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An Autonomous Agent Approach to the Investigation of Intra-Site Movement and Visibility: The Visual Consumption of Theran Murals from the Public Spaces of LBA Akrotiri (Thera, Greece)

Abstract: This paper examines the potential of agent based models of pedestrian movement in order further insights into the visual experience and social meaning of Aegean Late Bronze mural painting. An autonomous agent approach that is founded on Helbing's behavioural force model is proposed and applied aiming to investigate the visibility of murals from the public spaces of Late Bronze Age (LBA) Akrotiri (Thera, Greece, ca. 1646? BC). Some preliminary results suggest that the proposed methodology could enrich archaeological interpretations both conceptually and methodologically

Introduction

The idea that the social meaning and human experience of the environment are inextricably linked with movement through space underlies a vast number of social theory works (Bourdieu 1977; Goffman 1969; Giddens 1984) that have significantly influenced archaeological interpretations of past spaces. To date, a variety of spatial analysis approaches have been proposed that are interested in investigating in a formal way the patterns and dynamics of human presence within past environments, mainly focusing on large and medium spatial scales. Most widely applied are GIS-based models that have aimed to explore movement through ancient landscapes by placing emphasis on concepts such as network and path connectivity, topographic cost, visibility, attraction and repulsion of monuments (e.g. Kanter 1996; Llobera 2000). In addition, there is an increasing interest in the application of space syntax theory and methodologies (alpha and gamma analysis [Hillier / Hanson 1984; Hillier et al. 1993], and visibility graph analysis [Turner et al. 2001]) for the investigation of movement within buildings or along streets. Although these computational methods offer possibilities in explaining particular spatial and social phenomena, they appear to be limited when it comes to the investigation of certain social processes that are related to human experience and engagement with space at very fine spatial and temporal scales. While agent-based models of pedestrian movement that can be more successfully applied at the micro-scale have been proposed in the field of urbanism (Helbing et al. 2001; Haklay et al. 2001; Batty 2003), they have not been discussed in an archaeological context.

This paper attempts to explore the opportunities offered by such models to enrich, conceptually and methodologically, archaeological investigations into the visual experience and engagement with past built space. In particular, it discusses the potential of autonomous agent approaches and micro-simulations of pedestrian movement, which are founded on Helbing's behavioural force model (Helbing et al. 2001), to enlighten the issue of the visual access to Theran mural paintings from the public spaces of Late Bronze Age Akrotiri.

The Behavioural Force Model and Autonomous Agent Approaches

Archaeological approaches to spatial analysis of past built space (e.g. Kaiser 2000; Grahame 2000; Brusasco 2004) are mainly founded on space syntax theories and methods, which rest on the premise that patterns of movement in a built environment are generated primarily by properties of spatial form, such as visibility, accessibility, and integration in an urban network (Hillier / Hanson 1984; Hillier et al. 1993; Turner et al. 2001). Nonetheless, real-life observations of pedestrian motion (Helbing / Molnar / Schweitzer 1994; 2001) suggest that human movement is not solely affected by spatial configuration; interactions among pedestrians, as well as the intentions of individuals are also important

(i)

$$\boldsymbol{f}_a(t) = \boldsymbol{f}_a^0(\upsilon_a) + \boldsymbol{f}_{aB}(\boldsymbol{r}_a) + \sum_{\beta(\neq\alpha)} \boldsymbol{f}_{a\beta}(\boldsymbol{r}_a, \upsilon_a, \boldsymbol{r}_\beta, {}_i\upsilon_\beta) + \sum \boldsymbol{f}_{ai}(\boldsymbol{r}_a, \boldsymbol{r}_i, t) + \xi_a(t)$$

(Helbing et al. 2001)

(ii)

$$\begin{bmatrix}\text{new}\\ \text{position}\end{bmatrix} = \begin{bmatrix}\text{old}\\ \text{position}\end{bmatrix} + \begin{bmatrix}\text{desired}\\ \text{position}\end{bmatrix} + \begin{bmatrix}\text{geometric}\\ \text{repulsion}\end{bmatrix} + \begin{bmatrix}\text{social}\\ \text{repulsion}\end{bmatrix} + \begin{bmatrix}\text{social}\\ \text{attraction}\end{bmatrix} + \varepsilon$$

(Batty 2003)

Fig. 1. (i) A mathematical description of the social force model (Helbing et al. 2001, 366). (ii) A similar model suggested by Batty (2003).

in determining the modes in which people move in urban space (Helbing et al. 2001; Batty 2003). A mathematical description of the way such factors influence movement has been made by Helbing et al. (2001) *(Fig. 1)* who have suggested a social force model, that acknowledges important similarities between the ways individuals move in medium and high pedestrian densities and particle dynamics (Helbing / Molnar / Schweitzer 1994). According to this model a pedestrian's position, orientation and velocity in any given moment is determined by a behavioural force which is the sum of several force terms that express internal motivations of the individual, e.g. his/ her wish to keep a desired walking speed, to maintain a distance from obstacles of the environment and other individuals, or move together with other pedestrians. This model, despite its simplicity, can form the foundation of dynamic microsimulations of human crowds which are able to successfully describe and predict phenomena of pedestrian movement that are frequently observed in real life, such as oscillations of the passing direction at bottlenecks and lane formation in crowds of pedestrians that move in opposite directions (Helbing / Molnar / Schweitzer 1994; 2001).

Mainly for this reason, the social force model has met growing popularity in recent years in urban studies, and especially in autonomous agent-based approaches to pedestrian movement (Haklay et al. 2001; Batty 2003). Contrary to space syntax, these models aim to study the process of moving through the built environment from the bottom up, by examining non-linear phenomena that emerge as a result of decisions made by individual agents that represent people situated in real-world environments. Briefly, agents in this case can be defined as software objects that act "autonomously", meaning that they are directed by a set of tendencies or individual goals rather than a user's commands (Ferber 1999, 9). Although autonomous agent models were introduced in archaeology more than a decade ago, but with only a few exceptions they have not been employed for the study of pedestrian movement in an urban context (e.g. Gutierrez et al. 2005).

The remainder of this paper discusses some of the difficulties associated with the study of the visual experience of Theran mural painting and the potential of micro-scale agent-based models of pedestrian movement to address them.

The Visibility of Theran Murals from the Public Spaces of LBA Akrotiri

The wall paintings that have been unearthed at Akrotiri (Thera, Greece) in the last thirty years constitute a rich source of information for life in the Aegean Bronze Age and up to now have been among the most well studied examples of Aegean painting. Nonetheless, their meaning and function within the society in which they were produced is still an issue of debate. In the numerous and often controversial interpretations of the paintings, besides iconography, the visibility of murals in their original architectural context has been considered an important indicator of meaning. The visual access to the paintings and the different modes in which they were seen by an observer located within the decorated spaces, or even at the outdoor public spaces of the settlement, have been central in discussions on both the iconographic meaning and the social significance of mural decoration. Up to date these discussions have revolved around questions on the identity of the possible viewers of the paintings, the intentions of the painter or those that commissioned the painted themes, and the relationship between visual emphasis and hierarchy of meaning in pictorial programs (Marinatos 1984; Marinatos / Hägg 1986; Morgan 2000; Chapin 2004; Doumas 2005; Paliou / Wheatley 2007).

It has to be noted that any investigation into the visual experience of Theran murals in prehistoric

built space is inevitably hindered by the present appearance of the settlement, which enables the modern viewer to have only a fragmentary impression of its past form. Although Akrotiri is the best preserved Aegean Late Bronze Age town, the picture that the archaeological site presents nowadays is still far different from the one suggested by the archaeological record: murals can no longer be seen in situ and most of the walls that the paintings used to embellish have collapsed along with other architectural elements, such as door jambs of pier-and-door partitions[1] and window frames. On many occasions these features would have occluded the decorated wall surfaces or parts of them (Palyvou 2000, 432). For these reasons computer-based three-dimensional reconstructions of the settlement and the digital restoration of the murals are essential in understanding the ways in which the paintings would have been visually perceived in space (Paliou 2001; Palyvou 2005, Plates 2, 3).

While the virtual navigation in a 3D model can give a 'direct' but often subjective[2] impression of the appearance of murals within LBA buildings, spatial analysis methods that couple the functionality of GIS and 3D rendering software have the potential to approach visibility issues in a formal and rigorous way (Paliou / Wheatley 2007; Earl 2005). Such methodologies enable the recording of the visible and non-visible areas of a pictorial theme from a great number of observer points equally distributed in space, and consequently the creation of summary maps that indicate the degree of visibility (percentage of visible area) of painted figures for all locations within the decorated rooms. This approach differs from isovist (Benedikt 1979; Batty 2001) and visibility graph analysis (Turner et al. 2001) in that it relies on fully three-dimensional representations of built space: it is the visibility of vertical wall surfaces that is recorded in this case and not the visual properties of space that lies between them. The identification of exposed (or hidden) to the observer pictorial elements is accomplished with the use of common functionalities of 3D modelling software: a light source that emits light in all directions is placed at each one of the observer's locations at the height of the viewer. Illuminated areas of the wall surface, namely areas that are not obstructed by architectural features, are classified as visible; areas that fall within shadows are characterised as non-visible. Consequently, the wall textures (raster) that hold information on illumination are extracted for further GIS based analysis, which mainly involves the association of the wall area (in cell count or percentage) that is visible from each viewpoint to the viewer's locations. This approach has so far aimed at identifying the pictorial elements that would have been more visible in a given context and at exploring the relationship between the visual exposure of the paintings and hierarchy of meaning in individual scenes (Paliou / Wheatley 2007).

An issue that still remains to be investigated is the visual access to the wall paintings from the public spaces of Akrotiri. It has been suggested that in the past a pedestrian walking outside a private building should have been able to see the mural decoration of its interior spaces through the open windows (Doumas 2005). In this case the messages of the painted themes would have been received not only by those that would have been allowed in the buildings, but by any passer-by traversing the street network in the course of his/ her daily activities and social interactions. This possibility could precipitate new insights into the identity of the intended viewers of the paintings, and the social significance of mural decoration, as up to date it has been maintained that the paintings, which as a rule used to embellish the most elaborate Minoan buildings, would have be seen solely by those that inhabited or visited the decorated spaces (Chapin 2004).

However, even though it is true that some of the decorated rooms had large windows that opened to the squares and streets of the prehistoric town, in most cases it is hard to define the degree to which a painted theme would have been exposed to a viewer located in the public spaces of the settlement. The likelihood of a pedestrian encountering the paintings would have greatly been determined by the location, distance and angle of view from which the paintings would have been visible, as well as patterns of pedestrian movement within the settlement. Some of the complexities entailed in understanding visual access to mural decoration from the outdoor public spaces of Akrotiri are well illustrated in the attempt to examine the visibility of the murals that used to adorn Room B1 of the Beta South complex.

[1] It is reasonable to assume that transportation of goods took place in this area as all buildings around the Square of the Mill House had storage spaces in which storage jars and vessels of various sizes have been discovered.

[2] J. Shaw (2000) argues for the location of the harbour at the south of the settlement.

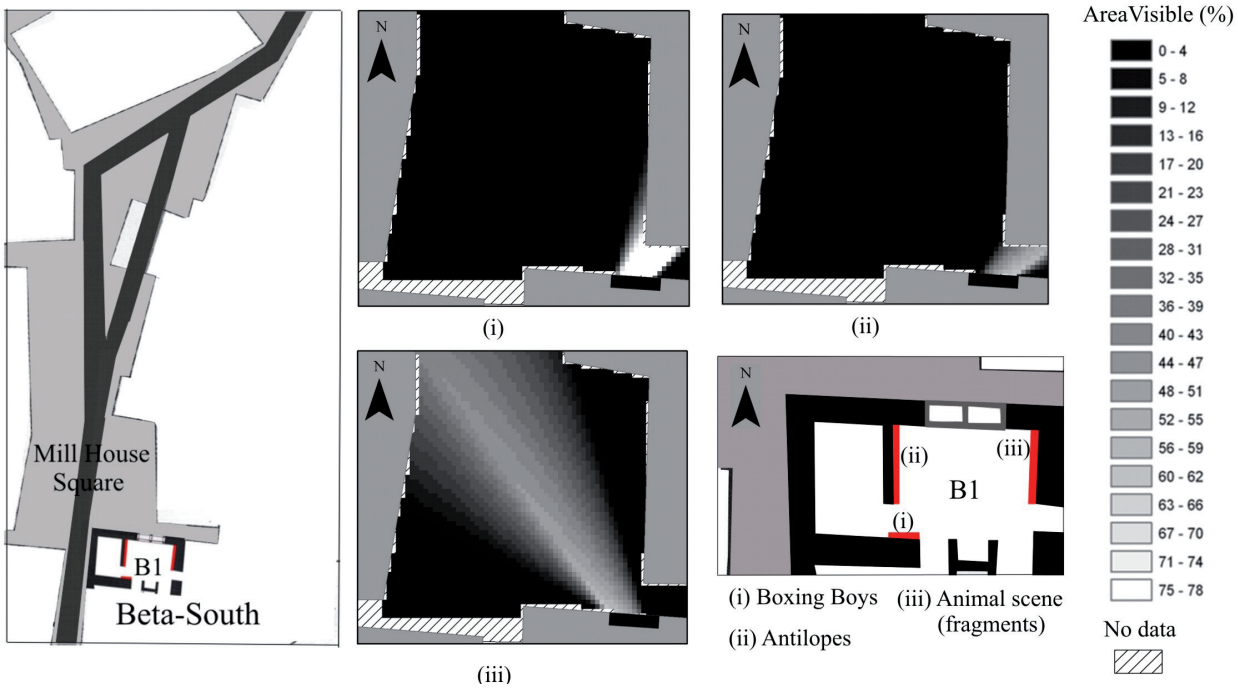

Fig. 2. Left: Town plan of the area of the Square of the Mill House with indication of the main N-S traffic axis (Telchines / Daktylon Street) - based on Palyvou 2005, Fig. 29; 76. (i), (ii), (iii): Percentage of visible wall surface from the Square of the Mill House. Bottom right: Plan of B1 (based on Palyvou 2005, Fig. 76.)

The Wall Paintings of Beta 1

The excavation of Room B1 *(Fig. 2)*, which is located at the north of the Beta South complex, brought to light some of the most impressive examples of Theran mural painting, among which are the well-known "Antelopes" and the "Boxing Children" (Doumas 1992, Fig. 78–84). All four walls of the room were covered with painted themes which were interrupted at the north by a large window that opened to the southeast corner of the Square of the Mill House, one of the many open public spaces that have been excavated up until now in Akrotiri. It has been suggested that through this opening those passing by the square would have been able to see and admire the paintings that embellished the west, east and south walls — an animal scene, the "Antelopes" and "The Boxing children" respectively (Doumas 1992, 110) — and that mural decoration in this case would have aimed to reinforce the prestige and social status of the proprietor of the house (Doumas 2005, 79).

In order to explore the degree to which the paintings in question would have been exposed to a viewer located at the Mill House square, a 3D model of the area at the north of Beta South was created and the visibility of the east, west and south walls of B1 was recorded for about 3000 locations (a sample every 20 cm) at a viewer height of 1.55 m using the methodology described in chapter "The Visibility of Theran Murals from the Public Spaces of LBA Akrotiri". The percentage of visible wall surface seen from each viewpoint was then correlated with the observer's locations, as appears in *Fig. 2 (i, ii, and iii)*. These maps demonstrate that although the wall painting of the east wall *(Fig. 2iii)* could have been viewed from a great part of the Square of the Mill House, the south and the west walls (The "Boxing children" and the "Antelopes") *(Fig. 2i–ii)* would have been visually accessed only from a small area at its south east corner, just outside the window of B1. It is noteworthy that this area does not fall within the main traffic axis that traverses the public open space from north to south *(Fig. 2, left)*. It could be argued, therefore, that a pedestrian walking along the street network having a south orientation would not have been in a position to see the "Antelopes" and the "Boxing Children". Such statement perhaps appears convincing in the case when an individual would have walked through the square in absence of other people. However, in the most likely situation of inhabited space, the interactions among pedestrians must also be taken into account before any persuasive suggestion on pedestrian movement can be made.

An Agent-Based Approach to the Investigation of Intra-Site Movement and Visibility

Basic Assumptions

In order to examine the relationship between the locations that could have enabled the visibility of the wall paintings and possible patterns of pedestrian movement in the settlement an agent-based microsimulation was carried out. Before describing the model two points should be made. Firstly, it is necessary to acknowledge that any successful approach to the experience and movement in past environments should take into account, or at least attempt to discuss, the possible activities that would have occurred in the spaces in question. Regarding the nature of practices within the public spaces of Late Bronze Age Akrotiri many suggestions can and have been made, including public gatherings of social or religious significance, processions, and trade (Marinatos 1984, 51; Boulotis 2005). Nonetheless, in most cases it is difficult to identify with certainty the exact locations, where these activities would have taken place. For this reason initially, the suggested model discusses movement in the outdoor open spaces of the settlement focusing upon to the most basic function of streets and squares, namely their use as passageways, and simply assumes the existence of pedestrians that would traverse the street network in opposite directions in the area around Beta South complex. It is also held that this area would have been a busy passing point in the past, at peak times at least. Perhaps, it is hard to imagine that the nowadays ruined and deserted region around the Mill House Square was once a lively district of the prehistoric town. Nonetheless, our current knowledge about the settlement seems to support such a suggestion. The square, as it applies to the entire excavated area, is located at (or close) to the centre of the town. Furthermore, it is crossed by Telchines / Daktylon Street *(Fig. 2, left)*, a road with a high degree of integration within the street network, as it is the main traffic axis that traverses the excavated town plan from north to south (Palyvou 2005, 31, Fig. 29). In the past, this road would have been a thoroughfare that would have given access not only to the two positively identified public buildings of the settlement, Xeste 3 and Xeste 4, but possibly to the harbour[3] (Shaw 2000; Palyvou 2005, 63), the socioeconomic centre of the flourishing maritime settlement in Late Bronze Age.

Simulating the Dynamics of Pedestrian Movement

The agent-based model was implemented with the Crowd simulation engine of 3ds Max 8 that enables the creation of autonomous software objects with cognitive abilities and behaviours, called delegates. Delegates are capable of "sensing" obstacles in the environment and other agents in their surroundings, as well as acting according to a predefined set of goals and rules. During a simulation the delegates' intentions are expressed as repulsive or attractive forces that ultimately determine each agent's position and velocity. In this case the behaviour of delegates was set with respect to Helbing's et al. social force model. All agents (12 to 14 in number for the particular scenario) aimed to keep a distance from boundaries in the environment and other individuals, while moving in a north or south orientation within Telchines/ Daktylon traffic axis. Delegates represented mainly pedestrians, although some larger objects were also modelled that stood for animals or groups of people transporting goods[4].

The simulation was solved a number of times by randomly changing the agents' starting position before each simulation run. The delegates trajectories where then exported in ArcGIS 9 and density and speed maps were created similar to those presented in *Figs. 3b, c*. For the creation of the speed maps the agent trajectories were collapsed to splines in equal time intervals and were exploded in 3ds MAX before they were imported into the GIS. In this way the length of individual line segments gave an indication of velocity (e.g. distance walked over a certain time span – meters/ second in this case). Following the application of lines statistics, the map of *Fig. 3c* was created which illustrates the average pedestrian speed in the square for 40 simulation runs. The areas in which the agents tended to slow down or stop as a result of the geometry of space and the presence of other agents are represented by the low values (dark grey-black).

[3] Meaning that navigation and visual experience within a 3D environment depends on an inevitably subjective selection of viewpoints made by the user.

[4] Built structures that consist of at least three or more doors in a row (polythyra).

Results and Interpretation

The results of multiple simulation runs that are presented in *Fig. 3* suggest that the wall-paintings at the south and west walls of B1 were likely to be visible, at least in part, by a pedestrian walking in a populated space. This is mainly due to encounters and repulsive interactions among individuals moving in opposite directions that would have occurred near the entrance of the narrow passage at the west of the Beta South complex. More specifically, individuals walking towards the south would often had to move away from the main road when they approached the passage in question, slowing down or even stopping close to the window of B1 *(Fig. 3)*, in order to allow pedestrians coming from the opposite direction enter the Mill House square. The patterns of movement that emerge in this case are similar to oscillations of the passing direction that are often observed at bottlenecks in real life (Helbing et al. 2001, Fig. 7).

The case study of B1 sheds light into the ways in which the natural process of walking in urban space would on certain occasions bring individuals close to the walls and windows of buildings in Akrotiri making a pedestrian's encounter with the paintings more likely than it would initially appear. In the area outside the window of B1 the wall-painting of the "Boxing Children" would have potentially been exposed up to 75–78% *(Fig. 2)*. A view of the 3D reconstruction of the building indicates that the part of the south wall always hidden to the viewer (the missing 22%) corresponds to the lower part of the painting (the painted dado). The "Antelopes" and the wall-painting of the east wall would have been visible up to 64% and 59% respectively. The degree of visibility of these murals, which depict three-quarter life size figures, indicates that in this case a viewer gazing towards the window may have been able to identify particular themes. The fact that s/he would have to slow down or even stop close to the window further reinforces this possibility. It has to be noted, of course, that the visual exposure of the wall paintings would have also been affected by elusive and transient elements of the visual experience in the built environment, such as illumination, the bodies of moving individuals or perhaps curtains and mats. Nonetheless, the occlusive effects of such elements would not have been permanent. It appears, therefore, that in some cases Theran frescoes would not have been solely interior decorations, but to a certain extent part of the everyday experience of the prehistoric townscape, perpetuating their messages to the inhabitants and visitors of the LBA town.

Future Work – 3D Visualisation

The understanding of the visual experience of mural decoration from the public spaces of Akrotiri could further benefit from the visualisation of the process of movement within the Square of the Mill House in a 3D environment. Although 3D visualisation is not necessary for a better appreciation of patterns of pedestrian movement which in fact, these can be more easily understood in 2D views of space. Nonetheless, it will offer a more direct impression of the modes in which the wall paintings would have been experienced by a pedestrian approaching the open windows. An advantage of using 3D modelling software, such as 3ds Max, for the simulation of pedestrian dynamics is that avatars with virtual

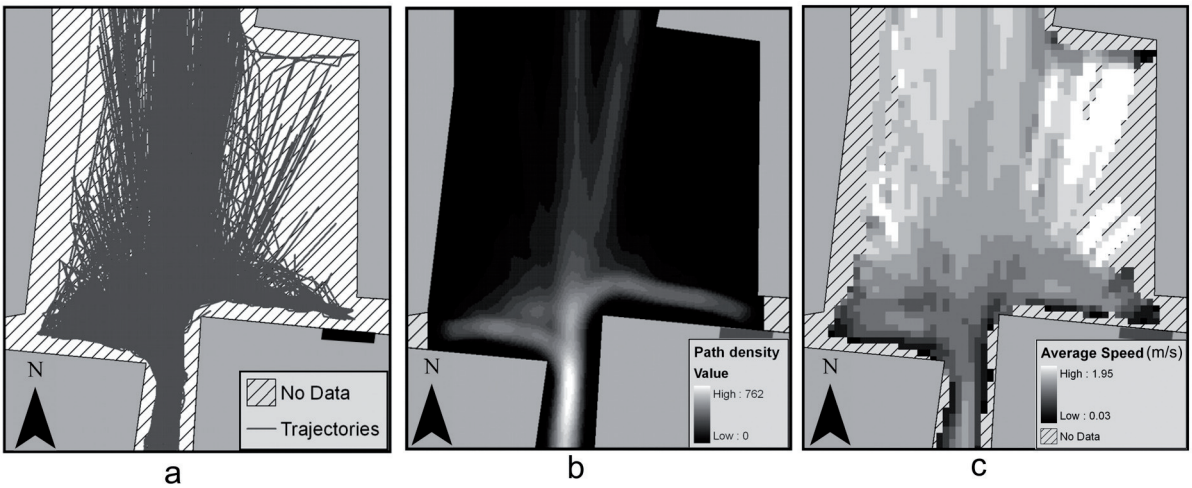

Fig. 3. a) Agent trajectories derived from 40 simulation runs. b) Path density. c) Average pedestrian speed.

cameras attached at eye level could be added in the model. Besides, this 3D visualisation will enable an appreciation of how the different modes of illumination affected the visibility of the paintings.

Conclusion

The above application of agent based modelling enables a first evaluation of the potential usefulness of this methodology to archaeological investigations. Perhaps the most obvious benefit of the use of autonomous agent approaches to the study of movement in past environments is that they encourage archaeologists to think about human practices, experience and the process of socialisation in inhabited space, as opposed to unpopulated environments. Furthermore, far from simply providing a mere prediction of an alleged past reality, they can form a robust and theoretically informed methodology for the exploration of the various possibilities of moving through space that is capable of producing repeatable results. Finally, the dynamic nature of such simulations offers what viewshed approaches into the experience of past space essentially lack, that is the dimension of time and a chance to appreciate the pace of the human visual experience within the built environment.

Saying this, it has also to be noted that the social force model is well suited mainly for scenarios that involve pedestrian movement along a path and in predetermined directions. At larger scales, where individuals normally would have a choice of destination, models of agents with advanced cognitive abilities (vision, cognitive maps etc.) should be considered. Current developments in urban studies can enable the realisation of such models (Haklay et al. 2001; Turner / Penn 2002), whose applicability and usefulness to archaeological pursuits still remain to be tested.

Acknowledgements

I wish to thank Dr David Wheatley and Dr Graeme Earl for discussing various aspects of the approach presented and for reading and commenting on earlier drafts of this paper. This work is part of an ongoing PhD research funded by I.K.Y. (Greek state scholarship foundation).

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