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Spatial Technologies hardware; software; issues; archaeological location models.

Spatial technologies (ST) are integral to how data are collected, managed, analyzed, and published in current archaeology and, indeed, have brought about tremendous changes to the discipline. Advances in the 21st century have occurred in hardware and software, profoundly affecting the conduct of research and how we perceive, approach and model the archaeological record.

Hardware Developments in Spatial Technologies

Hardware advances in archaeological ST have seen numerous improvements in the 21st century. In field contexts, total stations and Global Positioning Systems (GPS) permit rapid and accurate mapping of features within large areas. Field computers, touch pads, and even smart phones permit data recording and bring GIS to the field. The proliferation of digital cameras is revolutionary because unlimited numbers of images are now acquired. While not commonly regarded as ST, near-vertical images have documented and even mapped excavations after their rectification and registration within GIS.[1]

Three-dimensional (3D) scanners represent an important recent field technology. Architectural scans yield accurate 3D models and a form of mapping associated with a new perspective in conservation—models are so accurate they may continue to represent structures long after they vanish.[2]

Geophysical prospecting has also seen major advances in faster instruments with better sensitivity, but the largest change lies in multi-sensor arrays holding, for example, 8–12 ground-penetrating radar antennas with GPS positioning. Pulled by vehicles, they allow enormous areas to be surveyed in short periods of time.[3]

Aerial archaeology is also associated with new ST using flight guidance by GPS and imagery that is now largely digital. An exciting development is the slow and low-flying unmanned aerial vehicles that serve as a platform for cameras or multi-spectral sensors guided by GPS-controlled waypoints.[4] The biggest change lies in the advent of Lidar, which permits creation of high-resolution (usually 1–4m) digital elevation models through laser range-finding from aerial platforms. Lidar has taught us that subtle terrain changes are frequently associated with ancient sites and has been revolutionary in the number of new sites revealed, even in previously surveyed areas and forested landscapes.[5]

1 Mitchell, Kvamme, and Kvamme 2011.
2 Al-Kheder, Al-Shawabkeh, and Haala 2009.
3 Linford et al. 2010.
4 Hendrickx et al. 2011.
5 Doneus et al. 2008.

Satellite remote sensing has seen tremendous advances through platforms such as Quickbird or WorldView 2 that offer sub-meter spatial resolutions which have made space-based data comparable in quality to aerial imagery, with the advantage of near-global availability. WorldView 2 also offers high spectral resolution with eight bands that permit identification of subtle anthropogenic changes previously invisible.[6]

The significance of the foregoing hardware advances is that (1) they improve our ability to more accurately and rapidly map and record, and (2) they facilitate archaeological discovery. In each domain, a cadre of specialists has formed, contributing to a "culture change" in the discipline. Moreover, these technologies yield digital outputs that require computer finesse, forcing greater technical literacy. ST also yield vast amounts of data that must be managed, processed, and analyzed. These requirements have caused new demands in computer hardware for increased storage and processing speed, but large impacts in software have also occurred for data management and in other exciting domains of ST.

Software Developments in Spatial Technologies

To work with the vast data sets generated by geophysical sensor arrays, 3D scanners, Lidar or high-resolution satellites, significant advances in software have occurred. Although many special-purpose programs have been developed for 3D point clouds, geophysical data or for computer-aided design, GIS remains a core management, analysis, and reporting tool. Improvements exist in modules for image registration, 3D displays, spatial, geostatistical, and network analysis, and much more, including graphical interfaces for complex procedures and models.[7] More realistic viewshed computations and travel times via cost-surface analyses are also possible. GIS also serves as a backbone for many other spatial problems.

One such domain lies in "visualization," which McCoy and Ladefoged[8] categorize into "data" versus "representational." The former seeks new information, patterns, and relationships through Exploratory Spatial Data Analysis using powerful statistical, graphical, and mapping techniques, often in a GIS setting. The latter attempts to represent past places or objects by rendering them through advanced computer graphic methods. 3D laser scans are a frequent data source. Architectural models have also been "built-up" out of ground plans revealed by geophysical surveys. These reconstructions lead to virtual worlds with fully immersive representations of past cultures, architecture, environments, and even past peoples.[9]

The growth of the internet in this century has had a profound influence on databases and software applications, which are becoming more frequently available on-line. Governments and private companies offer wide choices of digital data for download, greatly facilitating database creation. Increasingly, state and regional archaeological databases are becoming available on-line, promoting access. Internet offerings such as Google Earth supply ready access to global aerial and satellite imagery that is useful for initial prospecting[10] and tools like Google SketchUp that offer powerful 3D modeling tools.

A domain that well illustrates the enormous changes in data volume and software complexity now commonly confronted lies in the area of regional simulations, many of which focus on models of archaeological location, sometimes referred to as "predictive models."

6 Banks 2011.
7 Lake and Conolly 2006.
8 McCoy and Ladefoged 2009.
9 Rua and Alvito 2011.
10 Parcak 2009.

Archaeological Location Models (ALM)

This controversial topic focuses on means of modeling or "predicting" archaeological locations based on (1) their statistical relationships with landscape variables or (2) on models of human location behavior, which can be mapped over regions by GIS.[11] Such models have seen many applications in Cultural Resource Management (CRM) to the point where it has become a multi-million dollar industry in the USA and elsewhere, but they are often seen as theory-weak, static, or "environmentally deterministic."[12]

In the past decade, new approaches have arisen that attempt to address these deficiencies. They rest in the increased power of computing, the improved sophistication of ST like GIS that permit linkages to many related spatial databases, software that permits simulating complex behaviors, and improved graphical portrayals. In essence, based on complex rules of a multiplicity of human behaviors and, indeed, the behaviors of everything from wild to domesticated animals, to plant health, rainfall, erosion rates and climate change, entire past societies have been "canned," and simulations, frequently agent-based, are permitted to run over the course of centuries.[13] Although fraught with countless problems ranging from data reliability, to faulty behavioral assumptions, incomplete knowledge of processes, equifinality, and other factors, remarkable successes (as shown by correspondences between model predictions and archaeological knowledge) and significant new insights have been achieved. More time will be necessary, however, to realize the full potential of these approaches and to address their many difficulties.

An alternative data-driven approach *not* based in simulation for ALM is also examined that utilizes quantitative concepts of Niche Theory developed in Biology in the 1950s and its transformation to a geographic theory of human settlement in the 1960s.[14] It has a well-traveled theoretical basis at its foundation and permits other theoretical models to be superimposed relating to economic choice, competition, and maximization, to name a few. It considers the social and the physical landscape and is flexible because cultures with different environmental adaptations and social requirements will realize different niches. The approach achieves power because it focuses on stable principal components associated with *lowest* variance that characterize basic location requirements associated with a particular class of activity. Within this space, locations are evaluated according to a standardized distance, expressed by a Mahalanobis D^2 statistic and mapped via GIS.[15] A well-understood cultural landscape, that of early Euroamerican farmsteads of northwest Arkansas, USA, illustrates the approach.

Conclusions: Effects and Issues

Advances in ST improve our ability to undertake complex models and to examine large areas for archaeological remains through ground-based, airborne and space-based sensors. If the archaeological site, as conventionally defined, represents only a concentration of material culture and certain past activities, it is clear that "sites" represent only a fraction of the human experience.[16] Many of the foregoing ST, because they permit examination of vast areas, promote a greater focus on the landscape or region as opposed to the site, which is surely a positive result. With so much rapid technological change, data quality and standards are a great concern, but data formats and their longevity are of special

11 Kamermans, Leusen, and Verhagen 2009.
12 Verhagen and Whitley 2012.
13 Wilkinson et al. 2007.
14 See Kvamme 2006.
15 Dunn and Duncan 2000.
16 Dunnell and Dancey 1983.

interest as we approach a half-century of archaeological computing. With so many archaeological databases constructed by individuals, institutions, and states, the growth of an archaeological cyberinfrastructure with integrated regional or even worldwide data is a growing need.[17] Additionally, many individuals and regions are denied participation in ST owing to hardware and software costs. The promotion of open source software will at least alleviate part of this dilemma.

17 Kintigh 2006.

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