to identify some anomalies the thermal data that were not present in the LiDAR data suggesting there were no topographical differences and did not correspond with vegetative features. The authors suggest that a multi-disciplinary approach, with the highest spatial resolution possible, is the best way to use remote sensing tools in archaeological identification.

**Additional Sources**


