Human Energetics and the Modelling of Cultural Landscapes

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Abstract

Landscape archaeology is a broad field that seeks to place what we consider “archaeological” into a spatial context, whether that be literal, theoretical, or conceptual. With more recent approaches to social-spatial simulation (through GIS or agent-based modelling techniques) this has entailed complex mathematical methods or procedures which can be quite difficult to evaluate or even understand as a representation of past human activity. It could be said that archaeological remains often drive the construction of the simulation, or conversely that social complexity is expected to organically emerge from simple programmed “rules” of behaviour in a frictionless or highly generalised manifold. Naturally, the result has been models that have been dismissed as missing the point, or being too simplistic to be of any use because they neither consider past people’s cognitive intentions nor the material remains that have been eradicated by taphonomic processes. Perhaps we need to redefine what it is that interests us as archaeologists. Is it finding sites, features and artefacts? Or is it understanding past human behaviour in the context of objective-oriented mechanisms, preferably within a spatial framework? If it is the latter, then maybe we need to look at modelling human energetics as both a past “spatial currency” and as a primary unit of analysis. Sites, artefacts and features are by-products in the human expression of energy across the landscape, and they should be defined and used as such in understanding and evaluating complex spatial models. A large-scale GIS simulation of the first century BC Helvetian subsistence economy (an on-going project) is used to illustrate these ideas.

Keywords: GIS, Simulation, Economic Modelling

Introduction

There are two theoretical and methodological assumptions made about traditional archaeology that go almost entirely unquestioned. The first is that archaeology is primarily the study of humanity through its past material culture examined in context. The second is that the archaeological “site” is inherently the proper unit of study for that context. This is why we have a world-wide industry (Cultural Heritage Management) dedicated, in part, to the recording and documentation or preservation of “sites” that have their “significance” determined almost entirely by their observed material record. I do not think that these two assumptions are necessarily always wrong, yet I think that to never question them is to have a very biased view of past human behaviour (Dunnell, 1992; Ebert, 1992).

For several decades now we have distinguished “landscape archaeology” from more traditional materially-focused approaches. This is the practice of putting archaeological interpretation within the larger spatial context of physical, ecological or social surroundings. The approach is implicitly, if not explicitly, a questioning of those two primary assumptions regarding sites and material culture. But there are many forms of landscape archaeology and they look at many different dimensions of the past (David & Thomas, 2008a). One person’s definition of the landscape might be very different from someone else’s. Typically though, landscape archaeologists see their unit of study as an undefined area somewhat larger than the site but smaller than the region, and they often identify it
as a “cultural landscape” of some kind, or with the term “social space” to specifically elicit the idea of its human element (e.g. Delle, 1998). As a field of endeavour within archaeology, the examinations of “the landscape” can be seen to have passed from a period where it was a subfield largely of both environmental and processual concerns (in the 1980s) to one today where it specifically carries more social, contextual, and interpretive meanings (David & Thomas, 2008b).

As envisioned by Delle (1998) cultural landscapes could be classified into three categories: material, social or cognitive. But these categories are broad and not mutually-exclusive. Material landscapes might be those things which were made or altered by people and which we can still physically see; the “archaeological” environment so to speak. Social landscapes are those areas within which people engaged each other in all manner of human behaviour. Cognitive landscapes would be how people represented space within their own minds based on immediate or recalled information and used it to make decisions. But the landscapes important to past people generally include all of these things.

Without question, the remaining material landscapes are usually what we can most easily work with today. In contrast, social and cognitive landscapes (plus perishable material ones) are no longer present. For that very reason archaeological examinations still consider the landscape as a predominantly physical entity and often focus on its current visual prominence or use archaeological sites and preserved material as tests for hypotheses about cultural behaviour. This again

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**Fig. 1. Simplified Schema for the Human Management of Subsistence Energy using Energy Systems Language (ESL; Odum & Odum 2000).**
derives from the dominance of the site concept and the idea that material culture is the only valid representation of the past for archaeology. This perspective presupposes that the creation of material culture, and its deposition in the physical environment, is the primary objective of humanity, or at least the primary activity of interest to us as archaeologists.

‘Archaeology has always been concerned with material culture – that’s what it does!’ (Zubrow, 2013: 13). Clearly, that quote is accurate from a theoretical and methodological perspective, but must it always be so, and at the expense of more holistic understandings? Even post-processual and phenomenological archaeologists focus on the physical landscape despite the fact that they often invoke terms such as ‘being-in-the-world’ and ‘entanglement’ (David & Thomas, 2008b: 38) to suggest the importance of the cognitive elements. Such descriptors are actually not intended to explain human behaviour, past or present. Rather, they are meant to suggest that such notions are in the vague realm beyond a “scientific” explanation. In this way, they add no clarification to our understanding of what took place in the past. Emphasising the nature of spatial locations as places of immersion, performance or experience does not add clarity when we still extrapolate from small scales to larger ones and from material point-sources to poorly defined landscapes.

Likewise, we see a heavy bias towards understanding human interaction with the external world as derivative of our material and specifically archaeological interpretations, whether you choose an environmentally-focused perspective or one which may be more socially enriched (e.g. Gheorghiu & Nash, 2013). Archaeological landscapes are not the same as social or cognitive ones. We treat the location of an artefact as a place where something happened and a site as a place where perhaps many things happened. But these are minimal constructs. You cannot assume nothing occurred elsewhere, and material remains are not a proxy for generating insight into social or cognitive landscapes without an explanatory understanding of their relationships.

However, researchers often still refer to landscapes as things, entities, relationships between things, objects or some other kind of physically-delineated construct. We can easily acknowledge the very “thing-like” nature of cultural landscapes and we spend a lot of time using vague terminology to describe them in the same ways that we describe and classify archaeological sites; with a distinctly physical representation. But there are social, ideological and experiential contexts to past cultural landscapes that do not currently exist and have never existed as physical entities. There is a vast amount of data that has been destroyed, was never there, or may be otherwise incomplete. Computational modelling and simulation might provide the opportunity to fill in some of these gaps. But how we carry that out can be exceedingly complex and involve some theoretical ideas that go beyond what we tend to deal with in both traditional and landscape archaeologies (Whitley, in press).

People as Managers of Energy

Perhaps we need to consider people from a different perspective, not simply as material culture producing agents. At a fundamental level people, like all sentient life-forms, are energy-managing organisms. With the term “energy” I am referring specifically to the quantifiable nutritional unit which gives any individual the ability to affect motion or fire brain synapses, measured in kilocalories or kilojoules. All organisms must acquire nutritional energy in some form or another to engage with the world around them and to maintain some level of consciousness. But we survive and continue to interact with the world around us because we always strive to maintain a net-positive energy income versus expenditure. This is described as the “fundamental object under contention” in biological competition (Lotka, 1922: 147 as derived from Boltzmann, 1896) and is the basis for the “maximum power principle” or the contentious “fourth principle of energetics” in open system thermodynamics (Odum & Pinkerton, 1955).
My contention is that much of human behaviour is largely the process of managing that energy balance. This has been elaborated upon before and is a characteristic element of some aspects of human and anthropological thermodynamics, as well as "ethno-energetics" (e.g. Bazargan, 1956; Georgescu-Roegen, 1993; Gilsen, 2006; Hauriou, 1899; Helm, 1887; Hornburg, 2001; Polgar, 1961; Ruyle, 1973; White, 1949; Winiarski, 1898). In essence, "culture" and all sociocultural attributes are expressions of both the learned and innovated choices people make while simultaneously managing their energy balance. This is not to say that all human behaviours have an energy-positive outcome or that all of human cognition and activity is designed with energy maintenance in mind. Only that, on the whole, each human being must have at least a neutral energy balance to survive. They expend energy, collect it, store it and exchange it in many different ways. This is largely done through the control of three key elements: matter, energy and information.

What we consider to be diagnostic cultural signatures are essentially similarities in how people make those specific management choices as a function of their genetic, cultural or spatial relatedness as well as the materials and information they have available. This, in no way, denies agency, human choice, or perception. It also, in no way, suggests that human behaviour is determined solely by environment or ecology. Rather, it specifically invokes the idea that energy maintenance is a pedagogical endeavour, and inherently practiced by members of a community with shared knowledge, experience, and objectives.

On an essential scale then, human activity is the controlled transformation of nutritional (or potential) energy into activity (or kinetic energy), or calories into work. Some of that energy is lost but most of it is re-invested into all aspects of culture with the perceived understanding that all sociocultural constructs will ultimately have a net-positive (or at least net-neutral) return on that investment over the long term. In typical archaeological parlance the minimal form of this process is called "subsistence". If we isolate subsistence as a mechanism of its own, we can represent the human energetics involved in a subsistence economy using Energy Systems Language (ESL; Odum & Odum, 2000). Figure 1 illustrates this as a simplified schema. In it energy flows from a source through its acquisition, storage, consumption and loss, to be turned into all other aspects of society, including all forms of material culture and cognitive information.

There are though, many individual behaviours, decisions or other cultural constructs that people engage in which are detrimental to survival, particularly in the short term. I wholeheartedly agree that environmental adaptation is not a required element of human behaviour, spatial or otherwise. However, every thought or action of every individual in human history involved the transformation of potential energy into kinetic energy, regardless of the intended outcome of that action. That expression of energy transformation is particularly idiosyncratic to both the individual’s context and the cultural mechanisms within which they were operating. So it would seem to make logical sense that some form of energy notation could function as a unit for analysing those contexts.

The creation of a complex material culture is a uniquely human approach to the manipulation of energy balances. Any energy expended in the process of manufacturing a tool, a feature or even a landscape is expected to pay off in returned energy during its use-life. In essence, it should provide a perceived energy benefit at least as high as that which was invested. This means that what we see as artefacts are in fact representations of stored potential energy. This is exactly the same notion as "embodied energy" which developed from the concept of "the value of substance" in the Physiocracy school of economic theory and was later expanded in the theories of both agricultural and ecological energetics (Martinez-Alier, 1990; Mirowski, 1991; Weiner, 2000). This is also expressed by Odum (1995) as the "maximum empower principle" and is used in modern economic simulations to calculate things such as carbon footprints and the costs of materials manufactured.

The more inherent "value" a tool has for the
people who made it, or acquired it in some other way, the more potential energy is expected from it in return. When that payoff is exhausted, the tool is discarded. In this sense, it represents a “currency” or unit of exchange between an energy source and its expenditure. But artefacts, features, or landscapes include material remains that represent a wide range of potential energies. For example, a piece of debitage may be the by-product of energy expenditure during tool manufacture and have too little potential energy to be of use for any other immediate purpose, while a prestige object might be a proxy for the future labour of many slaves. The same principles apply to landscapes as a whole, in terms of their energy potential, its extraction and its exchange. The amount of embedded energy in a landscape unit is a measure of its value as a spatial currency. Material landscapes are the embodiment of potential and kinetic energies as matter, while cognitive landscapes are the embodiment of that energy as information. Social landscapes are the articulation of human agents within their material and cognitive landscapes.

In this sense then we cannot directly equate the quantity of artefacts at a site with the potential energy they might represent. We need to know a great deal more about the context, such as how much energy was expended in their manufacture, exchange, use or discard. Yet, we still often treat site locations as if their significance is determined by the size of their assemblage and a landscape by the number of archaeological sites it contains. This is a short-hand way of ascribing archaeological value because it is erroneously assumed that more, or higher quality, units of study will always result in better, or more complete, archaeological interpretations. Theoretically, this is a form of “deductive chauvinism” or the idea that better data always leads to better interpretations [Coffa, 1974; Salmon, 1984: 111-20; Hållsten, 1999]. It also presupposes that explanation will reveal itself from the archaeological record given enough time.

In contrast, I would argue that we need to construct mechanistic explanations for human behaviour. They will not reveal themselves from the archaeological record alone, because it only represents the preserved portion of the material landscape. Simulations in archaeology are intended to go beyond the static display of materials or information itself and to provide a dynamic context in which to situate what we know, or think we know, about past behaviours. The assumption is that human agency (or cognitive decision-making) is either implicit or explicit in the simulation. As a result, a social simulation is mechanistic in nature, articulates with both material and cognitive landscapes and should have explanatory objectives.

Immersive re-creations generally have no such objectives and cannot be assessed as simulations of past behaviour, merely present-day interpretations. They are only static models of the past which interface with the immersed viewer. Simulations, on the other hand, engage a temporal or dynamic process. Many agent-based models (ABM) or multi-agent simulations (MAS) that are dynamic though, often forego explanatory objectives for simple pattern recognition and therefore largely fall within the realm of data-mining rather than describing, or explaining, a mechanism. My contention is that the causal/mechanical approach to explanation (i.e. Salmon, 1984) is far more suited to the objectives of digital simulation in archaeology than are other scientific, or non-scientific, approaches [see Whitley, in press].

I would like to briefly address some of these points using an on-going project in Switzerland known as L’homme de la Mandement [Whitley et al, 2013]. This project involves the creation of a mechanistic simulation of a portion of the Helvetic economy around 58 BC, the period of Julius Caesar’s First Gallic War. It also includes geophysical research, looking for archaeological traces of Helvetic campsites and villages in an area outside of Geneva and an MAS simulation of the exodus of the Helvetii from the Rhône Valley through le Pas d’Écluse. The large-scale computational component is a GIS-based simulation and intends to spatially articulate a model of human energetics.
Figure 2 shows our interpretation of the specifics of the Helvetian subsistence economy in ESL; an elaboration of figure 1 for this project’s context.

In this schema, the “ecosystem” is represented as an external system which produces energy in the form of available calories principally from three sources: crops, livestock, and wild (including semi-wild) plant and animal resources. The available calories enter the subsistence mechanism and form three primary components of the energy economy:

1) Potential Energy – All sources of calories: extracted, stored, or exchanged.
2) Kinetic Energy – All activities engaged in to extract, transform, store or generate additional calories. This is energy used productively for survival, subsistence tasks, and all other social constructs. But all activities that relate to those other social processes exit the mechanism.
3) Lost Energy – The potential energy which was not captured productively by the mechanism. This correlates analogically to “thermal” energy but it refers to both energy expended unproductively, as well as that which was lost through other means such as inefficiency, decay, discard or loss.

The goal of the simulation is to develop a spatial application of this schema in such a way that we can define the input parameters for Helvetian subsistence at around 58 BC and generate the cumulative potential energy surfaces for a given season, or time period. Using a model for kinetic energy expenditure on the scale of the community, we can then simulate the energy requirements in that same time frame given a range of population estimates. Caesar (circa 44 BC) claims a population of 263,000 Helvetii living in twelve oppida (regional centres) and 400 smaller villages scat-
<table>
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Tab. 1. Helvetii 58 BC, Modelled Food Sources.
tered throughout the countryside. Other estimates (Appian, 1912; Delbrück, 1900; Furger-Gunti, 1984; Plutarch, 1919) range downward to as few as 100,000 people. The simulation distributes these 412 village points around Helvetia based on about 50 known historical/archaeological locations and choosing the highest productivity areas for the remaining 362 locales (as the most conservative locations for ancient settlement). It also includes another 40 Gallic and Raetian oppida located outside of Helvetia, but which were known to engage with their Helvetic neighbours as the means by which to generate an outflow or inflow of calories from neighbouring sources (i.e. trade).

Potential Energy Surfaces

The available energy sources are modelled by first defining the different types of foods that constituted the diet. For the Helvetii in 58 BC that includes livestock, produce and agriculture, gathered resources and those which were hunted or fished (tab. 1). The list is not exhaustive but is intended to be fairly comprehensive. It is also defined by average (period-appropriate) gender and age weights, nutrition per kilogram and percentage of usability. Commodities and harvested resources are measured as kilogram (or litre) units and they assume only the usable portions. We also created a set of diet models that represent people living in different portions of the countryside (oppidum, lakeshore, floodplain, upland, and highland villages, as well as a diet which represents the Roman soldier).

The diet models are expressed as a proportion of each food source that constitutes the average consumption for a family of four or six and based on estimates of maximum and minimum caloric requirements from the historical and archaeological literature. Family sizes were assumed to represent households in various settlement types but at an internally stable population rate. It
assumes as little internal stress as possible as the starting point by fitting each specific diet model to the surrounding catchments of its villages. Later iterations may include changes to this assumption using different family or social units, or more dispersed spatial patterns at each of the village types.

Existing environmental datasets (both vector and raster in a variety of formats) were gathered from the Swiss government’s GIS data portal (http://map.geo.admin.ch/) and used to create 20 raster analytical variables at a 30m resolution and covering the defined area of Helvetia (fig. 3). These included numerous variables for climate, soils, water and terrain but moderated according to historical reconstructions and ideas about environment and agricultural practices at the time of the Gallic Wars. Figure 3 also illustrates the locations of the villages in the simulation including those both inside and outside of Helvetia. An alternate version of these locations uses the assumption that the Helvetii were not situated in the Alpine or Jura highlands.

We then generate a series of standardised suitability surfaces by applying formulas to the analytical variables that represent the suitability, or habitat, for each of the 45 defined food sources. These raster surfaces represent the potential return on energy investment as a digital decimal scale ranging between zero and one; where zero represents little or no suitability and one represents the highest level of suitability. A suitability surface exists for each of the food sources, as an average for the two years preceding 58 BC. The total amount of available energy for each food source is then defined by applying formulas to each spatial unit that derive the caloric return as a function of meat weights, gender differences,
population or crop densities, fecundity and range sizes. The results provide an overall snapshot of the predicted total number of calories available for any 30m raster square in Helvetia in 58 BC for all 48 modelled food sources. The diet models are then used as multipliers to define the predicted "returned" calories given the expected differences in food sources, preferences, or availabilities for oppida or villages in different locational contexts. In essence, this is a model for how much energy was available for the Helvetic population i.e. the potential energy.

Kinetic Energy Surfaces

The kinetic energy portion of the simulation uses a series of formulas to model the distribution of energy expended by people doing non-subsistence activities, agriculture, animal husbandry, gathering, hunting or fishing, across the landscape and tied to each modelled oppidum or village (fig. 4). Assumptions are made about the dispersal of energy expended in the act of carrying out each type of subsistence activity. This is a function of cost-distance. So it is calculated on a distance evaluation modified by a friction surface which represents travel on foot for local activities or by boat (in the case of fishing).

Given Caesar's population estimates, for example, we can then define a surface which shows a prediction of how much energy was required to support the people he says were there (fig. 5). Using other population estimates as well allows us to identify the upper and lower limits of minimal kinetic energy requirements. Figure 5 shows a representation of the total daily expended kinetic energy from land-based activities including non-subsistence ones, animal husbandry, agriculture, collecting and hunting. Although it is based proportionally on the population estimates provided by Caesar, and using the Gaussian models depicted in figure 4, it is not yet calibrated to a
final caloric range. It also does not yet incorporate
the transport of foodstuffs from low stress to high
stress areas i.e. the energy exchange analysis.

By contrasting the potential and kinetic ener-
gy surfaces (the available and required caloric
landscapes) we can generate an initial “stress”
surface. By further delineating the limitations of
caloric transport costs through modelling friction
surfaces (using four modes of transport: by foot,
horse, oxcart, and watercraft) we can simulate the
dispersal of surplus calories from low stress areas
to high stress ones. The output is a final stress
surface that represents how well the total amount
of available energy can meet the needs of the Hel-
vetian population as a function of spatial locations
and in proximity to the modelled villages. The
results will be a complete spatial articulation of
the human energetics schema depicted in figure 2.
The simulation will allow multiple iterations with
different configurations of population parameters
and assumptions about energy requirements and
its dispersal across the landscape.

Conclusions

There are some additional caveats to consider.
First, the simulation does not include the entire
Helvetian economy, only the subsistence aspects
of it. The people living in Helvetia around 58 BC
had a very rich and complex culture and they
created and traded many kinds of things (not just
food sources) within the region and with their
neighbours. None of those things are considered
in the initial runs of the simulation. They are ener-
getically accounted for as non-subsistence activ-
ities but their potential input into the subsistence
mechanism (via trade into the store of calories) is
not initially included. It is possible that the Helvetii
could still have imported enough food to feed a
population the size Caesar suggested, and build
up a two-year surplus without producing it them-
selves but by trading other things to their neigh-
bours. This idea will be explored using iterative
inflows of surplus calories from the neighbouring
non-Helvetian oppida.

It is also not intended to answer every question
one might have about the Helvetian subsistence
economy. It is only intended to illustrate how energy
management may have operated as a process
in 58 BC, given certain assumptions. Further, it
is intended to allow the alteration of any or all of
those assumptions to test competing ideas. Sub-
sistence is naturally dependent upon other mech-
anisms and probably cannot be seen strictly as an
isolated mechanism. However, an examination of
the outputs in the form of stress indicators should
be seen as corroborating evidence for hypotheses
that may have already been suggested by archae-
ological data; not as something which has to be
supported by physical archaeological data itself.

This project is also not so much a simulation
of past human behaviour per se, but a simulation
of what we think about past human behaviour.
It could be considered the placing of us into that
Iron Age context. In that sense, the questions
addressed are not objectively about the Iron Age
subsistence economy but about creating a simu-
lation that acts like we would expect an Iron Age
subsistence economy to act given certain param-
eters. Does it look like it can function effectively?
And where are the problem areas? If the results
suggest the simulation cannot account for enough
internal or external stress to cause the Helvetii to
abandon their villages, they could initiate a whole
new line of inquiry. It might then provide a small
insight into the idea that the Iron Age mind was
somehow fundamentally different from what we
might expect.

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