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Beyond Patterns: The Explanatory Potential and Theoretical Limits of GIS in Archaeology

Ashish Kumar Verma

Introduction

The centrality of space in human lives necessitated the development of spatial analysis in archaeology (Gillings, et al., 2020). The application of Geographic Information Systems (GIS) is a result of this need to represent space and study the human past. Conceptualised as a database management system with a spatial component, it has evolved over time. Georeferenced thematic layers of data can be input, processed, and subsequently analysed and modelled; thus, distinguishing it from conventional database management systems (Kvamme, 1989). Correlating sites with environmental characteristics such as soil types, drainage, forest cover, land cover, and irrigation can be applied for predictive modelling (see (Wescott & Brandon, 1999; Verhagen & Whitley, 2012) for a discussion). Simulation typically entails predicting the human behaviour and environmental processes to address archaeological inquiries or validate findings. GIS serves as a simulation tool for modelling the movement of people across landscapes (Bevan & Wilson, 2013) and simulating agricultural (Kosiba & Hunter, 2017) and erosional/depositional processes (Barton, et al., 2015).

Before dwelling further into the role of GIS in interpreting human–space interactions, an understanding of key terms like patterns, processes, and behaviours in archaeology is crucial. Patterns refer to recurring arrangements in archaeological data, including artifacts, settlements, and cultural patterns. Processes involve natural and cultural activities that unfold over time, shaping the archaeological record, with cultural processes driven by human actions. Behaviours encompass past human actions inferred from material remains, involving interactions with the environment, technology, and peers. In archaeology, these elements are interconnected. Human behaviours, influencing activities, contribute to cumulative societal and environmental transformations (processes). These processes generate patterns in the archaeological record. The association does not exhibit a linear causality, resembling a web network with various feedback loops. Identifying and analysing these patterns is essential for reconstructing the past, providing insights into processes and behaviours. GIS investigates these terms to provide a picture of the past.

What archaeologists study using GIS? Few theoretical considerations

Assemblage of space

Archaeologists explore the concept of space as an amalgamation of different themes. GIS layers, akin to themes, collectively form spatial assemblages when overlaid, offering a representation of space. These assemblages, traceable through materials, emerge from accumulating iterative interactions among humans, animals, materials, and their environment. Maps, serving as visualisation tools, extend beyond empirical pattern observations to depict intrinsic processes and behaviours. They function as innovative depictions of space, offering a subjective understanding of place and landscape rather than a resurgence of positivism (Aldred & Lucas, 2019).

Archaeological applications of GIS employ different types and nested levels of ‘models’ (Burg, 2017). At the foundational level, each GIS layer (or input) serves as a simplified model-representation of reality, varying in accuracy for both the past and present. Typically, these ‘models’ are layered within a GIS to identify patterns or trends between human and environmental features and processes. Although George Box underscores the fallibility of all models, he questions their utility threshold to argue for their functionality in exhibiting elements of truth (Burg, 2017, p. 116). Inherent uncertainties stem from assumptions, biases, data acquisition, and goals. Recognising these uncertainties is crucial to assess fitness as a representation of the past. Methods like verification, calibration, sensitivity analysis, and validation address these uncertainties.

Representation of space

For spatial understanding, it is important to conceptualise Lefebvre’s “representations of space” (Lefebvre, 1991) in archaeology. This is attained by examining maps and spatial models that illustrate spatial and social interconnections. It is through this process that representations establish a link between spatial practices and lived environments (Gillings, et al., 2020, p. 3). Thus, space can be construed as an active characteristic of people’s lives which contrasts the Childean idea of a passive space (Childe, 1925).

Wheatley and Gillings (2002, p. 113) suggest the use of GIS not as a panacea for archaeological interpretation but as an “extension of our observational equipment” and recognise its utility in studying space regardless of theoretical considerations. It is important to distinguish between identification and summarisation of spatial patterns one hand and their investigation on the other hands, both requiring individual techniques. Querying, reclassification, and map algebra can be

categorised as summarisation tools, and function as a precursor to spatial analysis (Wheatley & Gillings, 2002). Statistical techniques aid in the second aspect, i.e., an examination of patterns, or more formally its spatial analysis. Humans tend to identify patterns even when they are absent (e.g. when gazing stars in the night). Spatial statistics considers this observational bias to conclude whether patterns are significant and not random.

A critique of GIS is that it is useful only at the regional scale of mapping rather than at a humanistic scale (Lock & Pouncett, 2017). It is often termed as “environmentally deterministic” (Van & Rajala, 2004) with ‘black box’ logic (Gillings, et al., 2020, p. 13) and is unable to map or explain the experiential processes (Bevan & Connolly, 2002). To address this, scholars recommend adopting a spatial thinking approach, which involves a comprehensive framework encompassing space concepts, representation tools, and reasoning processes (Lock & Pouncett, 2017). A further focus on spatial narrative is argued rather than spatial analysis which relies on formal analysis for its ‘output’ and interpretation. In contrast, the former involves an intuitive, dialectical relationship between ‘data’ and interpretation, integrating analysis and interpretation within the narrative rather than separating them, as in spatial analysis (Lock & Pouncett, 2017, p. 130; Gillings, et al., 2020, p. 8). Focus should be on discussing the potentials of GIS rather than finding definitive answers which can be achieved by bridging theories and practice to find a ‘middle ground’ (Verhagen & Whitley, 2012; Llobera, 2012). Gillings (2012) urges archaeologists to develop independent theoretical approaches rooted in GIS applications, emphasising affordance's role in experiential landscape analysis, and exploring ‘experiential affordances’ offered by topography and landscape features.

Mobility and visibility across space

A crucial focus of archaeological enquiry is the mobility across a space, which affords different possibilities and reflections on the remnants of the past. A distinction exists between actively navigating through space with physical movement and passively observing space for analytical and delineative purposes. The former involves a dynamic engagement, wherein one closely tracks moment-to-moment spatial formations within a forward trajectory. Contrarily, the latter encompasses a contemplative approach, aiming to analyse and delineate space by scrutinising specific outcomes, such as spatial patterns to reveal underlying causes (Gillings, et al., 2020, p. 2).

Visibility has been characterised as an inherent functional or aesthetic property, and sometimes as a perceivable act, which is projected via locational configurations in a specific environment (Gillings & Wheatley, 2020; Lake & Woodman, 2003). Observable patterns related to visibility

and intervisibility can be systematically recorded and quantified as visual structures. They distinctly separate the empirical documentation and quantification of patterns and regularities from their subsequent meaning and interpretation (Wheatley, 2014, p. 120). Their emergence within landscapes and the built environment stems from patterns of human behaviour and meaningful actions. This pattern persists even if there are variations in the conceptualisation of space among contemporary researchers or individuals from the past, thus satisfying the contentions of post-processualism (Wheatley, 2014).

Affordances in archaeological GIS was first introduced for examining experientiality of the built environment (Llobera, 1996) and later advanced by Gillings (Gillings, 2009; Gillings, 2012). Gillings suggests affordances are independent of both the animal and its environment; it is a relational concept involving both. They are possibilities for an action under a specific configuration of environmental characteristics and a specific set of the interacting agent's abilities (Wernke, et al., 2017, p. 23).

Affordances formulate power dynamics and through manipulation, power relations can be modified. An inquiry into affordances can systematically explore the formulation of space and its effects on social perceptibility. Thereby, implying that affordances are socially produced because as power relations unfold, they are both enacted and re-enacted within various spatial structures (Wernke, et al., 2017, p. 24).

The following case studies exemplify these theoretical discussions of what GIS ought in principle to be able to contribute to understanding past human processes. The discussion makes a case for the potential of GIS in understanding patterns, behaviours, and processes in conjunction with new theoretical methodologies, contextual information, and user interpretation.

Affordances in movement and visibility at a Peruvian colonial town

Wernke et al. (2017) modelled movement and visibility within a planned colonial town in Peru, namely Santa Cruz de Tuti by utilising the affordances of its built environment to present a more experiential approach through GIS-based methodologies. A modified spatial network analysis incorporating anisotropic-walking model and population (estimated per house) was used to calculate travel costs and average transit density maps along paths. ArcGIS's Closest Facility function with travel duration as impedance values was used to yield an everywhere-to-everywhere walking simulation by calculating the most efficient route between every house and buildings. Walking velocity calculated from Tobler's Hiking function depicted the walking affordance, thus, the agent's "ability" in reference to the slope.

Subsequently, cumulative viewshed of the settlement was constructed incorporating both terrain and architectural features. By weighing the resultant viewshed with the transit density at each point, the movement simulation was integrated with the visual experience. Finally, using raster algebra, a transit density-weighted cumulative viewshed was produced. The model was run twice using an unlimited and 50 m viewshed radius to simulate the visual/movement experience. Getis–Ord GI* statistic was used to evaluate the statistical significance of the results. It examines each feature concerning its neighbouring features, pinpointing hotspots or coldspots relative to a randomly distributed set of values across those same input features.

Movement patterns revealed central plazas with churches and chapels having high aggregate transit, alongside low transit areas. This simulation facilitates insights into collective movement, emphasising the challenge of moving through the town without passing the plazas, depicting movement affordances in the *reducción*. The 50-m radius weighted viewshed yields a similar outcome, emphasizing the significance of plazas, notably Plaza Real. The statistic indicates multiple visual hotspots with a confidence interval of 99 or higher, underscoring the importance of these public spaces in terms of both location and network centrality, as revealed by the walking simulation. In the near visual field analysis, the hotspot statistic indicates that the most visible structures surround the plazas, including the main church, parish buildings, and chapels. This also underscores the affordances, demonstrating a visual contiguity for colonial religious architecture.

GIS facilitates these analyses through its diverse functions, addressing the God’s eye view argument by employing the affordances approach. The objectively derived results can be correlated with specific characteristics, yet it is crucial to note that correlation does not imply causation. GIS effectively maps the active movement patterns and provides a reasoning for the behaviour. However, to comprehend the underlying causes for these behaviours, a contextual understanding of the region becomes imperative. In this case, it is the colonial policies and underlying social differences that reflect the propinquities of movement and visual experiences within the built environment.

Comparative Strength of GIS

One of the strengths of GIS-based viewshed analysis is its ability to compare several sites at different scales, made possible because of the huge computing power of modern computers. Lake and Ortega (2016) use this capability to analyse patterning in British stone circles and critically investigate claims about its visual configurations. They quantified the landscape visual properties using a statistically

rigorous framework. Using Bradley's concept of a "circular perception of space" (Bradley, 1998), they measured the size and fragmentation of viewshed, in addition to its horizon properties. They calculated 29,624 viewsheds of 529 stone circles in total, using GRASS GIS software (GRASS Development Team, 2012). Monte Carlo simulation was used to find statistical evidence for intentional configurations of stone circles in relation to specific visualities.

No correlation of the viewshed area with the elevation was found, which is contrary to the general belief of a large viewshed from higher points. Moreover, different viewshed sizes occurred in various geographical areas, which was inferred from the patterning observed from maps. Simulation analyses found no evidence that this variability is anything other than differences in terrain. However, they did find some correlation of the viewshed locations with horizon, particularly its elevation and inclination, providing evidence for a preference of basin-like viewshed. However, large stone circles may offer a

"circular perception of space" and limit the visual encounter of these sites because of their small viewsheds and high mean horizon inclination with little variations (Lake & Ortega, 2016, p. 237). Moreover, no intentionality behind the location of these stone circles was concluded.

The results evaluate the validity of general claims in understanding their patterning, and consequently the behaviour of its builders. Most of the conclusions can be simply derived from formal GIS spatial analysis. However, an in-depth explanation of the processes behind such patterning is based on theoretical considerations, which is an interpretive leap from a simple GIS application.

Land—an active entity

Kosiba and Hunter (2017) used GIS analysis to present a political ecological framework for exploring changes in agricultural patterns. Using the relational database capabilities of GIS, they provide insights into the fluidity of environmental processes, specifically usage of land for wheat and maize production in Ollantaytambo, Peru. Multiple socio-ecological variables such as artifacts, buildings, erosion, water sources were collected, forming assemblages of spatial data. GIS can then be used in an analytical framework to study the underlying social and political processes. Representation of potential maize (MPT) and wheat production terrain (WPT) were calculated by reclassifying a digital elevation model using raster functions. Different configurations of optimum slope, elevation, sunlight (mapped through hillshade), irrigation, and soil drainage are required for good maize and wheat production.

The authors created different ‘models’ representing environmental variables to map and predict the agricultural growth as assemblages. Diverse socio-ecological factors were unveiled in hillsides and valleys, impacting agriculture, and fostering localized management. Valleys exhibited better conditions, leading to increased settlements. During the colonial era, diseases caused reduced MPT, prompting shifts to mixed grain farming and larger settlements as evident from historical documentation. This altered social structures, influencing land growth and nucleation by prominent farmers. Indigenous attempts to enhance social standing through land occupation led to conflicts among landholders, tribute payers, and workers.

GIS analysis through assemblages, modelling of natural factors, and visualisation reveals land as an active process that influences social changes. Understanding these processes requires a situated history of the region; however, this does not undermine the utility of GIS in identifying and visualizing patterns, modelling environment processes, or the corresponding human behaviour.

Conclusion

In conclusion, the case studies highlight GIS as a potent tool for interpreting human–space interactions, creating spatial assemblages, and unravelling mobility patterns. The affordances approach in the Peruvian colonial town case study showcases GIS's capability in understanding experiential aspects of space. Comparisons of stone circles and agricultural patterns in Ollantaytambo underscore GIS strength in conducting comparative studies and providing socio-ecological insights. However, it lacks in providing the reasons behind the patterns, behaviours, and processes and requires context, interpretation, and theoretical considerations. Thus, it cannot be considered a comprehensive tool for spatial analysis but certainly a powerful one.

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