CREATING eRESEARCH TOOLS FOR ARCHAEOLOGISTS:

The Federated Archaeological Information Management Systems project

Shawn Ross[1], Adela Sobotkova[1], Brian Ballsun-Stanton[1] and Penny Crook[2]

Abstract

In this article, the Federated Archaeological Information Management Systems (FAIMS) project presents its stocktaking activities and software development towards the creation of a comprehensive digital infrastructure for archaeologists. A National eResearch Collaboration Tools and Resources (NeCTAR)-funded initiative, the FAIMS project aims to develop tools to facilitate the creation, sharing, re-use and dissemination of high-quality digital datasets for research and cultural heritage management. FAIMS has engaged in an extensive stocktaking and liaison programme with archaeologists and related professionals, the results of which have shaped the development plans. Project development is focusing on highly customisable mobile applications for data collection, a web application for data processing, and an online repository for archiving and disseminating data, with provisions for creating semantically and technically compatible datasets embedded throughout. Data exchange using standard formats and approaches ensures that components work well together, and that new, externally developed tools can be added later. Our goal is to create a digital system that respects the current workflow of archaeological practice, improves the availability of compatible archaeological data, and delivers features that archaeologists want to use.

Introduction

This paper presents the activities of the National eResearch Collaboration Tools and Resources (NeCTAR)-funded Federated Archaeological Information Management Systems (FAIMS) project. This project interrogates the entire archaeological data lifecycle for opportunities to improve efficiency and enhance the quality of data. Its ultimate aim is to produce and disseminate compatible datasets in a way that accommodates current archaeological practice and is broadly acceptable to the archaeological community. To accomplish these goals, we present a suite of modular, federated tools focusing on digital data creation, online archiving and data portability. The principal components of FAIMS developed during 2012–2013 include extensively customisable Android mobile applications, web applications for data editing and analysis, and an online repository for long-term data storage and dissemination. Each part of the system encourages mapping to shared concepts in order to produce datasets that are as compatible as possible, without placing an undue burden on researchers to alter their current methods and practices.

A Review of Archaeological Data Management

Archaeology stands on the brink of major change, propelled by converging technologies. In recent years, a revolution in mobile devices has occurred, epitomised by Apple's iPhone and iPad, but now extending to a vast array of devices built around Google's open-source Android operating system. At the same time, robust open-source ecosystems for data management, mapping and GIS, and other features of interest to archaeologists, have matured. High-quality online archives and publication services for archaeological data, such as the Australian Historical Archaeology Database (AHAD, <http://www.ahad.edu.au>) in Australia, or Open Context (<http://opencontext.org/>) and the Digital Archaeological Record (tDAR, <http://www.tdar.org>) in the United States (US), have been implemented. Grant-awarding agencies, including the Australian Research Council (ARC) and the National Science Foundation (NSF) in the US, are beginning to require data management plans, while data produced through consulting and public archaeology held in cultural heritage registers is gradually becoming more accessible, particularly overseas, for example, through the Archaeology Data Service (ADS, <http://archaeologydataservice.ac.uk/>) in the UK. Taken together, this environment provides fertile ground for the development of archaeological information management systems that shepherd data from digital creation, through editing and analysis, to online archiving and publication of reusable datasets. Such an ecosystem would improve the scope and rigor of archaeological research and cultural heritage management by facilitating reinterpretation, promoting regional and comparative studies, and broadly contributing towards the repurposing of data.

Archaeological information management, however, has yet to reach its full potential. Worldwide, archaeology suffers from 'small science' data problems that inhibit the production and dissemination of high-quality, compatible data: diverse and idiosyncratic datasets, customised methodologies and recording systems, lack of core data standards, and limited budgets, among others (Crook et al. 2003:35–43; Kansa and Bissell 2010; Kansa et al. 2010). In 2006 a US NSF-funded workshop concluded:

> ... for archaeology to achieve its potential to advance long-term, scientific understanding of human history, there is a pressing need for an archaeological information infrastructure that will allow us to archive, access, integrate and mine disparate data sets (Kintigh 2006:567).

[1] School of Humanities, Faculty of Arts and Social Sciences, The University of New South Wales, Sydney NSW 2052, Australia <shawn.ross@unsw.edu.au> <a.sobotkova@unsw.edu.au> <brianb@unsw.edu.au>

[2] Penny Crook, Faculty of Humanities and Social Sciences, School of Humanities, La Trobe University, Melbourne Vic. 3086, Australia <p.crook@latrobe.edu.au>

Articles

These conclusions were echoed in the 'Policy Forum' of the journal *Science* (Snow et al. 2006:959), which observed that 'archaeological research remains a mosaic of parochial efforts … [r]esearch on large geographical areas is particularly difficult at present'. Snow et al. suggested a way forward built around data standards and translation protocols, concluding that 'Federated databases and ontology-based database integration … provide the means for coordinated data management' (2006:959). Progress has been made, largely in the realm of discrete tools or resources, but there has been little attention paid to the development of information systems that manage the entire data lifecycle and full range of archaeological data. As a result, less technical and semantic interoperability has emerged than might be hoped (Kansa et al. 2011; Ross and Sobotkova 2009).

The availability of primary datasets has also been disappointing, despite the emergence of archiving and publication platforms like tDAR and Open Context, and the efforts of individual research projects (Crook and Murray 2006). Although such repositories are growing, only a small percentage of archaeological fieldwork results in the publication of a comprehensive online dataset, in part because the preparation and submission of data has not been integrated into typical workflows and data lifecycles (Fleischer and Jannaschk 2011). The most important exception is the ADS, which has become integral to the conduct of archaeology in the UK, dramatically improving the availability of data and the efficiency of archaeological research and heritage management[1].

In Australia, primary data publication is hindered not only by technical or workflow issues, but also by the fragmentation of cultural heritage regimes, including site and object registers, across states and between historical, Indigenous and maritime domains (Burke and Smith 2004:4.2; State of the Environment 2011 Committee 2011:22–29). This problem is compounded by comparatively restrictive intellectual property arrangements for commercial projects (Gibbs and Colley 2012:95), and widely adopted ethical obligations to protect culturally sensitive data. This situation has some parallels in the US but, in the latter, efforts to place publicly-funded or mandated cultural heritage information in the public domain are more advanced (e.g. tDAR), as are attempts to federate state and federal cultural heritage registers[2]. In Australia, initiatives such as La Trobe University's AHAD have sought to overcome these problems, storing and disseminating datasets related to historical archaeology—an accomplishment that FAIMS seeks to extend.

The challenges faced by data management projects, including FAIMS, therefore include the heterogeneity and complexity of archaeological data, fragmentation, IP and sensitive data issues, and a lack of shared standards. These technical, semantic, legal and ethical obstacles are compounded by the culture of the discipline, which has thus far preferred one-off solutions developed for individual projects or, at best, products geared for a single jurisdiction or destination archive—a situation that leads to duplication, under-resourced development efforts and sustainability problems. Software development for archaeology, as a result, has a mixed history. The FAIMS project is acutely aware of these failures and the challenges they represent, as well as the fact that many such attempts represented considerable expenditures of time and money. Data-capture applications in particular have rarely seen wide adoption. Web applications for online data management, archiving and publication have fared somewhat better, but still face challenges with uptake and sustainability. Although a full review of archaeological data management is beyond the scope of this article, a brief look at previous efforts provides necessary background to the FAIMS project.

Mobile data capture applications, whether designed for portable computers or smaller devices like PDAs, smartphones or tablets, have a key role to play in reforming archaeological information management, but their potential remains seriously underutilised. Mobile data capture systems have been produced since the 1990s, but very rarely have they advanced beyond the 'experimental' or 'prototype' phase. Moreover, in a review of mobile applications to date, we could find no evidence of a system that is used beyond a single organisation. Mobile applications for archaeology fall into four broad categories: (1) custom-built applications; (2) generic data loggers; (3) ESRI applications for PDAs; and (4) web 'apps'. Custom-built applications include early tools such as Nick Ryan's context-aware data logger from the late 1990s (Morse et al. 1998; Pascoe et al. 1999), or digital pens and hand-held devices developed during the Virtual Environments for Research in Archaeology project in the UK (Clarke and Riordan 2009; Fisher et al. 2009).

Generic data loggers exist for multiple platforms. There are several iPad apps (Wallrodt 2012) and, more recently, Open Data Kit (ODK) for Android has seen archaeological customisation for use at the site of Zagora in Greece (Havlicek and Wilson 2012). Its functionality, including its ability to deal with complex data or spatial information, is limited, as ODK was designed for simpler information gathering tasks, such as surveys and interviews.

ESRI ArcGIS, commercial geographic information systems (GIS) software, and its mobile component, ArcPAD, have been the most popular mobile development environment amongst archaeologists. ArcPAD has seen numerous archaeological customisations over the past decade (Campana and Sordini 2006; Ross et al. 2010; Sapienza 2013; Tripcevich 2004; Tripcevich and Wernke 2010). Implementing such a system has high barriers of entry, however, from the cost of an ArcGIS license, to knowledge of relational database design, to command of the complexities of ArcGIS itself, plus Visual Basic or Python programming if automation and validation are desired. In addition, hundreds of hours can be spent producing a well-developed ArcPAD application.

These ArcPAD-based mobile systems have demonstrated clear efficiency advantages over paper-based recording (Huggett 2012:525; Morgan and Eve 2012:542; Ross et al. 2010; Wagtendonk and De Jeu 2007), but most represent bespoke deployments limited to individual projects or organisations. Not only does this fragmentation duplicate effort and expense, but it produces idiosyncratic datasets that vary greatly in quality and complexity and are rarely compatible.

The last decade has seen a proliferation of web-based applications for the entry, editing and analysis of archaeological data. A team at the University of California San Diego has

[1] A recent impact study, presented by Holly Wright at the CAA conference in Perth, 2013, underscored the cumulative value of ADS as a resource for both the users and depositors of archaeological data.

[2] One such example is the Digital Index of North American Archaeology, a multi-institutional undertaking to create interoperability models for archaeological site databases in the eastern US (Kansa 2012).

developed ArchField for 3D recording of excavations. The application requires a local network and is currently in beta release (Smith and Levy 2012). A team of consulting archaeologists at L-P Archaeology in the UK has built an archaeological data collector called the 'Archaeological Recording Kit' (ARK) (Morgan and Eve 2012). ARK has a web-based front-end and provides a wide range of data editing, visualisation and sharing functions to users with internet connection. The Integrated Archaeological Database (IADB) project in the UK, which has mature desktop and web applications, is now working on an early prototype of mobile applications for multiple platforms. IADB was developed in the mid-1990s with a focus on excavation; it is currently used by 10 projects and has a fixed data structure originally geared towards cultural heritage management in Scotland (Rains 2011). Finally, there is Heurist, a web application for editing and analysing archaeological and related data developed by Arts eResearch at the University of Sydney. Heurist is a FAIMS component discussed later in this paper.

Web applications are well suited to the digitisation of existing data, the editing of complex datasets and visualisation of relationships between data, but they require continuous connectivity (again, to the internet or a local server), a limiting factor for field archaeologists. Given the connection constraint, the uptake of these applications has been limited, despite the fact that modern Android, iOS and Windows 8 mobile devices are much more capable than legacy PDAs used by ESRI.

Online archiving and publication are the most mature sectors of archaeological information management. Datasets are sometimes made available by individual projects (e.g. Catalhöyük [Çatalhöyük Research Project 2013]). Regional online catalogues (e.g. Fasti Online) also exist, but contain only coarse-grained site-level data. State or national cultural heritage registers are common, but they are designed for site-level cultural heritage management; not only can their data be very coarse-grained, but they also often restrict access, limiting their use for research (e.g. MEGA-Jordan, or the various historical and Indigenous registers in Australia).

The ADS in the UK represents the most mature digital archiving initiative[3]. It was launched in 1998 by the Council for British Archaeology and a consortium of eight universities. The first collections it hosted were the National Monuments Record's Excavation Index for England, National Monuments Record for Scotland and an Index to Microfilmed Archaeological Archives. Since its inception it has grown to include a wide range of digital data (fieldwork data from academic and public projects, archaeological bibliographies, consulting reports or 'grey literature', museum collections, etc.). Its grey literature publication initiative alone has been so successful that the collection has become a standard reference in the UK (ADS 2012:17; Hardman 2005). The ADS has come to be the official repository for UK archaeological data, and is now expanding its activities to Europe through the Carare project and Europeana network of content aggregators.

Two notable examples of online repositories from the US include tDAR and Open Context, both of which are FAIMS partners. These repositories have been cited by the US NSF as models for data management[4]. Each can sustainably house large, detailed and varied archaeological datasets, although each has slightly different aims. tDAR has been designed for data preservation (McManamon and Kintigh 2010), while Open Context is optimised for the online publication of reusable datasets (Kansa and Bissell 2010; Kansa et al. 2011).

An Australian implementation of tDAR, mirroring and contributing to the underlying code, forms the basis of AHAD, an expanded version of which will serve as the FAIMS repository (see below). Also in Australia, New South Wales Archaeology On-Line (NSW-AOL), another FAIMS partner based at the University of Sydney, represents an attempt to preserve and promulgate historical archaeology consulting reports (Gibbs and Colley 2012). Taken together, these archives represent significant progress, but most are geographically, chronologically or thematically limited, and offer varying capacity for interoperability or export of data in formats amenable to analysis and reuse. In comparison to the US and UK, Australian archaeologists have limited options for online archiving and publication of datasets.

In short, despite a number of notable efforts to date, the lack of high-quality, discoverable, accessible and compatible online datasets still hinders Australian archaeology (cf. Snow et al. 2006). This lack inhibits the re-interpretation and reuse of data, hampers regional and comparative study, and diminishes the value of archaeological research, as well as limiting our understanding of the past.

FAIMS

FAIMS is striving to overcome these challenges, particularly a troubling and frequent lack of uptake for data collection, sharing and archiving technologies. The cornerstone of our efforts has been a broad and deep engagement with the archaeological community in Australia and overseas. This engagement has sought to learn directly from large and small information management initiatives about what strategies for development, uptake and sustainability have proven to be relatively successful. It has also constituted a significant exercise in requirements assessment that led to fundamental project revisions. The end result, we believe, avoids as many of the shortcomings of previous systems as possible.

Project Background

The FAIMS project was initiated to develop robust information systems capable of managing the full range and diversity of archaeological data across its entire lifecycle, while also encouraging dataset dissemination and compatibility. Such systems are beyond the scope of individual research projects or organisations. What we had initially planned as a modest project to produce custom mobile device applications and databases quickly grew, leading to an (unsuccessful) ARC Linkage Infrastructure and Equipment Fund (LIEF) application in early 2012. The application was refined and the network of participants expanded over the course of two additional (unsuccessful) grant applications, eventually leading to a revised and expanded proposal that formed the basis of a successful NeCTAR eResearch Tools application underpinning the development described in this article.

[3] The ADS Impact project (ADS 2013), in particular, has demonstrated that ADS has achieved critical mass in UK archaeology and that its collection of grey literature reaches nearly systematic coverage.

[4] The NSF requirement for data management plans can be found in the Grant Proposal Guide, Chapter II.C.2 and endorsement of OC and tDar in Yellen (2011).

NeCTAR awarded the FAIMS project, led by UNSW, approximately $950,000 to develop archaeological information management systems between June 2012 and December 2013. Although this project was conceived and initiated in an Australian academic setting, and its primary focus was to boost archaeological research, broader participation has been crucial to its success. Most archaeologists in Australia work at consulting firms in the heritage management sector, producing the majority of Australian historical and Indigenous archaeological data (Ulm et al. 2005, 2013). The project, therefore, approached consultancies and state heritage agencies, offering to explore techniques for automating the acquisition and submission of required data and making that data more widely available for research. In an attempt to facilitate the participation of archaeologists not directly involved with development, the peak bodies representing the Australian archaeological community were also invited to review the project, leading to endorsement by the Australian Archaeological Association (AAA), the Australian Society for Historical Archaeology (ASHA), and the Australian Institute for Maritime Archaeology (AIMA). Global innovators in digital archaeology from North America and Europe were invited as well; with their support, we did not have to rediscover approaches or duplicate resources but could build on accumulated international experience.

With 40 partners drawn from the university, consulting, and government sectors from across Australia and overseas (Table 1), and total investment from NeCTAR and co-investment from partner organisations reaching over AUD$2.5M, the FAIMS project represents one of the largest international archaeology e-research initiatives undertaken to date. The enthusiastic response of the Australian archaeological community reveals its desire to address longstanding problems of data management and compatibility, and the scale of support offered by the NeCTAR scheme makes it possible for the FAIMS project to do so in a comprehensive manner.

Project Goals

FAIMS is developing a comprehensive information system for archaeology that is not only a first for Australia, but represents an improvement over similar systems internationally in terms of its breadth and flexibility. This system will allow data from

Lead Institution	Contributing Organisations
University of NSW	University of Sydney
	The University of Western Australia
Developing Organisations	The Australian National University
La Trobe University	The University of Queensland
Intersect	Flinders University
VeRSI	James Cook University
University of Sydney Arts eResearch	Macquarie University
Endorsing Organisations	Southern Cross University
Monash University	University of Canberra
University of Melbourne	Godden Mackay Logan
University of New England	Australian Cultural Heritage Management (Vic)
University of Sydney Library	Australian Cultural Heritage Management (SA)
Australian Archaeological Association Inc.	Eureka Archaeological Research and Consulting, UWA
Australian Society for Historical Archaeology	Central Queensland Cultural Heritage Management
Australasian Institute for Maritime Archaeology, Inc.	Snappy Gum Heritage Services (WA)
Heritage Branch, NSW Office of Environment and Heritage	Wallis Heritage Consulting
ACT Heritage (ACT Government)	Archaeological Research Facility, UC Berkeley
ACT Heritage Project	School of Information, UC Berkeley
Earth Imprints Consulting	Department of Anthropology and the Spatial Analysis Research Lab, Vanderbilt University
University of Texas Institute of Classical Archaeology	Department of Sociology and Anthropology, University of Indiana
Archaeological Research Laboratory at the University of Tennessee	MATRIX, Michigan State University
Archaeological Data Service	University of Leicester
	Archaeological Institute, Bulgarian Academy of Sciences

Table 1 FAIMS participating organisations. Developing Organisations are building the infrastructure, Contributing Organisations provided in-kind contributions and Endorsing Organisations endorsed the FAIMS project.

field and laboratory work to be 'born digital' using mobile devices, processed locally, edited and analysed using web applications, and archived and exchanged online through data repositories. Existing standards, components and tools have been incorporated where possible, with new ones developed only where they do not currently exist. Following recent trends in software development, the project has focused on open-source mobile and web applications, employing flexible and reusable data schema and user interfaces, rather than limiting users to fixed, predefined lists of entities and attributes or requiring them to create custom databases for every project or activity. This system streamlines the management of data and facilitates collaboration, reinterpretation and comparative study by allowing the production and dissemination of compatible, high-quality datasets.

Major initiatives of the FAIMS project include:

- Development of new, customisable Android applications to capture and process data.
- Incorporation and improvement of existing online applications for data editing, analysis and visualisation.
- Improvement and expansion of an existing online repository for archiving and sharing primary archaeological data produced in Australia or by Australians working overseas.
- Automation of the data transfer process between tools within the ecosystem and provision for the addition of new components in the future.
- Development of new approaches for the production of semantically, as well as technically, compatible datasets.

By the end of 2013, the project will have produced a stable public release of the Android applications, integrated an existing web-based application for editing and analysis (Heurist), and improved and expanded an existing online repository (AHAD).

Stocktaking and Requirements

FAIMS invested considerable time into stocktaking efforts, and fundamentally revised the project in light of these activities. We wished to identify and avoid the problems that have limited the uptake of other archaeological information technology projects. We have implemented as fully as possible the tenet that 'engaging closely with stakeholders is the precondition to designing a successful tool' (Jones and Williams 2005:34). Although our various stocktaking activities, including an online Digital Data Survey, a Stocktaking Workshop with workgroups and focus groups, and various follow-up outreach activities, may have been imperfect in their details, they substantially improved our development and offer a useful model for similar projects.

Digital Data Survey

The project's first formal outreach activity consisted of a Digital Data Survey (DDS), designed to gather information on the use of technology by archaeologists. The survey was aimed at academic, consulting and government archaeologists or related practitioners who produce or use archaeological or cultural heritage data, and included participants at all career levels. The survey focus was to capture current patterns of information technology use and define key obstacles to the increased use of technology within the archaeological community. While its goal was similar, its scope was smaller and its design less complex than the 'Strategies for Digital Data Survey' organised by the ADS in the UK (Condron et al. 1999). Our survey also complements the demographic analyses and vocational training survey of the archaeological community in the UK (Aitchison 2004; Aitchison and Edwards 2003) and US (Zeder 1997), and surveys of the archaeological profession in Australia (Ulm et al. 2005, 2013).

We collected 128 responses (79 from Australia, 39 from overseas; see Sobotkova 2013c). The sample of respondents was smaller than, but demographically similar to, that presented by Ulm et al. (2005, 2013). The main difference lies in the professional breakdown (see Figure 1), as the majority of FAIMS DDS respondents (n=32; 41%) identified their primary workplace as academic, whereas consultants dominated the Ulm et al. (2005, 2013) surveys. An element of self-selection seems also to have produced an over-representation of tech-savvy archaeologists in our sample. The results, nevertheless, imply that the initial target audience for FAIMS applications exists in Australia: a sizeable group of potential users falling on the left half of Rogers' (2003) bell

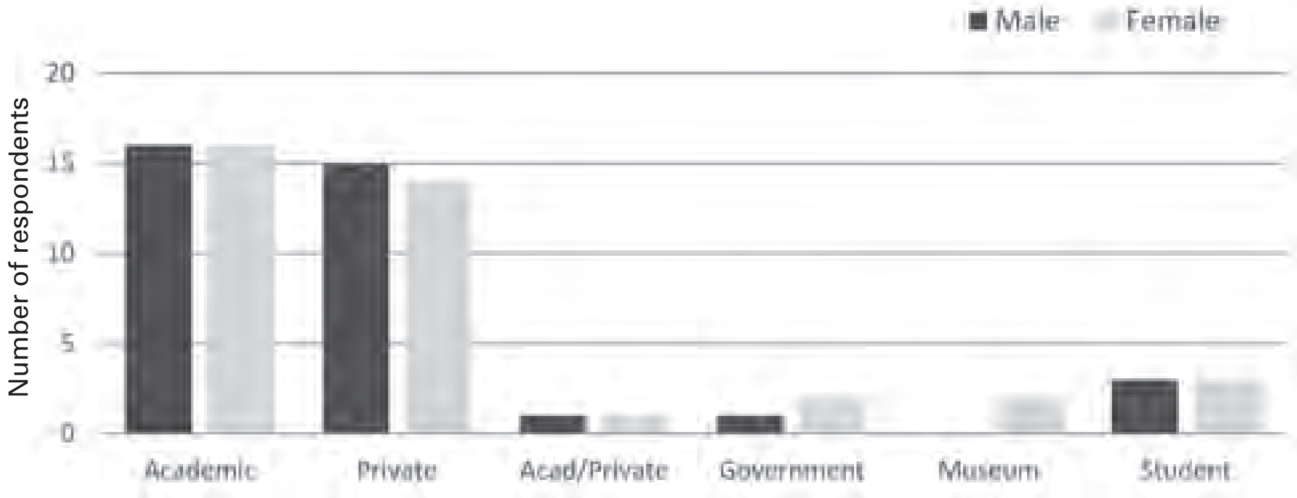

Figure 1 Breakdown of Digital Data Survey respondents by gender and primary workplace.

curve as 'innovators', 'early adopters' or 'early majority' with regard to the use of technology.

The results of our survey confirm a picture of archaeological data management in which practitioners use an idiosyncratic mix of data collection methods that includes many inefficient practices, such as paper recording with double entry. Figure 2 shows that, when asked about primary data collection methods, 84% of respondents use paper and 70% of archaeologists use laptops and desktops. These numbers reflect clearly the extent of double entry, as 84% of practitioners record information in the field on paper, so that 70% of them can later transcribe it into the appropriate spreadsheet or database in the office. PDAs are used by 5% and other mobile devices are used by 14% of respondents. These rates show that Androids and iPads have surpassed PDAs, but their usage is remarkably low, especially given the high (68%) reported rate of mobile device ownership.

The double-entry problem struck back when respondents were asked to rank a list of new tools according to their desirability (see Figure 3). The three most desired new tools were: laptop and desktop application for data entry (92% of respondents), data analysis tools (91%) and mobile device applications for field collection (87%). While there is no small interest in automating online data publication (81%) and data transfer (71%), tools facilitating initial data entry emerged as an absolute priority for the survey respondents.

Stocktaking Workshop

From its inception, the FAIMS project envisioned a major face-to-face Stocktaking Workshop with stakeholders prior to the start of development. The Workshop was held at UNSW on 16–19 August 2012, and drew about 80 archaeologists, associated researchers and software developers from Australia and overseas.

Principal topics of the workshop included information management technologies for creating and disseminating high-quality datasets, semantic barriers to producing comparable datasets, and the administrative, legal and ethical concerns surrounding data sharing. The workshop included plenary sessions providing context for smaller working groups (see <http://www.fedarch.org/workshop-proceedings/>). Plenary session speakers discussed current initiatives in digital archaeology from Australia and overseas, focusing on the challenges to their continued success. Many of the sessions raised issues surrounding data repositories and online publishing, areas less familiar to the Australian audience. Working groups concentrated on information management workflows, field recording needs and standards. They discussed specific problems, such as mobile device application requirements for data collection, editing and sharing, implementation of standards, and issues of sensitive data. The FAIMS project sought to learn the general characteristics of, and basic requirements for, proposed tools (such as mobile device applications for data capture), and specific strengths and weaknesses of existing tools adopted by the project (such as online repositories).

Working Groups

The working groups formed the heart of the workshop (Sobotkova 2013b). They included groups that focused on archaeological survey, excavation, artefact processing (divided between ceramics and lithics, the two most common artefact types), archaeological sciences (e.g. zooarchaeologists, palaeoecologists, geoarchaeologists, etc.), federation and data sharing, sensitive data and strategies for sustaining the tools and services developed by the FAIMS project. Group leaders, drawn from workshop attendees, were asked to discuss topics that included desirable tools for recording, analysis and research, and the core concepts and data standards necessary to produce compatible datasets. In practice, discussions began with these questions but ranged widely.

Outputs from the working groups often differed from what we had envisaged, but remained extremely valuable. Groups discussing data capture did not produce the detailed technical features we envisaged. Instead, they provided lists of general desires, excerpted in Table 2. The participants' overarching concern was that any applications developed must be extremely flexible and capable of accommodating their existing

'it needs to be as easy as paper recording',
'accommodate GIS input, output and visualisation of highest possible precision'
'it needs to facilitate data streamlining and cleaning'
'we need to be able to take paper notes, sketches, add files and annotate them'
'we want to control data input and impose vocabularies'
'increase commensurability and consistency'
'save, reuse, customise, proliferate schemas'
'work without web connectivity'
'synchronise data in the field'
'collect contextual and user data, such as weather conditions, identity of user, etc.'
'have auto-fill functions for dealing with repetitive data entry'
'indicate the 'level of confidence' or 'level of subjectivity' that the user/data entry person has with respect to any of the fields'
'capture changes when you upgrade/change records or schema (versioning), track to user'
'be able to re-label columns (aliasing)'
'be really rugged to handle Australian extremes (dirt, rain, heat, sun glare etc.)'
'have a LONG battery life'
'be affordable'

Table 2 Mobile device requirements articulated at the Stocktaking Workshop.

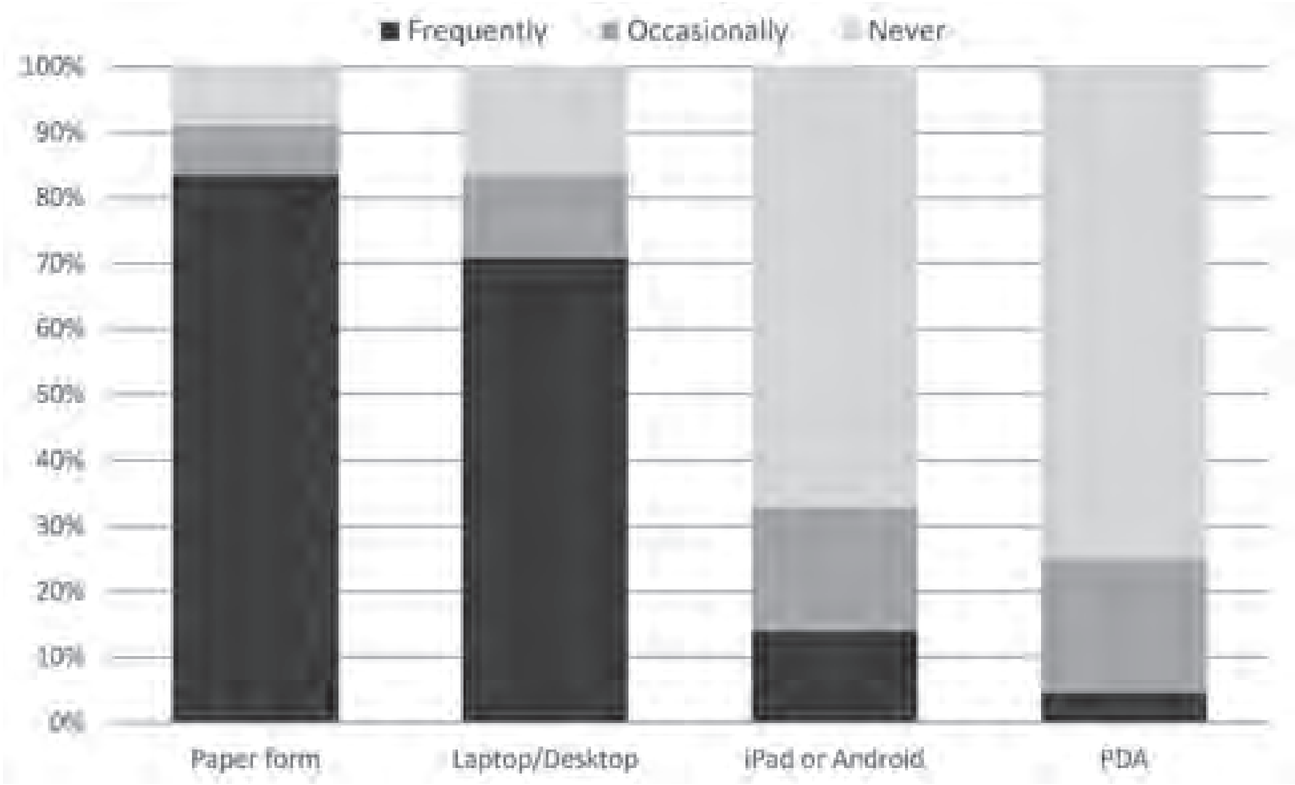

Figure 2 The frequency of media used by archaeologists for primary data collection.

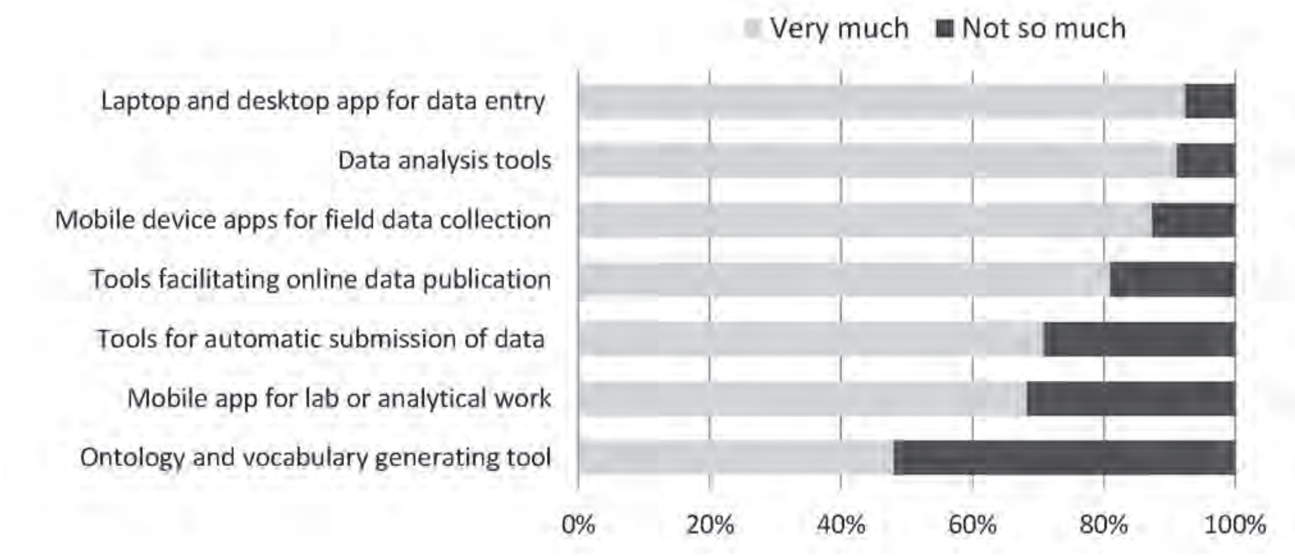

Figure 3 Digital tools rated according to their desirability by the DDS respondents.

vocabularies, workflows and practices. Workshop participants also insisted upon the ability to customise user interfaces and data schemata without having to create them from scratch, as is currently necessary when archaeologists use database management systems such as MS Access or MySQL.

Throughout the working groups, we saw little enthusiasm for adopting shared data standards or terminology. Few participants were willing to commit, for example, to adopting other vocabularies or to recording an agreed set of attributes about excavation contexts or lithic artefacts. However, many participants wanted applications to promote (but not require) data compatibility and other best practices in recording, so long as doing so did not require significant adjustment of existing research designs, workflows or terminologies. These user requirements, as per Table 2, forced a rethink of our approach to data capture and compatibility, which we had initially planned to build around a stable (if extensible) core of data standards, data schemata and user interfaces.

Participants reminded us that data can be deemed sensitive for a wide variety of reasons (e.g. legal, cultural, proprietary and protective), and that these reasons may vary over time, by geographical region, and between sub-disciplines. Therefore, online repositories need to be able to authenticate users and authorise the release of data only as desired by its owner.

We were advised to study carefully the sustainability plans of existing archaeological data archives, such as Digital Antiquity and the ADS. We intend to use these plans, as well as open source monetisation strategies (Kelly 2008), to justify providing free access to the outputs of FAIMS project, but to charge for data curation and individual customisation of the collection software.

Focus Groups
To maximise the value of the workshop, self-directed working groups were supplemented by six structured focus groups, facilitated by an experienced leader:

- Consulting archaeologists;
- Representatives of state heritage agencies;
- Managers of successful overseas online archaeological repositories;
- Field archaeologists (survey and excavation);
- Specialists in artefact processing (lithics and ceramics); and,
- Archaeological scientists (various disciplines).

The discussions of the focus groups were recorded, transcribed and analysed to supplement the information gathered in other fora, such as the survey and workgroup discussions (Sobotkova 2013a).

Focus group responses provided a broader view of archaeological information management, raising concerns about barriers to data sharing (especially challenging legal and regulatory frameworks), the risks for archaeologists of implementing new technologies, and the sustainability of FAIMS infrastructure. These concerns represent real risks to our project. Bringing the concerns to the forefront compelled us to reconsider the scope and direction of the FAIMS development and to elaborate our sustainability plan. Focus groups and members of the Steering Committee also recommended going beyond merely technological development and helping to improve Australia's regulatory framework by assessing the barriers to undertaking research using datasets held by state agencies, and promoting the convergence of reporting requirements around best practices.

Requirement Elaboration

After the results of the survey and the various workshop outcomes had been analysed, the FAIMS project undertook several months of elaboration, during which a significant portion of the project was reconceived. Elaboration involved developing user stories for various aspects of the project, turning these into technical requirements, and exploring what approaches could be taken to meet those requirements. We located suitable existing software, determined where new development would be needed, and estimated the difficulty and expense of that development. The result was a much better scoped and prioritised project, including a detailed software development plan and user requirements (Sobotkova et al. 2013).

FAIMS Development Plan

No information management system has yet been created which allows archaeologists to shepherd their data from digital creation through editing and analysis, to online archiving and dissemination. The FAIMS project aims to ensure that the critical parts of such a system are in place and working together by the end of 2013, prioritising the start (digital data capture with mobile applications) and end (archiving and dissemination through an online repository) of this workflow.

The most innovative part of FAIMS involves the development of new mobile device applications that exploit the power, screen size and other capabilities of modern mobile devices for the digital collection and management of data, including spatial data, structured data, free text, images, audio and video. The application is highly customisable, accommodating various tasks, including excavation, survey and artefact recording. At the same time, it facilitates the production of compatible, well-formed datasets, while remaining easier to implement than a bespoke database. This application will work offline, be 'versioned' (retaining a copy of all changes so that they can be reviewed and, if necessary, rolled back), synchronise across multiple devices, and support basic GIS functionality (display of raster images and display, creation and manipulation of vector data). The application is built for the Android ecosystem, which is more amenable than iOS or Windows to the open source approach promoted by NeCTAR and embraced by this project.

At the other end of the data lifecycle, we are contributing improvements to a proven online repository—tDAR—which will enhance its capacity for data sharing, allowing archaeologists to derive more utility from their own and others' data.

The middle steps of information management—data editing, analysis and visualisation—represent a mature and complex field, with many commercial and open source tools available. Our principal efforts in this direction involve demonstrating a complete workflow in which data is passed from the mobile device to editing and analysis platforms, and later submitted to a repository. Heurist has been chosen as a web-based, open source exemplar of such an application. Our data can also be exported in formats readable by ArcGIS and other commercial desktop applications.

Existing and future components not built internally by the FAIMS project are critical to our vision. We are not looking to build a 'walled garden', but hope to establish a system that includes choices at each stage of data management. Many of the components will, we hope, ultimately by developed externally to FAIMS but 'federated' so as to allow the automated exchange of data. Data created on the mobile device, for example, can be exported in a number of common formats, while tDAR provides for the import of diverse datasets. Use of open, widely accepted and well-documented standards and file types throughout the project ensures that the 'hooks' are in place to allow the federation of new components in the future.

Smartphones and tablets are rapidly replacing computers in many contexts (Schmidt 2011). Beyond the mobile realm, web applications are also displacing desktop software[5]. This article, for example, was produced using Google Apps for documents, spreadsheets and email, all of which are web applications. In light of these broader trends in software development, our project emphasises mobile and web applications rather than desktop software.

A Flexible Platform for Archaeological Research

The greatest challenge facing developers of archaeological mobile device applications involves providing sufficient flexibility

[5] For a discussion of the advantages of web applications, see the prescient and still-useful essay by Graham (2001).

without compromising performance and data integrity—particularly if we seek to improve the compatibility of resulting archaeological datasets. Initially, we planned to produce a data collection application built around stable, core recording standards. The FAIMS Stocktaking Workshop, however, revealed that archaeologists still disagree about fundamental aspects of data recording. Participants emphasised that project goals dictate recording strategies. They suggested that one reason no mobile application has yet come into wide use centres on the fact that few archaeologists are willing to accept applications that require them to conform to the terms, concepts, data structures and workflows developed for other projects or organisations.

We did not, however, want to create an application that required users to design and build data structures and user interfaces from scratch. Such an approach duplicates the strengths and challenges of existing mobile GIS applications like ArcPad and relational database management systems such as Access. Instead, our project has concentrated mobile application development on the production of an 'interpreter'—a program that generates a custom data schema and user interface from definition documents. These definition documents leverage a robust underlying system; they are easier to produce than a custom database, yet provide the desired degree of flexibility.

The Configuration Packet

FAIMS users customise the mobile application by adapting or creating a configuration packet. This packet consists of a project configuration file, plus four definition documents: data schema, user interface, logic (automation and validation of data entry) and concept mapping. These files embody the knowledge representation and tailored user experience required by an archaeologist for a specific project.

The configuration file contains project-level metadata, directory structures and file locations, and other project-level information. It allows projects to deploy this information across multiple instances of the mobile application. For example, all project-level information can be shared between two instances of the application: one for pedestrian survey and another for excavation.

The data schema document defines what archaeological phenomena and attributes are recorded. The basic approach to data assumes that any given archaeological activity (excavation, survey, artefact analysis) implies a limited set of indivisible record keeping entities. The fundamental entities for excavation, for example, might include 'stratigraphic unit', 'special find' and 'artefact group'. These entities are then described by attributes or observations (e.g. composition, dimensions, colours, etc.). Archaeological entities can, furthermore, be grouped. Individual stratigraphic units might be grouped into layers, features or horizons, which could then be described further by observations pertinent to the whole group. Entities and groups also need to be related to one another in various ways, with the nature of the relationship defined (e.g. above, below, adjacent to, part of, similar to, etc.). The data schema definition defines all such entities, attributes, groups and relationships.

The user interface and logic documents will allow customisation of the interface, including not only layout, but also a significant degree of procedural logic, automation and validation. Users will have the usual choices of various input types (e.g. checkboxes, radio buttons, look-ups, free text fields etc.), which can be distributed over a number of tabs, each of which will also scroll. The interface will inherit Android aesthetics, thereby offering a familiar visual environment. Procedural logic provides for a rich user interface, one which, for example, can populate drop-down lists based upon previous user choices (e.g. limiting the attributes in the list to those relevant to a particular type of artefact), perform complex validation as a function of other inputs (e.g. ensure that the individual attributes of a lithic artefact basically reflect expectations for its type, or generate the type from the attributes entered), and allows the automated creation of vector shapes (e.g. 'generate a 5 x 5 grid of pedestrian survey units with a walker spacing of 20 m').

The final component of the configuration packet is the concept mapping document, which maps local vocabularies used by individual projects against common archaeological concepts. Concept mapping represents a significant innovation developed by the FAIMS project, and will be discussed at length below.

FAIMS is in the process of building a library of definition packets, including customisations that accommodate current practice within sub-disciplines (e.g. historical or Indigenous archaeology), different field methods (e.g. continuous coverage vs site-based surface survey), state heritage recording requirements, or any combination of these parameters. FAIMS will also encourage and facilitate sharing of packets created by its user community. The publication and reuse of definition packets avoids the continual redevelopment of similar databases across multiple projects. In future, archaeologists will be able to select the existing packet that most closely meets their needs, then modify that packet as necessary, and finally resubmit their modification to the library for other projects to reuse (a development path similar to that of open source software itself). Over time, this ever-growing library will make the deployment of the mobile application easier.

Creating Compatible Data

As Kintigh (2006) and Snow et al. (2006) observed, the incompatibility of data from one project to the next hampers large-scale research. It became clear from our Stocktaking Workshop, however, that prescriptive approaches to data creation that require practitioners to conform to predefined standards and vocabularies remain unpopular. Much archaeological data is intrinsically compatible if barriers such as divergent terminology are breached; a small study currently in progress by Crook suggests that approximately 70% of data about any given class of artefact can ultimately be reconciled manually. FAIMS attempts to achieve this reconciliation automatically through non-prescriptive measures, where standard concepts are built into data applications and work in the background. FAIMS also shifts the building of compatible data to the time of its creation using the mobile application. In the past, alignment of datasets has been performed upon ingest of data into a repository or even later, at the time of use by a researcher. tDAR, for example, provides for 'ontology mapping', the manual correlation of concepts in an ingested dataset with a standard data model to create aligned datasets. Open Context, by contrast, facilitates the export of data 'slices' from different datasets in a manner that encourages their reuse and combination via open linked data (Kansa and Bissell 2010).

FAIMS accomplishes this task through techniques borrowed from 'internationalisation', an approach used in the information technology industry to adapt software to different languages (Esselink 2000; Texin 2010). The application can apply local aliases to shared core concepts, varied according to the practices of individual archaeologists, projects, organisations or archaeological communities. The core concept of 'stratigraphic unit', for example, could be mapped to any number of aliases (e.g. 'context', 'locus', 'spit', etc.). Creation and publication of core concept lists represents a significant research sub-project sponsored by FAIMS and led by Flinders University.

Versioning and Identity

The FAIMS application ensures a clear audit trail, identifying every user who changes project data. Since the design of the database only allows additions (the newest version of any given record is flagged as active, but older versions are retained), the mobile application ensures full 'versioning': changes can be tracked, linked to whoever made them and, when necessary, reverted, all of which were features requested during stocktaking.

Configuration, Synchronisation, Backup and File Management

For configuration, synchronisation and backup, we have implemented a local server, with the mobile devices as 'clients'. Initial setup takes place on the server, with the mobile application pushed out to connected mobile devices. After setup, mobile devices can operate independently of a connection to the server, but any time they join the server's wireless network they automatically synchronise their data with one another and with the server itself. All records are therefore available on all devices and fully up-to-date whenever connections to the server are present. These multiple copies also serve as a passive backup strategy, which, when combined with versioning, makes data loss extremely unlikely.

The FAIMS server can be accessed and configured through a web interface from any computer on the network, regardless of operating system. Records can be viewed and edited on the server or on the mobile devices. Users can also manage documents, images and other external files, linking them to records and attaching metadata. For example, scans of handwritten notes or drawings can be associated with individual records and annotated with creator information. Finally, the server application not only allows the data to be exported into other components of the FAIMS system, such as Heurist and tDAR, but also in a format accessible to other applications, as described below.

GIS and Mapping Features

Mapping and basic GIS features were flagged during stocktaking as requirements for the mobile application. The mapping features incorporated into the application meet the most common data entry and visualisation needs for pedestrian survey, excavation, and other activities, including:

- Display of georeferenced raster images (e.g. scanned maps and satellite images) in true position;
- Display of vector shapes (lines, points and polygons) in true position;
- Display of a user's position in relation to the raster and vector files;
- Drawing, selection and editing vector shapes;
- Generation of mathematically constrained vector shapes;
- Visualisation of multiple layers with control over symbology; and,
- Management of map projections.

In addition, the application will be spatially aware at all times using on-board or external Bluetooth GPS, allowing real-time and automated production of spatial metadata. In a significant improvement over most existing Android (and iOS) mapping software, all GIS functionality works offline.

Data Editing, Visualisation and Analysis

Initial FAIMS plans included data refinement, analysis and visualisation tools, which the elaboration phase of the project revealed as out of scope. As a result, we have prioritised mobile application development and online archiving and publication. Despite demand for data analysis and visualisation applications from stakeholders (Figure 3), this decision was taken for three reasons: the transformative potential of modern mobile devices, combined with the lack of existing options; the importance to the discipline of making primary datasets available online; and the relative availability of editing and analytical software. Existing software, such as ArcGIS, is currently in wide use and can continue to provide geospatial analysis and visualisation (Sobotkova 2013c). Data can be exported from the mobile application into ArcGIS. Spatial data will also be exportable in Keyhole Mark-up Language (KML) format, which can be displayed and shared via Google Earth.

The FAIMS project incorporates Heurist, an online data analysis and visualisation platform developed since 2005 by Arts eResearch at the University of Sydney (<http://www.heuristscholar.org/>), as an option for data refinement and analysis. Heurist can be used for routine data editing, but also facilitates fundamental reorganisation and rethinking of data. For example, its visualisation and association capabilities help with decisions regarding which excavation contexts should be included in which horizons, or which individual artefacts should be classified as which types. FAIMS is working with Arts eResearch to ensure a smooth, automated workflow that takes data from creation in the mobile application, through refinement in Heurist, to archiving and dissemination in tDAR and, potentially, other online repositories such as Open Context. Data and visualisations can also be exposed directly from Heurist for online publication, as has been done with the Dictionary of Sydney (<http://home.dictionaryofsydney.org>).

Online Archiving and Publication: An Australian Archaeological Repository

Online archiving and publishing are the most mature realms of the project. FAIMS builds upon the foundations laid by AHAD, an historical archaeological database established by La Trobe University (Crook and Murray 2006). FAIMS is improving AHAD to provide a stable, long-term repository for all Australian archaeological data.

AHAD is an implementation of tDAR, which includes intuitive interfaces enabling users to upload and manage their own data and create appropriate metadata without specialised training. It can accommodate datasets of any structure, and includes provisions for mapping project ontologies and vocabularies to its internal schemata, thus creating compatible datasets for integrated analysis (Spielmann and Kintigh 2011). In addition to copying structured data into its internal tables, tDAR stores imported datasets in their native format. tDAR encourages the creation of metadata to describe uploaded resources, including the allocation of one or more keywords for cultural groups, geographic locations, temporal phases, material classifications, investigation types, participants and sponsors. tDAR also has controls to protect sensitive data, a serious concern voiced repeatedly during the Stocktaking Workshop. It allows users to determine the availability of their data and, if the data is made public, the license under which it is distributed. Data can be embargoed for a set period of time. It can also be restricted to registered users, or even to individuals or groups based on identities determined at log-in. The FAIMS repository retains all of these features.

The FAIMS project expands AHAD to include Indigenous and maritime datasets, as well as data generated by Australian archaeologists working overseas. The repository will move from the La Trobe University library to the NeCTAR Research Cloud and the Research Data Storage Infrastructure.

Two other significant improvements are planned. Datasets created on the mobile devices and, optionally, edited in Heurist can be imported into the repository easily and automatically. FAIMS is also improving the granularity of data in the repository by allowing each record to be displayed as a single web page, following the 'one page per pot-sherd' model, in which the finest-grained entities in the database (e.g. artefacts and stratigraphic units) can be viewed individually.

With these improvements to the tDAR/AHAD repository, FAIMS will ensure that a stable, long-term archive is available for Australian archaeological data, one which will promote data discoverability and reuse.

Sustainability

A focus group of international participants in our project identified sustainability as the greatest short-term challenge facing the project. Currently, the FAIMS project is funded only through December 2013, with co-contributions from Development Organisations ensuring operation through December 2014. Plans for short- and long-term sustainability, however, are being produced based on recommendations from project participants who are involved with successful initiatives overseas.

Short-term plans for funding the project in 2014–2015 involve applying for further infrastructure grants. We have also secured the cooperation of a limited number of archaeologists based at Australian universities who have included costs for data management and archiving with FAIMS in their ARC applications, a practice we hope to expand in the future.

Long-term plans for 2015–2020 include moving to a model that is, where possible, sustained through mobile application customisation and repository data ingest fees[6]. Most online repositories, including tDAR, Open Context and the ADS, charge ingest fees, while selling implementation, customisation and hosting services is a proven way to raise revenue from free and open source software (Kelly 2008). The services offered by the FAIMS project also complement one another. Since by far the greatest cost related to data ingest into repositories arises from the refinement of 'messy' datasets, we plan to offer significant discounts to depositors with clean and well-structured data, such as that produced by our mobile application. Heurist, like other online data editing and analysis platforms, charges a project-based fee for use of the system. Federation between systems, like the FAIMS mobile application and Heurist, contributes to the sustainability of all components, as each increases its user base through the alliance.

Incentives for academic archaeologists to use FAIMS include the benefits of increased citation and professional credit that arise from the publication of primary datasets (Kansa et al. 2011:76). Grant-making bodies are also beginning to require open, online publication of research, including datasets[7]. FAIMS is prepared to help Australian projects and organisations to meet this expectation. At the same time, we hope to demonstrate to archaeological consultants that the mobile application will produce efficiency gains through the elimination of double-entry and the automation of report production that are sufficient to justify the costs of customisation.

Conclusion

The FAIMS project is building information infrastructure which incorporates mechanisms for the production and dissemination of high-quality and reusable datasets into the entire archaeological data lifecycle. We have consulted extensively to ensure that the tools we produce will meet the varied needs of users, and that approaches to data standardisation and compatibility are acceptable to practitioners. Surveying the archaeological IT landscape, the project chose to focus on developing new mobile applications for data collection, improving an existing online repository, and ensuring that these and other components work together in a modular, federated system. The mobile device application is uniquely adaptable, allowing archaeologists to retain control over how they record data on their own projects. Customisation is accomplished through a definition packet that is much quicker, easier and cheaper to produce than building a bespoke database with a field-deployable component. Concept mapping is built into the mobile device at project setup, promoting data compatibility unobtrusively within existing practices. Our mobile applications incorporate mapping, versioning and other key features. Data will be exportable from the mobile application ready for ingest into an implementation of tDAR for archiving and dissemination, or it can first be processed through a range of existing platforms for editing and analysis. Our repository will be enhanced to expose data in a more granular form, to improve accessibility, reuse and analysis. This holistic approach to the archaeological data lifecycle and our extensive consultation with archaeologists will produce tools that are more likely to see use in the field and laboratory, and therefore to address long-standing problems with information management and data availability that currently hinder archaeological research.

[6] Concerns about long-term sustainability of rapidly moving digital initiatives has dampened adoption rates (Jeffrey 2012).

[7] The ARC's Open Access Policy (<http://www.arc.gov.au/applicants/open_access.htm>) came into effect in January 2013. See also the data management requirements of the US NSF <http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_2.jsp#dmp>.

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We encourage readers to contact the FAIMS project with feedback and suggestions (<leadership@fedarch.org>).

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