Peopling the Past: Interpreting Models for Pedestrian Movement in Ancient Civic-Ceremonial Centres

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Abstract The study of complex societies, in particular urban spaces such as those of the ancient Maya, can effectively focus on the human interactions and entanglements that animated such locales. Further, many of the concerns related to crowd dispersal, pedestrian traffic patterns, the constitution of community, and socio-spatial control that underlay spatial analyses of modern urban centres were equally valid in past, non-Western, urban centres. From space syntax to agent simulation and crowd modelling, this paper adopts a methodological 'train of thought' with origins well outside the archaeological mainstream that may be applied in the creation of explanatory/exploratory models for socio-spatial interaction. Within Maya studies (and indeed, other ancient contexts), these models may be profitably invoked to direct research toward a deeper understanding of how the ancient Maya may have actually lived within the monumental built environments

that so strongly define them in both popular and professional consciousness. The unit of analysis in all such approaches is the plano-metric representation of architecture and space. In concert with the other papers presented in this volume, particular attention is focused on the analytical consequences (both opportunities and limitations) of such mapping. The Classic Period centre of Copan, Honduras, has been adopted as a case study.

Introduction

> "Every city has a sex and an age... Rome is feminine. So is Odessa. London is a teenager, an urchin, and, in this, hasn't changed since the time of Dickens. Paris, I believe, is a man in his twenties in love with an older woman... She also is Paris, and if every city has its own unique smile, in Paris it is hers."
> John Berger (1992: 101-2).

Cities are alive. For the poet, there can be no question of this fact: being born, growing, changing, and maturing, each city has a life and character all its own. Recent, exciting work by Luís Bettencourt and Geoffrey West (Bettencourt et al. 2007, 2009; Bettencourt and West 2010; Kühnert et al. 2006) has added scientific rigour to the poet's observations by demonstrating that biological scaling laws also apply to cities. Notably, from poet to physicist, it is the people who are the lifeblood of the city; thus, it is their movements and their interactions that provide the pulse.

These essential characteristics (i.e. the movement and interactions of people) have long been absent in the abandoned cities of the ancient world. In archaeology, cities are dead; therefore, there has been a tendency to treat cities as static entities. Diachronic studies that emphasize the historic development of structures or groups of structures are common, as are studies that emphasize the ideological principles referenced in architectural design and the technological innovations and limitations that may have underlain the formal characteristics of structures and spaces. Unfortunately, all of these studies remain apt to produce views of the built environment in which the day-to-day entanglements of people, places, and things that animate such spaces, along with the related principles and concerns of urban design, are rarely contemplated (Peuramaki-Brown 2012). The cityscape as a whole is rarely woven together through the movement of actors as a dynamic, functioning, living, urban space.

This volume comments on the proclivity to treat the cityscape as a static set piece, which has been a proliferating tendency in Western social sciences since at least the 15th century (Scott 1998). It seeks to challenge this position by explicitly exploring the topic of complexity within the dynamic, socio-spatial cityscape together with its possible methods of representation. As showcased by many of the papers in this volume, the authors borrow from (or adapt) methods and theories developed for understanding modern urban spaces, and apply these to past urban environments. Many of these other contributions are based on solid, if partial, historic datasets (e.g. Gauthiez, Zeller, and Guàrdia Bassols, this volume); however, for the archaeologist, the problems of particularism and context noted by these other contributors are multiplied and exacerbated by both temporal and socio-cultural distance. For most archaeological studies there are no texts, images, or footprints to aid reconstructions of the peopled cities of the past. The unit of analysis is thus the plano-metric representation of architecture and space (the modern Western map): a representation that has been critically analyzed in this volume. And yet, it is only through archaeology and the use of such representations that we are able to stretch our analyses back, beyond the Age of Exploration, over the eleven-or-so millennia of city life, and thus bring understanding from a variety of cultural groups. In this paper, we wish to explore the ancient Maya cityscape (or mapscape, as the case may be) of Copan, Honduras, and discuss some of the methods, theories, and models that we are employing to map not only architecture and space in the material sense, but also the dynamic changes that occur over time and through the movement of people. This paper is intended more as an exploration of method and consequence than as an interpretive work in its own right. In this light, we hope that the reader will agree that bringing life back to these long-dead cities opens the door for some extremely interesting and necessary discussions surrounding the archaeological record and its resulting representation.

Four Complementary Methods for Modelling Pedestrian Movement

From an operational standpoint, we will discuss four related methods for modelling pedestrian movement at the city level: axial line analysis, depth analysis (in both cases, focussing specifically on measures of integration), agent simulation, and crowd dispersal modelling. The first three are drawn from the literature on space syntax: a graph-based method for analyzing the relationship between human societies and the spatial configuration of buildings and settlements. Pioneered by a small group of young architects working out of London nearly four decades ago (Hillier et al. 1976), the methods and theories of space syntax have proven to greatly influence urban planners and theorists, particularly in Europe (e.g. Bafna 2003; Chang 2002; Ferguson et al. 2012; Haq and Zimring 2003; Hargreaves 2004; Kelbaugh 2001; Kusumo and Read 2003; Turner and Penn 2002; see also Knoespel 2003 for a recent historic example). Over the past decade and a half, a number of archaeologists have similarly explored many of the ideas that have continued to be developed by the practitioners of space syntax, with varying degrees of success (e.g. Chatford Clark 2007; Collins 2010; Dawson 2002; Fisher 2009; Morton 2012; Morton et al. 2012; Peuramaki-Brown et al. In Press; Seibert 2006; Shapiro 1999; Troncoso 2008; van Dyke 1999; Vaquer and Nielsen 2011; see also Bowser and Patton 2004 and Brusasco 2004 for ethnoarchaeological applications). While a survey of this research reveals that many (though by no means all) of these efforts continue to rely heavily on the theoretical and methodological strategies outlined in several seminal publications, particularly Hillier and Hanson's (1984) *The Social Logic of Space*, much has changed in the intervening years (particularly in terms of archaeological articulations with theory, see Smith 2010), and the methods and theories of space syntax have considerably more to offer from a data/theory standpoint than are typically utilized. The fourth method, crowd dispersal modelling, complements the aforementioned methods and, in many ways, is the easiest to apply (at least with regard to the simplified numerical calculations applied in this paper), though it lacks much of the theoretical foundation that has been constructed in support of space syntax. None of the approaches explored in this paper require any particular degree of technical aptitude; however, all require a critical approach to their application.

Axial Line Analysis

We have discussed the application of axial line analysis and depth analysis to archaeological contexts (their strengths and weaknesses) at length in previous publications (Morton 2012; Morton et al. 2012; Peuramaki-Brown et al. In Press). In our recent paper published in the *Cambridge Archaeological Journal*, we applied the methods of both axial line analysis and depth analysis to the city plan of Teotihuacan, Mexico, in order to explore structural similarities and differences at the individual apartment compound and broader city levels. While we will not explicitly revisit this analysis or its specific methods in detail, it should serve to briefly introduce both axial line analysis and depth analysis as applied to a best-case scenario.

The principal unit of space in an axial line analysis is the "grid": the pattern of linked spaces that define the system to be analyzed (Hillier 2002: 153). The particular aspect of the grid that we are interested in is the "structure": the pattern revealed by expressing the grid as an axial map and analyzing it configurationally (Hillier 2002: 153). The building blocks of this analysis are "convex spaces" and "axial lines": spaces in which all locations within them are mutually visible, and lines of visibility (or straight lines of potential movement) linking more than one convex space, respectively. There are a number of related measures within space syntax, discussed in the following paragraphs, which may be applied to this structure.

"Connectivity" (Hillier 1996: 94) indicates, quite simply, the number of immediately adjacent convex spaces to which any one space may be directly connected. Imagine that the room you are currently occupying is directly connected to three other rooms by three independent doors; thus, the room that you are currently occupying would have a connectivity of "3".[1] In the case of an axial line analysis, connectivity refers not to the number of immediately adjacent spaces, but to the number of other axial lines crossed by any particular line in question. As a general principle, relatively high connectivity is an important ingredient in determining how "busy" or "quiet" any particular space is likely to be (something we will return to shortly).

"Line Length" (Hillier 1996: 142) is another relatively simple measure. Referring to axial lines, this measure quantifies the relative lengths of individual axial lines within a system. In general, longer lines of travel are likely to be better connected within the grid than shorter lines.

"Integration", or "Total Depth"[2] (Hillier 1996: 25), is one of the most fundamental measures in space syntax and indicates the minimum number of adjacent convex spaces, or axial lines, that one must traverse in order to move from any one space to all the others in the system. At a fundamental level, this measure is tied closely to both line length and connectivity as long, well connected, and typically, central axial lines are likely to be highly integrated. For the purposes of our stated task in this paper, "examining the human pulse that animated the ancient city", integration is particularly important. Within the space syntax literature, the structure of the grid has independent and systematic effects on movement patterns. This "Law of Natural Movement" (Hillier 2002; Hillier et al. 1993) states that the degree of integration of a space can be used as a predictor for how "busy" or how "quiet" that space will be (i.e. spaces with a lower total depth are "more integrated" and are likely to be "more busy", see Dawson 2002: 471; Peponis and Wineman 2002: 271).

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[1] If your imaginary room were directly connected to three rooms by four or five doors (or 52 doors for that matter), the room would still have a connectivity of 3.

[2] In Hillier (1996), this measure is referred to as "mean depth"; however, the term is somewhat confused in the literature and as such, we have chosen instead the term "total depth" while the analysis remains the same.

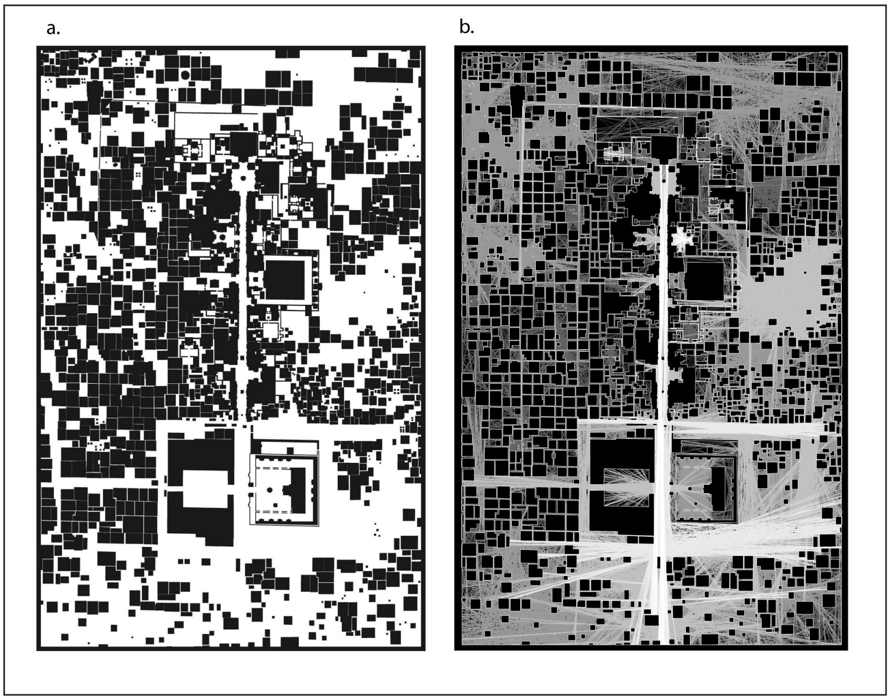

Fig. 1. a. Map of Epicentral Teotihuacan. b. Axial Analysis of Teotihuacan.

Turning back to our best-case scenario, using the map of epicentral Teotihuacan produced by the Teotihuacan Mapping Project (Millon et al. 1973: map 2), a base map was produced that identifies the grid to be analysed (Fig. 1a). White space on this map indicates areas of the spatial grid that are interpreted as having been open to public traffic. Temple platforms, apartment compounds, boundary walls, and bodies of water are marked as inaccessible by black blocks or lines. An all-line axial analysis was then completed for this grid.[3] Our analyses suggested, perhaps not surprisingly, that the major axis of the Street of the Dead and the large eastern and western streets that bisect it, are the most strongly integrated paths in the urban grid (represented in Fig. 1b by a greyscale gradient in which the most highly integrated lines are represented as white, blending to black as integration decreases).

Teotihuacan is particularly amenable to such architectural analyses: not only is architectural preservation such that the urban grid can be reconstructed with sufficient accuracy to support the analysis, but the city grid itself is adequately "structured" or "constrained" to ameliorate the "boundary effects" that are apt to clutter the analysis of more "open" systems (e.g. most Maya centres, an effect that will be explored below). Upon cursory examination, Teotihuacan appears to share many more similarities (at least, in a superficial spatial sense) with modern urban centres (the systems with reference to which space syntax was initially formulated) than do those of the Classic Maya. We must therefore ask whether it is in fact possible to apply the methods of axial line analysis and the associated body of theory to explore the urban grid of Maya centres as well.

[3] The analysis was conducted using a program called Depthmap, available for free academic download on the Space Syntax Laboratory website (www.spacesyntax.org).

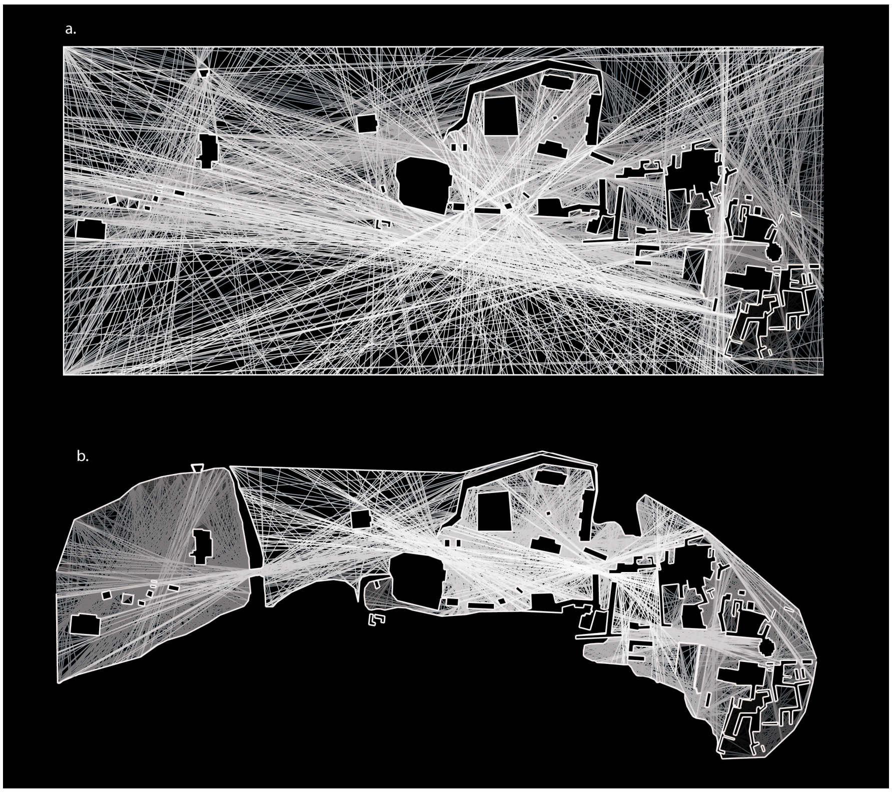

Fig. 2. a. Unbound Axial Analysis of Naachtun. b. Bound Axial Analysis of Naachtun.

We believe that we can apply such methods, although some sites are more amenable to these analyses than others. At Teotihuacan, the formal structure of the grid itself served to contain and bind the analysis. In a publication produced for the *Canadian Journal of Archaeology* (Morton 2012; see also Morton 2007; Peuramaki-Brown et al. In Press), we applied an axial line analysis to the site of Naachtun, Guatemala. As with the majority of Maya cities, the architectural layout of Naachtun is open: few if any of the recognizable structuring features (i.e. roads and regularly-spaced structures) characteristic of modern urban forms (or indeed, characteristic of Teotihuacan) are present. Most sites consist of networks of organized plazas and disorganized, open, peripheral spaces. An axial analysis of such a system (Fig. 2a) illustrates the aforementioned "boundary effect": the longest, best-connected axial lines within the system are located around the margins of the monumental core (i.e. outside our intended subject of analysis). In order to profitably apply an axial line analysis to a site like Naachtun, we must somehow "bind" the analysis (Fig. 2b): an inherently interpretive act. Some boundaries may be social; for example, at Naachtun (as at Teotihuacán) we restricted the analysis to a public or commoner level by excluding platforms and structure interiors from the analysis. This is in contrast to the work of Seibert (2006) who explicitly sought to examine the relationship between these public and private spaces through the inclusion of structure and group interiors. Other boundaries may be more practical; for instance, where steep or wet (but otherwise passable) terrains likewise serve as bounding features. In this manner, we force the analysis to conform more closely to the ways we expect people to have interacted with such spaces, while artificially forcing the analysis to focus on the lines of movement of most interest to us.

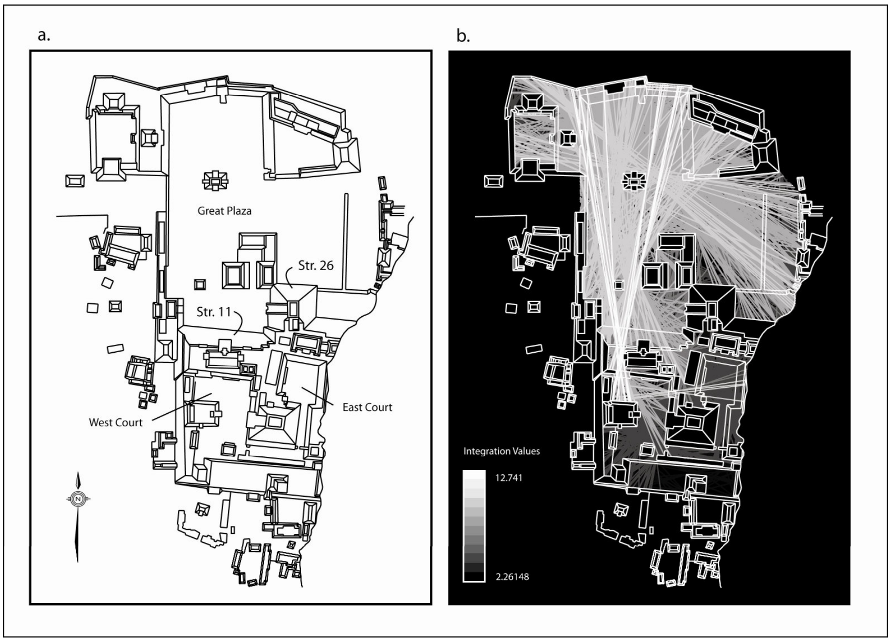

Fig. 3. a. Map of Copan. b. Axial Analysis of Copan.

Thankfully, not all sites require such extreme manipulation in order to support axial analyses. At sites such as Becan (a moated site in Campeche, Mexico), Cahal Pech (a spatially-restricted hilltop site in Belize), or Copan, Honduras, sufficient structure is offered by the site grid to support the analyses with little requirement of artificial bordering. Applying an axial line analysis to the monumental centre of Copan (Fig. 3), we find little evidence for the boundary effects seen at Naachtun; rather, the analysis is simply bound by limiting it to the large open plaza (the Great Plaza) in the north of the civic-ceremonial centre and the increasingly restricted courtyards (the West and East Courts) to the south. Perhaps not surprisingly, the paths of highest integration are found in the Great Plaza. Below, we explore the implications of this observation.

Depth Analysis

A parallel depth analysis of convex spaces at Copan was conducted and provides additional insight to our discussion. We have already noted a number of characteristics of "Total Depth" where they overlap with axial line analysis. In traditional space syntax literature, there is often a methodological division between the two forms of analysis based on the types of systems being analyzed. Typically, axial line analysis is applied to external spaces and larger systems (city streets, shopping centres, etc.). Depth analyses, as in this study, are more commonly applied to internal spaces and smaller systems (houses, office buildings, etc.). We previously applied such an analysis to a number of apartment compounds at Teotihuacan (Morton et al. 2012). Using the Zacuala Palace as an example, we divided the rooms of the compound into a series of distinct convex spaces and calculated the total depth of each space of interest. In Figure 4, the depth counts for one such space (shaded grey) is shown with the "total depth" being the sum of the minimum number of steps required to pass from the carrier space to each other space in the system.

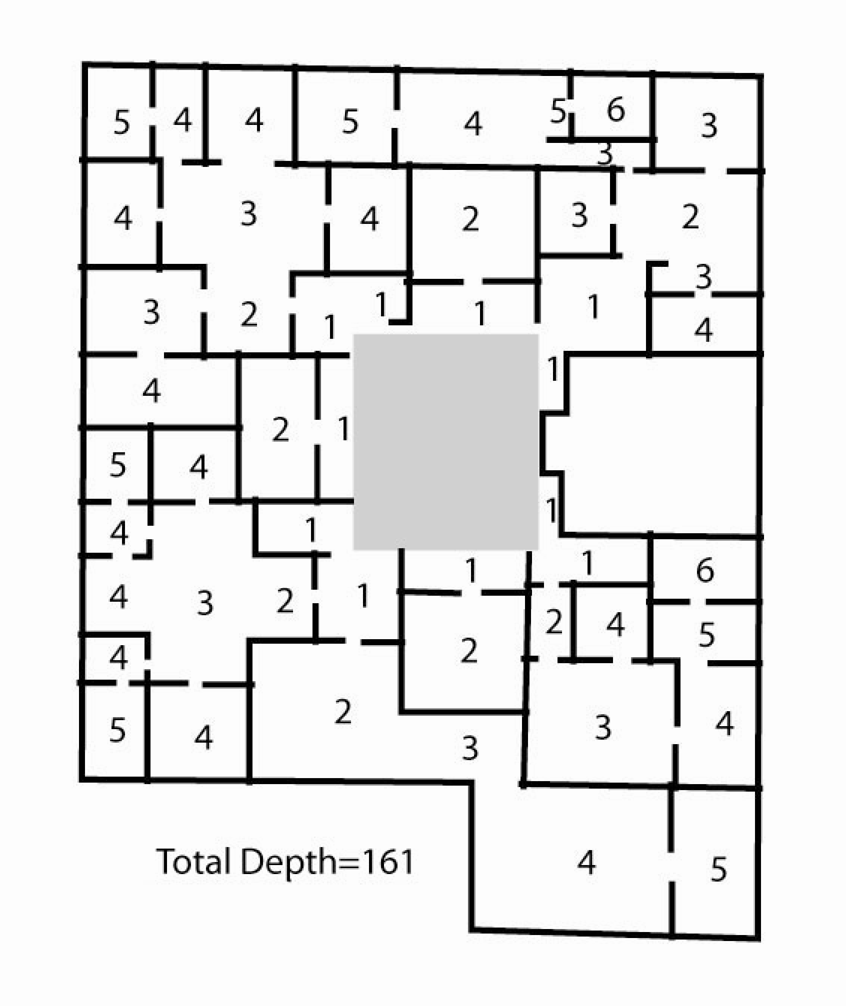

Fig. 4. Example of Depth Analysis at Zacuala Palace, Teotihuacan.

As noted above, Maya urban centres, including those that are spatially restricted such as Copan, do not conform to the typical city grid to which axial line analysis is typically applied. In many ways, such centres appear much more spatially analogous to structures/spaces such as Teotihuacan's apartment compounds or to modern architectural interiors. Applying such an analysis to the monumental core of Copan (Fig. 5) produces similar results to those produced by the axial analysis (with the lowest total depths being found in the Great Plaza), albeit with several interesting differences that will be explored below.

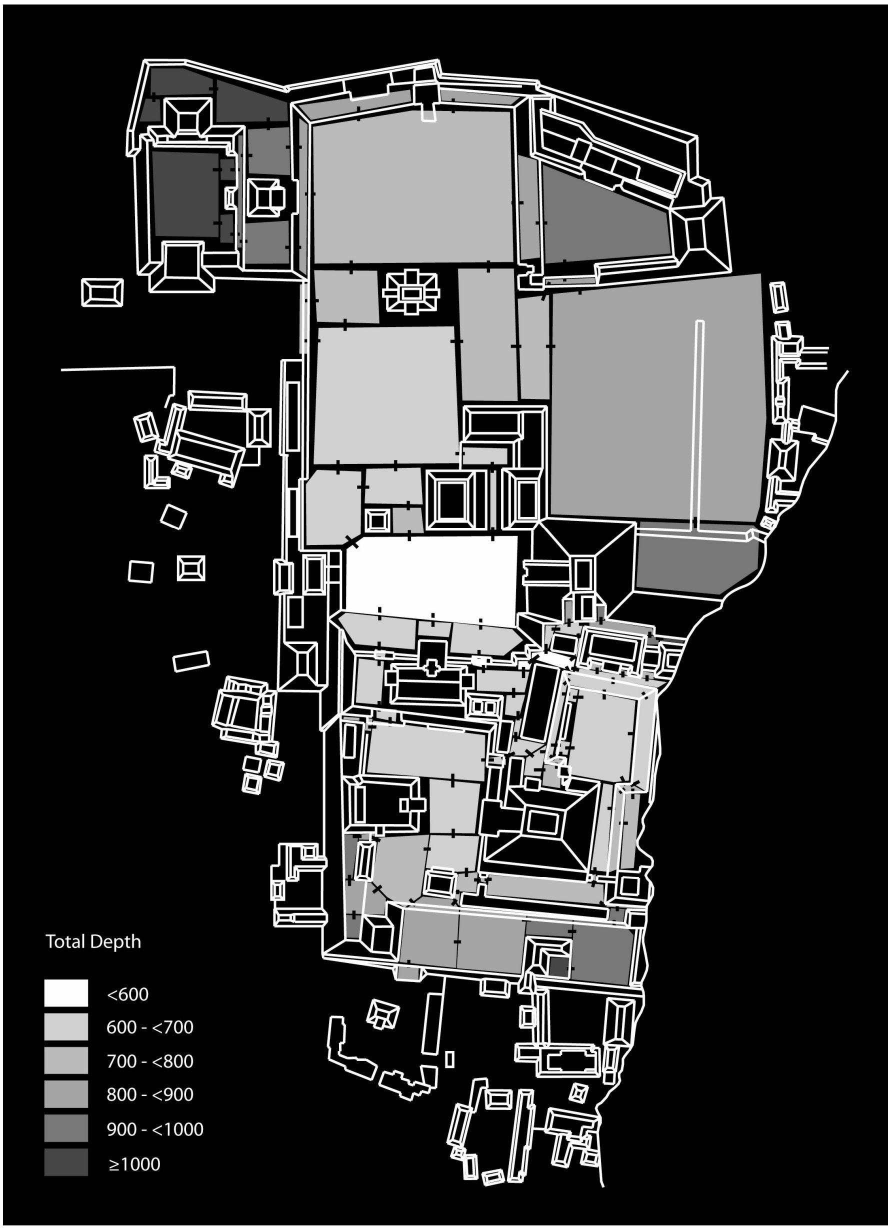

Fig. 5. Depth Analysis at Copan.

Agent Simulation

A related technique is Agent Simulation Modelling (ASM). ASM programs are designed to predict human movement within built environments and landscapes. Depending on the sophistication of the particular model employed, it is possible to simulate a variety of behaviours that vary according to the specific situation modelled (including the goals of individual or groups of agents), the size of the encounter modelled, and the user application adopted. ASM is widely applied in modern urban planning, not only for analytical purposes but also as a powerful visualization tool. Some simulations are incredibly complex and well beyond the scope of this paper. For now, we do not need to stray too far afield from our work with space syntax. Conveniently, Depthmap also contains a series of simple tools that can be of use for basic agent simulation. The agent model for Depthmap has somewhat different theoretical foundations than the space syntax model (though roughly analogous); nonetheless, it shares a fundamental emphasis with space syntax and axial line analysis in that the primacy of the visual field is what influences human movement.

In terms of the analysis, ordinarily the site plan in question is divided up into a more-or-less arbitrary grid, and a full 360-degree visual sweep is split up into 32-evenly-divided angular sections, or “bins” (each 11.25 degrees wide). The default settings in the analysis restrict this to 15 bins (a total 168.75 degrees) arrayed in front of the agent, approximating a standard human visual field (with slight back-and-forth movements of the head). From these, the agent decides which paths to follow. Gate counts on each grid space record the number of times that it is crossed by an agent. Following the broader rules of space syntax, agents populating our spatial grid are attracted to more expansive/longer visual fields and favour linear paths of movement to those that double back (i.e. changes in path are more likely when the change can be made at an obtuse angle rather than an acute). Other view fields produce different results; for instance, lowering the bin number (e.g. down to five) seems to encourage agents to follow exceedingly straight trajectories (and produces generally equal gate counts throughout the system), while raising the bin number (e.g. up to 32) seems to encourage the agents to cluster in open areas near where they spawned (with correspondingly higher gate counts in these areas). Raising and lowering the “steps before turn decision” seems to affect the simulation in the same way, with three steps being taken as optimal. Research by Al Sayed and Turner (2012; Turner 2004) indicates that Depthmap’s default settings seem to better model cross-culturally observed, non-purposive, movement than do other possible combinations.

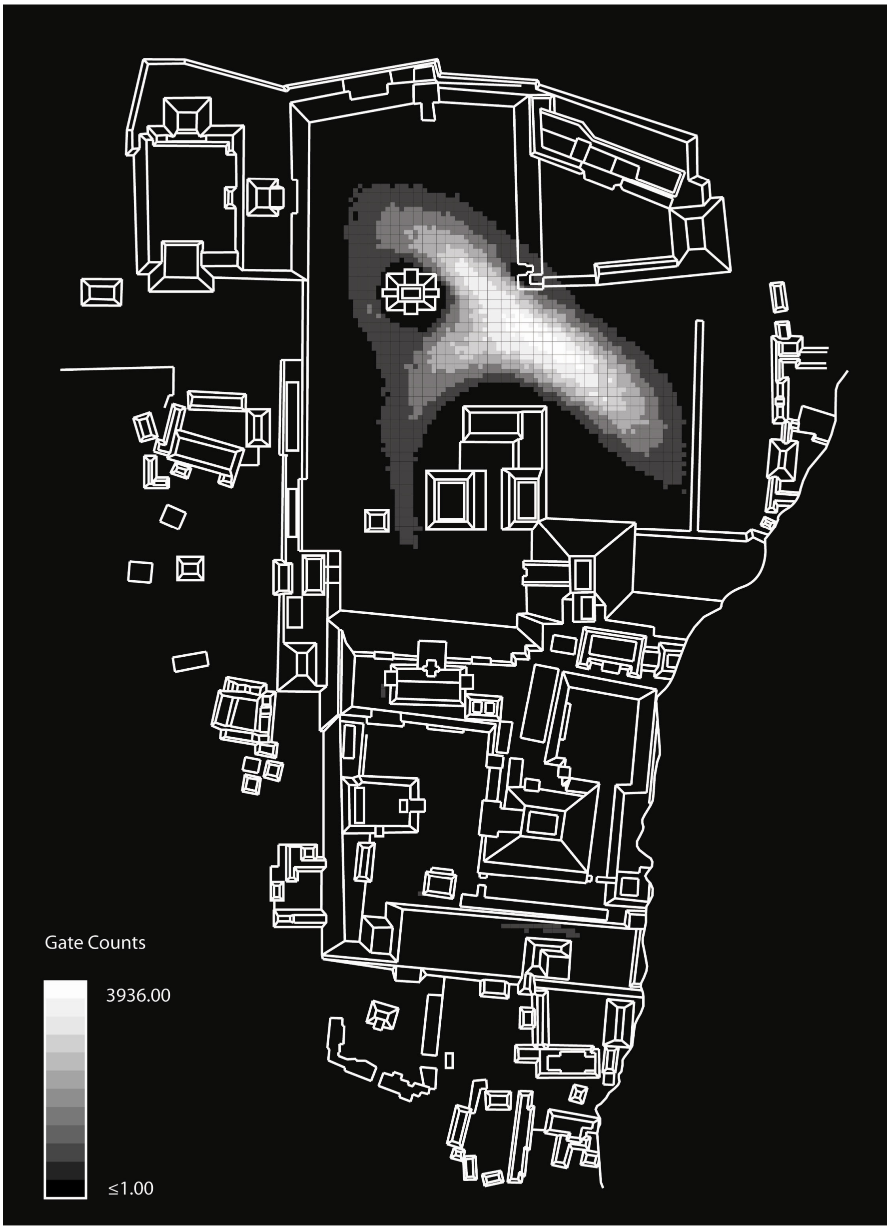

Fig. 6. Agent Simulation at Copan. Note: Great Plaza is Unobstructed.

An analysis of Copan's site core (Fig. 6), in which 10,000 agents were randomly released within the grid and their movements tracked over a thousand "steps" each[4], shows a similar pattern to that seen in the axial line and depth analyses, with one major exception: while the axial line analysis may be useful for predicting potential lines of travel that may have attracted movement, and the depth analysis models how "busy" or how "quiet" any particular convex space was likely to be, the agent simulation models how people may have actually moved through these spaces. There is analytical power in this and we will explore a number of insights afforded by the analysis (or more properly, *for* the analysis) in the following section.

Crowd Dispersal Modelling

We would end this exploration of method with a final, complementary technique for modelling human/space interaction. To this end, we move away from space syntax, axial line and depth analysis, and Depthmap.

There are generally two applications for crowd simulations. The first involves the use of photorealistic renderings of crowd scenes in Hollywood films, video games, and virtual heritage environments (Thalmann et al. 2009). The second is focused on developing effective crowd management scenarios during emergencies (Shendarkar and Vasudevan 2006). Both seek to simulate the behaviour of real crowds as accurately as possible, often using cellular automata or agents. At a very basic level, crowds behave in ways that are similar to fluids and gasses (Luo et al. 2009: 275); consequently, early studies utilized particle simulation models to predict the flow of human movement in various environmental settings. More recently, psychological and sociological models have been incorporated into crowd simulations (Helbing and Molnar 1998). Factors such as aggressive and non-aggressive behaviour, stimulated by collision-avoidance responses among agents, have proven effective in understanding human responses to changes in crowd density as well as environmental boundaries such as walls and narrow exits (Wang et al. 2012; Turkay et al. 2011). Advances in artificial intelligence (AI) allow for even more complex social forces to be explored. By way of illustration, managing human flow is often complicated by the fact that individuals are simultaneously trying to achieve their own objectives, frequently at the expense of other agents.

The use of Belief-Desire-Intent (BDI) architecture provides a means of simulating these forms of complex scenarios. BDI architecture imbues simulation agents with a mental architecture that allows them to behave in ways that are autonomous, cooperative, learnable, and adaptable (Shendarkar and Vasudevan 2006:546). Agents can also be assigned any number of unique characteristics such

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[4] Agent movement, in this case, is non-purposive (i.e. not goal oriented). Agents simply explore the urban grid of Copan for the duration of the analysis rather than trying to move from any particular space to any other.

as age, sex, knowledge of area, panic scale, leadership, interdependence, and injury scales (Helbing and Molnar 1998). These types of advanced scenarios have been used to examine the underlying causes behind some of the worst crowd disasters in recent history, including the Glasgow iBrox Stadium accident in which 66 people were killed; the 1996 Guatemala City tragedy in which 84 people died on a football field; and the Beijing Miyun disaster in which 37 people died in a stampede along the Mihong Bridge (Wang et al. 2012: 1). Simulations have demonstrated that crowd characteristics such as density, diversity, speed of movement, and motivation of individuals played a large role in these disasters.

While we have yet to attempt to produce these complex forms of simulation, existing research provides us with many insights into simulation variables that archaeologists need to consider when attempting these forms of study. Crowd diversity, density, speed, and direction of movement all play critical roles in simulation research. Crowd diversity includes such factors as age, sex, levels of aggression, and physical size (Wang et al. 2012; Turkay et al. 2011; Shendarkar and Vasudevan 2006). With respect to the latter, current crowd evacuation research has shown that body thickness and shoulder breadth of normal adults can play a role in determining the number of individuals that can comfortably occupy a unit of space (Wang et al. 2012:6). This measure is called maximum bearing density, and it demonstrates that crowd density can vary independently of its physical size. For example, the maximum bearing density in England can been calculated to be 7.7 people/m^2 while in Japan it is 10.3 people/m^2 (Wang et al. 2012:7). Consequently, estimates of the maximum physical size (body thickness and shoulder breadth) of past populations like the Maya may be necessary to produce accurate crowd simulation models.

Crowd density is perhaps the key to understanding crowd dynamics, as it directly influences speed and direction of movement (Wang et al. 2012; Turkay et al. 2011; Shendarkar and Vasudevan 2006). Generic simulations demonstrate that when crowd densities are low, pedestrians can move in a variety of directions at free walking speeds of 1.3 m/s (Wang et al. 2012: 4). From the perspective of social forces, collision-avoidance with other pedestrians and environmental borders is facilitated under these conditions, thereby reducing aggression among agents (Helbing and Molnar 1998). As crowd densities begin to increase, crowd speed is diminished whereas crowd flow continues to increase; for example, free walking speeds are attained at crowd densities of between 0.2 and 0.27 people/m^2. Crowd flow will continue to increase until a critical value of around 4.5 to 7 people/m^2 is reached, at which point movement stagnation occurs (Wang et al. 2012:4). At this stage, the occurrence of a critical incident such as a person falling down or an escape route becoming blocked, can cause the crowd to easily collapse, resulting in disaster. Interestingly, crowd simulation research shows that the number of exits available during an emergency evacuation is often inconsequential because no crowd flow can be formed when crowd densities are more than 5 people/m^2 (Wang et al. 2012:8); thus, it may not be necessary for archaeologists to determine all points of entry/exit from an area under study. Of the techniques explored in this paper, it is perhaps this last that may prove the most intriguing. Next, we will explore the particulars of this type of analysis as it applies to Copan.

Putting it all Together: Interpretation at Copan

The goal of this paper is to explore the complex entanglements that define urban spaces through the various lenses afforded by a reconsideration of the limitations imposed by, and opportunities fostered through, the analysis of mapped space (i.e. how our analyses are tied to the way we represent space). Other papers in this volume have discussed similar issues from a more theoretical perspective and have questioned the validity of the Western tradition of spatial representation. While we acknowledge these same limitations, it is our goal to demonstrate the nuanced methods that may nonetheless be applied to, and interpretations that may nonetheless be drawn from, such traditional representations (albeit, with application of a critical hand). Above, we discussed in brief the application of a number of techniques for analyzing the spatial form of urban centres, and applied these analyses to the ancient Maya site of Copan, Honduras. We will conclude this paper with an exploration of the socio-spatial interpretations and, perhaps more significantly, the new questions that may be generated through such applications (both of the archaeological record and our methods of representation).

Each of the three related methods for analyzing urban form from a space syntax perspective offers different but complementary insights. Where these analyses agree is in the identification of the Great Plaza as the busiest, or most heavily trafficked, portion of the site as a simple function of the urban grid itself. This is hardly an earth shattering observation, and has long been interpreted as such (e.g. Gordon 1899). Rather, where our analyses differ from one another is where the greatest insight is gained: each highlights slightly different areas of the Great Plaza based on the particular qualities of modelled pedestrian movement. These differences offer interesting interpretations/questions in their own right, while also pointing to a number of significant consequences of the traditional form of planometric mapping as it is particularly applied in Maya archaeology.

The depth analysis (Fig. 5) serves as a particularly potent framework within which to interpret the other two analyses. The depth analysis shows unambiguously that the areas of lowest total depth are those immediately in front of Str. 11 and the Str. 26 Hieroglyphic stairway, not to mention on the stairs of Str. 11 itself. The analysis does not seek to interpret specific paths of movement *per se*, but rather predicts how "busy" or "quiet" any individual convex space is likely to be. What the depth analysis highlights is the degree of spatial control exerted by the restricted access points to Copan's upper courts, effectively bisecting the site in two and presumably in reflection of very real social divisions: the West and East Courts (the restricted courtyards on the southern end of the site) are surrounded by smaller temple structures and élite residences/administrative buildings. Not only is space in these areas restricted, thereby limiting the number of individuals that could occupy them at any one time, they also both elevated over the larger Great Plaza to the north. Together, these characteristics may have fostered a sense of exclusivity (a pattern also noted at other sites, see Andres et al. 2010; Awe 2008; Awe et al. 1991; Hammond 1972) while also serving as an unambiguous symbolic tie between the open common space (north) and the exclusive élite space (south): hierarchical divisions writ large in the generations-old architecture of the urban core.

The axial analysis (Fig. 3), on the other hand, highlights the integrative qualities of specific paths of movement between convex spaces, in particular identifying the western half of the Great Plaza through to the West Court as the most heavily integrated paths (those most likely to encourage pedestrian movement). However, during Copan's apogee in the decades following the early 8th century rule of 18 Rabbit (*Uaxaclajuun Ub'aah K'awiil*), it is likely that access to these upper areas of the site core and their associated architecture were heavily restricted: if not from a spatial standpoint, then from a social one. Experientially, this particular social boundary (the shallow space in front of Str. 11) may have been rather acutely felt as the connection between the Great Plaza and the upper courts would have been a natural one, though artificially stifled; however, there remains cause to be cautious in making such interpretations.

As previously noted, the agent simulation (Fig. 6) operates on a slightly different set of formal criteria from the other syntax analyses. While the results generally accord well with the axial and depth analyses, where they differ are in the details. In this analysis, given a random origin for the agents, there is very strong clustering (observable as high gate counts) in the eastern portions of the Great Plaza. This is at least in part an artifact of the analysis itself: given a random point of origin for the agents in the simulation, there is likely to be more appearing in larger open spaces than in smaller restricted ones. What is more significant is that individual agents do not seem to follow the paths of highest integration as identified by the axial analysis.

This discrepancy highlights a serious flaw in the way we typically apply space syntax at the city level, and results from the way we traditionally perceive mapped space. The "God's View" of large urban spaces that is typical of Western representation can have a tendency to remove the human from the city. This does not mean that broader analyses are irrelevant. The spatial characteristics identified in the axial analysis (in this case) lie at the heart of the agent simulation that helps us understand the complicated ways that people may have actually interacted with the spatial grid in question: while agent movement is dictated by view field (as in the axial analysis), agents are programmed to follow a more "natural" meandering path, turning slightly every few steps and reassessing their view field at each point. Thus, as an agent progresses along the long vistas that are thought to attract movement in the axial analysis, they are simultaneously and with each step, reducing the scope of the view field that had attracted them in the first place. Eventually, other paths seem to preferentially draw their attention. Agents seem to cluster somewhat within larger open spaces and only rarely venture through the more restricted upper courts. With this information in hand, we might mollify our initial interpretation from the axial analysis that suggested a fundamental and acute tension between social classes fostered by the disjunction between the natural paths of movement identified in the analysis, and by the assumed social boundaries that would have restricted access to the upper courts. Our crowd dispersal analyses also benefit from a comparative approach.

The crowd dispersal analyses outlined above are the most provocative from a human/space perspective, and highlight a difficult series of questions for archaeological interpretation. Using simple measurements from the Copan site map, we can apply some of the basic observations from the generic crowd simulations discussed in the previous section. It is estimated that 15,008 people occupied Copan in AD 749 (a decade after 18 Rabbit's death), with population levels rising to 27,753 by AD 799 (Paine et al. 1996; Webster et al. 1992). Further, it has been suggested that the plenum of the population occasionally gathered for important socio-political rituals within Copan's site core, specifically centred in the Great Plaza. Although such events have been interpreted as extremely important to the proper functioning and legitimisation of the State, archaeologists have not examined the potential consequences of such gatherings from a crowd control perspective.

Knowing the size of the Great Plaza at Copan (35,800m^2), a dimension that remained static despite the need to accommodate a bloating population, allows us to calculate the crowd density for each of these periods. At AD 749 we can calculate a maximum crowd density of 0.4 people/m^2, rising to 0.8 people/m^2 in the later period of highest occupation. Given that free walking among pedestrians occurs at crowd densities of 0.2 to 0.27 people/m^2, we can speculate that ceremonial events occurring in the Great Plaza would have mildly restricted multi-directional flow and required some measure of collision-avoidance among attendees. The degree to which this would have affected the character of the crowd is unknown though it would seem that pedestrian flows into and out of the Plaza could have been maintained under these crowd densities.

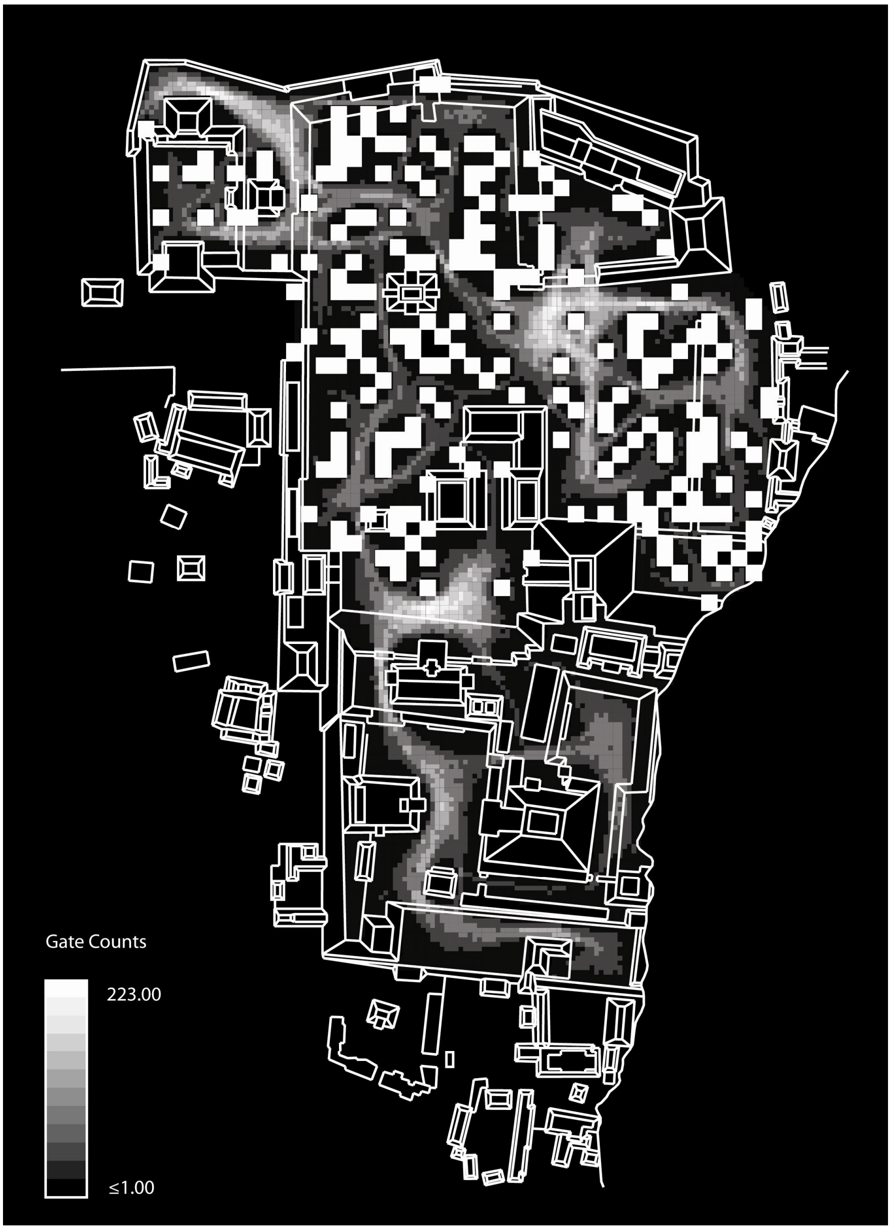

Fig. 7. Agent Simulation at Copan. Note: Great Plaza with 20% Random Distribution of Obstacles.

It is at this point that the perceived spaces as traditionally represented, may be substantially misleading. Recent work at other ancient Maya centres has suggested that plaza spaces may not have been the open, empty, flat areas that have typically been assumed. At the site of Buenavista del Cayo, Belize, Bernadette Cap (2013) has demonstrated that the East Plaza was cluttered with both semi-permanent activity areas and more substantial masonry foundations for perishable superstructures. At the sites of Tipan Chen Uitz, Yaxbe, and Cahal Uitz Na, all in central Belize, plazas appear to have been only roughly finished, with bedrock outcrops and associated terracing being common. From an analytical standpoint, the consequences of these obstacles may be extremely relevant; for example, the effect of imposing a randomly distributed series of obstacles in the Great Plaza. In the case of the agent simulation pictured in Figure 7, though only 20% of the plaza space was directly impacted, the potential effects on movement within the system are staggering. The simulation demonstrates a much more evenly distributed series of gate counts than did the open simulation pictured in Figure 6. While the interpretive consequences of this remain to be explored in another venue, here we would focus on the methodological consequences.

These factors may be directly significant in consideration of our crowd dispersal data. Simulations show that crowd densities of between 7-13 people/m^2 constitute extreme situations that can lead to movement stagnation, injury, and death. Although in this case only 20% (or ~7,160 m^2) of the Great Plaza was directly cancelled by the hypothetical presence of structures (in absolute terms, only raising the maximum crowd densities to 0.5 people/m^2 and 1.0 people/m^2 for early and late periods, respectively), such structures may have had even greater effects by simultaneously cancelling space and parcelling/blocking other areas; for instance, if the structures and impediments as modelled in Figure 7 effectively segregated large portions of the plaza, then the effects on crowd density (and the axial analyses completed earlier, for that matter) may have been significant. For now, it is sufficient to note that, depending on the degree to which permanent or semi-permanent obstacles were present, dangerous overcrowding was perhaps an issue faced by later planners in Copan. If so, then events similar to the Mihong Bridge stampede and the 2010 Khmer Water festival disaster may also have occurred in antiquity. Being the largest architectural element at most sites, it would be logical to devote more time to the exploration of the plaza.

Final Thoughts

We hold that the study of complex societies, in particular urban spaces such as those of the ancient Maya, can effectively focus on the human interactions and entanglements that animated such locales. Further, we hold that many of the concerns related to crowd dispersal, pedestrian traffic patterns, the constitution of community, and socio-spatial control that underlay spatial analyses of modern urban centres were equally valid in past, non-Western, urban centres. The advent of computer simulation programs allows the development and exploration of models and implications of ever more complex hypotheses concerning human behaviour, enabling potential simulations to be compared with the archaeological record. Archaeologists, in particular Mayanists, have been slow in adopting any simulation models beyond 3D virtual reality settings; thus, presenting architectural stages without the actors. This is unfortunate as the continual development and advances in technological simulation are allowing the input and integration of an increasing number of data sets: what should be viewed as an extremely useful tool in a field where practitioners are constantly struggling to organize and compare information. However, these techniques should not be applied uncritically. Hence, in this paper, and in concert with the other papers presented in this volume, we have paid particular attention to the analytical consequences (both opportunities and limitations) of such mapping. These forms of analysis are still very much in their infancy in Maya archaeology; however, we believe they represent a strong and viable avenue for future research.

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