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Fill in the Gap between Theory and Practice: Making a GIS-Based Digital Map of Pachacamac

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Abstract. As previous major studies have demonstrated, Geographic Information Systems provide archaeological research with powerful analytical capabilities as well as ease of data creation and management, nearly infinite scalability, and compatibility with various external data and modules. However, archaeological researches tend to occur in the regions that have not yet established an efficient (or reliable) geographical data management or related infrastructures and thus do not have enough data sources to achieve the research aims. Archaeologists are almost always required to produce their own maps within budgetary restrictions. Thus, in reality, even digital map making is not an easy task and does not make the desired progress, to say nothing of expected analytical endeavour. Through the digital mapping at the archaeological site of Pachacamac on the Peruvian Central Coast, I highlight a notable gap between theory and practice and urge the need of: (1) selection of the most efficient way to achieve immediate goals on the basis of a clear understanding of given resources and surrounding realities; (2) contribution to data accumulation based on a long-term plan for establishment of a more reliable site database; and (3) establishment of a collaborative work environment and active data sharing among archaeologists and/or projects.

Introduction

Since a handful of archaeologists began to employ Geographic Information Systems (GIS) for their analyses of spatial phenomena in the early 1980s, previous major studies on GIS (Aldenderfer and Maschner 1996; Allen et al. 1990; Conolly and Lake 2006; Forte and Williams 2003; Gaffney and Stančič 1991; Lock 2000; Maschner 1996; Robertson et al. 2006; Westcott and Brandon 2000; Wheatley and Gillings 2002) have put their primary focuses upon the analytical capabilities of the technology and attempted to improve the methods of conventional spatial archaeology originally borrowed from New Geography in the late 1960s and sophisticated by pioneering works such as Hodder and Orton (1976) and Clarke (1977). These earlier GIS studies were all premised on ready-made digital maps at hand and failed to discuss mapping procedures in detail. Coupled with practical problems discussed below, however, making digital maps is not an easy task. Although it is obvious that GIS hold some promise for archaeological research, I argue that its appropriateness and efficacy for our discipline needs to be more fully assessed. In so doing, digital site mapping, I believe, is worth focusing our attention on at this time.

Given ample funds, it would be feasible to map in great detail the whole area of interest using the most advanced digital survey equipment. However, in reality, this is not the case for most of us. Constraints such as tight budget and consequent limited resources will always complicate the situation and often lead our colleagues to suffer from "GIS-phobia." Furthermore, ethnographic and archaeological research tend to occur in the regions that have not yet established an efficient (or reliable) geographical data management or related infrastructures and thus do not have enough data sources to achieve our goals. It is not until we overcome a series of practical problems that the time efficiency and succinctness of GIS-based digital mapping and related data management will be gained.

The main objective of this paper is to highlight a notable gap between theory and reality and how such a gap may be filled in. As a case study, I will refer to my digital site mapping of Pachacamac, which is a part of the ongoing long-term archaeological project on the central coast of Peru, the Pachacamac Archaeological Project (PAP), directed by Izumi Shimada (Southern Illinois University at Carbondale). PAP has a clear vision for data creation and storage in both digital and analog formats. Following this vision, I worked during the spring of 2004 to create a digital map of the site and took part in the excavation in the subsequent summer to collect field data for the corrections and further refinements to the map.

Settings

The site of Pachacamac is located approximately thirty kilometres southeast of Lima on a plateau on the north bank of the Lurín River and approximately one kilometre inland from its mouth. The plateau looks onto the river mouth, the Pacific Ocean, and a cluster of small islands offshore. While the full extent of the site still remains unknown, the site occupies an area of approximately 5.2 square kilometres (Matsumoto 2005). Three massive roughly concentric walls partition the area into four major sectors, I through IV, extending from southeast to northwest. The site is thought to have been one of the most powerful religious centres in pre-Hispanic Peru for over a thousand years or at least from the time of Late Lima occupation (Uhle 1991 [1903]).

Mapping Techniques and Procedures

Currently available techniques of GIS-based site mapping can be broadly divided into two types: (1) small-scale mapping methods relying primarily on remote sensing data and techniques; and (2) large-scale mapping methods based on location surveys in the field.[1] Both require their own hardware and software, and the capability of the equipment and/or the reliability of data sources one selects will directly reflect the quality of final products. PAP adopted the former methods.

If one needs to cover a large area even at the expense of precision, the former approach would be recommended. Its relatively light workload does not cost too much to execute. The methods that we employed for our site mapping were relatively handy and thus may be more appropriate for preliminary survey or reconnaissance prior to the fieldwork. For the latter approach, on the other hand, there is no choice but to slowly build up the map by taking measurements in the field. You should choose this approach only in cases where you need a very precise map and are prepared to conduct location surveys with perseverance.

In Pachacamac, there is another ongoing archaeological project, the Ychsma Project, directed by Peter Eeckhout (Université Libre de Bruxelles). This project represents a notable contrast to our mapping and employs large-scale mapping techniques based on meticulous location surveys by means of a laser total station in order to represent the architectural features in three dimensions (Ychsma Project 2005). Their heavy workload would be fathomable from the fact that their mapping project inaugurated in 2002 was not expected to be completed until 2007.

As shown in this contrast, archaeologists in the United States tend to be compelled to individually and annually or biannually seek their research funds, whereas their colleagues in Europe and other regions of the world have relatively easier access to multi-year funding. Thus, many of the multidisciplinary research projects that implement digital site mapping and related technical examinations are based in European institutions with greater long-term stability and personnel support (cf. Bard et al. 2003; Campana and Francovich 2003; Cavalli et al. 2003; Johnson 2005; Lambers 2004). Given the difference, important future developments in the archaeological application of GIS are more likely to come out of major European projects.

Our digital mapping consists of three broad phases: (1) prototype map preparation based on the resources available prior to the fieldwork in the summer of 2004; (2) ground-truth checking of the archaeological structures and Ground Control Point measurements by means of Real-Time Kinematic Differential GPS[2] (RTK DGPS) of the highest accuracy; and (3) data post-processing and consummation of the map (Figures 14.1 and 14.2). This stepwise approach dovetails the basic design of GIS sub-systems, which allows separate data manipulation and display. Because any quest for perfection cannot be readily accomplished, we should make efforts to set up and achieve a sequence of midterm goals, depending upon the resources available.

With budgetary restrictions and an optimistic assumption that we could blend productively the conventional data sources and digital photogrammetry techniques, we chose to begin with a combination of traditional 1:5,000-scale topography maps and old film aerial photographs taken in 1957 (Figures 14.3a,b). Instead of conducting location survey on the ground, we planned to put those data in a GIS overlay and digitize archaeological structures and other topographic features on them. Because photographs in general suffer from various systematic and nonsystematic errors, to be used as planimetrically true

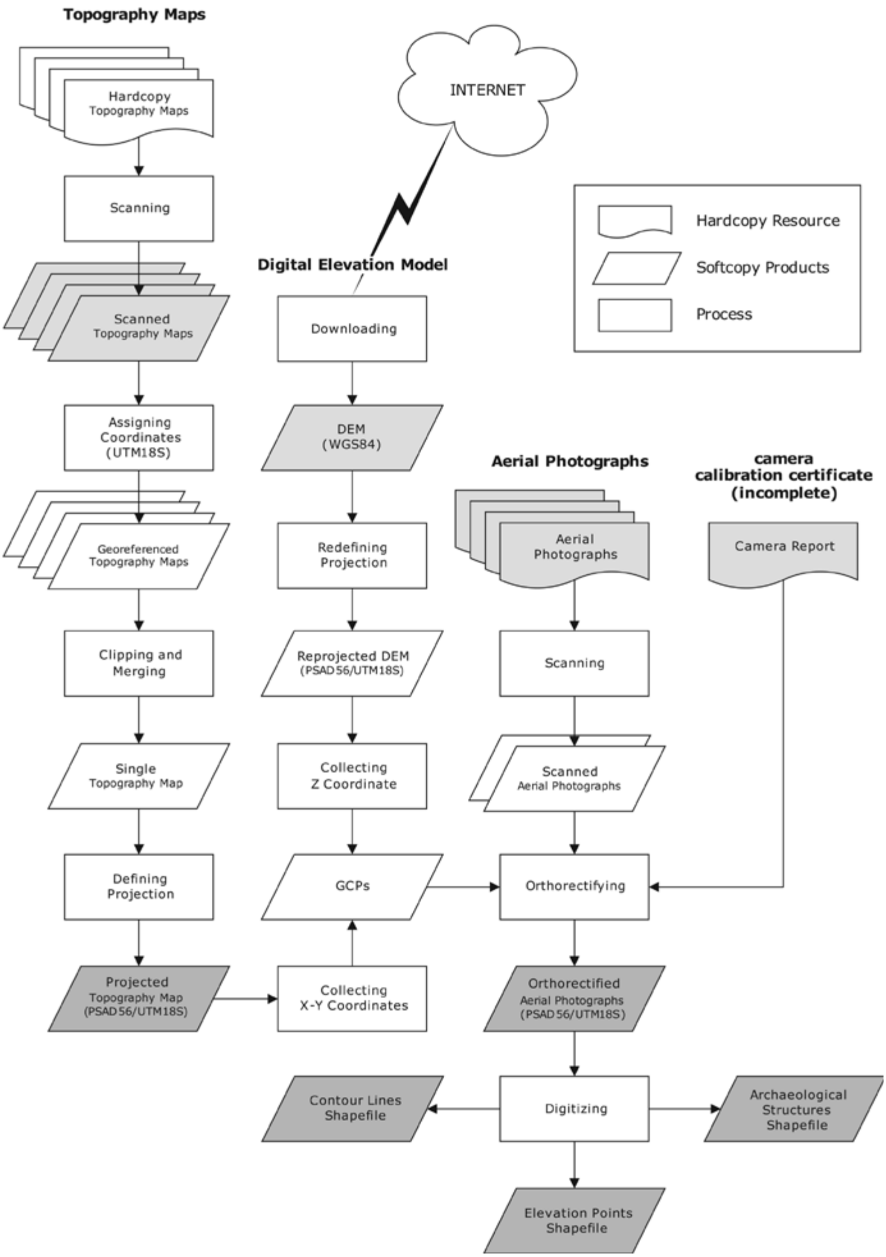

Figure 14.1. The workflow of prototype map creation (Phase I).

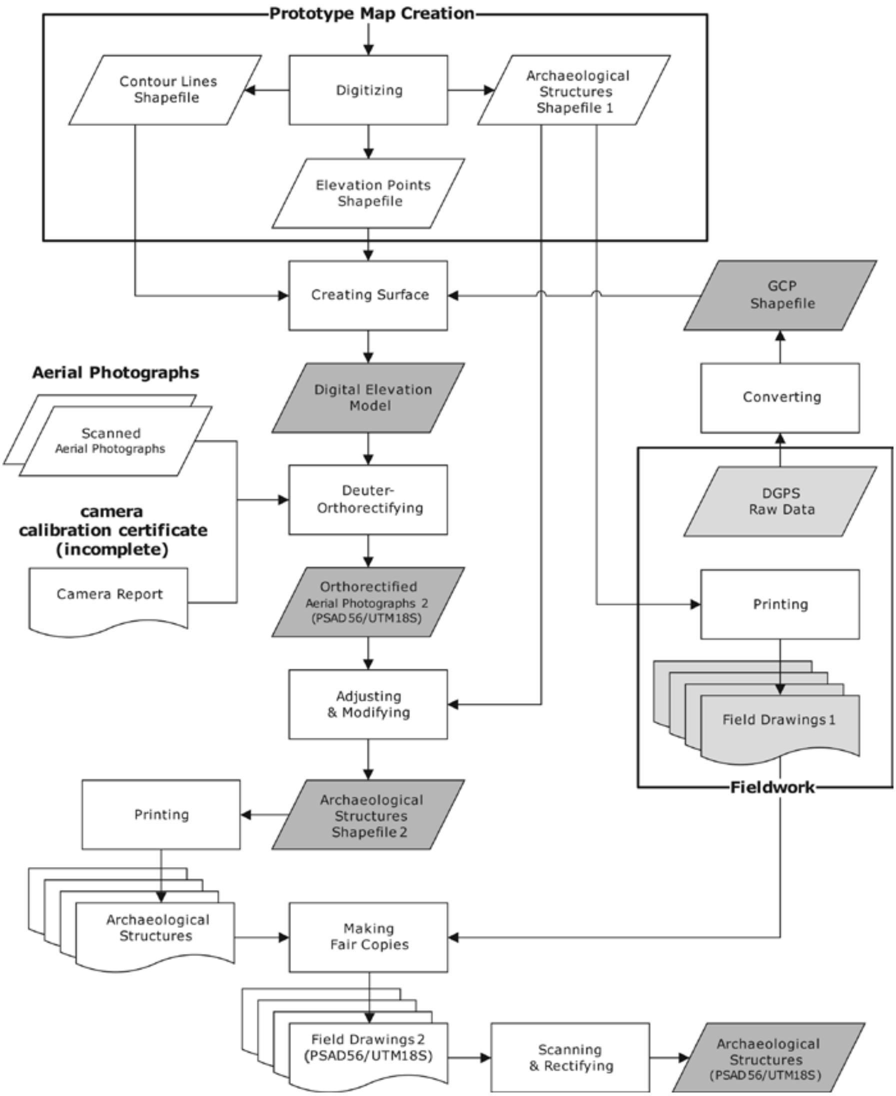

Figure 14.2. The workflow of post-fieldwork data processing (Phase III).

orthoimages, they need to be transformed from a perspective projection to a scaled orthographic projection in combination with the correction processes of various geometric errors. The success and failure of my site mapping primarily depended upon the success of this process. However, I confronted serious problems that defied a quick and simple solution. As a result, I had to be very inventive to resolve them. Below I discuss these problems.

Practical Problems

Most of the problems emerged in the forementioned transformation process that is called "block triangulation." The block triangulation basically requires four sets of data: (1) a stereopair of aerial photographs; (2) a minimum of three known Ground Control Points; (3) Digital Elevation Model (DEM) or Digital Terrain Model[3] (DTM); and (4) camera calibration report. Strictly speaking, however, none of them could be obtained in the form that we wished from the Servicio Aerofotográfico Nacional (SAN) or the Instituto Geomilitar. This difficulty stems mainly from the defectiveness and scarcity of data resources in Peru.

1: Pseudo-stereopair

The producer of the aerial photographs that I used confidently claimed that they were a stereopair (Figures 14.3a,b), but they were not. A stereoscopic parallax requires the photographs to be acquired at exposure stations from one or two flight lines at the same altitude on the same side of the terrain feature usually with 55 to 65 per cent overlap between them (Lillesand et al. 2004:131). The orientation of the images and states of exposure led me to conclude that our photographs were most likely taken from different sides and at different times. The overlap between them is no more than 51.3 per cent. The only solution to this problem is simply to process this pseudo-stereopair as a true stereopair since the processing software will not make any query about its validity. Of course, however, we should keep in mind that the resultant orthoimages may be problematic to some extent.

Figure 14.3. a. Aerial photograph 6512-57-5-626 taken on March 12th, 1957 by Servicio Aerofotográfico Nacional, Peru.

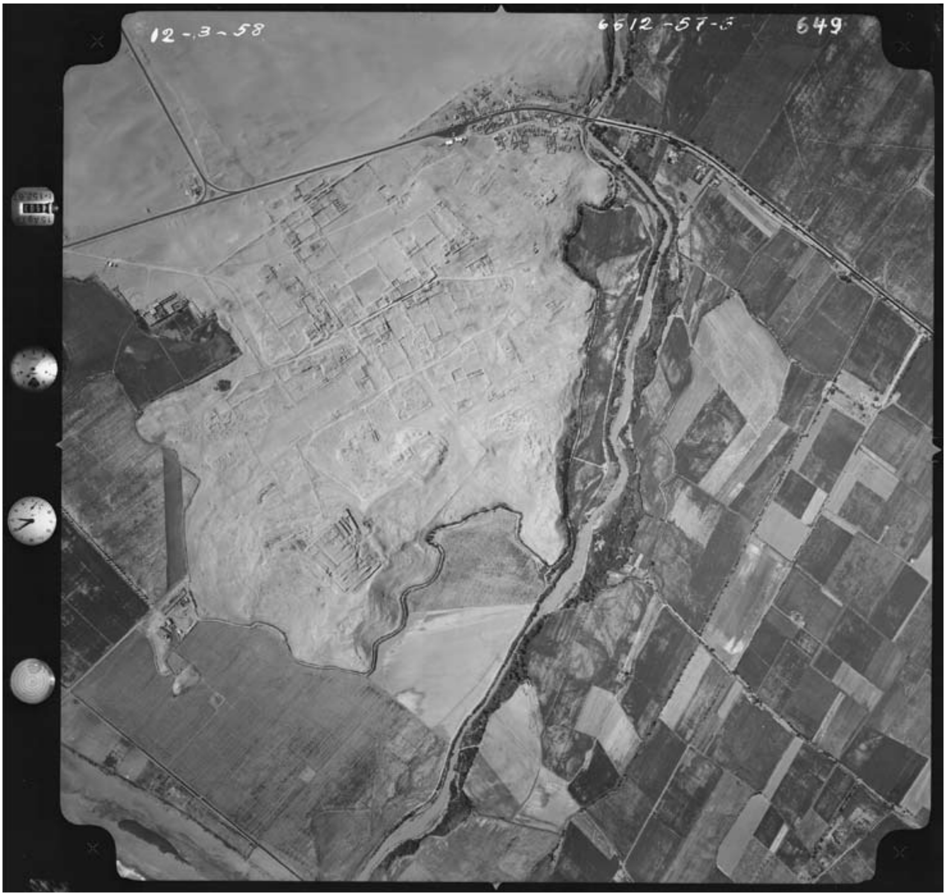

Figure 14.3. b. Aerial photograph 6612-57-5-649 taken on March 12th, 1957 by Servicio Aerofotográfico Nacional, Peru.

2: Absence of Ground Control Points (GCPs)

Prior to the fieldwork, I had no coordinate information that I could use as GCPs. The GCPs should contain *X*, *Y*, and *Z* coordinates, and a minimum of three should be evenly distributed throughout the study area and clearly identifiable on the aerial photographs. Alternatively, I collected *X* and *Y* coordinates from the georeferenced topography map that I created by clicking the points at which I wished to place the GCPs. In the same manner, *Z* coordinates were extracted from a DEM of 90-by-90 m spatial resolution derived from Shuttle Radar Topography Mission[4] (SRTM) arc-3 interferometric radar data available on the web for free.

3: DEM of very low spatial resolution

In order to properly eliminate the spatial discrepancies caused by terrain relief, elevation information such as DTM, DEM, and Triangulated Irregular Network (TIN) is required to be integrated during the correction process. Because we could not afford to purchase expensive high-resolution DEM or DTM, the SRTM arc-3 DEM was again used for this purpose. However, as might be expected, topographic prominences within each 90-by-90 m cell cannot be depicted and rather are represented as a smooth surface, which means that it is not suitable for large-scale detailed contextual analysis.

4: Incomplete and/or incorrect camera report

A regular camera calibration certificate was not available for the aerial photos we purchased. A replacement document provided by the producer of the photographs contains only: (1) project number, (2) picture numbers, (3) date of shooting, (4) scale, (5) airplane altitude, and (6) focal length. It is lacking critical information for the triangulation process such as principal point, fiducial marks, and rotation angles. Furthermore, the document is not only incomplete, but also evidently inaccurate. The altitude of 50 m, for instance, is apparently hard to accept if you take into account that each photograph covers the ground area of about 2,300 x 2,300 m. Supposing the scale (1:10,000) and focal length (152.67 mm) stated in the document are true, the altitude should be about 465 m. The content of the document is internally inconsistent.

This problem was partially solved by consulting the data strip shown on the margin of the photograph. The data strip confirms that the focal length is

152.67 mm as stated in the document but concurrently indicates that the altitude at the time of exposure was 1,600 m rather than either 50 or 465 m. This value sounds quite reasonable for the forementioned ground area. According to the information of the data strip, the scale will be 1:10,480.

Without the film coordinates of the principal point of each photograph, I had no choice but to define them as (0, 0) assuming that the principal point was placed completely in the centre of the photo image with absolutely no displacement. The film coordinates of fiducial marks also had to be replaced with theoretical values. The producer's website states that they have been using 9-inch Wild-type film cameras such as Leica RC series. According to the FAQ of the Environmental Systems Research Institute Japan's website (ESRI Japan 2002), moreover, approximate values of 106 and –106 can be used for the film coordinates of fiducial marks in the photograph taken by 9-inch Wild-type camera. Although it goes without saying that I must be prepared to face substantial margins of error, as long as I use these theoretical values for interior orientation parameters during the error-correction processes, I had no choice.

Effective Solutions and Results

Effective solutions to the difficulties described above were offered by the ground-truth checking and GCP measurements in the field (Figure 14.2). This is obvious in a comparison of the qualities of pre-fieldwork prototype map and post-fieldwork counterpart (Matsumoto 2005:Figures 5–24 and 4–2). The extremely accurate GCPs of only several-millimetre difference derived from the RTK DGPS readings, in particular, allowed us to produce high-quality Digital Terrain Models for the overlap area of the aerial photographs and to minimize the margins of error in the subsequent triangulation process based on the DTM. The resultant orthoimages show that the new data reduced a substantial amount of horizontal displacements between DGPS readings and the corresponding points in the orthoimages. Archaeological features on the ground were again digitized on the orthoimages in reference to the field drawings. The subsequent shapefile[5] was finally superimposed over the other shapefiles of topographic and architectural features (e.g., contour lines, water bodies, and modern roads) in a single overlay and printed as the finalized site map (Figure 14.4). It is very important to note here that we have to pay attention to the fact

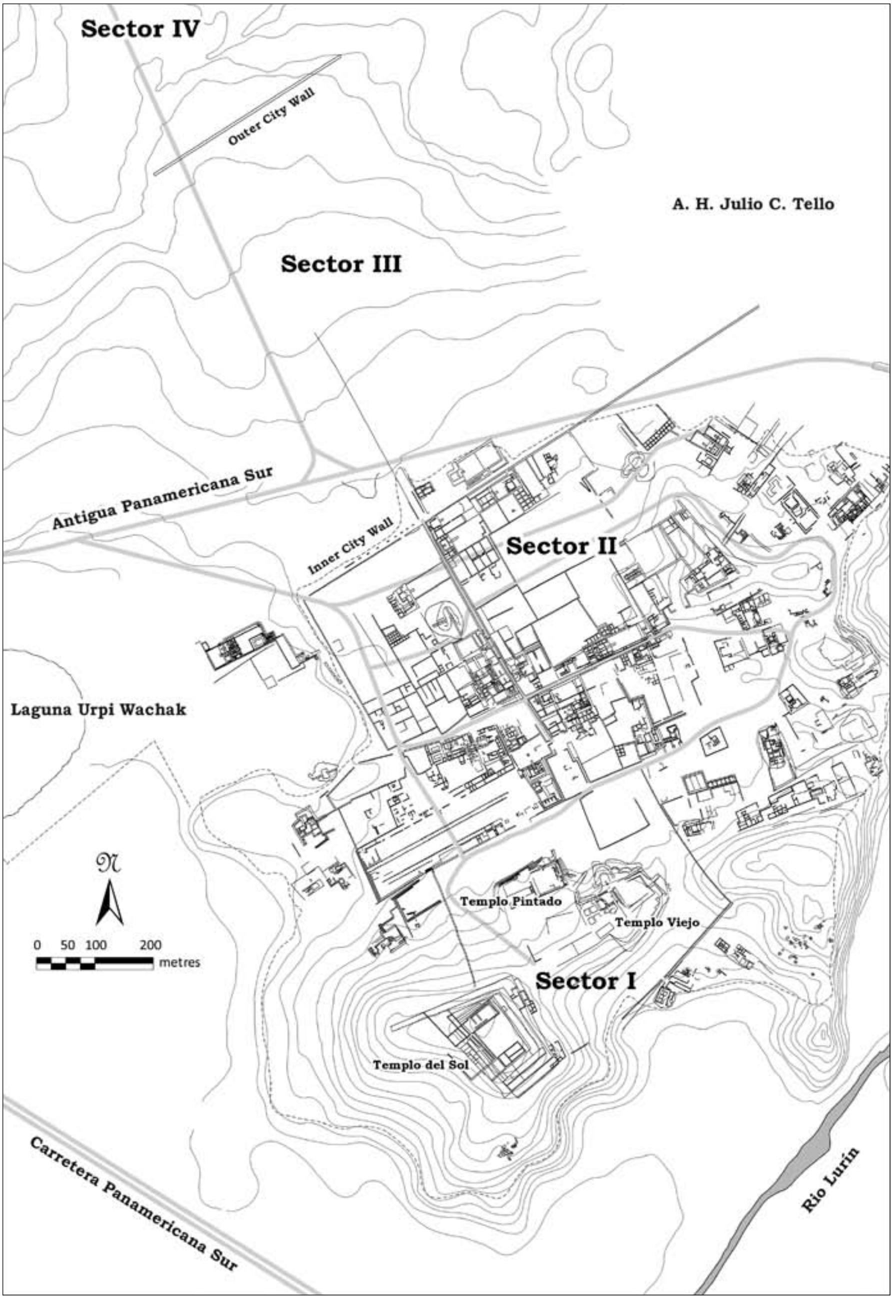

Figure 14.4. The resultant site map of Pachacamac (Scale = 1:10,000).

that the conversion process of the DGPS readings into a new shapefile induced a substantial amount of vertical displacements up to about 15 m in comparison with the conventional data sources. The discrepancy is probably due to the lack of a locally fitting geoid model for Peru.

Discussion

Over the last few years, we have obtained a growing number of external data sources inherently compatible with GIS; however, many old and new data available to us have considerable limitations in regard to precision, accuracy, and information density. Thus, as long as we have to use problematic data sources, both old and new, it would be virtually impossible for us to conduct site mapping and related data collections that are precise and accurate enough to undertake truly scalable analyses ranging from intra-feature to macro-regional levels. This implies that a full-scale application of GIS in archaeology is not yet practical or feasible in a true sense. Furthermore, even though one can obtain very precise and accurate data by means of the state-of-the-art equipment and techniques, they may not fit well into the conventional site data collected by old, planimetrically less accurate methods.

Since we inevitably face and have to accept substantial margins of error that stem from various practical details, it may not be worth pursuing the highest precision and accuracy at the expense of limited resources (Matsumoto 2005). Not only the selection of the most appropriate mapping techniques, but also the required level of precision and accuracy needs to be carefully considered according to our research interest, field conditions resulting from varied natural and cultural formation processes, expertise of field crew, and available data. Under no circumstances should we adopt any kind of technique without deliberate consideration. Inefficient applications will not only waste precious resources but also unnecessarily detach us away from our own duties such as explanatory explorations of material remains and, if temporarily, lead us to become absorbed merely in technology. We should keep in mind that GIS and other related techniques are nothing but research tools.

It is important to note here that I do not mean to be so realistic that I foreclose the prospect of future development of archaeological applications of GIS and surrounding technologies. It goes without saying that it is one of the critical issues for GIS-based archaeology to build and integrate more reliable site databases for subsequent archaeological analyses and discussions. However, the implementation of such an ambitious enterprise will require very careful planning based on a long-term perspective and a substantial amount of effort and perseverance to obtain and organize high-quality data. In order to maximize the efficiency with the minimum of exertion and expenditure, I argue that the establishment of collaborative work environment and active data sharing among archaeologists and/or projects would be most desirable.

In this regard, GLOBALBASE sets out architecture of great promise based on excellent philosophy (Mori 2005, n.d.). With its ultimate goals of storing every piece of existing spatial information within a single knowledge system and making it available free to the general public, this system enables us to share map information linked to each other through the World Wide Web (WWW) and to go freely back and forth between them, irrespective of the differences in coordinate system and whereabouts of map information. It no longer requires any resources except for a computer connected to the Internet. The only fear is that the system relies exclusively on the spirit of international volunteerism as with the case of WWW and open-source software. By improving its practicality and data quality, GLOBALBASE would not be impossible to get closer to the ideal in our mind.

Most of the serious problems that I have encountered in the course of map-making have not been explained elsewhere and thus can be resolved only through a continuing process of trial and error. A series of valuable know-how gained from such processes should be accumulated and made available freely to those interested. They are no less useful than what can be gained from formal in-class training, often complemented by laboratory exercises. Fully aware of this fact, a handful of graduate students of archaeology recently inaugurated an online study group in a Social Networking Site (SNS) and have organized offline workshops for active interaction and information sharing among the registered members (Archaeo-GIS Workshop 2007). I hope that such a grassroots attempt, together with the data sharing scheme noted above, trigger macro-regional level cooperation among archaeologists.

Conclusion

In order to fundamentally resolve the aforementioned practical problems, as I noted above, there is no alternative but to sweep the slate clean and start over to slowly and meticulously build up the maps by taking measurements in the field by the use of state-of-the-art survey equipment. However, to aspire to perfection is virtually impossible, and there is little point in pursuing extreme precision and accuracy for archaeological problem-solving even though it is backed up by sufficient funds. What is most practical and sensible is to find the most efficient way to achieve immediate goals (e.g., rough mapping for preliminary research and precise large-scale mapping for detailed contextual analysis) on the basis of a clear understanding of given resources and surrounding realities, and concurrently to contribute to data accumulation based on a long-term plan for establishment of more reliable site database. Furthermore, the digitalization of archaeological resources for the years to come will also encourage active in-depth discussions concerning data acquisition and management at the stage of research design. Subsequently, I hope, many archaeologists will argue for the need to establish a collaborative work environment and active data-sharing networks among them. I believe that a critical key to filling the gap between theory and practice in GIS-based archaeology would be found in mutual collaboration and voluntarism of archaeologists.

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NOTES

1 It should be recalled that a small-scale map covers a large area, while a large-scale map covers a small area.

2 The difference between the known coordinates and the GPS-calculated coordinates is the error that needs to be corrected for the accuracy of survey or mapping grade GPS applications. The correction of this error can be done either by bringing the data from the Reference Station and Rover together in an asynchronous, post-processing mode after the field measurements are completed (Post Processed Kinematic or PPK) or by instantaneously broadcasting the error correction information produced by the Reference Station to the Rover for real-time corrections (Lillesand et al. 2004:34).

3 DEM and DTM are three-dimensional digital representations of the earth's surface or topography.

4 SRTM is a joint project of the National Imagery and Mapping Agency (NIMA) and NASA to map the world in three dimensions. During a single Space Shuttle mission on February 11 to 22, 2000, SRTM collected single-pass radar interferometry data covering 119.51 million square km of the earth's surface, including over 99.9 per cent of the land area between 60°N and 56°S latitude. This represents approximately 80 per cent of the total land surface worldwide and is home to nearly 95 per cent of the world's population (Lillesand et al. 2004:712).

5 Shapefile is a vector data format developed by Environmental Systems Research Institute (ESRI).