PIA Volume 21 (2011), 80-90 DOI: http://dx.doi.org/10.5334/pia.381

Advancing Theory? Landscape Archaeology and Geographical Information Systems

Di Hu*

This paper will focus on how Geographical Information Systems (GIS) have been applied in Landscape Archaeology from the late 1980s to the present. GIS, a tool for organising and analysing spatial information, has exploded in popularity, but we still lack a systematic overview of how it has contributed to archaeological theory, specifically Landscape Archaeology. This paper will examine whether and how GIS has advanced archaeological theory through a historical review of its application in archaeology.

Introduction

Despite the increase in popularity of GIS in archaeology in the past decade, there is still a rift between those who are enthusiastic about its promise to advance theory and those who believe that GIS is mainly a map-making tool that does not warrant this high level of enthusiasm. Through a historical treatment of the development of GIS in Landscape Archaeology, this paper seeks to evaluate the contributions to theory made by GIS applications in Landscape Archaeology. Has the use of GIS generated new theory? Have the practical limitations of GIS prejudiced its potential to generate archaeological theory? This paper will argue that while GIS cannot be credited with the emergence of innovations in spatial analysis, such theoretical innovations are enriched through testing with the aid of GIS.

Definitions of Landscape Archaeology

Landscape Archaeology has played an ever more important role in understanding the past since the 1920s, and enjoyed great popularity during the 1960s and 1970s at the height of the New Archaeology movement (Bintliff 1996: 246). Landscape Archaeology can be broadly defined as the study of cultural and environmental variables influencing the way humans interacted with their landscape (Yamin and Bescherer 1996; David and Lourandos 1999; Ingold 1993).

Despite its great popularity, defining what Landscape Archaeology is and has been is contentious. On a practical level, Landscape Archaeology is the study of "diffuse" human remains or the cultural spaces "between the sites" (Knapp and Ashmore 1999: 2). From a theoretical standpoint, however, 'landscape' remains difficult to define clearly because there are different conceptions of space and thus what a landscape is (Witcher 1999). The two main definitions of 'landscape' can be characterised as 'scientific/abstract' and 'humanised' (Tilley 1994). The first definition sees landscape as quantifiable, universal, objective, neutral, a-temporal, static and absolute (among other things), whereas the second definition sees landscape as qualitative, experienced, contextual, relative, temporal and dynamic (Tilley 1994: 14). This latter definition of landscape, as summed up

* University of California, Berkeley

Fig 1: The 'humanised' landscape.

by Ingold (1993), is "the world as it is known to those who dwell therein, who inhabit its places and journey along the paths connecting them." Archaeologists who espouse this second definition argue that space is not a neutral receiver of human action but rather a meaningful medium for, and product of, human action (Wheatley and Gillings 2002: 8). This definition of landscape treats space as socially constructed, subjectively experienced, and inextricably tied to multiple meanings at multiple times (Bender 1993: 3; Boaz and Uleberg 1995: 252; Green 1990b: 358; Hirsch 1995). Therefore, there is no 'neutral' space that researchers can abstract from social life. Since the mid-1980s, this second definition has become much more popular than the 'scientific/abstract' view (Attema 1999: 23; Winterbottom and Long 2006: 1356; Witcher 1999: 13-14).

However, as Tilley has observed, these two conceptions of space and landscape are not mutually exclusive of each other, and archaeologists tend to define "landscape" using a combination of the two (Tilley 1994). For example, Witcher emphasised that the second definition of "landscape" does not preclude the first: "Integral to such hermeneutic and phenomenological approaches has been a de-quantification of space, permitting landscape to be social and qualitative, as well as economic and geometric" (Witcher 1999: 13-14). From the two definitions, one can derive a view of landscape as the context in which humans survive, cognise the world, act, and make meaning.

Because the advent of the second understanding of landscape coincided with GIS technological advances in the late 1980s and early 1990s, most of the studies that aimed to innovate methodologically often drew from some form of the second definition of landscape. For that reason, this paper focuses on studies that have attempted to understand past landscapes through the second 'humanised' definition of space.

What is Geographical Information Systems (GIS)?

Geographical Information Systems (GIS) is a set of computer tools for making and analysing spatial information (Bolstad 2005: 1). While all of the fundamentals of spatial analysis methods pre-date computer applications, the advantage of a GIS is its ability to compute thousands of complex spatial relationships from data, something impossible with traditional maps. In a GIS, data can be computed from a 'raster' or a 'vector' model, and layers of vectors and rasters can be overlaid, giving even more power in computing spatial relationships (Aldenderfer 1996: 4). 'Vector' models employ points, lines, and areas to represent spatial data, and are good for non-continuous data like boundaries or representing spatial relationships in the form of topology. 'Raster' models are based on small square cells and are better for representing more continuous or mixed data, such as frequencies of artefacts, terrain, and distributions of people (Bolstad 2005: 33-49). Vector and raster models are easily interchangeable. Because data can be represented in layers, spatial data over time can be easily analysed, with each layer representing a period in time, not unlike traditional archaeological stratigraphy (Allen *et al.* 1990). GIS software can help researchers see the contingent effects of many factors over space and time, which gives it a big advantage over static maps (Bolstad 2005).

Scale is also less of an issue in GIS because one can analyse different types of spatial data (for example, artefact distributions at a single site alongside the inter-visibility of sites) using one single dataset. The continuity of scale and integration of statistical and spatial programmes afforded by GIS therefore make it ideal for Landscape Archaeology (Aldenderfer 1996; Daly and Lock 2004).

Applicability of GIS in Landscape Archaeology

Because GIS organises spatial data and integrates tools to analyse spatial data, it is an ideal and versatile tool for the study of landscapes (Gillings and Mattingly 1999). GIS was used almost immediately by archaeologists as soon as the tools were available. In fact, the case studies in the highly influential volume *Interpreting Space: GIS and Archaeology* all dealt with landscape (Allen *et al.* 1990). In the volume's introduction, Green argued that *only* landscape-based archaeological approaches could fully take advantage of the capabilities that GIS has to offer as well as advance archaeological theory (Green 1990b: 5). Whether or not *only* landscape-based approaches could fully take advantage of GIS is debatable, but there is a general consensus that GIS is a very powerful tool to study landscapes because of its ability simultaneously to analyse space, time, and form (Green 1990b: 356).

In addition to analysing the environmental and economic factors in culture change, Wheatley argued that GIS was ideal for analysing social and ritual landscapes because one could test different proxies for visual perception (Wheatley 1993; 1996). Wheatley also argued that GIS can help researchers explore social organisation more contextually (spatially) instead of using terms like "chiefdoms" that are ambiguously defined (Wheatley 1996: 76-77). Wheatley's argument for using GIS to explore social organisation came after Crumley's influential article about using multi-scalar approaches to study social organisations and landscapes (Crumley 1995). Llobera argued that GIS could be used to study social space and meaning from more practice-based approaches (Llobera 1996; for a more detailed review of the capabilities of GIS and how it relates to questions that researchers attempted to answer, see Kvamme 1999).

GIS can be used not only to help answer archaeological and anthropological questions, but also to help us approach such questions in a multi-scalar way (Daly and Lock 2004). This is especially useful because Trifkovic described how many of the problems plaguing Landscape Archaeology have

to do with the tension between the molecular (individualised) and global scales of agency-landscape relationships (Trifkovic 2003: 2-3). Daly and Lock also maintained that GIS databases of survey and excavation data avoid the de-contextualisation of archaeological material common among specialists (Daly and Lock 2004).

Has the Use of GIS Generated New Theory?

Despite the applicability of GIS in archaeology, Lake and Woodman showed how GIS analyses of visibility have recapitulated pre-GIS methods (Lake and Woodman 2003: 692). This leads us to the question of whether GIS is merely a new, albeit more precise and efficient, way of doing old things, or whether it is a methodology that can advance archaeological theory (Lock and Harris 1997). This preoccupation has spurred many archaeologists to find ways to use GIS to advance archaeological theory, most notably in the areas of cognition, ritual, and viewshed analysis (e.g., Wheatley 1993; Llobera 1996; Ruggles *et al.* 1993). Wheatley considered that some views of GIS as "theoretically neutral" were untenable because other technological advances, such as carbon-14 dating, had influenced archaeological theory greatly (Wheatley 1993: 133). Maschner argued that investigating how humans perceive landscapes might be one of the biggest future contributions to social science (Maschner 1996b: 305). Other authors were also optimistic about GIS advancing archaeological and social theory (Attema 1999; Wise 2000; Witcher 1999). Maschner argued that GIS use in archaeology can become more sophisticated through an increase in the number of archaeologists incorporating it into their research agendas (Maschner 1996b: 302). More recently, Verhagen and Whitley have proposed ways of making generally a-theoretical predictive modelling relevant in theory and model formulation (Verhagen and Whitley 2011). While there is no doubt that GIS can advance our understanding of middle range theory (e.g., Bevan and Conolly 2002 on 'site' definition), it is not clear whether GIS can advance higher levels of theory. Is the optimism expressed by such archaeologists about GIS advancing archaeological and anthropological theory unwarranted?

On one hand, the methods often associated with GIS existed pre-GIS, and applications of theory in GIS reflect wider theoretical debates. For example, the GIS-based cumulative viewshed analysis developed by Wheatley was methodologically identical to Renfrew's 1979 analysis of the viewsheds of Rousay cairns in which he overlaid the viewshed of each cairn to show the areas of overlap (Wheatley 1996; Renfrew 1979). Similarly, non-Euclidean distance maps had already been calculated pre-GIS to reflect more realistic site catchments (Ericson and Goldstein 1980) and cost distance maps based on travel times (Gorenflo and Gale 1990).

Archaeological analyses using GIS also tended to reflect rather than generate theoretical developments. After the publication of key books addressing history, memory and practice, and perception in landscape archaeological theory (i.e. Bender 1993; Bradley 1994; Ingold 1993; Renfrew 1994; and Tilley 1994), there was an explosion of GIS applications of such theories (e.g., Ruggles *et al.* 1996). These advances in landscape archaeological theory, however, did not result from insights gained from previous GIS applications in Landscape Archaeology. Rather, the advances were inspired by and were part of the milieu of the proliferation of various post-structuralist, post-positivist, and post-modernist social theories of practice (i.e. Bourdieu 1977; Giddens 1984) and phenomenology (i.e. Gosden 1994; Thomas 1993). The different theories employed in GIS-based archaeological analyses had less to do with the practical capabilities of GIS and more to do with the theoretical leanings and inspirations of the practitioners (Lake and Woodman 2003: 692-693).

For example, when there was a shift away from environmental functionalism in the

early 1990s, practitioners of GIS in archaeology debated two ways of moving away from environmental determinism: one trying to look at cognition and the other trying to understand human practices and meaning through analysis using a structuration and practice theory approach. Zubrow (1994), Gaffney *et al.* (1995), Wheatley (1993; 1996), and Stead (1995) believed that GIS could help archaeologists at least approximate the ancient cognition of landscape. Maschner (1996b: 305) was especially optimistic about GIS's role in advancing understanding of human cognition: "The investigation of how humans perceive landscapes may be one of our most important future contributions." The interest in cognition, viewsheds, and ritual did not wane with the coming of the new millennium due to ongoing theoretical debates (e.g., Llobera 2003; 2007; Mack 2004; De Silva and Pizziolo 2005; Soetens *et al.* 2005; Tschan *et al.* 2000).

Baldwin *et al.,* on the other hand, were sceptical about these developments and questioned how researchers could model modern, let alone ancient, cognition with uncritically-employed spatial-statistical tools of GIS (Baldwin *et al.* 1996). Having administered surveys to modern respondents to see how they cognised their landscape, the researchers then made parameters from the survey data to find a method for modelling the different ways of perceiving the landscape using GIS. The parameters turned out to be very complex, and Baldwin *et al.* inferred that mapping ancient cognition, without the ability to survey people in the past, would be exceedingly difficult. Fleming argued that it is very difficult for archaeologists to be sure that their conceptions of how ancient cognition functioned are not just flights of fancy (Fleming 1999; 2006). In order to even begin to study cognition, one needs to understand processes that are not even well understood in psychology. Because archaeologists do not have a detailed understanding of the fields of research required to address cognition, "interpretations about movement, visual concealment, aspects of landscape perception in general, are pursued in a very simplistic manner" (Llobera 2001: 1006).

Llobera and Daly and Lock advocated that researchers should instead use a structurationist approach (Llobera 1996; 2001; Daly and Lock 2004). Rather than focusing on cognition, this approach focussed on how the landscape can structure and characterise cultural practices. In this way, both space and humans can be considered active agents in the constitution of society (Lock 2001). Llobera especially made use of work by Giddens and Gibson to flesh out a GIS methodology focusing on the social space on the landscape over time to study past human meanings and practices, while Daly and Lock draw from Gosden and Tilley (Giddens 1984; Gibson 1986; Gosden 1994; Tilley 1994).

Despite these theoretical debates, and the cleverness with which GIS applications were used to utilise or test them, GIS approaches to Landscape Archaeology never generated new theory (e.g., Llobera 1996; Maschner 1996a; Wheatley 1996). Nevertheless, this does not mean that GIS is useless in the advancement of archaeological theory; Bradley's study of Wessex linear ditches from the late Bronze Age suggested that such ditches were territorial markers meant to be seen only from within their respective territories (Bradley 1994). However, through a visibility analysis of the ditches, Llobera was able to prove using GIS that Bradley's hypothesis was not true (Llobera 1996). Through his analysis of landscape orientations (aspect), Llobera found that the ditches conform to changes in landscape orientation and other topographical features (Llobera 1996: 218). Rather than demarcating territories through visibility, Llobera was able to argue that the ditches are information markers of permeable territories (Llobera 1996: 619-620). This study was innovative because it generated a counter-theory with the aid of GIS. Such a study would not have been possible without GIS because of the thousands of mathemati-

cal calculations of visibility and aspect (orientation) involved. Furthermore, studies like this one helped to advance debate by demonstrating how GIS can allow researchers to test theory against different case studies.

So, whilst it is true that GIS has not generated new theory and wholly new methods, nor steered the direction of wider theoretical debates, GIS *has* increased the inferential rigour of archaeological studies (Lake and Woodman 2003: 693). The advantage of GIS is that it allows researchers to test hypotheses relatively quickly and establish spatial statistical significance (e.g., Armstrong *et al.* 2009; Swanson 2003). However, I would argue that such inferential rigour is a necessary condition for theory generation but not sufficient in itself.

Practical Limitations of GIS

Although GIS-based Landscape Archaeology has often been used to utilize and test theory, there are no clear examples of GIS directly generating new theory. Why is this the case? First, as Maschner (1996b: 302) noted, if more archaeologists were to incorporate GIS into their research design, a relative increase in the sophistication of analyses and, presumably, conclusions, could be expected. Therefore, there needs to be a critical mass of people using GIS with theory generation in mind before there is any likelihood of new theories being generated.

As GIS software became easier to use and required less programming knowledge, the use of GIS in Landscape Archaeology became more theoretically engaged and methodologically sophisticated. In the late 1980s and the early 1990s, the first wave of archaeological studies using GIS could mainly be grouped into those studies which provided predictive models to find site locations (for Cultural Research Management), those studies which examined the possibility of uses of GIS in archaeology, and those that focused on the spatial relationship of humans and their environment (Savage 1990a). In this early period, researchers were optimistic, sometimes overly optimistic, about the capabilities of GIS, and most studies were done without much regard to archaeological or social theory. One of the more sophisticated early GIS-based Landscape Archaeological studies was Savage's investigation of Late Archaic landscapes (Savage 1990b). Savage utilized Thiessen polygons to model subsistence catchment areas and boundaries, and his research was probably the first GIS-based Landscape Archaeology study that explicitly worked from archaeological theory.

In the mid-to-late 1990s, the sophistication of GIS-based spatial analyses in Landscape archaeology and theoretical engagement improved significantly. Software capability coincidentally improved also, requiring users to have less programming knowledge. New studies were made practically possible by advances in "line-of-sight (LOS, or viewshed) analysis, cost-surface generation, optimum corridor selection, and watershed delineation on a user defined landscape" (Madry and Rakos 1996: 104). During this period, creative uses of viewshed analysis (e.g., Gaffney *et al.* 1996; Llobera 1996; Madry and Rakos 1996; Wheatley 1996) and creative uses of predictive modelling (Maschner 1996a) were most often employed. Furthermore, during this period, archaeologists began using GIS to test theory (e.g., Llobera 1996).

After the late 1990s, the inferential rigour of GIS-based Landscape Archaeology studies improved yet again due to an increase in the use of spatial statistics, and the increasing availability of GIS software, as well as improved ease of use, opened up the use of GIS to more people. Also, the theoretically-laden debates surrounding GIS in the 1990s generated widespread interest. Rather than using one or two GIS functions to solve archaeological problems, an increase in methodological complexity saw archaeologists combining functions to achieve complex analytic sequences (e.g., Armstrong *et al.* 2009; Bell *et al.* 2002; Swanson 2003; Whitley 2002, 2004). This trend of increasing sophistication in both method and theo-

retical engagement was due to the increasing number of people using GIS, wider theoretical debates generating interest in the capabilities of GIS, and increasing software capabilities. If this trend continues, we might expect GIS to directly contribute to the development of new theory in the future.

The second reason why the use of GIS in Landscape Archaeology has not directly generated theory is the limited availability of user-friendly software that enables rapid Exploratory Data Analysis (EDA). To develop software mainly for academic use is not profitable, and this has impeded the pace of innovation in user-friendly GIS software. For example, only in the last ten years have the spatial syntax theories of Hillier and Hanson (1984) been automated in software such as Depthmap (Turner 2001) and Axialgen (Jiang and Liu 2010). Before then, generating isovists (viewsheds) and axial lines was a cumbersome process. Because GIS's strength is in Exploratory Data Analysis (Maschner 1996b), having access to intuitive software will increase the number of users of GIS, and this in turn drive further sophistication in inferential rigour in analyses and more engagement with, and possibly generation of, theory.

Conclusions: Future of GIS applications in Landscape Archaeology

The purpose of the paper was to evaluate whether GIS has helped advance landscape and other archaeological theory. Some of the overly-optimistic claims about how GIS would easily generate new theory seem to have been unfounded given the lack of clear positive precedents in theory generation. GIS cannot generate theory; people do. The theories and methods had existed before GIS. However, GIS can, and indeed did, aid in the advancement of archaeological theory. Specifically, by testing theory with some degree of statistical confidence, GIS helped researchers advance theoretical debates. However, the florescence of ideas, more than practical advances in computation, was responsible for the increase in sophistication of GIS analyses; it was theory, not GIS, that generated widespread interest.

One of the most exciting trends of current GIS-based archaeological studies is the movement toward understanding commonly used, but often vaguely applied, terms like "state," "city," "chiefdom," "ritual space," and "empire." Instead of defining each of these terms based on localised research and then trying to apply it universally, GIS can help us approach each of these terms in an inductive way (Exploratory Data Analysis) and understand the range of variation of social organisation and space. What is heartening about this recent trend is that it has the potential of empirically developing the post-structural idea of "overdetermination," where there can be multiple causes for a phenomenon, none of which are both necessary and sufficient (Voss 2008: 4). The advantage of using GIS in Landscape Archaeology is the ability to *characterise* rather than to categorise phenomena. Therefore, by seeing the various spatial manifestations of similar phenomena, for example the rise of states, we can begin to understand how their development is "overdetermined." In this way, GIS can help us rigorously test our assumptions about social evolution.

Because of the "overwhelming spatiality" of archaeological data (Conkey 1991), it is encouraging to see a recent increase in integrative and theoretically-laden archaeological GIS-based studies. If such a trend continues, and more researchers learn GIS methods, we can expect to see more communication between archaeological specialists as well as with other disciplines, leading to acceleration in the generation of theory.

Acknowledgements

I would like to acknowledge M. Steven Shackley for reading a draft of this paper and Nicolas Tripcevich for conversations on GIS in archaeology. The comments of an anonymous reviewer greatly improved the focus of this paper. I would also like to thank Adam Webb for help editing.

References

Aldenderfer, M 1996 Introduction. In: Aldenderfer, M and Maschner, H (eds.) *Anthropology, Space, and Geographic Information Systems.* New York, NY: Oxford University Press, 3-18.

Allen, K, Green, S, and **Zubrow, E** (eds.) 1990 Interpreting Space: GIS and Archaeology. London and New York: Taylor and Francis.

Armstrong, D, Hauser, M, Knight D, and **Lenik, S** 2009 Variation in Venues of Slavery and Freedom: Interpreting the Late Eighteenth-Century Cultural Landscape of St. John, Danish West Indies Using an Archaeological GIS. *International Journal of Historical Archaeology* 13(1), 94-111, DOI: http://dx.doi.org/10.1007/s10761-008-0066-6.

Attema, P 1999 Cartography and Landscape Perception: A Case Study from Central Italy. In: Gillings, M, Mattingly, D, and van Dalen, J (eds.) *Geographical Information Systems and Landscape Archaeology.* Oxford: The Alden Press, 23-34.

Baldwin, J, Fisher, P, Wood, J, and **Langford, M** 1996 Modelling Environmental Cognition of the View with GIS. Unpublished paper. Leicester: University of Leicester Department of Geography.

Bell, T, Wilson, A, and **Wickham, A** 2002 Tracking the Samnites: Landscape and Communications Routes in the Sangro Valley, Italy. *American Journal of Archaeology* 106(2), 169-86, http://www.jstor.org/stable/4126242.

Bender, B 1993 *Landscape: Politics and Perspectives.* New York, NY: Berg Publishers.

Bevan, A and **Conolly, J** 2002 GIS, Archaeological Survey, and Landscape Archaeology on the Island of Kythera, Greece. *Journal of Field Archaeology* 29(1/2), 123-38.

Bintliff, J 1996 Interactions of Theory, Methodology and Practice. *Archaeological Dialogues* 2, 246-255, DOI: http://dx.doi.org/10.1017/S1380203800000799.

Boaz, J and **Uleberg, E** 1995 The Potential of GIS-Based Studies of Iron Age Cultural Landscapes in Eastern Norway. In: Lock, G and Stancic, Z (eds.) *Archaeology and Geographical Information Systems: A European Perspective.* London: Taylor and Francis, 249-59.

Bolstad P 2005 *GIS Fundamentals: A First Text on Geographic Information Systems.* White Bear Lake, Minnesota: Eider Press.

Bourdieu, P 1977 *Outline of a Theory of Practice.* Cambridge: Cambridge University Press.

Bradley, R 1994 Symbols and Signposts: Understanding the prehistoric petroglyphs of the British Isles. In: Renfrew, C and Zubrow, E (eds.) *The Ancient Mind: Elements of Cognitive Archaeology.* Cambridge: Cambridge University Press, 95-106.

Crumley, C 1995 Heterarchy and the Analysis of Complex Societies. *Archaeological Papers of the American Anthropological Association* 6(1), 1-5, DOI: http://dx.doi.org/10.1525/ap3a.1995.6.1.1.

Daly, P and **Lock, G** 2004 Time, Space and Archaeological Landscapes: Establishing Connections in the First Millennium BC. In: Goodchild, M and Janelle, D (eds.) *Spatially Integrated Social Science.* Oxford: Oxford University Press, 349-65.

David, B and **Lourandos, H** 1999 Landscape as Mind: Land Use, Cultural Space and Change in North Queensland Prehistory. *Quaternary International* 59, 107-23, DOI: http://dx.doi.org/10.1016/S1040-6182(98)00074-3.

De Silva, M and **Pizziolo, G** 2005 "Signs", Place, Continuity and Changes: Investigating the "Landscape Perception" through the Integration of Chronological and Typological Sources in the Tuscan Plains. In: Forte, M (ed.) *The Reconstruction of Archaeological Landscapes Through Digital Technologies.* Oxford: British Archaeological Reports.

Ericson, J and **Goldsten, R** 1980 Work Space: a new approach to the analysis of energy expenditure whithin site catchments. In Findlow F J and Ericson J E (eds.) *Catchment Analysis: Essays on Prehistoric Resource Space.* Los Angeles: University of California in Los Angeles Press, 21-30.

Fleming, A 1999 Phenomenology and the Megaliths of Wales: A Dreaming Too Far? *Oxford Journal of Archaeology* 18(2), 119-25, DOI: http://dx.doi.org/10.1111/1468-0092.00074.

Fleming, A 2006 Post-Processual Landscape Archaeology: A Critique. Cambridge Archaeological Journal 16(3), 267-80, DOI: http://dx.doi.org/10.1017/S0959774306000163.

Gaffney, V, Stancic, Z and **Watson, H** 1995 The Impact of GIS on Archaeology: A Personal Perspective. In: Lock, G and Stancic, Z (eds.) *Archaeology and Geographical Information Systems: A European Perspective.* London: Taylor and Francis, 210-30.

Gaffney, V, Stancic, Z and **Watson, H** 1996 Moving from Catchments to Cognition: Tentative Steps Toward a Larger Archaeological Context for GIS. In: Aldenderfer, M and Maschner, H D G (eds.) *Anthropology, space and geographic information systems.* Oxford University Press, New York, NY, pp. 132-54.

Gibson, J 1986 *The ecological approach to visual perception.* London: Erlbaum.

Giddens, A 1984 *The Constitution of Society.* Berkeley and Los Angeles: University of California Press.

Gillings, M and **Mattingly, D** 1999 Introduction. In: Gillings, M, Mattingly, D and van Dalen, J (eds.) *Geographical Information Systems and Landscape Archaeology.* Oxford: The Alden Press, 1-4.

Gosden, C 1994 *Social Being and Time.* Oxford: Blackwell.

Green, S 1990a Introduction. In: Allen, K, Green, S and Zubrow, E (eds.) *Interpreting Space: GIS and Archaeology.* London: Taylor and Francis, 3-8.

Green, S 1990b Sorting Out Settlement in Southeastern Ireland: Landscape Archaeology and Geographic Information Systems. In: Allen, K, Green, S, and Zubrow, E (eds.) *Interpreting Space: GIS and Archaeology.* London: Taylor and Francis, 356-63.

Gorenflo, L J and **Gale, N** 1990 Mapping regional settlement in information space. *Journal of Anthropological Archaeology* 9, 240-274, DOI: http://dx.doi.org/10.1016/0278-4165(90)90008-2.

Hillier, B and **Hanson, J** 1984 *The Social Logic of Space.* Cambridge: Cambridge University Press.

Ingold, T 1993 The Temporality of Landscape. World Archaeology 25 (2), 152-74, DOI: http://dx.doi.org/10.1080/00438243.1993.9980235.

Jiang, B and **Liu, X** 2010 Automatic generation of the axial lines of urban environments to capture what we perceive. *International Journal of Geographical Information Science* 24(4): 545, DOI: http://dx.doi.org/10.1080/13658810902950351.

Knapp, A and **Ashmore, W** 1999 Archaeological Landscapes; Constructed, Conceptualized, Ideational. In: Knapp, A and Ashmore, W (eds.) *Archaeologies of Landscape: Contemporary Perspectives.* Oxford: Wiley-Blackwell, 13-19.

Kvamme, K 1999 Recent Directions and Developments in Geographical Information Systems. Journal of Archaeological Research 7(2), 153-201, DOI: http://dx.doi.org/10.1007/s10814-005-0002-9.

Lake, M and **Woodman, P** 2003 Visibility Studies in Archaeology: A Review and Case Study. Environment and Planning B: Planning and Design, 30: 689-707, DOI: http://dx.doi.org/10.1068/b29122.

Llobera, M 1996 Exploring the Topography of Mind: GIS, Social Space and Archaeology. *Antiquity* 70, 612-22.

Llobera, M 2001 Building Past Landscape Perception With GIS: Understanding Topographic Prominence. *Journal of Archaeological Science* 28(9), 1005-14, DOI: http://dx.doi.org/10.1006/jasc.2001.0720.

Llobera, M 2003 Extending GIS-based Visual Analysis: The Concept of Visualscapes. *International Journal of Geographical Information Science* 17(1), 25-48.

Llobera, M 2007 Reconstructing Visual Landscapes. *World Archaeology* 39(1), 51-69, DOI: http://dx.doi.org/10.1080/00438240601136496.

Lock, G 2001 Theorising the Practice or Practicing the Theory: Archaeology and GIS. *Archaeologia Polona* 39, 153-64.

Lock, G and **Harris, T** 1997 Analysing Change Through Time Within a Cultural Landscape: Conceptual and Functional Limitations of a GIS Approach. In: Sinclair, P (ed.) *Urban Origins in Eastern Africa.* World Archaeological Congress, One World series.

Mack, A 2004 One Landscape, Many Experiences: Differing Perspectives of the Temple Districts of Vijayanagara. *Journal of Archaeological Method and Theory* 11(1), 59-81, DOI: http://dx.doi.org/10.1023/B:JARM.0000014617.58744.1d.

Madry, S and **Rakos, L** 1996 Line-of-sight and Cost Surface Analysis for Regional Research in the Arroux River Valley. In Maschner, H (ed.) *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research.* Occasional Paper 23. Carbondale: Center for Archaeological Investigations, 104-26.

Maschner, H 1996a The Politics of Settlement Choice on the Northwest Coast: Cognition, GIS and Coastal Landscapes . In: Aldenderfer, M and Maschner, H (eds.) *Anthropology, Space, and Geographic Information Systems.* New York, NY: Oxford University Press, 175-89.

Maschner, H 1996b Theory, Technology, and the Future of Geographic Information Systems in Archaeology. In Maschner, H (ed.) *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research.* Occasional Paper 23. Carbondale: Center for Archaeological Investigations, 301-06.

Renfrew, C 1979 *Investigations in Orkney.* London: Society of Antiquaries of London Research Report no. 38.

Renfrew, C 1994 Towards a Cognitive Archaeology. In: Renfrew, C (ed.) *The Ancient Mind: Elements of Cognitive Archaeology.* Cambridge: Cambridge University Press, 3-12.

Ruggles, C, Medyckyj-Scott, D and **Gruffydd, A** 1993 Multiple viewshed analysis using GIS and its Archaeological Application: A Case Study in Northern Mull. In: Andersen, J, Madsen, T, and Scollar, I (eds.) *Computing the Past: Computer Applications and Quantitative Methods in Archaeology.* Aarhus: Aarhus University Press, 125-31.

Savage, S 1989 *Late Archaic Landscapes.* Columbia: South Carolina Institute of Archaeology, University of South Carolina.

Savage, S 1990a Modelling the Late Archaic Social Landscape. In: Allen, K, Green, S, and Zubrow, E (eds.) *Interpreting Space: GIS and Archaeology.* London: Taylor and Francis, 330-55.

Savage, S 1990b GIS in Archaeological Research. In: Allen, K, Green, S, and Zubrow, E (eds.) *Interpreting Space: GIS and Archaeology.* London: Taylor and Francis, 22-32.

Soetens, S, Sarris, A, Vansteenhuyse, K and **Topouzi, S** 2005 GIS Variations on a Cretan Theme: Minoan Peak Sanctuaries. In: Foster, K P and Laffineur, R (eds.) *Metron: Measuring the Aegean Bronze Age.* Proceedings of the 9th International Aegean Conference, New Haven, Yale University, 18–21 April 2002, 483–9.

Stead, S 1995 Humans and PETS in Space. In: Lock, G and Stancic, Z (eds.) *Archaeology and Geographical Information Systems: A European Perspective.* London: Taylor and Francis, 313-18.

Swanson, S 2003 Documenting Prehistoric Communication Networks: A Case Study in the Paquimé Polity. *American Antiquity* 68(4), 753-767, http://www.jstor.org/stable/3557071.

Thomas, J 1993 The Hermeneutics of Megalithic Space. In Tilley, C (ed.) *Interpretative Archaeology.* Oxford: Berg, 73-97.

Tilley, C 1994 **A Phenomenology of Landscape: Places, Paths and Monuments.** Oxford: Berg.

Trifkovic, V 2006 Persons and Landscapes: Shifting Scales of Landscape Archaeology. In Lock, G and Molyneaux, B (eds.) *Confronting Scale in Archaeology: Issues of*

Theory and Practice. New York: Springer, 257-271.

Tschan, P, Raczkowski, W and **Latalowa, M** 2000 Perception and Viewsheds: Are They Mutually Inclusive. In Lock, G (ed.) *Beyond the Map: Archaeology and Spatial Technologies.* Amsterdam: IOS Press, 28–48.

Turner A 2001 Depthmap: a program to perform visibility graph analysis. In Peponis, J, Wineman, J and Bafna, S (eds.) *Proceedings of the, Third International Symposium on Space Syntax, Atlanta 2001 31.1-31.9*. The Bartlett Graduate School, University College London.

Verhagen, P and **Whitley, T** 2011 Integrating Archaeological Theory and Predictive Modeling: A Live Report from the Scene. *Journal of Archaeological Method and Theory,* DOI: http://dx.doi.org/10.1007/s10816-011-9102-7.

Wheatley, D 1993 Going Over Old Ground: GIS, Archaeological Theory and the Act of Perception. In: Andersen, J, Madsen, T. and Scollar, I (eds.) *Computing the Past: Computer Applications and Quantitative Methods in Archaeology.* Aarhus: Aarhus University Press, 133-138.

Wheatley, D 1995 Cumulative Viewshed Analysis: A GIS-based Method for Investigating Intervisibility, and its Archaeological Application. In: Lock, G and Stancic, Z (eds.) *Archaeology and Geographical Information Systems: A European Perspective.* London: Taylor and Francis, 171-85.

Wheatley, D 1996 The Use of GIS to Understand Regional Variation in Earlier Neolithic Wessex. In Maschner, H (ed.) *New Methods, Old Problems: Geographic Information Systems in Modern Archaeological Research.* Occasional Paper 23. Carbondale: Center for Archaeological Investigations, 75-103.

Wheatley, D and **Gillings, M** 2000 Vision, Perception and GIS: Developing Enriched Approaches to the Study of Archaeological Visibility. In Lock, G (ed.) *Beyond the Map: Archaeology and Spatial Technologies.* Amsterdam: IOS Press, 1-27.

Wheatley, D and **Gillings, M** 2002 *Spatial Technology and Archaeology: The Archaeological Applications of GIS.* Oxford: Taylor and Francis.

Whitley, T 2002 Landscapes of Bondage: Using GIS to Understand Risk Management and Cognitive Spatial Dynamics in a Slave Society. Paper prepared for the Computer Applications in Archaeology 2002 Conference, Heraklion, Greece, April 2-6, 2002

Whitley, T 2004 Spatial Variables as Proxies for Modeling Cognition and Decision-Making in Archaeological Settings: A Theoretical Perspective. *Internet Archaeology* 16.

Winterbottom, S and **Long, D** 2006 From Abstract Digital Models to Rich Virtual Environments: Landscape Contexts in Kilmartin Glen, Scotland. *Journal of Archaeological Science* 33(10), 1356-67, DOI: http://dx.doi.org/10.1016/j.jas.2006.01.014.

Wise, A 2000 Building Theory into GIS-based Landscape Analysis. In Lockyear, K, Sly, T, and Mihilescu-Birliba, V (eds.) *Computer Applications and Quantitative Methods in Archaeology.* BAR International Series 845. Oxford: Archaeopress, 141–49.

Witcher, R 1999 GIS and Landscapes of Perception. In: Gillings, M, Mattingly, D, and van Dalen, J (eds.) *Geographical Information Systems and Landscape Archaeology.* Oxford: The Alden Press, 13-22.

Yamin, R and **Bescherer Metheny, K** (eds.) 1996 *Landscape Archaeology: Reading and Interpreting the American Historical Landscape.* Knoxville: University of Tennessee Press.

Zubrow, E 1994 Knowledge Representation and Archaeology: A Cognitive Example Using GIS. In: Renfrew, C and Zubrow, E (eds.) *The Ancient Mind: Elements of Cognitive Archaeology.* Cambridge: Cambridge University Press, 107–18.