Studying Angkor: Integration of GIS, GPS, Remote Sensing and Contemporary Observation

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Background

The city of Angkor in Cambodia is the largest pre-industrial city on earth covering more than 1,000 square kilometres (Figure 1). Several hundred temples, not necessarily contemporaneous, were built between AD 800 and AD 1430 (Higham 2001), supported by an extensive low density occupation of farming villages. A complex network of reservoirs and canals, along with village ponds, provided water to the city. The city was abandoned around AD 1430, ostensibly due to sacking by the Thais but more probably due to breakdown in the system, or a combination of these reasons, and was overtaken by jungle.

Angkor received occasional western visitors between the late 16th century and the 19th century, but the first systematic record was by a French team in the mid 1860s (Rooney 2000:35). From 1898 it became the subject of intensive recording by the Ecole Francaise d'Extreme Orient (EFEO) founded in the provincial capital, Siem Reap. Monuments were cleared of forest (with the notable exception of the Ta Prohm, which was partially cleared and left as a 'romantic ruin', with vast tree roots intertwined with the structures - it featured prominently in the film "Tomb Raider"), meticulously mapped as architectural monuments and reconstructed with large teams of local workmen. This work has continued to the present, though today on a reduced scale, apart from the hiatus due to war between 1972 and the early 90s.

More recently, large numbers of foreign missions and organisations - from Australia, Finland, France, Germany, India, Japan, Poland, the USA and many other countries - have carried out a variety of work including temple restoration, conservation of brickwork, excavation, mapping, hydrological and social studies. Apart from the broader mapping and hydrological studies, these projects have tended to be narrowly focussed on particular temples or specific conservation issues. The many organisations involved with Angkor gather annually for the ICC (International Coordinating Committee) meeting in Siem Reap, under the aegis of the UNESCO World Heritage Center.

Angkor was declared a World Heritage site in 1992. Placed on the endangered list from 1992 to 2004, it has now been removed from this list owing to better controls over development and preservation of monuments. However the extensive Angkorean period

Fig. 1 Composite archaeological map of the city of Angkor 2003 (courtesy Damian Evans)

archaeology in between the major monuments - production and habitation sites, field boundaries, roads, bridges, canals and so forth - is under immense pressure from forest clearance, development and farming by the contemporary population of rural villages, totalling some 200,000 people in Siem Reap province, the archaeological park and surrounding areas. The problem is simply that the fabric of Angkor outside the monuments, particularly the immense hydrological network, was largely built of earth. The archaeological sites which represent the life of the vast majority of the Angkorean population are, like today, scatters of unassuming material around trapeang (village ponds) and along the banks of canals, which are prime targets for reinstatement as working systems (Figure 2).

Not only will this fabric not withstand developments such as airports, residential construction, forest clearance and drainage works, but it is scarcely visible at ground level, has none of the conventional heritage appeal of stone and brick built monuments and is ubiquitous in the landscape. It is therefore both hard to raise the attention required to conserve it and problematic through its ubiquitous presence - as with all conservation issues, it does not become an issue until it is already too late. Furthermore, there is an inherent conflict between the European notion of heritage and the need of the contemporary Cambodian population to pursue their lives within the landscape, a tension well illustrated by the issue of the Ta Prohm - Cambodians find it hard to understand the European notion of this site as a 'romantic ruin' and instead see it, much more realistically, as a religious monument spoiled and threatened by damage from uncleared vegetation.

Mapping of Angkor

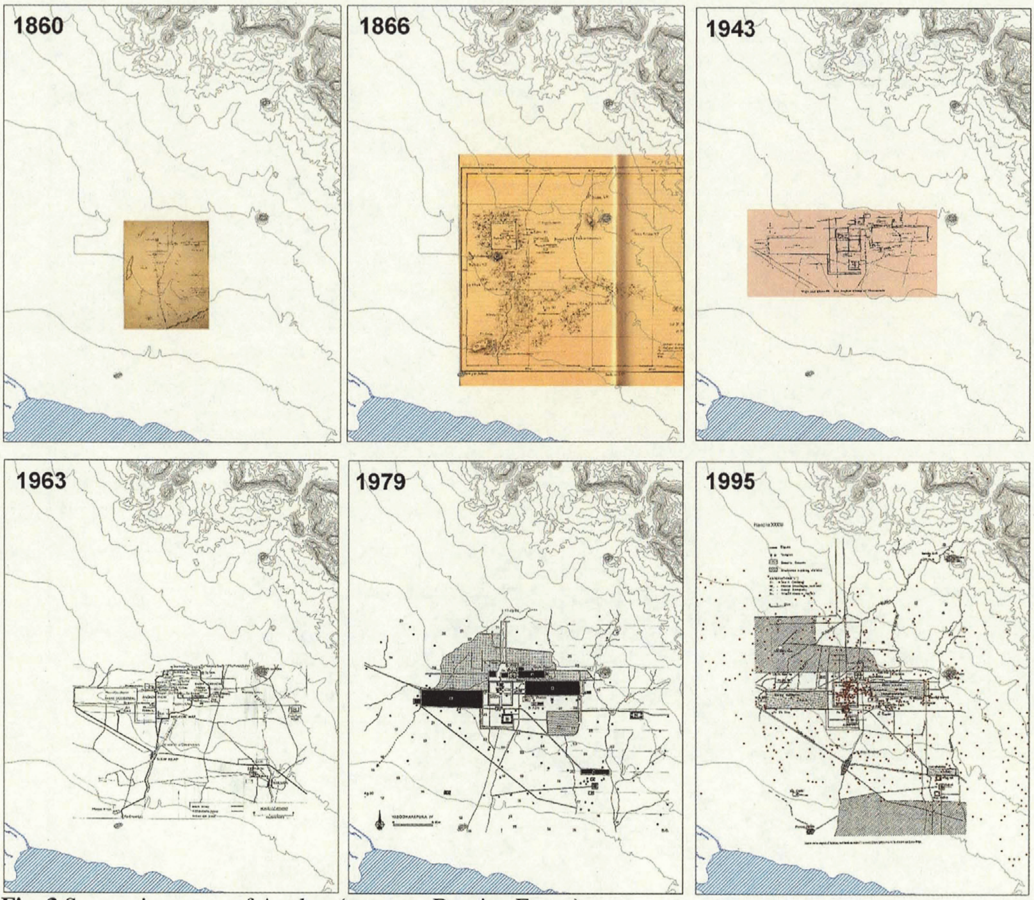
The extent of Angkor has been extended by successive surveys of the city as illustrated in Figure 3. The known area grew from an initial focus on a few major monuments to encompass some of the major elements of the hydrological system and the scatter of smaller temples, many of which were mapped in detail by the EFEO. However the fabric of the Angkorean period city between the temples was largely ignored. The UNESCO-sponsored ZEMP project (Zoning and Environmental Master Plan), covering the whole of Siem Reap province (approx. 5000 sq. km) and completed in 1993, was the first project to assemble consistent mapping of visible monuments and contemporary features such as rivers, roads, villages, population and land use. ZEMP defined five management zones with the central zone focussing on the major monuments as the primary protected area, with zoning recommendations for development of surrounding areas. Unfortunately these recommendations were not substantially implemented. The JICA project (Japan International Cooperation Agency) has also developed map data for central and southern Angkor.

Drawing on this framework mapping of the area, Christophe Pottier of the EFEO, as part

Fig. 2 Khmer houses on a canal bank (photo courtesy Andrew Wilson)

of his extended study of Angkor, used existing maps to manually register aerial photographs of Angkor onto a transparent master plan and trace archaeological features from them - temples, earthworks, canals, ponds etc. The identification of these features was based on experience on the ground and a sample was verified in the field. Pottier's study (1999) was the first to map the important archaeological material lying between the visible monuments. Owing to photographic coverage and conditions on the ground - notably heavy forest, inaccessibility and danger from remnant Khmer Rouge and landmines in the north - this study was largely restricted to the southern part of the site, encompassing the identified monument protection zone of the World Heritage Site and outlying temples and villages surrounding it. Figure 4 shows the extent of knowledge from Pottier's work at the end of 1999.

The University of Sydney's Greater Angkor Project (GAP), commenced in 1999 under the direction of A/Prof. Roland Fletcher, supported by the staff and technical facilities of the University of Sydney Archaeological Computing Laboratory (ACL) and School of Geosciences, has taken a broad-based multidisciplinary approach to Angkor as an archaeological landscape in an attempt to understand the reasons for the development and eventual decline of Angkor. The ACL has brought together and integrated the available digital



Fig, 3 Successive maps of Angkor (courtesy Damian Evans)

map data as a mapping infrastructure for the project; reservoirs, moats and other waterlogged locations have been cored to recover their sedimentation and botanical histories; the network of canals and waterways have been examined to try and understand the hydrological system; selective excavations have been carried out to determine stratigraphic sequences and the relationships between features; and detailed artefactual analysis has been carried out to build a pottery chronology. Graduate students are also studying the Khmer roads leading to and from Angkor, the architectural styles of temples, data on exchanges of goods derived from the inscriptions recovered from temples across the region and contemporary issues related to tourism and landscape change. Five further graduate scholarships commencing over the next two years have been funded as part of the Greater Angkor Project (GAP) and Living With Heritage (LWH) grants received from the Australian Research Council.

In 2001-2002, Damian Evans used AIRSAR (airborne synthetic aperture radar) imagery, flown by a NASA mission with the Angkor coverage funded by the University, to extend the mapping of archaeological features across a much wider area (Evans 2002). Evans used two

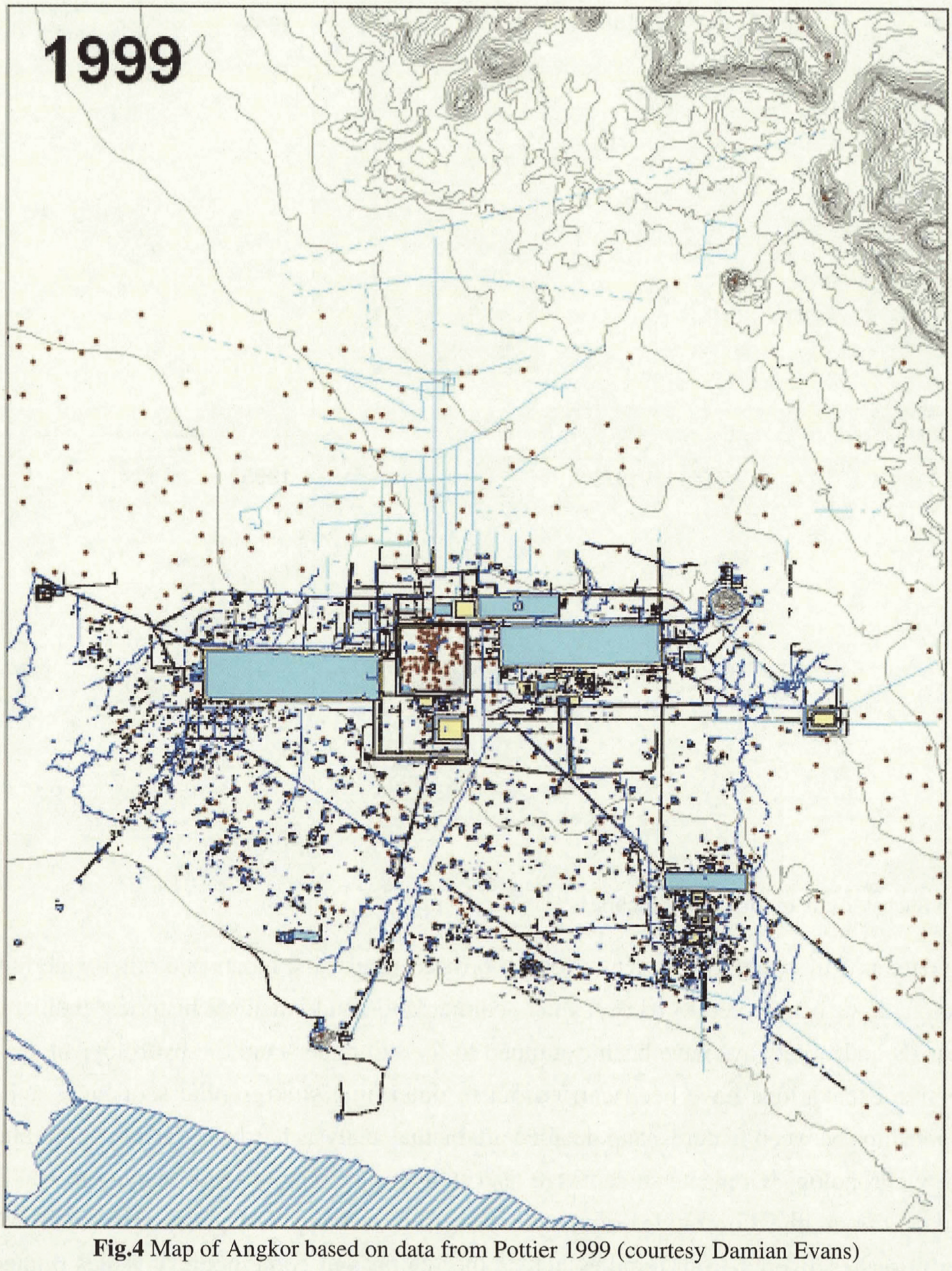


Fig.4 Map of Angkor based on data from Pottier 1999 (courtesy Damian Evans)

false-colour images derived from different bands, processed by Ian Tapley at the CSIRO in Perth, to emphasise different features of the landscape (see Figure 5: CvvLvvPvv emphasises the impact of modern activities on the vegetation, whereas LhhLhvPvv brings out underlying Angorean period features such as field boundaries, even where modern cultivation has obscured them on the ground). The images, which have a horizontal spatial resolution of about 5 m, were georegistered in ArcGIS and superimposed with modern features recorded by ZEMP and JICA, then used as a background for heads-up digitising. The digitising process took some hundreds of hours, as each feature digitised had to be carefully assessed and assigned to an appropriate class.

As with Pottier's study, a training set of locations with known feature types was recorded on the ground, and in a subsequent season a sample of the features digitised were visited on the ground to check the accuracy of the interpretations. Ground visits to specific pixels identified in the GIS were greatly assisted by loading a general map of Angkor into ESRI's ArcPad software running on an IPAQ handheld computer linked to a Bluetooth GPS unit, allowing navigation to specific locations.

The extent of features recorded through this heads-up digitising process is shown in Figure 6. The results demonstrate that the city was in fact far larger than suspected, with the unsurveyed northern section showing similar densities of features to the surveyed southern section. A wide peripheral band of low density occupation surrounding the core of the site gradually merges with the background scatter of rural agricultural villages extending throughout the country.

New research on Angkor

Starting in January 2005, we have two parallel grants from the Australian Research Council (ARC) for further work on Angkor, totalling over A$2M. The first is a 5 year ARC Discovery grant continuation of the GAP project which will build on the study of the hydrological system to look more closely at the relationships between temples, villages and environment. The second is a 5 year ARC Linkage grant which establishes a new project, "Living with Heritage" (LWH), which will focus on the legal and social framework of heritage management, methods for monitoring development impacts and the involvement of local communities through participatory GIS. This project is a collaboration with APSARA (the Angkor management authority), the UNESCO World Heritage Center, the Ecole Francaise d'Extreme Orient and several other partners.

Data infrastructure

The two projects - GAP and LWH - will share common infrastructure and fieldwork organisation. As part of this common infrastructure, over the next year we will be doing further work on the integration of the existing GIS data sources for Angkor, which we have recently inventoried as numbering over 200 including historical maps. We will prepare detailed metadata for these resources and set up a distributed index using new software under development at the ACL. This software, which is being developed as part of the Australian Partnership for Sustainable Repositories (APSR), provides a robust, distributed Java middleware (Figure 7) which allows individual agencies to retain custody of their data resources whilst making them discoverable and usable (subject to authorisation) by appropriate client software (including the TimeMap Java mapping client). It is designed to encourage sustainability of resources, migration to new platforms and to handle resources which go offline or are intermittently available. It will handle a wide range of data types including text documents, spreadsheets, sound, video and images as well as GIS datasets.

Part of our work over the coming year, commencing with fieldwork in January 2005, will be to introduce the APSR software to the many agencies working at Angkor and to encourage them to be a part of this distributed data system. This will entail demonstrating the advantages of becoming part of an integrated system and overcoming their natural resistance to 'giving away' data. It will require substantial further development of the APSR middleware to the point where it is a no-bother solution to making data searchable and available, under strict control, through the Internet.

A second aspect of the work over the next year will be the organisation of our existing photographic resources (numbering well in excess of 15,000 images) as a geographically-based online dataset. We have been developing a web-based image management system, ArchImage (Figure 8), which indexes and records metadata for digital images (and other documents) on a file server without imposing a specific structure. The authors of the images continue to store them in their own folders, and can manipulate, rename and move them with normal file and image management tools. The ArchImage system tracks the images on disk, provides a persistent URL independent of their location, generates thumbnail and watermarked web resolution images on-the-fly, allows digitisation of geographic location and entry of metadata over the web, and provides mechanisms to search the database, select and reorder images and generate a presentation.

The major work involved will be to retrospectively enter metadata and digitise image locations, using the composite map of Angkor we have developed as a reference, so that they can be searched for and accessed through an interactive web map interface based on *Time*Map. The image database will continue to grow over the next 5 years of the GAP and LWH projects, but will require less work to maintain in subsequent years, as we have developed a methodology for generating geographic location automatically by matching GPS tracklogs with digital camera images using the tracklog and image timestamps.

As part of the GAP project, and also through work with the Electronic Cultural Atlas Initiative (www.ecai.org), we have been involved in teaching a number of GIS training workshops in southeast Asia, including workshops at Siem Reap (Figure 9). Part of our involvement with Angkor, through the ongoing GAP and Living with Heritage projects, will continue to be the development of data and software solutions (including the distributed GIS data index, APSR middleware, ArchImage, *Time*Map and tools for linking GPS location with digital photographs), the development of appropriate training materials and the conduct of training workshops in the use of these tools.

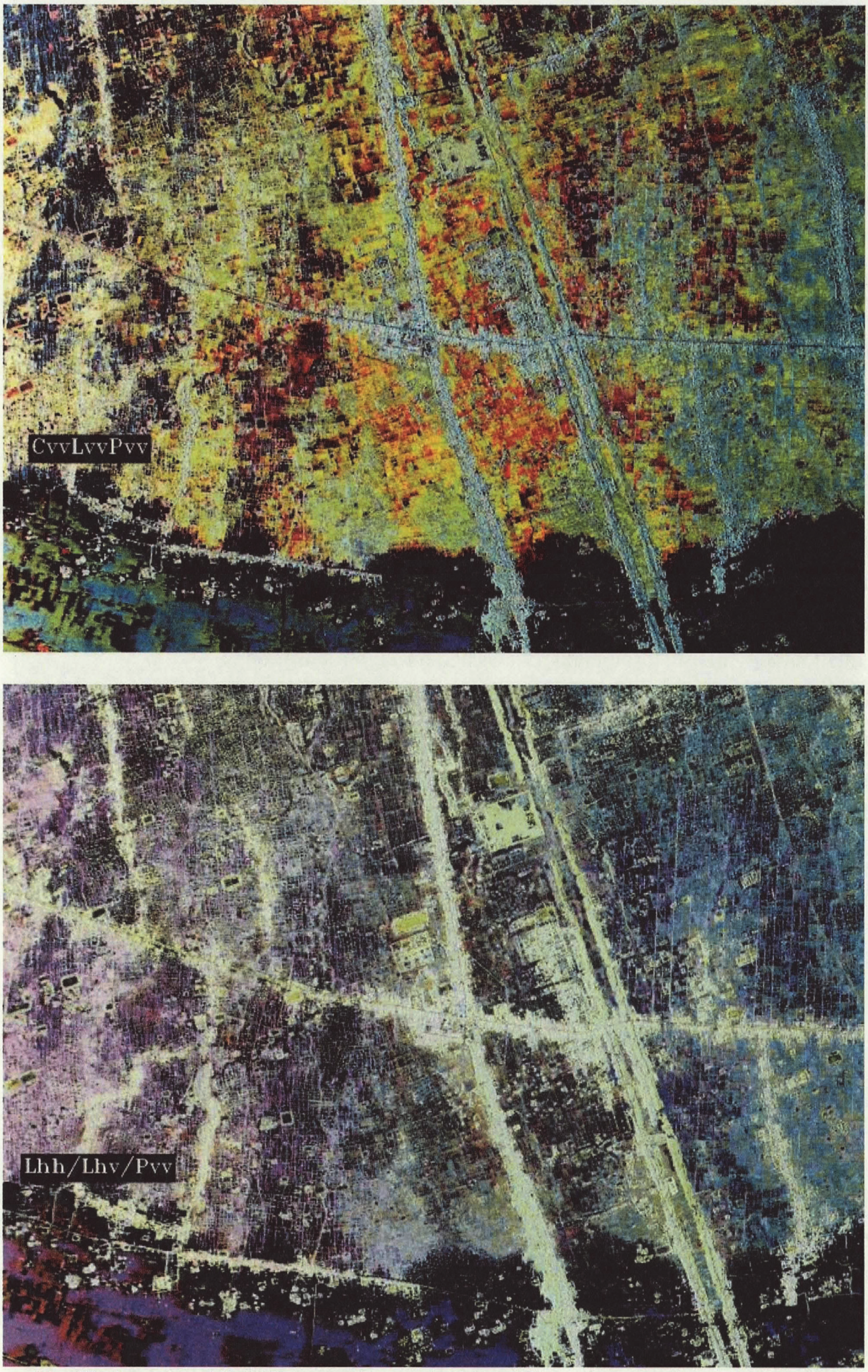


Fig. 5 False-colour AIRSAR composites emphasising different features of the landscape (courtesy Ian Tapley, CSIRO)

Monitoring development

The next major step in our research for the Living with Heritage project will be to design measurement and sampling strategies to monitor the impact of development on the heritage landscape. These methods will include simple indicators and protocols which can be applied by local communities with minimal training, as well as remote sensing methods based on repeat aerial coverage (which will be partially funded by the project) to examine change over wide areas. In our first field season (January 2005) we will carry out reconnaissance to identify the processes of landscape change associated with development pressures, matching remote sensing evidence with field observation ('ground truthing') to identify development indicators which can be recorded with simple technology on the ground, appropriate to heritage landscape management in developing countries. We will also investigate how different communities perceive landscape change - we are interested in determining, for example, whether local residents identify different indicators of development from ourselves. We aim to develop a methodology and protocols which can be applied easily by local organisations, not just by academic researchers, and to test their performance in subsequent years through observation of the methodology in use, through interviews and through focus groups.

One of the key features of the methodology will be a concern with spatial location so that, for example, we expect to record the spatial location of the indicators measured and, where interviews or focus groups are undertaken, the spatial location of these activities and/or the participants. We also intend to investigate the role of low cost data collection devices such as digital cameras and consumer level GPS, and the potential for direct entry of field data into GIS using browser-based maps. Figure 10 illustrates our first experiments with browser-based location collection using the *Time*Map TMJava software as part of the ArchImage image management system. What is needed is highly streamlined and intuitive methods of data capture requiring a minimum of both technology and training. Browser-based data entry has many advantages, even where Internet connections are not available, in largely removing the need for the installation of specialised software on computers which may not have the minimum technical specifications required.

We are particularly interested in capturing contemporary experience and perceptions, including the views of administrators, tourists and residents, and recording these within a spatial database. If a site such as Angkor is to be monitored and managed effectively, there is clearly a wide range of opinions and perceptions which must be taken into account, and a need for methods of collecting, organising and using this information effectively. Differences in opinion and perception will also lead to conflicts and negotiation, and the database must therefore be able to handle events as well as static observations. The

Fig. 6 Map of Angkor derived by heads-up digitising from AIRSAR coverage 2002 (courtesy Damian Evans)

incorporation of such qualitative information within a spatial database presents considerable challenges, not only in terms of developing appropriate database structures to hold the data, but in developing workflow models for systematic collection of such data and methods of searching for and using the data. Angkor will act as a testbed for this work, but the methodologies we develop are intended to be generally applicable to extensive heritage sites/landscapes with large contemporary populations in developing countries.

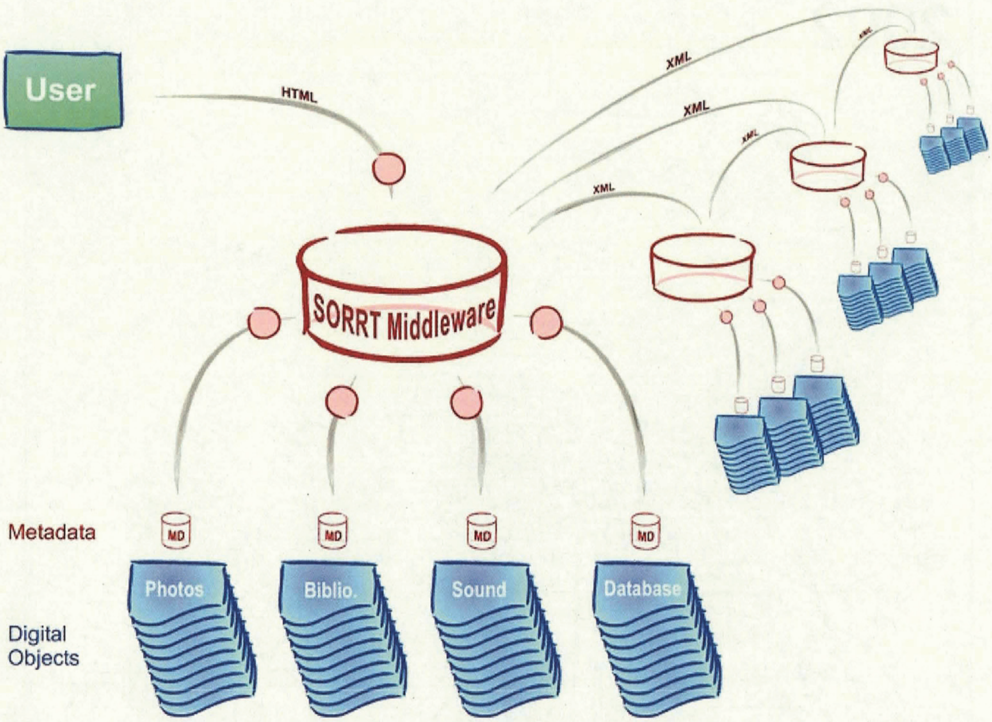


Fig. 7 Organisation of a distributed data repository using middleware developed for the Australian Partnership for Sustainable Repositories.

The end product of our work in the Living with Heritage project must be a sustainable system appropriate to the organisational structures and technical constraints of the Siem Reap region. At the present time we cannot presume on highly trained IT specialists, the latest hardware, stable Internet connections or even stable power, so the system constructed must be flexible, easily maintained and robust to the exigencies of the situation. Many of these issues will be tackled coincidentally through our work for the Australian Partnership for Sustainable Repositories. Our hope is to deliver a system with an intuitive web-based interface which emphasises the use of interactive maps based on the *Time*Map web mapping system, to place information in geographic context. I believe that the visual interface provided by interactive maps allows contextualisation of information in a way that is far more intuitive than the textual interface of most database software.

However, we hope to go further. Modern GIS software, such as the ArcGIS package we use for data and map development, also allows extrusion of features into a third dimension, the incorporation of 3D models and 3D navigation (fly-throughs) of a virtual landscape. The ACL has done some experimental work on using World Construction Set to develop 3D landscape models with embedded structures. Richard Fletcher built a through-time model of an archaeological site in Italy incorporating vegetation communities constructed according to rules rather than statically specified. David Hobson has modelled temples and landscape at Angkor, in some cases merging virtual reconstructions with contemporary digital video footage. Edmond Bina, an intern at the ACL, did some experiments on incorporating these models into a web-based delivery system (Active Worlds). Tom Chandler (Monash University), an associate of the GAP project, has experimented with rule-driven 3D modelling of the Angkorean urban habitat (Figure 11). Sara Kenderdine (Museum of Victoria) has embedded stereo panoramas into a 3D landscape model developed by the ACL for the museum's VROOM Virtual Reality display system. Erik Champion (University of Melbourne), funded by an ARC Linkage grant in partnership with Lonely Planet, has been testing user reaction to alternative ways of delivering 3D models of heritage monuments.

Over the next few years we expect to take our work on 3D models much further. Most modelling work in archaeology, heritage management and heritage delivery is based on static, constructed 3D models using specialised software such as 3D Studio Max. The only way of updating the models is through editing of the files in these specialised, expensive tools which require trained operators. What interests us is the generation of geographically-based 3D landscape models with embedded structures directly from a backend database which can be updated through simple browser-based tools, and web delivery of the resulting models on demand using the current database. This sort of technology is rapidly becoming a practical reality. We already do this for 2D web maps, and Open Source software is now appearing which will deliver 3D models over the web. We anticipate the use of such 3D models as an increasingly intuitive interface for contextualising the types of qualitative and quantitative information which we will be collecting and delivering for Angkor. Part of our work at Angkor will be in assessing the response of users -administrative authorities, residents and visitors - to these alternative methods of information delivery.

Conclusion

Angkor provides an extraordinary testbed, not only for archaeological work relating to the development and decline of the city - with all its implications for large scale pre-industrial settlements and, by extension, for sustainable modern development - but also for the development of methodologies for monitoring development in extensive World Heritage sites in developing countries. Such sites present complex problems of conflicting interests, differences in perception, negotiation of compromise and limited technical infrastructure.

For us the challenge is to develop spatially-based systems for recording and delivering information - both quantitative map data and qualitative observations - which are

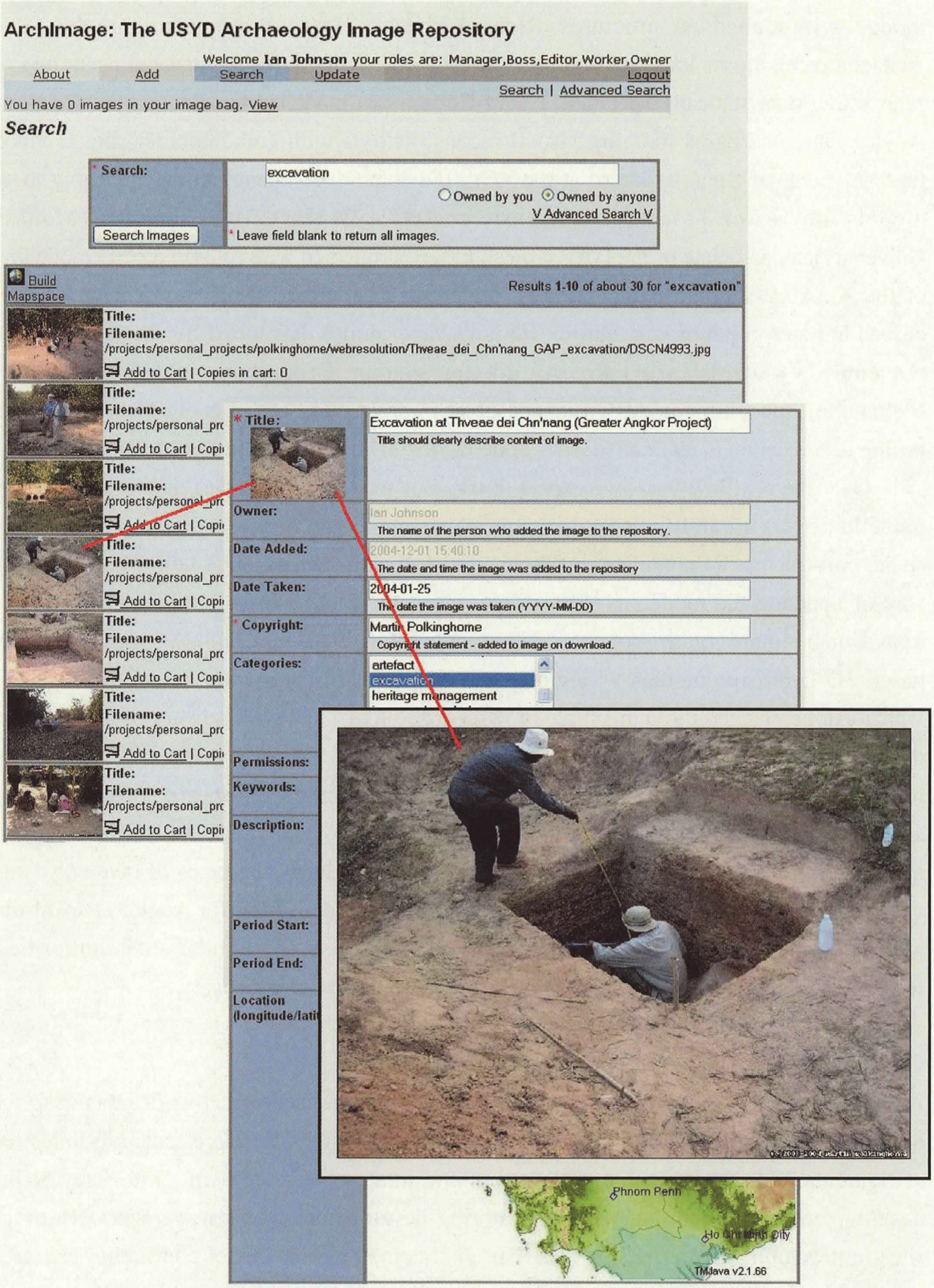


Fig. 8 The ArchImage system for management of digital images

Fig. 9 GIS training workshop at Siem Reap (photo courtesy Andrew Wilson)

appropriate to the structural context of sites with large contemporary populations. While there are of course significant technical problems, their resolution presents less complexity than the development of a methodology which respects the legal and social framework within which it must operate.

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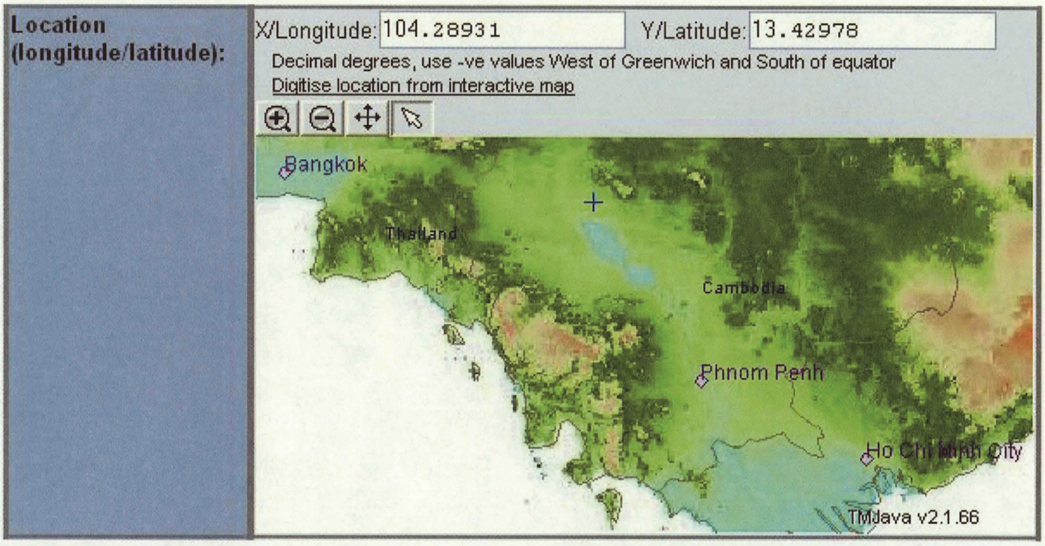

Fig. 10 Browser-based location recording from a TMJava map within the ArchImage system.

Fig. 11 Rule-based 3D model of the Angkorean landscape (Courtesy Tom Charlton)

アンコール研究：GISとGPS,
リモートセンシングと調査データの統合

イアン・ジョンソン

シドニー大学

シドニー大学チームは、数年間、カンボジア・アンコール遺跡において考古学調査を実施してきた。この調査では、2000km²以上の広大な範囲に点在するアンコール遺跡群の包括的なイメージ構築のために、基盤GIS、AirSARレーダー画像、その他のリモートセンシングデータが利用された。こうした技術は、従来の地図作製の範囲を2倍以上に拡大し、その構造と広大な用水システムに関する我々の理解を飛躍的に向上させた。このGISによる地図作製は、都市の成立、運営そして崩壊に関する新たな問題意識を励起させる。

2005年1月，我々は新しいプロジェクトのためにフィールド調査を開始する。この新しいプロジェクトは、開発による文化遺産景観への影響をモニタリングする方法を開発するため、まず既存のGISを基盤にして構築していく。このプロジェクトでは、同じように文化遺産管理者、観光客、住民なども含めた景観の経験や理解に関する情報をも地図化することを予定している。

開発に関する指標の識別のために、リモートセンシングデータを地表観察データとをマッチングさせる。この指標は、開発途上の国々において遺跡景観になじむような単純な技術で記録することができる。また、コミュニティーの視座とその他の質的データの文化遺産管理GISへの統合方法を開発している。これは地理的、考古学的、あるいは文化遺産管理に関わるデータを包括的に処理する情報システムである。このプロジェクトは、アプサラ機構（※カンボジア政府アンコール地域保存維持管理機構)、ユネスコ世界遺産センター、フランス国立極東学院などいくつかの機関と協力して進めている。ここで開発された方法論は、地域住民とともに広域に文化遺産・遺跡に適用できるよう意図されている。

この論文では、リモートセンシング、GIS、そしてGPSを用いた現地調査で得られたアンコール遺跡の広域と細部にわたる情報を地図化する方法と、これまで議論されてきた考古学的な問題について概説する。また、統合化された情報システムの中に、多様な権限の情報管理者を，分散型GISのデータセットとリンクさせるためのロバストな方法論の開発に関する新しい仕事について紹介する。さらに、質的なコミュニティー情報をGISに格納することに関する方向性と、Webを通じてコミュニティー情報を収集・抽出するTimeMap ウェブマッピングソフトウェアの利用についても議論する。