Preprint of Huvila, I. & Uotila, K. Putting the pieces together: collaborative management of archaeological research data on the web. Uotila, K.; Mikkola, T. & Vilkuna, A.-M. (ed.) Castella Maris Baltici X, Suomen keskiajan arkeologian seura - Sälskapet för medeltidsarkeologi i Finland, 2012, XVII, 209-217.

Putting the pieces together: collaborative management of archaeological research data on the web

Isto Huvila and Kari Uotila

1 Introduction

Archaeologically relevant research data consists of a variety of different kinds of information including measurement data, photographs, charts, maps, drawings, notes, literature references and archival records. In most cases, the different types of documents are kept in physically separate places. Photographs are kept in archival boxes, digital photographs as files on a hard-drive or in a photo-management system. Notes are kept in notebooks and word processor documents, drawings on paper and in various digital files and references in notebooks or in a reference manager. The problem with having data in all these different formats and physically separate locations affect both an effective management and use of the assets. It is difficult to keep track of what material is where and in what condition, and what is the general status of the preserved data. For the same reason, the material does also tend to be difficult and time consuming to access and use.

Various approaches to merge individual types of archaeological data and to preserve it in integrated repositories have been discussed in the literature (e.g. Banning, 2000; Braccini and Federici, 2010; Carver, 2005; Dunn, 2006; Esteva et al., 2010). At the same time, for practical reasons, different archaeological institutions and national heritage boards have developed integrated systems, both manual and computerised, in different countries. In the majority of cases, however, the systems have been built for rather specific institutional and contextual purposes and the integration of different types of data has been limited by multiple technical and practical factors.

This article discusses a series of case studies of using a web based collaborative semantic wiki to store multiple types of archaeological and historical research data within one system that is accessible to the different stakeholders of the data. The notion of stakeholder is

understood broadly to include all conceivable parties with potential interest in the data including (but not limited to) excavating archaeologists, researchers, general public, cultural heritage administrators. The aim of this article is to map and discuss various possibilities and challenges related to using a wiki in the management of the archaeological research data. The article is based on three case studies of information management trials on three Finnish sites, Saari Manor (Mynämäki) and the castles of Kajaani (Swe. Kajana) and Kuusisto (Swe. Kustö).

2 Archaeological information

Archaeological information differs from other types of information and, more specifically, cultural heritage information in several respects. The accumulation process of archaeological information resembles that of archives (Shepherd, 2010) by the processual nature of how information builds up as a result of archaeological excavations and surveys. That process is in clear contrast to several other cultural heritage disciplines that are based on more explicit conscious selection and collection of materials and information. The second consequential similarity to archives relates to the appraisal and conscious disposal of material of less significance (Craig, 2004). The primacy of materiality and physicality of archaeological evidence distinguishes it from disciplines that focus on texts and makes archaeological information similar to other disciplines that study material culture.

The core information sources used by archaeologists consist of archaeological primary materials (e.g. finds and sites), scholarly literature and personal communication (Huvila, 2006). The general patterns of information source use are in line with the findings of the earlier studies on the humanities scholars, but unlike in several other humanities disciplines, the cross-disciplinary and scientific tendencies of the archaeological practises are considerably more typical on the level of individual information sources and information seeking archaeologists. The general tendency to make a distinction between primary and secondary materials, a variety of utilised information sources, and the long lifespan of the relevant literature are shared by the archaeologists and the majority of the humanities scholars (Tibbo, 1994; Tibbo, 2003).

Another aspect of significance of archaeological information is that all documents tend to serve a dual purpose of being both information containers and pointers to new information. Sources may contain direct links such as bibliographical references, but also indirect references to potentially interesting follow-ups such as the material,

find spot and the form of an object. The dual role of information can be traced back to the sporadic publication of results, but it seems to penetrate also to the contextual diversity of archaeological information needs. Archaeological material and information about the material are important, but even more important is to know the provenience of the material, the method of its acquisition and for which purpose it was originally collected. The information on the provenience is a prerequisite for the capability to use a set of secondary data (i.e. first-hand observations made and documented by another archaeologist) as a primary material. The importance of provenience applies broadly to all social science research, but archaeology may be argued to be especially sensitive to poor documentation of contextual information for two specific reasons. In comparison to many other fields of humanities and social science research, some individual pieces of archaeological data, for instance pottery sherds, are not as self-describing as texts, images or oral accounts. The second aspect of archaeological data relates to contextual distance between researchers and the objects of study. Even if it is risky to make analogies between the context of researcher and that of the subject of study, in archaeology it is often more difficult than with contextually closer topics. The consequence of poor contextualisation is that researchers are reluctant and unable to use secondary data if it is lacking information about the data collection methods used in its acquisition. Rice underlines the salience of proper contexts by stating that "the problem of access for research data is more than discovery" (Rice, 2005). The difficulties of understanding earlier information, and the consequent reluctance and inability to make tenable references to it, challenges the rationality of preserving any data. Therefore the process of collecting and preserving data should emphasise the importance of capturing and recreating the relevant and trustworthy contexts of the original information. Ulisse recognises a similar problem in the web publication of the archaeological records. The information is often available without being usable for most of the visitors (Ulisse, 2004). Researchers need to know how information was obtained and how conclusions were made in order to be able to judge whether the claims make sense from the point of view of their own perspective. The validity of data acquisition pertains to the technical validity of data collection methods, but also to contextual validity of the viewpoint of the archaeologist that collected the data.

A final aspect of significance for archaeological information as for any scholarly information is its political and purposive nature. Shanks and Tilley underline the political nature of archaeological claims noting that "archaeology is of the present" and it "involves

taking an ethical and political stand on the past in the present" (Shanks and Tilley, 1992). The values of archaeology are not merely subjective (Shanks and Tilley, 1992) and the interpretation of archaeological material is not a value-free process of documenting and disseminating objective facts about the human past. Archaeology is about expressing contextual and situated *claims* on the implications of the gathered evidence on past human activity (Lavento and Suhonen, 2003). The human past and the purposes, meanings and values related to its scholarly study and preservation depend on an individual viewpoint.

3 Challenges of information management in archaeology

Earlier studies of the information use of archaeologists have identified several information management related challenges. Archaeologists themselves have indicated that registers, catalogues and databases are important for their work, but records tend to be lacking in comprehensiveness and often also in the relevant information (Huvila, 2006). In general, archaeological information is only sporadically available. The problem is especially immanent in field archaeology. Reports on earlier investigations may be entirely non-existent or consist of some scattered notes, un-catalogued finds and fragmentary data (e.g. Rímon, 2005). An occasionally lacking documentation, the small number of researcher-archaeologists, and consequently, of publications, in many special fields of archaeology, limit the comprehensiveness and quality of the available information resources.

The observations made on the practices of archaeological work and information work processes during the present study provide indication of the resonance of several factors, which contribute to the construction of the situations and contexts in which knowledge emerges. The explicit processes of information work address the constituency of archaeological material, data and published information as the primary locus of knowledge formation. The effects of the situation and contexts of the emergence of the archaeological material and information, personal influence of the individual archaeologists and the social life-world within and outside of the communities of archaeologists, are implicitly acknowledged in their practises of information work. The implicit processes remain, however, highly tacit and thus unmanageable in other than *ad hoc* terms. Experienced archaeologists tend to have an instinct of how to 'read' archaeological information, but when the context of the reading becomes sufficiently alienated from the original context of

the data (e.g. because of the time), their capability to understand the information becomes diminished.

The interpretation of the archaeological material and the subsequent formation of archaeological knowledge is affected also by a number of subjective factors on each level of the interpretation (Trigger, 1993). Innovation and novel interpretations of archaeological data are 'products' created by individuals on the basis of their own conceptions and frames of reference. These internalised conceptions and frameworks are, on their turn, springing from the social and cultural context of the referrers. The notion of furthering the emergence of knowledge is dependent both on the coming up of the new interpretative frames and a continual critique of the current and past approaches.

Because of the contextual diversity and embeddedness of archaeological information work, successful management of information requires sensibility to the process of how archaeological information comes into being and its context. Orlandi (1999) summarises the constituent premises of archaeological informatics while discussing the ideas of Guimier-Sorbets (1996) on the role of multimedia in the publication of archaeological materials:

1. Like all scientific disciplines, archaeology is concerned with the treatment of information: The relation of archaeology and informatics and multimedia may thus be divided into three phases: elaboration of the documentation, interpretation, and diffusion of the results.

2. The third phase, diffusion, has to be based to the notion of publishing cumulative information.

3. The second notion begets a need to make effective typologies and to standardise archives and the archival processes.

4. Empowering the communication of ideas and information between researchers is constituent to the archaeological work.

According to the premises, first, archaeological information systems need to focus and accommodate the information work processes related to archaeological work instead of emphasising atomic data objects. The systems should grasp not only documentation, but also the following steps of interpretation and diffusion of the results. Furthermore, the systems should support accumulation of information, not only data. In order to be cumulative, a relevant degree of standardisation is needed. However, standardisation should be seen as instrumental to the accumulation of information and communication of ideas instead of being an aim in its own right.

According to Huvila (2006), the knowledge organisation related challenges of the practices of organising archaeological information

may be classified into two major categories, 1) structure and 2) dynamics related issues. The first category relates to the technical issue of how a data structure is capable of representing the complexity of archaeological information (the critical success factor of *fit* archaeological information work, Huvila, 2006). The second category is related to the question of how data structures support its dynamics *(sustainability*, Huvila, 2006). Knowledge organisation schemes and data structuring approaches discussed in the literature and used in practice encompass different approaches to address the challenges related to these categories.

Most of the current data management systems used in archaeological documentation and information processing are based on the relational data model (Codd, 1970; ref. e.g. Drap and Long, 2001; Hynst et al., 2001; and Papalexopoulos et al., 2001). The relational model is technically very efficient. A consequent reason for its popularity in archaeology is that it is the regular data model used in the majority of commercial and open source database management systems (ref. Bell and Eiteljorg, 2006). The major problems with the model is that it is not optimal for processing complex and heterogeneous data, and the attempts to process complex data lead to highly complex and difficult to manage relational structures.

The problems of the relational model have led to proposals of using more tractable data models. Hyperlinking represents an exemplary alternative approach, which has been suggested as a substitute to the relational model (e.g. Agnello et al., 2003). XML, Semantic Web and ontology related technologies promise flexibility, man and machine readability and extensibility (Niccolucci and Cantone, 2003; Schloen, 2001; Niccolucci, 2002; Barchesi, 2004; Bell and Eiteljorg, 2006; ref. also Cantone, 2002 and Ross, 2003). Neither hyperlinking nor ontology based approaches are entirely unproblematic. Veltman summarises the essential cultural heritage related problems of the present ontological approaches advocated by the Semantic Web movement to the issues relating to the 1) management of different world-views, 2) evolution of the definitions and meanings, 3) distinction between the words and concepts, 4) handling of the new classes of relations and 5) dynamism of the models of knowledge organisation (Veltman, 2004).

The first problem of the digital data processing relates to the use of absolute estimations instead of subjective interpretations, which are prevalent in the real-life contexts (ref. Gabucci, 2005). The poor fit of formal data structures in archaeology, is a result of the nature of the archaeological knowledge, which is primarily based on hermeneutical interpretations instead of ontological representations of truth (cf. Bénel et al., 2001). In an attempt to implement a support

mechanism for a more advanced degree of subjectivity, Niccolucci et al. have demonstrated the possibilities of using fuzzy logic to represent confidence and reliabilities (ref. Niccolucci et al., 2001; Hermon and Niccolucci, 2003; Hermon et al., 2004 and D'Andrea, 2004). Besides the subjectivity, similarly pressing problems relate to the representation of the complete dimensionality of the archaeological space (ref. Barceló and Vicente, 2004), the persisting issue of the huge amount and fast accumulation of data, and the linking and organising of all related information in meaningful entities.

The Semantic Web approach addresses the notion of multiplicity of knowledge claims by multiple coinciding ontologies (i.e. 'multiple overlapping truths') (Maedche et al., 2003). From the (non-philosophical) ontology point of view, the overlap, evolution and different versions are an issue that requires specific attention (Noy and Klein, 2004), but are basically a "solvable" problem. From the hermeneutically aligned point of view, on the other hand, the approach of seeing the overlap as a problem is a problem in itself. In the context of human knowledge, knowledge is perceived to be overlapping *per se* and here are the solutions in a sense of definite or parallel objective answers (Rittel and Webber, 1973). There is a clear difference between expressing a claim as an interpretation or as a parallel truth.

A further approach to counter the rigidity of the ontologies and taxonomies is based on participatory description and management of information. Folksonomies are based on collective tagging of resources and statistical clustering of the tags. Kansa (2006) suggests a folksonomy based approach for archaeological documentation. Zhou and Bénel (2008) have implemented such a system for studying Greek vases. Tags are potentially useful, but they do not *per se* negate the need of formal taxonomies or controlled vocabularies. From the management point of view, the most pressing concern with this approach is that folksonomies are equally difficult to control and manage as 'knowledge' or a piece of non-specific information. Social tagging may empower usability and make information more findable (Morville, 2005; Golder and Huberman, 2006), but it does not contribute specifically to making it more manageable.

Fox (2005) and his research group have focussed on a theoretically founded methodology for constructing a generic digital library framework, which may be used as a basis for domain specific digital libraries. The so called 5S methodology is based on an idea of first providing a highly general data structure. The new items and collections are imported with their respective schemas and directly

mapped to the existing framework. When needed, the existing schema is augmented with new additional objects (i.e. entities). The proposed approach has much strength. The inherent problem with such an approach is, however, the increasing complexity of the growing system when new collections are added. Simultaneously, the number of objects within each dimension increases and due to partial matches between them (Raghavan et al., 2005). For instance, objects VESSEL and POTTERY discussed by Raghavan et al. (2005), are not necessarily exclusive as object types. They merely originate from different collections.

4 Wiki approach to information management

Because of multiplicity of issues related to earlier models of managing archaeological information, the authors chose to explore an alternative approach with a specific aim of addressing the dilemma of formality and flexibility. Wiki is a web based software for collaborative writing and data management best known for its use in Wikipedia, the free encyclopaedia (www.wikipedia.org). Wikipedia is not, however, the only example of a wiki. Thousands of wiki-systems are used to manage a diversity of information all over the web and within different organisations. The word wiki is Hawaiian and means “fast” (Leuf, 2001). Wikis allow users to edit web documents using a simplified mark-up language. The languages vary between different wiki-systems, but the approach and functionality is similar. It is possible to mark text as title, create links and separate paragraphs, mark italics and strong text style using the mark-up. It is also possible to create links to documents that do not yet exist.

Besides being a technology, wikis represent also a particular type of approach to information management characterised by openness and participation. One of the key principles of the wiki approach is anyone (of those who have been granted a login, or, or instance, all web users) can edit a document. Even though many wiki systems have functions to restrict access to their content, in contrast to traditional information systems, the principal approach of wikis is based on openness. In a wiki, everyone can do anything unless explicitly forbidden (Ebersbach, 2008). Wiki systems save information on all changes made to documents and provide easy-to-use functions to revert to an older version (Ebersbach, 2008). In practice, in case of error or malicious edits, it is easier to repair the damage than to cause it.

5 Semantic wikis

A simple definition of a semantic wiki is that it is a traditional wiki

system augmented with Semantic Web technologies (Tazzoli, 2004). The purpose of these technologies is to improve searchability and machine-readability of the information available on the Web (Berners-Lee et al., 2001). In the context of semantic wikis, it is possible to enrich wiki data with semantic descriptors that make the information more findable and easier to integrate in other contexts of use.

The semantic wiki systems may be categorised into two broad groups. In the first type of semantic wikis the wiki functionality is built on top of a highly structured formal data model. KiWi (http://www.kiwi-project.eu) and Metaweb used in Freebase (http://www.freebase.com) are examples of this approach. The second type of semantic wikis is based on the wiki approach and the semantic functions are typically built on top of an existing wiki platform. An example of this approach is Semantic Mediawiki (http://www.semantic-mediawiki.org), a semantic wiki used in the present study, which is an extension to Mediawiki software, the wiki system used in Wikipedia. Semantic Mediawiki is used in diverse scholarly, professional and hobby related contexts (for examples, see http://smw.referata.com/wiki/Special: BrowseData/Sites). Most of the Semantic Mediawiki sites have been built to serve as digital libraries, document and information management systems. The semantic markup used in Semantic Mediawiki is based on RDF-triplets (subject, predicate, object). The triplets are used to formally describe documents. For instance, *a document HAS a version* CALLED *"report 2009-01-01"*. The triplets are inserted within normal Mediawiki documents using specific mark-up coding.

6 Mneme system and the management of archaeological data

The present study discusses a set of preliminary findings and observations from the first phase of an action research project on developing semantic wiki based documentation of archaeological sites. The focus of the documentation was on castle and manor sites. The project started in June 2008 with a development of the first 0.1 version of a semantic wiki based documentation system called Mneme. Both the scholarly study and development was done in short cycles using an approach inspired by agile software development methods and pair work (Conboy and Fitzgerald, 2004) of the two authors of the present article with frequent consultation of other experts. The data model, user interface and documentation process were planned, evaluated and revised simultaneously in an attempt to develop a comprehensive documentation approach with a special emphasis on the development and integration of new working

methods and the new documentation system. After an initial two weeks of field trials at Kuusisto Castle (Kaarina, Finland) and Saari Manor (Mynämäki, Finland) conducted in rapid development cycles, the work was continued off site with launches of new iterative versions of the documentation system on an approximately monthly basis.

An analysis of the project work and the first versions of the documentation system revealed several significant factors that relate to the documentation work and the development of systems to support it. A SWOT analysis of the strengths, weaknesses, opportunities and threats of semantic wiki based documentation systems was conducted to systematise the observations.

Strengths	**Weaknesses**
Flexibility (work routines) Flexibility (data) Collaboration support Single platform Linking Media integration	Learning curve Difference from traditional practices Management Network connection and synchronisation
Opportunities	**Threats**
Collaboration Dissemination Integration of work process Data integration Organisational change	Lack of collaboration Lack of organisation Process integration

Table 1: A SWOT analysis of a semantic wiki based archaeological documentation system

Semantic wiki based approach offers a mix of flexibility and formality both on the level of data models and on how documentation work is organised. *Flexibility* was clearly found to be a significant strength during the evaluation of the Mneme system. Trials at different sites and the contexts of building and field archaeology revealed both the need to adapt the preliminary data models in iterations and to adapt documentation to fit in the specific conditions of individual contexts. Similarly, it was possible to adapt the system to different work routines of individual archaeologists and projects by suggesting alternative procedures of inputting documentation. Semantic Mediawiki provides all *collaborative*

features of Mediawiki platform and as a web based solution and possibility to manage different *media* formats (images, tables, documents, text, structured data) on a *single platform* either as native data or attached documents, to *link* them to open and proprietary web contents.

The major weaknesses of the approach seemed to relate to the *learning curve* of the system and the *differences* between the wiki approach and the traditional work practices of archaeologists. Using Semantic Mediawiki in documentation work requires at least one person able to manage the complete repository and to construct the documentation framework. The need for better technical and information skills have been noted by the authors before (Uotila and Huvila, 2006), but there are many obstacles in the way. The principal difference between the wiki approach and the traditional archaeological documentation process is that in a wiki the documentation is inserted directly into the documentation system instead of first producing preliminary field notes. Another difference is that the semantic wiki forces to consider structures and relations between documented entities in an earlier phase than before. Another, weakness of the approach relates to the technical architecture of Semantic Mediawiki based on client/server model. Although networking technologies, computers and portable devices have developed rapidly, not all archaeological sites are located within the reach of reliable wireless communication and the possibilities to connect to remote servers. Local networks always need maintenance and due to the time constraints of archaeological work, the reliability of the documentation system is important. Running two copies of the system is also somewhat problematic, because it currently only partly solves issues related to the synchronisation of the two Semantic Mediawiki repositories.

The major opportunities of the discussed approach pertain to *collaboration* and *dissemination* of documentation and research results. Earlier studies have shown that the small number of published research papers and difficulties of access to documentation are major issues in archaeological information work (Huvila, 2006; Fox, 2005). For the same reason, it is difficult and time consuming to conduct comprehensive comparative studies. Another opportunity of the wiki approach is the possibility to *integrate the entire archaeological documentation process* within one system that allows flexible structuring and presentation of different versions and stages of data and interpretations. Similarly, it is possible to link and archive all relevant data files into the same easily accessible place.

Besides being flexible and adaptable to the premises of archaeological work practices, a semantic wiki based approach may be used also as a management instrument. Information systems may be, however, also used to facilitate positive *organisational change* in workplace procedures. At present, archaeological documentation consists of cycles of documentation and re-documentation directly in the field, after each work day in the field, post-excavation and publications phases. Even though it is clear that iterations are necessary to develop a thorough understanding of the documented archaeological site, it might be beneficial to reduce the amount of purely technical re-documentation work. A semantic wiki can function as an evolutionary documentation environment that allows the first field notes to develop into reports and final publications within a single integrated environment reducing the need for manual rewriting and processing of data.

The most apparent threats to this approach relate to work procedures and a lack of seizing of the opportunities. Even though a wiki based system affords *collaboration*, there are many social and technical reasons why the collaboration might not work. The flexibility of Semantic Mediawiki can be an advantage, but simultaneously it can be an issue. Because the platform does not enforce a specific approach to information organisation, the responsibility for the integrity and *organisation* of the documentation and the repository lies on its users and contributors. In contrast to digital libraries of similar or quasi-similar documents and information objects, the complexity of archaeological sites can make it difficult to manage a repository well. Finally, a significant threat is that the work procedures do not match effectively with the wiki approach. The advantages of evolutionary development and enrichment of documentation can work only if participants engage in the documentation work within the system.

7 Conclusions

In summary, the principal assets of a wiki-based approach is the relative ease of use of wiki-based systems, the flexibility of editing, describing and structuring data, support for basically any kind of data and the possibilities for collaboration in distance. The difference between the traditional and semantic wiki based work procedures is a major challenge for wider adaptation of the Mneme documentation system. In general, it is less advisable to adopt information systems that do not support current work practices. The development work of the Mneme system gave several insights into practical issues with the order of individual tasks supported by Semantic Mediawiki and

required by archaeological documentation work that required specific attention. One crucial difference is that wikis are based on the assumption that entities (i.e. wiki pages) are created first and images and other documents are linked to these entities thereafter. In archaeological fieldwork, however, the observation tends to come first before an archaeologist interprets it as an entity.

References

F. Agnello, R. Corsale, V. Franco, M. Lo Brutto, P. Midulla, P. Orlando, and B. Villa. Cultural Heritage and Information, An investigation into a Dedicated Hypertext. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXIV(5/W12): 7–12, 2003.

E. B. Banning. *The Archaeologist's Laboratory : The Analysis of Archaeological Data*. Kluwer Academic Publishers, New York, 2000.

Juan A. Barceló and Oriol Vicente. Some problems in archaeological excavation 3d modelling. In Magistrat der Stadt Wien Referat Kulturelles Erbe Stadtarchäologie Wien, editor, *Enter the Past, The E-way into the Four Dimensions of Cultural Heritage. CAA 2003 Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 31st Conference, Vienna, Austria, April 2003*, volume 1227 of *BAR International Series*, pages 400–404. Archaeopress, 2004.

L. Barchesi, C. Ceccarelli. Linguaggi dichiarativi per la ricerca archeologica. *Archeologia e calcolatori*, 15:95–113, 2004.

Tyler Bell and Harrison II Eiteljorg. XML: Panacea or panettone? Abstract of a paper presented in the 34th Annual Meeting and Conference of Computer Applications and Quantitative Methods in Archaeology CAA2006, Fargo, April 18-21, 2006.

Tyler Bell and Harrison II Eiteljorg. Still more on XML - finding a common ground. *CSA Newsletter*, 18(3), Winter2006. URL `http://csanet.org/ newsletter/winter06/ nlw0601.html`.

Aurélien Bénel, Elöd Egyed-Zsigmond, Yannick Prié, Sylvie Calabretto, Alain Mille, Andrea Iacovella, and Jean-Marie Pinon. Truth in the digital library: From ontological to hermeneutical systems. In *Proceedings of the fifth European Conference on Research and Advanced Technology for Digital Libraries, Darmstadt, September 4-9, 2001*, volume 2163 of *Lecture Notes in Computer Science*, pages 366–377, Berlin, 2001. Springer.

T. Berners-Lee, J. Hendler, and O. Lassila. The semantic web. *Scientific American*, 284(5):28–37, May 2001.

Alessio Maria Braccini and Tommaso Federici. An IS for archaeological finds management as a platform for knowledge management: The ArcheoTRAC case. *VINE*, 40(2):136–152, 2010. ISSN 0305-5728. 10.1108/03055721011050659.

Francesca Cantone. 3D standards for scientific communication. In Göran Burenhult and Johan Arvidsson, editors, *Archaeological Informatics: Pushing the Envelope CAA 2001. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 29th Conference, Gotland, April 2001*, volume 1016 of *BAR International Series*, pages 163–172. Archaeopress, 2002.

Eric Carver. Archaeological information systems (AIS): Adapting GIS to archaeological contexts. In Wolfgang Börner and Susanne Uhlirtz, editors, *Proceedings of the Workshop 9: Archäologie und Computer 3.-5. November 2004*. Stadarchäologie Wien, 2005.

E. F. Codd. A relational model of data for large shared data banks. *Communications of the ACM*, 13(6):377–387, June 1970.

Kieran Conboy and Brian Fitzgerald. Toward a conceptual framework of agile methods. In Carmen Zannier, Hakan Erdogmus, and Lowell Lindstrom, editors, *Extreme Programming and Agile Methods - XP/Agile Universe 2004*, volume 3134 of *Lecture Notes in Computer Science*, pages 19–32. Springer, Berlin, Heidelberg, 2004.

Barbara. L. Craig. *Archival Appraisal: Theory and Practice*. KG Saur, 2004.

A. D'Andrea. L'entropia dell'archeologia computazionale ovvero dall'ordine al disordine. *Archeologia e calcolatori*, 15:219–238, 2004.

Pierre Drap and Luc Long. Towards a digital excavation data management system: the "grand ribaud f" estruscan deep-water wreck. In *VAST '01: Proceedings of the 2001 conference on Virtual reality, archaeology, and cultural heritage*, pages 17–26, New York, NY, USA, 2001. ACM Press.

Stuart Dunn. ECAI – E-Science methods in archaeology: Development, support and infrastructure in the UK. Abstract of a paper presented in the 34th Annual Meeting and Conference of Computer Applications and Quantitative Methods in Archaeology CAA2006, Fargo, April 18-21, 2006.

Maria Esteva, Jessica Trelogan, Adam T. Rabinowitz, David Walling, and Stephen Pippin. From the site to long-term preservation: A reflexive system to manage and archive digital archaeological data. In *Archiving 2010*, volume 7, Den Haag, 2010. Society for Imaging Science and Technology.

Edward A. Fox. Digital libraries: Archaeology, automation, and enhancements. Technical report, Invited talk. The International Advanced Digital Library Conference (IADLC), Nagoya University, Japan, August 25-26, 2005.

Ada Gabucci. *Informatica applicata allarcheologia*. Carocci, Roma, 2005.

Scott Golder and Bernardo A. Huberman. Usage patterns of collaborative tagging systems. *Journal of Information Science*, 32 (2): 198–208, 2006.

Anne-Marie Guimier-Sorbets. Le traitement de l'information en archéologie: archivage, publication et diffusion. *A&C*, 7:985–996, 1996.

Sorin Hermon and Franco Niccolucci. A fuzzy logic approach to typology in archaeological research. In *CAA 2002 The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 30th Conference, Heraklion, Crete, April 2002*, pages 307–310. Archive of Monuments and Publications, Hellenic Ministry of Culture, 2003.

Sorin Hermon, Franco Niccolucci, Francesca Alhaique, Maria-Rosa Iovino, and Valentina Leontini. Archaeological typologies - an archaeological fuzzy reality. In Magistrat der Stadt Wien Referat Kulturelles Erbe Stadtarchäologie Wien, editor, *Enter the Past, The E-way into the Four Dimensions of Cultural Heritage. CAA 2003 Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 31st Conference, Vienna, Austria, April 2003*, volume 1227 of *BAR International Series*, pages 30–34. Archaeopress, 2004.

Isto Huvila. *The ecology of information work – A case study of bridging archaeological work and virtual reality based knowledge organisation*. Åbo Akademi University Press, Åbo, 2006. Diss. Åbo Akademi University.

Stefan Hynst, Michael Gervautz, Markus Grabner, and Konrad Schindler. A work-flow and data model for reconstruction, management, and visualization of archaeological sites. In *VAST '01: Proceedings of the 2001 conference on Virtual reality, archaeology, and cultural heritage*, pages 43–52, New York, NY, USA, 2001. ACM Press. ISBN 1-58113-447-9. http://doi.acm.org/10.1145/584993.585000.

Eric Kansa. Data integration with ArchaeoML and tagging. Abstract of a paper presented in the 34th Annual Meeting and Conference of Computer Applications and Quantitative Methods in Archaeology CAA2006, Fargo, April 18-21, 2006, 2006.

Mika Lavento and Mervi Suhonen. Arkeologinen hypermedia: taidetta, tosiseikkoja, artefaktituotantoa. *Muinaistutkija*, (1):41–46, 2003.

A. Maedche, B. Motik, and L. Stojanovic. Managing multiple and distributed ontologies on the Semantic Web. *The VLDB Journal*, 12 (4):286–302, 2003.

Peter Morville. Presentation "Ambient Findability" in the "Panel on the intersection of IA (information architecture) and KM (knowledge management) at the Second International Conference on Knowledge Management 2005: Nurturing Culture, Innovation and Technology. Charlotte, NC. 27th October 2005. 2005.

Franco Niccolucci. Xml and the future of humanities computing. *SIGAPP Applied Computing Review*, 10(1): 43–47, 2002.

Franco Niccolucci and Francesca Cantone. Legend and virtual reconstruction: Porsenna's mausoleum in x3d. In M. Doerr and Sarris A., editors, *CAA 2002 The Digital Heritage of Archaeology. Computer Applications and Quantitative Methods in Archaeology. Proceedings of the 30th Conference, Heraklion, Crete, April 2002*, pages 57–62. Archive of Monuments and Publications, Hellenic Ministry of Culture, 2003.

Franco Niccolucci, Andrea d'Andrea, and Marco Crescioli. Archaeological applications of fuzzy databases. In Zoran Stancic and Tatjana Veljanovski, editors, *Computing Archaeology for Understanding the Past, CAA 2000, Computer Applications and Quantitative Methods in Archaeology, Proceedings of the 28th Conference, Ljubljana, April 2000*, volume 931 of *BAR International Series*, pages 107–115, Oxford, 2001. Archaeopress.

Natalya F. Noy and Michel Klein. Ontology evolution: Not the same as schema evolution. *Knowledge and Information Systems*, 6 (4): 428–440, 2004.

Tito Orlandi. Multimedialità e archeologia. *Archeologia e calcolatori*, 10:145–157, 1999.

Dimitris Papalexopoulos, Eleni Kalafati, and Sakis Papadopoulos. Building memory. In *VAST '01: Proceedings of the 2001 conference on Virtual reality, archaeology, and cultural heritage*, pages 27–32, New York, NY, USA, 2001. ACM Press.

A. Raghavan, N.S. Vemuri, R. Shen, M.A. Gonçalves, W. Fan, and E.A. Fox. Incremental, Semi-automatic, Mapping-Based Integration of Heterogeneous Collections into Archaeological Digital Libraries: Megiddo Case Study. In *Proceedings of the European Conference on Digital Libraries, ECDL 2005, Vienna, Sept. 18*, volume 23, 2005.

Ilana Rímon. Arkeologista aaltoliikettä - Porwoon tutkimushistoriaa 1800-luvulta nykypäivään. *SKAS*, (3):21–29, 2005.

H.W.J. Rittel and M.M. Webber. Dilemmas in a general theory of planning. *Policy sciences*, 4(2):155–169, 1973. ISSN 0032-2687.

Seamus Ross. *Towards a Semantic Web for Heritage Resources*, volume 3 of *DigiCULT Thematic Issue*, chapter Position Paper on integrity and authenticity of digital cultural heritage objects, pages 7–11. DigiCULT, Salzburg.

J.David Schloen. Archaeological data models and web publication using xml. *Computers and the Humanities*, 35(2): 123–152, May 2001.

Michael Shanks and Christopher Tilley. *Re-Constructing Archaeology: Theory and Practice*. Routledge, London, 2nd edition, 1992.

Elizabeth Shepherd. Archival science. *Encyclopedia of Library and Information Sciences, Third Edition*, pages 179–191, 2010.

Bruce G. Trigger. *Arkeologins idéhistoria (orig. A History of Archaeological Thought)*. Symposion, Stockholm/Stehag, 1993.

F. Ulisse. Considerazioni sulla reale usabilitá di mappe, gis e cartografia a contenuto archeologico su web. *Archeologia e calcolatori*, 15:521–529, 2004.

Kari Uotila and Isto Huvila. The Education of Little Archaeologist? Reflections on the digital education and training of archaeological professionals. In *Proceedings of the International Congress Kulturelles Erbe und Neue Technologien Workshop-10 Archäologie und Computer*, Wien, 2006. Magistrat der Stadt Wien, MA 7 - Referat Kulturelles Erbe - Stadtarchäologie.

Kim H. Veltman. Towards a semantic web for culture. *Journal of Digital Information*, 4(4), March 2004.

Xiaomu Zhou. Student archival research activity: An exploratory study. *American Archivist*, 71(2):476–498, September 2008.