Journal of Archaeological Science 84 (2017) 22–39

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

A GIS of affordances: Movement and visibility at a planned colonial town in highland Peru☆

Steven A. Wernke [a,*], Lauren E. Kohut [b], Abel Traslaviña [a]

[a] Vanderbilt University, USA
[b] Tougaloo College, USA

ARTICLE INFO

Article history:
Received 18 January 2017
Received in revised form
30 May 2017
Accepted 2 June 2017
Available online 12 June 2017

Keywords:
GIS
Affordances
Spatial network analysis
Viewshed analysis
Spatial analysis
Andes
Colonialism

ABSTRACT

Archaeological GIS is moving towards increasingly detailed, embodied, multidimensional simulations and analyses of human experience in the past. Most of the emerging GIS research synthesizing spatial modeling and subject-centered approaches has been concerned with practices and perceptions of landscape. This paper tightens the analytical focus to the more intimate scale of a single settlement, combining models of movement and visual experience within a planned colonial town in highland Peru. Such a rendering is important, since controlling movement and visual experience were central to the colonial project that built this and other such towns in the Viceroyalty of Peru. This study centers on an exceptionally well-preserved, relict planned colonial town in highland Peru to investigate affordances of movement and visibility within it. Several GIS-based simulations and analytical techniques are brought together, including drone-based high resolution three dimensional modeling, spatial network analysis, walking models, and cumulative viewshed analysis, to simulate aggregate visual experience as people moved through the town. The results are suggestive of how the layout of the town specifically routed transit to facilitate the visual prominence of the church and original Inka plaza of the reducción, as well as the prominence of indigenous elite households. Both continuities and discontinuities of movement and visual experience relative to Inkaic and Spanish colonial spaces are evident. By extension, this paper also provides a pathway for quantitative and reproducible modeling of site-scale movement and visual affordances as dimensions of subject and community formation in other global contexts.

1. Introduction

Colonialism proceeds in large measure through attempts to reorder space in the likeness of the colonizers' ideal self-image—through a colonization of landscape, settlement, domicile, and ritual space (Scott, 1998; Sluyter, 2002). In the case of the Spanish invasion and colonization of the Americas, such placemaking was anchored to urbanism, as Spaniards founded colonial cities and enacted programs of forced resettlement of indigenous populations (Cummins, 2002; Kagan, 2000). Nowhere are the effects of enforced Spanish urbanism more evident than in the Andean region of South America, where much of the population continues to reside in planned colonial towns built during a mass resettlement program in 1570s (Mumford, 2012).

Rarely, however, have archaeologists attempted to use GIS to explore processes of Spanish colonial placemaking at the level of everyday practice in particular settlements (but see Liebmann, 2012; Quilter, 2011; VanValkenburgh, 2012; Wernke, 2007, 2011, 2012). Here, we use GIS-based modeling to model movement and visual experience within a planned colonial town in highland Peru. We build on the perspectives of Gillings (2012, 2009), Howey (2007, 2011), Llobera (1996, 2012), Lock (2010, 2000), and others (e.g., Kosiba and Bauer, 2012; McEwan, 2012; Rennell, 2012) who explore past placemaking by using GIS as a heuristic and interpretive tool through reproducible and robust spatial modeling. In this sense, this paper works in the “middle ground” (McEwan and Millican, 2012) between quantitative, spatial analytic perspectives and experiential or phenomenological approaches. The model of movement and visual experience presented represents a significant step toward a more comprehensive model of the *affordances* of walking and visibility within the built environment in a planned colonial town. The model builds a high resolution three dimensional model of the town and enables a view of combined and aggregate movement and visual experience—that is, areas where

☆ The special issue was handled by Meghan C.L. Howey and Marieka Brouwer Burg.
* Corresponding author.
E-mail address: s.wernke@vanderbilt.edu (S.A. Wernke).

http://dx.doi.org/10.1016/j.jas.2017.06.004

people were more and less likely to traverse, and what they were more and less likely to see. This is a different pathway to past experience from that of the phenomenological approaches that first emerged in the 1990s (e.g., Bender, 1993; Tilley, 1994), in which the subject position of the archaeologist was variably privileged as a vessel for conveying experience or sublimated as a kind of ventriloquist's dummy for past social actors (For discussion, see Brück, 2005; Gillings, 2012). Here, no claim is made about experience from any particular subject position, but rather movement and visual experience in aggregate—the affordances of movement and visual perception—is simulated in a high fidelity spatial framework.

Such an experiential approach promises to advance understanding of how a new kind of society emerged in the Andean region of South America following the Spanish invasion. A colossal Spanish colonial program of forced resettlement—what is known as the *Reducción General de Indios* (General Resettlement of Indians; hereafter *Reducción*)—displaced some 1.5 million native Andeans into over a thousand compact towns (*reducciones*) built around plazas and churches in a single decade—the 1570s (Mumford, 2012). After a generation of plunder, indirect rule, and in-fighting among Spaniards, the crown sent the Viceroy Francisco de Toledo in 1569 to hammer out the basic forms of colonial governance in Peru. Toledo's reforms called for the reorganization of Andean settlement and community life from the ground up through the Reducción and an accompanying census (to calculate a new head tax), a regimented tribute and labor quota system, and a corps of provincial magistrates (*corregidores de indios*) to oversee it all (Spalding, 1984). As the centerpiece of the reforms, the Reducción was predicated on the notion (based on certain Mediterranean cultural assumptions) that building idealized urban spaces in miniature would *produce* a new kind of colonial society. That is, Toledo saw resettlement as not just a precondition for the production of properly Christianized and civilized subjects, but as actually generative of them (Cummins, 2002; Mumford, 2012; VanValkenburgh, 2012; Wernke, 2013).

2. Toward a theory and GIS of relational affordances

Toledo was mistaken, of course, since relationships between the built environment and social forms and forces are not so deterministic. As Thomas Gieryn succinctly put it, “Buildings stabilize social life. They give structure to social institutions, durability to social networks, persistence to behavior patterns … And yet, buildings stabilize *imperfectly* … Buildings don't just sit their imposing themselves. They are forever objects of (re)interpretation, narration and representation” … (Gieryn, 2002: 35, emphasis in original). Buildings channel movement, constrain and accommodate possibilities for interaction, and afford certain experiences. But they are also products of human agency. Settlements and buildings are embedded in and constitute landscapes, even as they are rebuilt, remodeled, repurposed, reinterpreted, abandoned, and demolished (Lefebvre, 1991; Smith, 2003). In a colonial context such as the viceroyalty of Peru in the late 16th century, the significance of buildings, settlements, and cities was very much in flux in semiotic terms (what buildings mean, and thus, what buildings do) and in relation to their historical landscapes (Cummins, 2002; VanValkenburgh, 2017; Wernke, 2011, 2013). Clearly, building gridded towns around plazas and churches would not so unproblematically produce model Christian subjects.

It is appropriate to begin an analysis of the built environment in a colonial settlement with an eye to the *affordances* of movement and visual experience. Here we build on the concept of affordance as a framework for examining the experiential qualities of the built environment. The affordance concept was initially adapted in archaeological GIS by Llobera (1996), and recently has been further elaborated by Gillings (2009, 2012).[1] The term is derived from the theory of direct perception as first articulated in the field of ecological psychology by James Gibson (1966, 1979). Gibson's theory begins with the premise that in an act of perception, meaning is not just produced in the brain of the perceiving agent (human or nonhuman animal), but rather that it is embedded in the environment. The corollary is that the environment is not only made up of its physical constituents, but meaning as well. Such a construction runs counter to the modern consensus of the world as irreducibly physical, so the theory of direct perception requires an ontology (Chemero, 2003). This is what Gibson's concept of affordances intended to provide.

However, as pointed out by Chemero (2003), and more recently in the archaeological literature by Gillings (2012), Gibson's own writing on affordances was not entirely coherent. His most commonly cited formulation suggests that an affordance is essentially a resource “out there” to be gathered through the abilities of an interacting organism; thus, an environmental affordance is “… what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill” (Gibson, 1979:129). But elsewhere he describes an affordance as evanescent and dependent on the presence of an interacting organism: it is “… neither an objective property nor a subjective property; or it is both if you like.” Later, perhaps most clearly, Gibson comes around to affordances as the essential perceptible properties relative to one's habits of biophysical and cognitive engagement with the environment:

> The psychologists assume that objects are *composed* of their qualities. But I now suggest that what we perceive when we look at objects are their affordances, not their qualities … what the object affords us is *what we normally pay attention to* (Gibson, 1979:134, emphasis added).

Subsequent debate hinged on whether affordances were essentially resources or emergent properties (Chemero, 2003; Gillings, 2012:605; Jones, 2003; Stoffregen, 2003). Llobera (1996), and recently Gillings (2012), building on Chemero (2003), advocate a *relational* theory of affordances, which bridges this dichotomy by positing that affordances are properties of neither animals nor environments, but rather exist as *relations* between the two. In this framing, affordances are conceived as the possibilities for action under a given set of environmental features and a given set of *abilities* by the interacting agent (Stoffregen, 2003:118). “Ability” here is doing some heavy conceptual lifting. Much of the discussion settled on ability as directly related to body scale and biomechanical measures (Heft, 1989; Warren, 1984; Cornus et al., 1999). For example, Warren (1984) has modeled the affordance of stair climbing as a ratio between leg length and stair riser height. Others in the ecological psychology literature have emphasized abilities as mutable biophysical and cognitive capacities or aptitudes—in the case of stair climbing, how ability over the life course can change independent of leg dimensions (Chemero, 2003; Stoffregen, 2000; Turvey, 1992). However, both approaches are concerned with the epistemological status of affordances as objective (albeit relational) properties.

It is on this point that positions appear to diverge in the importation of the affordance concept in anthropology in general, and archaeological GIS in particular. Gillings (2009:606) advocates for their objective status, citing an illustrative example by Chemero. Chemero (2003:193), likens a (relational) affordance to an object that is “lovely”—in his example, a female hippopotamus. As he puts it, a female hippopotamus is lovely regardless of the presence of a

[1] For an overview of the concept, see Jones (2003).

male hippopotamus. That is, she is lovely to a male hippo by her nature, "just in case" a male hippo were to be present (this is the relational aspect). Chemero argues that affordances are "lovely" in this (objective) sense—in relation to the physiological and cognitive apparatus (the abilities) of an observer, but nonetheless extant independent of an observer. Affordances-as-lovely in this sense are a kind of irreducible perceptual grounding or orientation (Chemero terms this "feature placing") of an organism in its environment. Chemero contrasts this objectively-present relational affordance with observer-dependent properties of an object, such as a "suspicious" object. That is, an agent or object can only be under suspicion if an observing agent is present to place it under suspicion (Chemero, 2003:193).

We agree with this distinction. However, in humans, knowledge and the significance of what is perceived is shaped by power and seems pragmatically inseparable from it. We see abilities as broad parameters of perception, but we also agree with anthropological interventions in this discussion, which emphasize "what we normally pay attention to" (to return to Gibson's formulation)—is not simply innate or unmediated. It is also (as articulated by Ingold, 1992) constituted by cultural transmission and social reproduction, and thus by power relations, as mediated by bodily hexis, habitus, and structure in social practice (see Gillings, 2012; Llobera, 1996). To bring this back to the research context of this study, we might ask, for example, how might a colonial church be "lovely" (not in the common usage, but as conceived by Chemero)? We would argue that in practice, the ways it might be lovely would also depend on the subject position of the beholder, since even bodily dispositions, or the ontological status of "object", "subject", or "building" are culturally mediated (for discussion in the Andean context, see, Allen 1998; Bray 2015; Chase 2015; Quilter 1990).

Conversely, affordances shape power relations, and can be manipulated (in contextually-dependent degrees and qualities) to alter power relations. The social production of space has been of primary concern to human geographers, anthropologists, and archaeologists at least since Lefebvre (1991). But how, specifically, in context, is space socially produced, and to what effect? The affordance concept, and its study through GIS, enables us to systematically address this question: how space is manipulated, and the effects of that manipulation on perception. In these senses, then, we agree with Llobera's original suggestion, that "… ultimately, affordances may be associated with the organization of power and domination, as power relations are acted and re-enacted within *structures*" (1996:614, italics in original).

The significance of affordances in our reading is culturally- and ontologically-relative. In a colonial context such as the Reducción General, the situation is especially complex, as (sometimes radically) distinct ontologies, abilities, and environments are set in flux and opposition. That is, both sides of an affordance relation—environment and ability—are destabilized and become sites of struggle. GIS provides the means for reproducible and robust characterization of affordances. To explore the affordances of movement and visual experience in a colonial planned town, the GIS modeling for this paper are computationally complex, but we agree entirely with Gillings (2009:335) that the utility of GIS in conveying an experiential perspective will not be advanced on technical innovation per se; it is dependent on its integration with contextual understanding and a clear research program.

3. Research context

Here we make an initial step toward characterizing the affordances of movement and visual experience and their contested significance in a town that was built as part of a colonial program designed to reorder and reorient the perceptions and interactions of indigenous Andean subjects. The context for the study is an exceptionally well-preserved relict reducción in the upper reaches of the Colca Valley of southern highland Peru. This site, the reducción of Santa Cruz de Tuti (today known as Mawchu Llacta), is situated in the *puna* (high altitude grasslands) at 4100 m above sea level, in a high basin hemmed in by steep colluvial slopes (Figs. 1 and 2). It was also built in the location of a major Inka center, which likely functioned as the top tier administrative center for this high altitude area of the valley populated mostly by pastoralists of the Aymara-speaking Collagua ethnic polity (Wernke, 2016).

Since 2012, the first author has directed intensive architectural survey, surface collections, and excavations at Mawchu Llacta. Its unusually well-preserved fieldstone architecture presents the opportunity to render a detailed view of the role of the built environment in the everyday life of a reducción. It is a large town, measuring 0.5 km on a side, and is composed of a checkerboard grid of roughly 100 urban blocks. The blocks are quite uniform, varying between 40 and 43 m on a side, which corresponds to 50 *varas* (Spanish yards) or one *cordel* (the size stipulated in Toledo's ordinances) (Fig. 3). Laying out the urban grid was clearly the first step in construction of the reducción, given that several blocks were delineated with fieldstone walls but no buildings were built in them. Within the blocks, considerable variability in the forms of domestic compounds and their constituent structures suggests that direct state oversight of the construction of the town was probably limited to the layout of the grid. One notable aspect of the town layout is the large blank spot in the middle with no appreciable standing architectural remains. This area was gridded off with the rest of the town during its construction but was apparently never built up, undoubtedly because a perennial springfed high altitude marsh known as a *bofedal* runs through this part of the town. Bofedales provide the highest quality and highest density forage for Andean camelids, and this area was surely used for pasturage and corralling of camelids (primarily alpacas) kept by the population, much as it continues to be used by the descendent community today.

Santa Cruz de Tuti is also exceptionally well-documented in regional archives, which include several complete, detailed censuses from the 16th and 17th centuries, and parish records through the 19th century. We know from parish records that the town fell into a derelict state by the turn of the 19th century and was abandoned by 1843, when the population had moved 1.5 aerial km (4 km by footpath) downslope to the current village of Tuti, which is also built around a central square and church (Wernke, 2016). Its combined archaeological and documentary endowments thus provide an unusually detailed window into life in a reducción through the entire colonial era and into first two decades of the republican era.

As is common in Andean communities, the population of Santa Cruz de Tuti was divided between two ranked (probably endogamous) moieties, or *sayas*, called *Hanansaya* (upper ranking moiety) and *Urinsaya* (lower ranking moiety). Each moiety in turn was composed of a number of named, lineage-like kindreds (*ayllu*). Colonial censuses (*visitas*), used for setting colonial head tax quotas, were conducted by moiety. Complete censuses exist from 1604 for the Urinsaya moiety, and 1617 for the Hanansaya moiety. The combined population from these closely-spaced census is 1015 people. Nearly half (41%) of the population is composed of a single ayllu, which is the ranking ayllu from the upper ranking Hanansaya moiety (its headman is identified as the *kuraka principal* [paramount kuraka]). This ayllu and the corresponding ranking ayllu from Urinsaya are markedly more pastoralist in economic orientation, with the highest per capita livestock (Andean camelid) declarations. Given their large populations, their ranking status, and their pastoralist economic orientation (recall that Mawchu

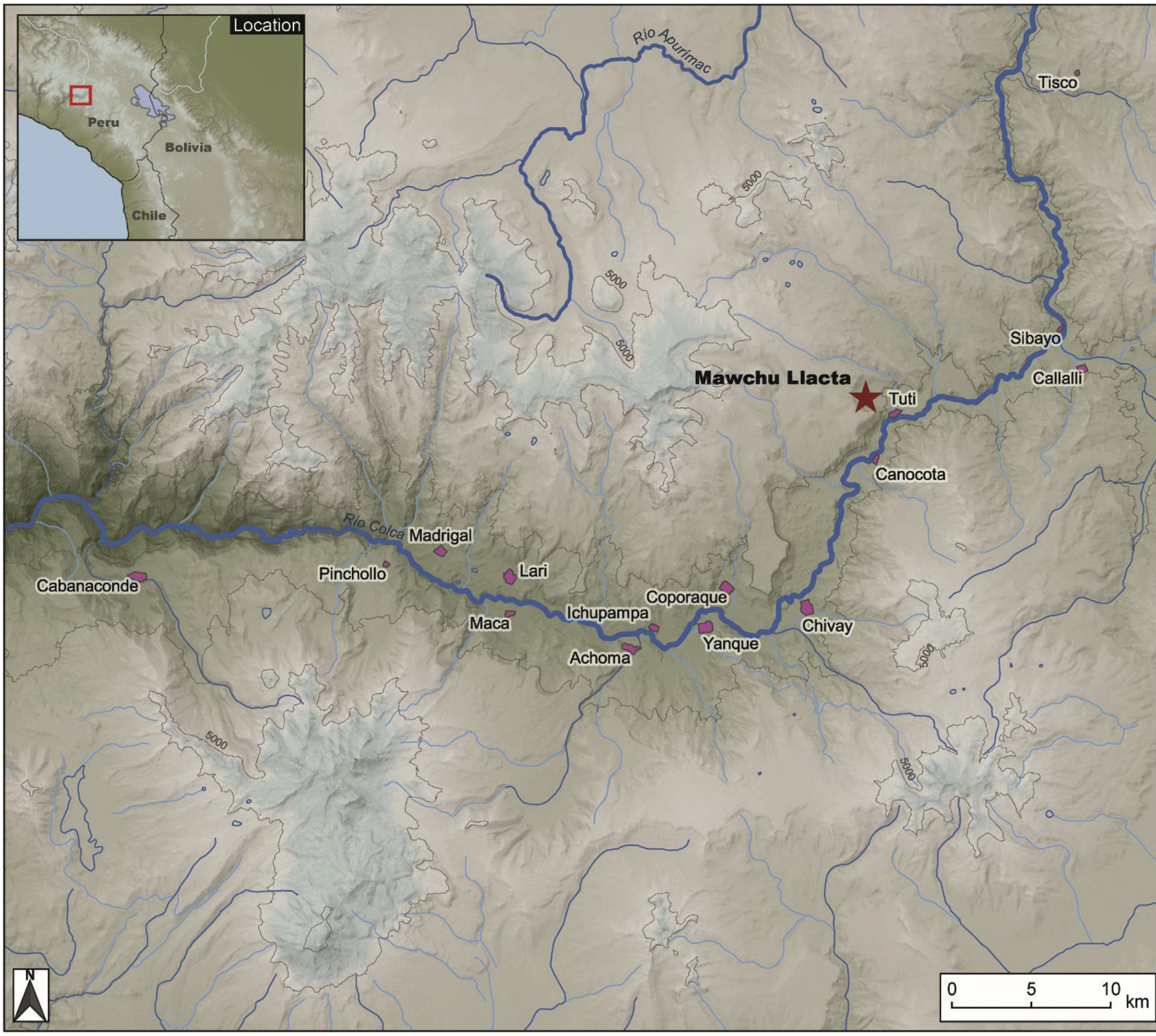

Fig. 1. Location of Mawchu Llacta within the Colca valley.

Llacta is located in the high altitude puna herding zone), these were likely the descendants of the originary inhabitants of the Inka era settlement. The remaining ayllus, predominantly from the lower ranking Urinsaya moiety, were much smaller and composed of households with higher per capita landholdings, indicating an agriculturalist economic focus. Thus, it appears that the reducción was built in the location of large, high ranking ayllus of pastoralists—the Inka era ancestors who likely mediated Inka imperial administration much as their descendants did under Spanish colonial administration (see Wernke, 2016).

Intensive architectural survey establishes clearly that reducción was indeed built over a major Inka era settlement with elaborate Inka cutstone masonry (Wernke, 2015, 2016). The built features of this Inka center were not entirely demolished by the reducción, however, and what was left in place is especially intriguing. A striking feature of this reducción compared to others is that its main church is flanked by not one, but two plazas: one situated off the lateral portal of the church to the north, and the other in front of the church to the east (Fig. 4). Moreover, the plaza in front of the church does not fit the orthogonal grid in either its form or dimensions: its placement does not coincide with the rest of the grid, and it is *trapezoidal*, not rectangular. This was almost certainly the central plaza of the former Inka center. The original entry of the Inka era settlement was likely through the main incoming path, which gives access to a broad corridor with no domestic architecture to the southeast of the trapezoidal plaza (see Fig. 4). The preservation and orientation of the reducción around the former Inka plaza follows a pattern of Spanish colonial recycling of Inka plazas locally and elsewhere (Wernke, 2013, 2015). Inka settlements are generally plaza-centric; Inka state installations were generally built around large public plazas that acted as stages upon which the state performed its largesse in elaborate commensal rituals, thereby enacting an ideology of reciprocal obligation between the state and its subject communities (Coben, 2006; Dillehay, 2003; Moore, 1996a, 1996b; Morris, 2013; Morris and Thompson, 1985).

After the reducción was built, this trapezoidal plaza was symbolically “squared” to accommodate Catholic liturgical ritual

Fig. 2. Overview of the main church and parish of Mawchu Llacta, taken by UAV from the east. Note gridded street plan.

through the placement of four altar platforms (called "posas") near the corners of the plaza, forming a rectangle between them. Such posas are common features in mendicant evangelical complexes in the Americas (see, e.g., Schuetz-Miller, 2000). The Colca Valley was among the first major mission fields of the Franciscans in Peru, and these posas are likely part of an initial Franciscan remodeling of the former Inka ceremonial core of the settlement (Wernke, 2015). The main church is also oriented frontally to the trapezoidal plaza, and the dominant axes of the urban grid align with it as well.

Thus, the core of the reducción—and the grid of the reducción as a whole—was oriented around the central ceremonial complex of the Inka settlement. Further, we know from a parish inventory from 1785 that the trapezoidal plaza was called the *Plaza Real* (Royal Plaza), connoting its paramount importance, while the rectangular plaza with six chapels was referred to merely as a *plazuela* (minor plaza) (AAA, 1785). The parish inventory goes on to describe even the names of the two principal streets of the town, both named "Calle Real" (Royal Street)—one running east-west through the Plaza Real, and one running north-south to the adjacent west of the parish complex (see Fig. 4). Division of the urban grid between Hanansaya and Urinsaya is a ubiquitous feature of reducciones, here and elsewhere in the Andes. Of these two principal streets, the Calle Real running through the Plaza Real is most likely the dividing line between Hanansaya and Urinsaya. These contextual details guide discussion of movement and visual affordances within the reducción, presented below.

4. Modeling movement and visual experience: methodology

Our GIS-based model leverages the excellent architectural preservation at Mawchu Llacta to model movement and visual experience within the reducción using combined spatial network analysis and cumulative viewshed analysis. Our goal is to produce a generalized simulation of movement through the reducción, so the model is designed with minimal assumptions about how individuals moved through the site. The model is comprised of two core aspects, each discussed in greater detail below: (1) construction of an aggregate transit density map using a spatial network dataset based on the well-defined streets and pathways through the settlement; and (2) construction of a transit density-weighted cumulative viewshed. In outline, the model first simulates movement between every house and every other building—an everywhere to everywhere walking matrix—to produce an aggregate transit density map. Observer points are then distributed evenly throughout the network, and a cumulative viewshed analysis is run. Each viewshed is weighted by the number of walkers who passed through its observer point in the everywhere-to-everywhere walking simulation. This produces a transit density-weighted cumulative viewshed. The model thus simulates the elementary effects of the built environment on movement and visual experience in the reducción: that is, its most basic movement and visual affordances in relation to a walking simulation from each house doorway to every other doorway in the town via the shortest routes. This seems a most appropriate starting point for a broader and more contextually-attuned exploration of affordances in this town. Future iterations will apply this kind of approach to specific events such as processionals through the plazas and calls to worship—events we know from textual sources to have occurred regularly in the town. However, at this stage we first seek a characterization of the basic parameters of movement and visual affordances by minimizing assumptions about the structure of movement.

Fig. 3. Architectural basemap of Mawchu Llacta, based on in-field digitization of high resolution aerial imagery. DEM derived from photogrammetrically-processed UAV imagery.

4.1. Dataset

Modeling movement and visibility at this scale requires high-resolution topography and 3D architectural base data. The data used in the model are derived from two seasons of architectural survey, which we conducted with the aid of high resolution orthomosaics from UAV imagery (Fig. 5). The UAV imagery was collected via autonomous missions, resulting in an orthomosaic of 4.0 cm resolution, and a DEM of 15.9 cm resolution (Fig. 6). The imagery was georeferenced to a series of ground control points set by RTK GNSS with horizontal and vertical accuracy of less than 1.5 and 3 cm, respectively.[2]

4.2. Transit density map

Spatial network analysis provides the basis for constructing the aggregate transit density map of the site. Our model makes two major modifications to standard spatial network analysis: (1) incorporation of an anisotropic walking model for calculating travel costs; and (2) use of per-house population estimates to approximate density of transit along paths in the network. Spatial network analysis models travel through a user-defined network, which makes the approach especially useful for examining movement in contexts such as Mawchu Llacta where both streets and pathways within its blocks are clearly identifiable. The model uses the Closest Facility function of the Network Analyst extension of ArcGIS to generate an everywhere-to-everywhere walking simulation by finding the most efficient route between every house and all other buildings at the settlement.

Significantly, our model incorporates a custom implementation of anisotropic walking costs in the Closest Facility calculation of least cost network paths. The model resolves an estimate of the time to traverse each path segment in the network based both on

[2] The imagery was collected via autonomous flight using the Drone Pilot application by Maps Made Easy, which automatically generates drone survey passes based on the drone model, area of interest polygon, height above surface, image overlap, and camera parameters. In this case, we chose a height above surface of 57 m and image overlap of 70%. The resulting aerial survey produced N = 518 12 megapixel RGB photos using a DJI Phantom 4 drone.

Fig. 4. Central area of Mawchu Llacta. The Calle Real running east-west through the Plaza Real likely divided Hanansaya (upper moiety) to the south from Urinsaya (lower moiety) to the north (see text).

distance and the slope for each direction of travel along the path. Unlike other movement analyses, such as least cost path analysis, which natively integrate raster datasets like elevation and slope to model travel, spatial network analysis is entirely vector-based and uses attribute values as impedances to define a travel cost for each path segment and direction of travel. For this reason, previous applications of spatial network analysis in archaeology have relied on constant velocities based on mode of travel (Livarda and Orengo, 2015; Orengo and Livarda, 2016; Scheidel, 2015; Wernke, 2012). However, slope can have a significant impact on not only travel time, but also route selection for pedestrian travel (Pingel, 2010).

Our model calculates a direction-dependent, slope-based travel time along each path segment as an attribute in the network edge theme, which is then used as an impedance value in the Closest Facility function. Each path was segmented using the raster resolution of the underlying DEM (in this case, 15.9 cm). The slope of each segment was calculated from the elevation change based on the DEM-derived elevation at each segment endpoint. We use Tobler's Hiking Function (Tobler, 1993) to calculate the effect of slope on walking velocity (for both directions across each segment). Tobler's equation calculates walking velocity as follows: W = 6e^(-3.5|S +0.05|), where W is walking velocity in km/h and S is the slope of the terrain. The resulting equation calculates the time to traverse each sub-segment:

$$T = \frac{0.06}{6e^{-3.5|S+0.05|}} \times \left(\sqrt{D^2} + C^2\right)$$

where T is time in minutes, S is slope, D is distance in meters, and C is the change in elevation along the line in meters. Tobler's model thus provides an initial approximation of walking affordance by providing a proxy for "ability" (of a modal agent) in relation to slope values through the network. The total time cost of each network edge (line between two junction points) was then calculated by summing of its corresponding segments (once for each direction across the edge).

We then use these anisotropic time costs as impedance values in the everywhere-to-everywhere walking simulation. In ArcGIS, the Closest Facility function in the Network Analyst extension was run

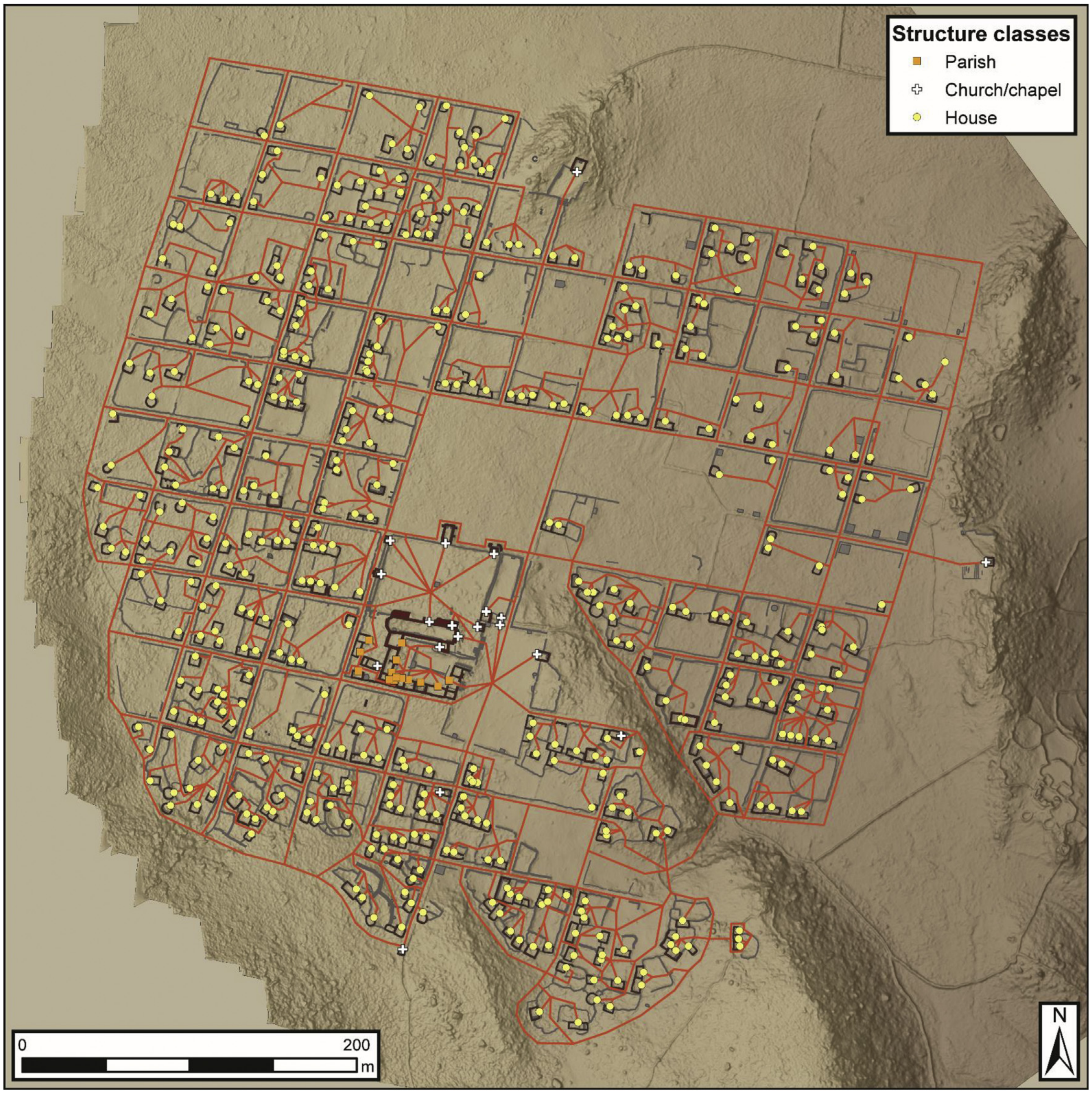

Fig. 5. Spatial network of Mawchu Llacta. Derived from in-field observations and well-preserved walls delineating blocks and patio groups.

to resolve the least cost network path from every house (n = 473), to every other structure (n = 507), for a total of 239,338 routes ([473 × 507]-473). Initial results showed high transit density along several paths through the interior of residential blocks and patio groups; a result that seemed unrealistic in terms of how individuals would typically move through the site. Residential blocks are enclosed by walls that line the streets of the town, clearly setting them off as domestic, rather than public, spaces. They almost certainly would not have been used as major thoroughfares, as resulted in the unrestricted walking model. We therefore added turn restrictions so that walkers would preferentially route through the streets of the town, using points of access to the blocks and domestic compounds only when exiting or entering them as points of departure or final points of arrival. This approach ensured that walkers would not cut through blocks or patios mid-journey. The initial unrestricted iteration also produced high volumes of traffic through the bofedal. This is a perennially marshy area, and the spaces between the demarcated blocks likely did not function as streets. We therefore also introduced turn restrictions to prohibit walkers from cutting across the bofedal.

Having only one walker per house in the everywhere-to-everywhere routing matrix would not produce a realistic result, as house sizes vary considerably, and household sizes varied accordingly. We therefore used per-house population estimates to simulate aggregate traffic along each path segment. For each house of origin, Naroll's constant of 6 m^2 per person was used to derive the number of walkers from each house (thus, a house of 24 m^2 would have 4 walkers) (Naroll, 1962). In this way, the designated number of walkers from each house walked to all of the 507 buildings via the shortest (in time) routes. For each path segment, a final transit density was calculated via spatial join of all 239,338 routes, summing the total number of walkers across each path segment.

4.3. Weighted cumulative viewshed

The next step was to construct a cumulative viewshed of the settlement weighted by the aggregate path use derived from the aggregate transit density map discussed above. First, 1000 observer points were distributed evenly throughout the network. Viewshed

Fig. 6. Example of UAV-based orthomosaic resolution: main church and parish of Mawchu Llacta (with excavations in progress [left]). This 4 cm resolution orthomosaic is derived from 518 photos taken during autonomous UAV survey at a height of 57 m.

analysis from each observer point was conducted (at an observer eye height of 1.5 m). The viewshed base data are derived from a base DEM derived from the UAV imagery, which has a very high resolution (15.9 cm), but required some preprocessing to adequately incorporate both the terrain and architectural features. Of interest is the original, full heights of buildings and other architectural features, rather than their heights in their current state of preservation. We therefore removed the current architectural heights from the UAV-derived point cloud via point classification (using Agisoft Photoscan 1.2.6). The building footprint vector map (derived from in-field survey using the UAV imagery as a basemap) served as the basemap for estimating original, full wall heights. We recorded all cases in which the full longitudinal height remained preserved in the field. In cases of houses in which full heights were not preserved, we used the median full height from the sample of cases in which the full height was preserved as a proxy. The building footprints, the walls defining streets, patios, and other unroofed areas, and other features from our architectural survey were then rasterized according to their full height values and merged to the terrain DEM (both at the same resolution of 15.9 cm) via raster algebra. All wall heights represent longitudinal wall heights and do not include gables. Gables were not included in the model due to the complexity of rendering them (given the irregular contours of the house footprints themselves). However, of primary interest is the relative visibility of buildings rather than absolute viewshed values. Exclusion of gables from all buildings therefore should yield similar relative visibility results to a model with gables included on all buildings. The resulting composite DEM is composed of a 15.9 cm resolution of the terrain with crisp architectural features coincident with their 3D-extruded vector counterparts.

The key to combining the movement simulation results with visual experience is weighting the resulting viewshed rasters by the transit density at each corresponding point in the network from the everywhere-to-everywhere walking simulation. That is, rather than a traditional binary viewshed (0 = not visible, 1 = visible), in this model, viewshed cell values with a visible result (1) were multiplied by the transit density value simulated at its

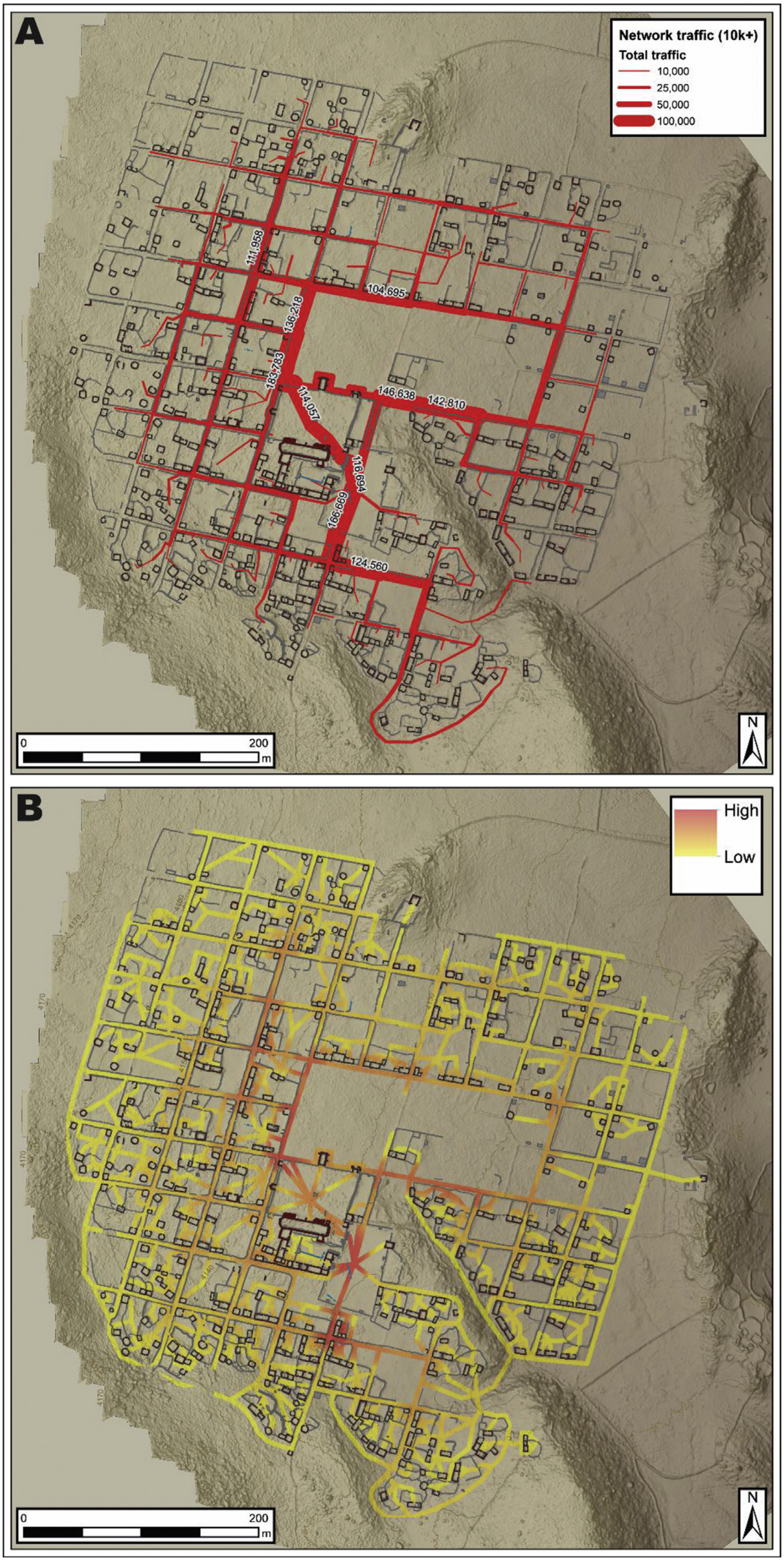

Fig. 7. Simulated transit density from everywhere-to-everywhere routing matrix (log scale). In the vector-based visualization (A), only network edges with 10,000 or more walkers are included. Network segments with 100,000 or more walkers are labeled with their corresponding traffic values. The raster-based visualization is derived from a line density function (a kernel density estimator) using the aggregate transit values for each network segment.

corresponding observer point (from the everywhere-to-everywhere walking model). Lastly, the visibility rasters from each of the 1000 observer points was summed via raster algebra to produce a final transit density-weighted cumulative viewshed.

We ran the model twice to simulate different scales of visual/movement experience. The first run used an unlimited viewshed radius to provide a sense of whole-site scale visual/movement experience. The second run used a 50 m radius viewshed radius to approximate what was most or least visible in the close visual field of walkers as they moved through the site. Below, discussion focuses first on the 50 m radius limit simulation to explore the proximal visual impact of the built environment (primarily buildings) while walking through the town—that is, as a measure of which buildings are most prominent in the close range visual field.

4.4. Statistical checks

Simple visual inspection of the resulting viewsheds may be suggestive, but would be prone to impressionistic interpretation. What is needed as a control is a counterfactual (null hypothesis) distribution with no spatial dependence of visibility. The Getis-Ord Gi* statistic provides such a solution. It analyzes each feature in relation to neighboring features, and indicates where features with high or low values cluster (hotspots or coldspots, respectively) relative to a random distribution of values on those same input features. In ArcGIS, the Getis-Ord Gi* statistic can be run through The Optimized Hotspot Analysis tool. The tool requires vector inputs with a magnitude value associated with each feature. To use it with our model, we extracted values from the transit density-weighted cumulative viewshed rasters. This was done with two vector themes to address distinct aspects of visual affordances.

First, to provide a general view of transit density-weighted visibility hotspots and coldspots, a 10 m grid of sample points was superimposed on the viewshed, using the extent of the architecture at the site to define the boundary of the sampling grid (N = 2323 sample points). At each sample point, the mean value of the coincident viewshed cell and its eight surrounding cells was extracted, and the Optimized Hotspot tool was used to generate Getis-Ord Gi* statistics for both the unlimited and 50 m transit density-weighted cumulative viewsheds to guide discussion.

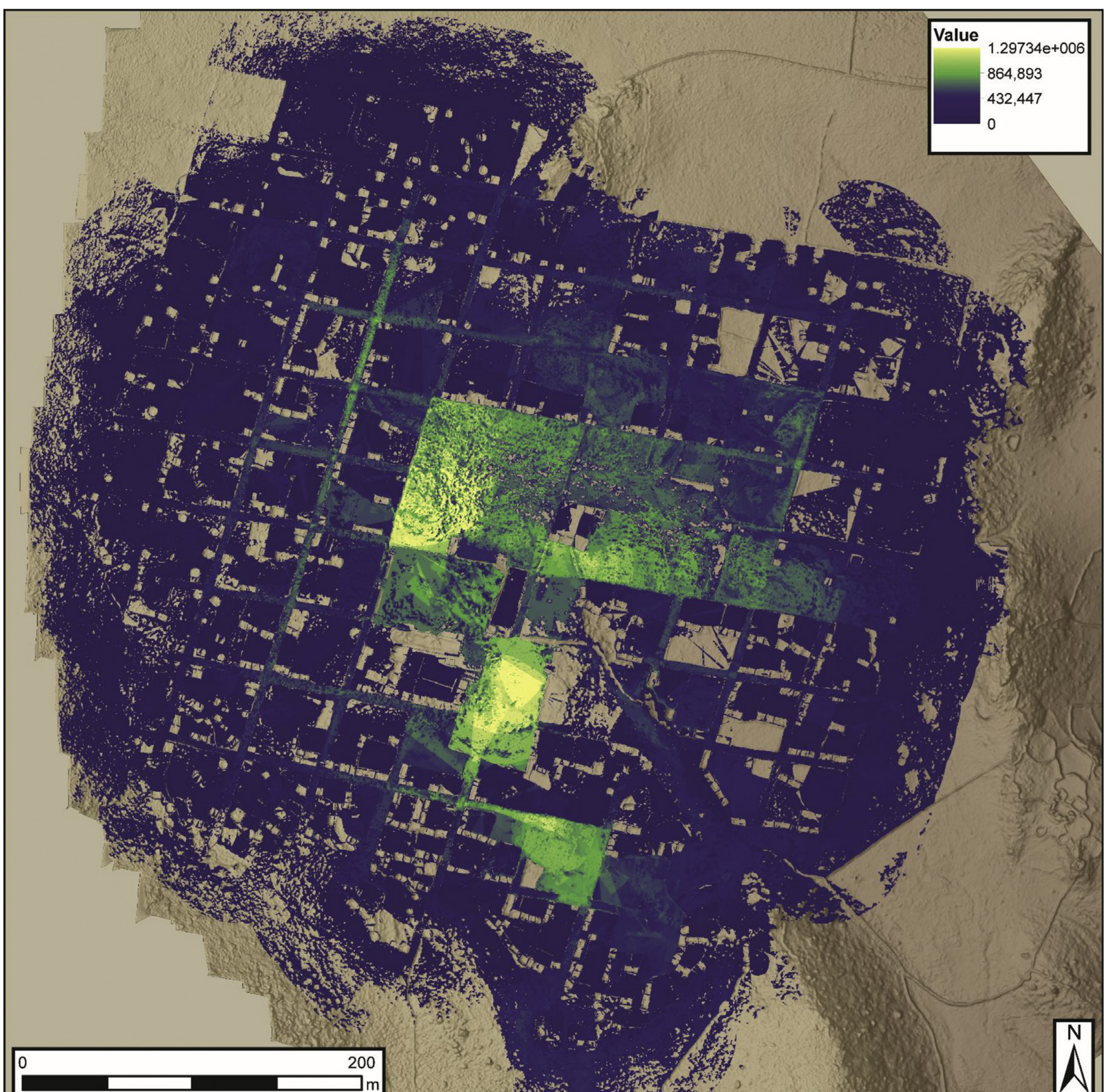

Fig. 8. Transit density-weighted cumulative viewshed with 50 m radius restriction.

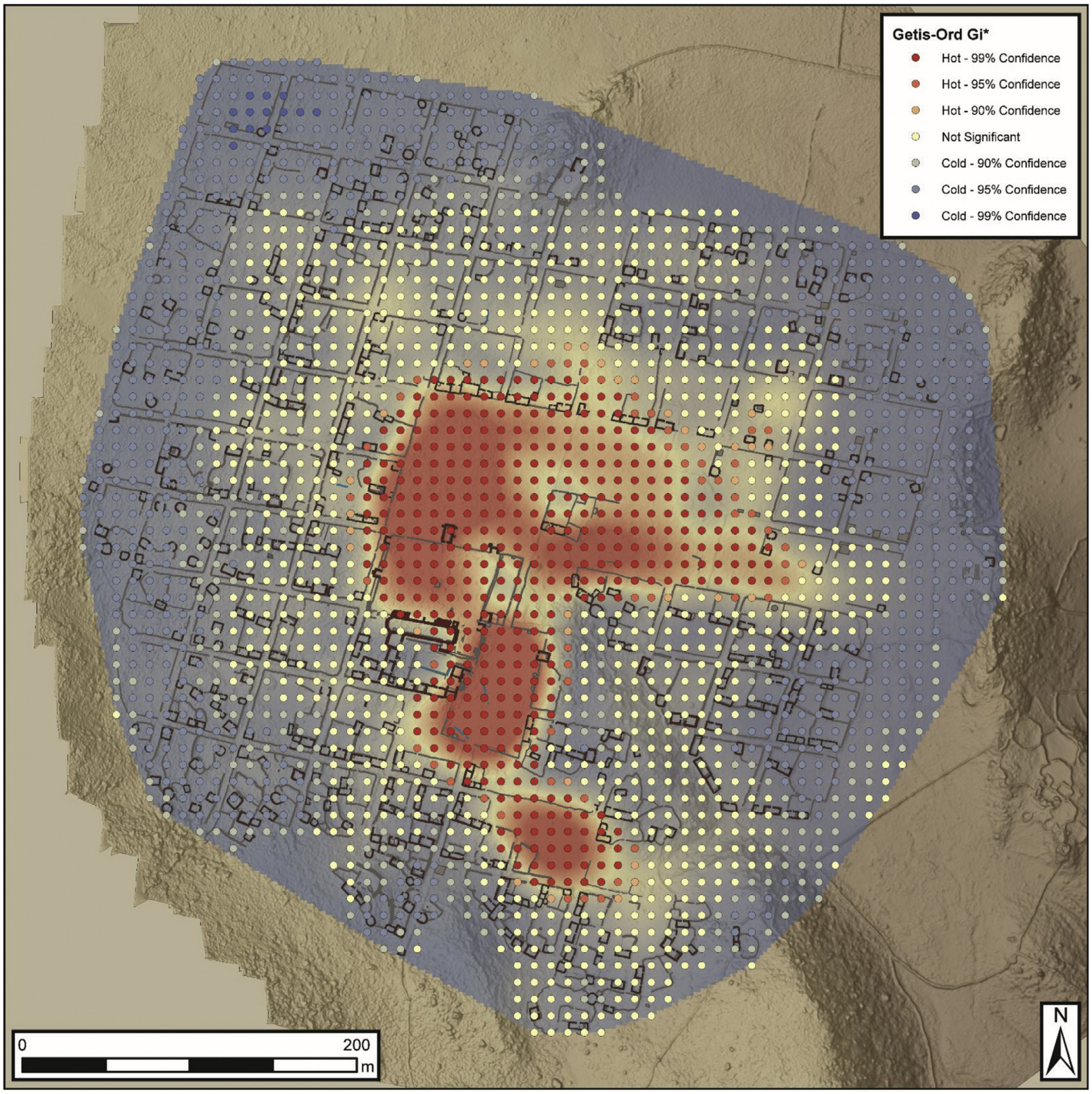

Fig. 9. Hotspot analysis based on 10 m grid sample of transit density-weighted cumulative viewshed with 50 m radius restriction.

Second, This point sample approach enables a view of general visibility hot and cold spots, but the visual prominence of the buildings themselves is not readily apparent. In part this is because the visible aspect of the buildings in a viewshed consists most often of a single pixel-wide shell corresponding to the exterior vertical surface of each building. A means of isolating and analyzing building viewshed values is needed. We did this by first using the rasterized version of the structure footprints as a raster mask over the 50 m and unlimited viewsheds. This step produced a raster that was a viewshed composed of only the building footprints. The building polygons were then overlaid, and the maximum viewshed value pixel from the resulting masked raster was then extracted to the building polygons (some buildings—especially large and complex ones, were composed of several polygons, enabling characterization of visibility of distinct parts of the building). Optimized Hotspot Analysis was run on the building polygons with their maximum viewshed values as the input value. This was done for both the viewshed with a 50 m viewing radius and the viewshed with an unlimited viewing radius.

5. Affordances of movement: everywhere-to-everywhere walking simulation

The walking simulation from every house to every other building provides a first index of affordances of movement within the reducción; that is, how the built environment imposed itself as a *colonizing* space, even as it recycled Inkaic imperial spaces within it. First we present the results of the everywhere-to-everywhere route matrix analysis. Transit density is presented in both vector and raster formats (Fig. 7). Fig. 7-A displays transit density by line thickness, excluding segments with less than 10,000 walkers. A kernel density raster (on a logarithmic scale) based on the total traffic on each segment of the network serves as a visualization of the transit density. Transit density values in the network vary widely from 0 (segments that do not lie on any least cost network paths) to 183,783 walkers. What is clearly evident in both representations is the centrality of both plazas, and especially the Plaza Real—that is, the original, Inka-era trapezoidal plaza, and the streets running into them. The street that enters the center of the south end of the Plaza Real is an area of high aggregate transit, and

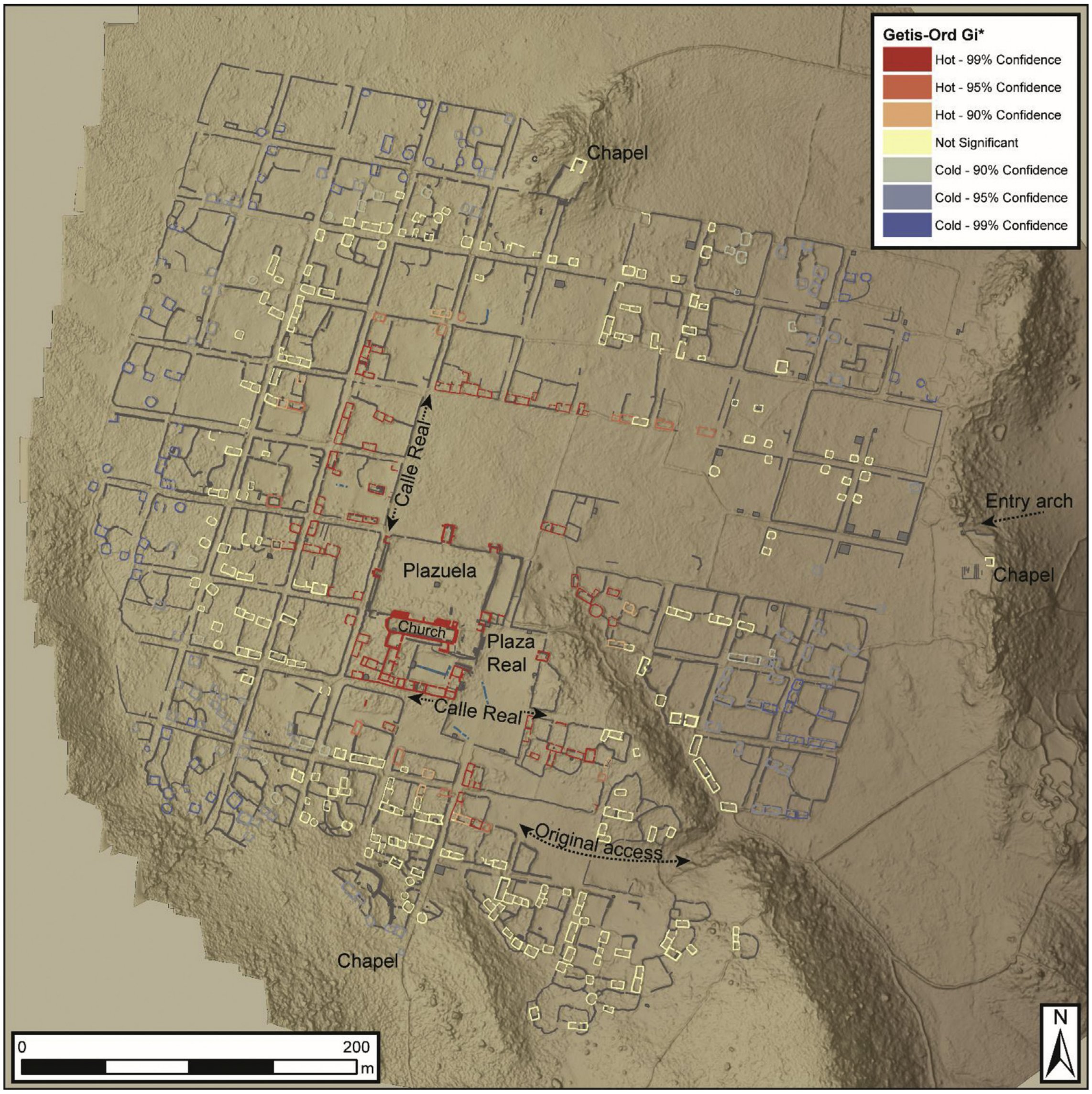

Fig. 10. Hotspot analysis of maximum visibility values of buildings in transit density-weighted cumulative viewshed with 50 m radius restriction.

the network edge with the greatest aggregate transit is the segment just outside the northwest corner of the Plazuela, along the Calle Real that runs east-west. Another area of high traffic is to the southeast of the Plaza Real, the area of the probable original access to the site and into the Plaza Real during Inka times.

The "primary" Calle Real—the one that runs east-west through the Plaza Real—had relatively low aggregate transit. As discussed above, this was likely the primary division of space in the town into upper (Hanansaya) and lower (Urinsayas) halves (moieties). Its low aggregate transit seems to be due to its poor integration with the urban fabric, which is reflected in its off-center intersection with the Plaza Real. The bulk of the transit into the Plaza Real was through the street running into its southern end. That street, which terminates in a small chapel structure on its southern end, appears to have high transit values due to the density of occupation in the Hanansaya residential area to the south of the Plaza Real.

These results suggest that the two plazas, along with the east-west Calle Real, were among the most central areas in the reducción in a spatial network sense—that is, they were the areas of highest density of transit in the everywhere to everywhere route matrix. Though not counterintuitive, this is an important insight that would not be demonstrable without this kind of simulation. Recall that what is being modeled is not a discrete event of movement, nor movement *to* the plazas, but a composite representation of movement from every house to every other building at the site, using least cost network path routing. Thus, quite literally, in aggregate, the inhabitants of Mawchu Llacta *would have had to go out of their way to avoid the plazas* (and especially the former Inka trapezoidal plaza—the Plaza Real) in their daily routines moving about the reducción. Stated differently, one is more likely to pass through the plazas—and especially the Plaza Real—than other areas of the site. This is a basic characterization of the affordances of movement through the reducción. It begins to show how its spatial structure *fostered a propinquity for transit* through the plazas and towards the church and the chapels of the plazas. But when considered in relation to our contextual understanding of the settlement's history, it also points to the contested significance of those spaces, as the Plaza Real was also the former principal ceremonial space of the site under Inka imperial administration. These implications will be explored further below, following exploration

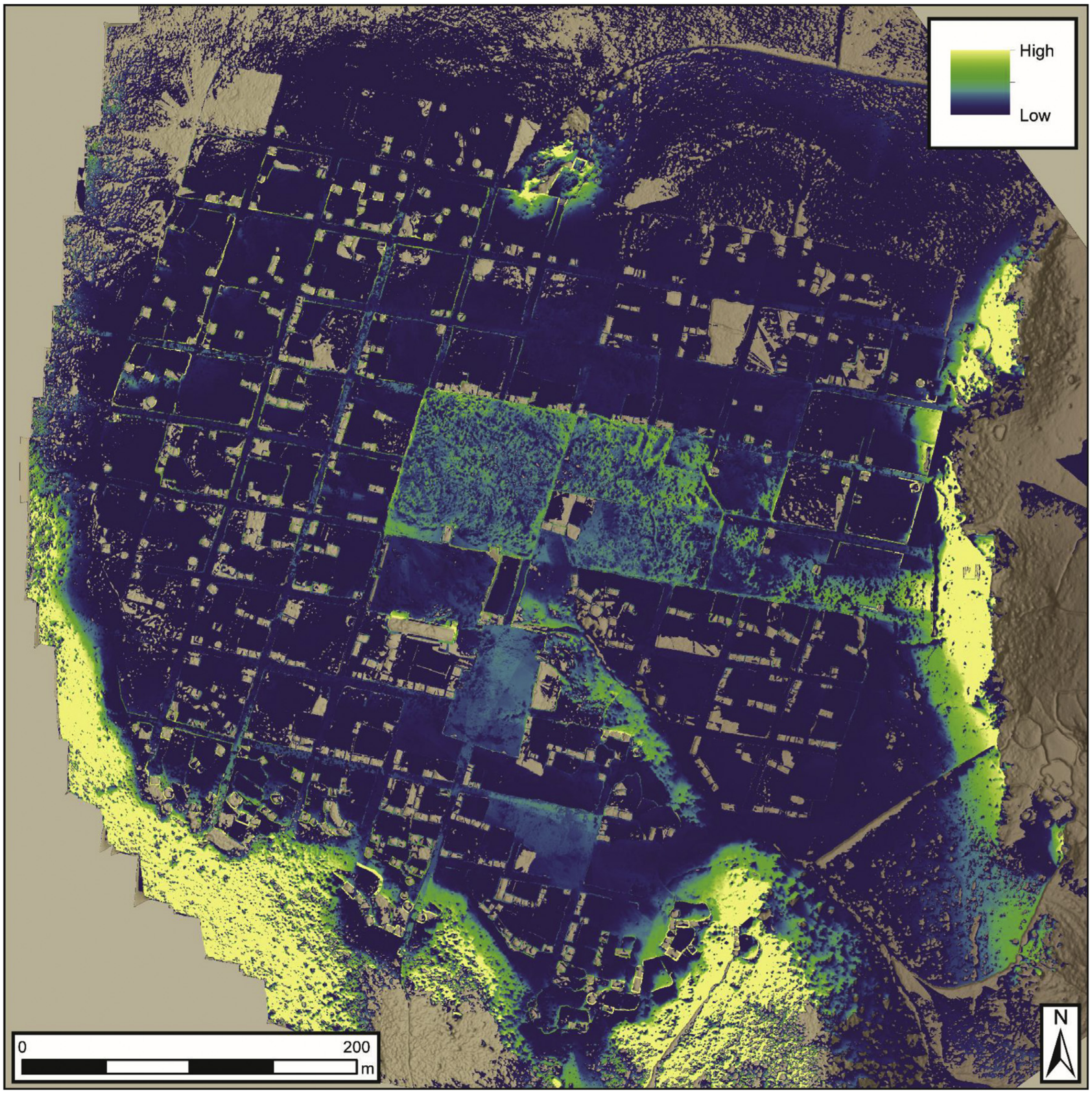

Fig. 11. Transit density-weighted cumulative viewshed with unrestricted viewing radius.

of how patterns of movement related to patterns of visual experience.

5.1. Movement and visual experience combined

Transit density-weighted cumulative viewsheds provide a robust and reproducible means for analyzing which aspects of the architecture and landscape were visually prominent or occluded as the people of Santa Cruz de Tuti moved through their reducción. Areas of visual prominence also varied markedly depending on whether the viewer was more focused on the near visual field (simulated using a 50 m viewshed radius limit) or looking out more generally (simulated using an unlimited viewshed radius).

First we discuss the 50 m radius transit density-weighted cumulative viewshed. Its raw result provides an initial visualization (Fig. 8). Here, the prominence of the plazas—again, especially the Plaza Real—is apparent, as is the open bofedal/corral in the center of the reducción, the secondary, east-west Calle Real as it runs along the western edge of the bofedal, and the likely original entrance area of the Plaza Real. The Getis-Ord Gi* statistic on the point sample grid (Fig. 9) shows extreme visual hotspots (that is, clusters of higher viewshed values at the 99 or higher confidence interval) in the Plaza Real, the probable original Inka-era site entrance, the Plazuela, and the bofedal/corral, surrounded by a thick cold spot band in much of the domestic areas of the site. This result conveys the visual prominence of these public spaces in the reducción, not only due to their relative central location and extents, but because of their network centrality as indicated in their high aggregate transit values in the everywhere-to-everywhere walking simulation. That is, if observers were randomly distributed throughout the town, and not in proportion to the aggregate transit pattern, it is highly unlikely that the Plaza Real and its original entrance, or the Plazuela or the bofedal would form visual hotspots. Conversely, we can infer that these areas were highly prominent in aggregate in relation to people's movement through the reducción. They were visually ubiquitous in the near field of view as people moved through the town.

Turning now to the visual prominence of the buildings themselves in the proximate visual field, the Getis-Ord Gi* executed on only the building polygons with their maximum cumulative

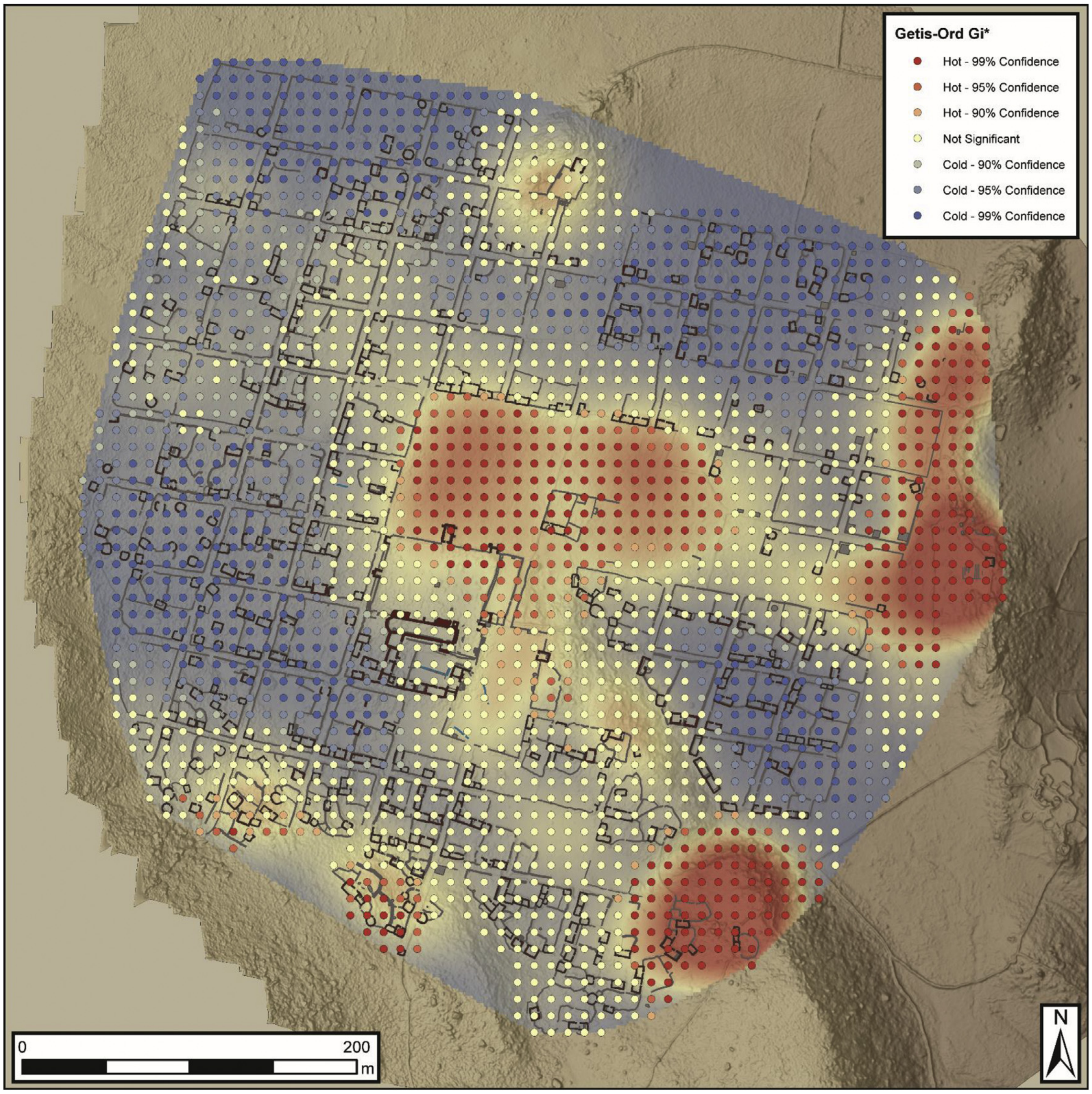

Fig. 12. Hotspot analysis based on 10 m grid sample of transit density-weighted cumulative viewshed with unrestricted viewing radius.

viewshed values shows a cluster of highly visible buildings surrounding the plazas, including the main church, parish buildings, and the chapels of both plazas (Fig. 10). Houses lining the north-south Calle Real, as well as those of the street running into the center of the south end of the Plaza Real are also part of this large cluster of highly visible structures. Conversely, as people moved through the reducción, if they focused more on the proximal visual field like this, the houses in the domestic compounds outside of these central areas were significantly less visible than would be expected if observers were distributed randomly throughout the settlement. This is a basic characterization of the affordances of building visibility in relation to movement through the reducción. That is to say, it shows how the spatial structure of the reducción *fostered a propinquity for visibility* (in the proximate visual field) of the colonial religious architecture and houses along its major thoroughfares.

Lastly, an unrestricted transit density-weighted cumulative viewshed provides a more generalized sense of visual prominence. In this run of the simulation, all parameters are the same except the 50 m radius restriction on the viewshed is removed. Interestingly, what results in the unrestricted transit density-weighted cumulative viewshed is a nearly inverse image (Fig. 11), with the highest visibility values around the margins of the reducción, in areas of high topography, and areas of lowest visibility near the center. The Getis-Ord Gi* on the sample grid of this viewshed shows clusters of visibility hotspots around the eastern, southeastern and southern edges of the town, which again correspond to promintories and the higher slopes surrounding the basin that the bulk of the reducción occupies. Interestingly, the corral/bofedal and parts of the Plaza Real and Plazuela continue to form visibility hotspots (Fig. 12).

When focusing analysis on the buildings (by running the Getis-Ord Gi* statistic on the building polygons with their corresponding maximum cumulative viewshed values), a similar picture emerges, but a large area to the northwest also forms a visibility hotspot (see Fig. 13). In this rendering in which the visual field extends beyond 50 m, the houses situated up higher on the slopes of the enclosing basin are the most visible in this generalized sense. These opposing axes of visual prominence roughly correspond to the spatial division of the reducción between Hanansaya and Urinsaya. The houses in the visibility hotspots to the south corresponds to what was

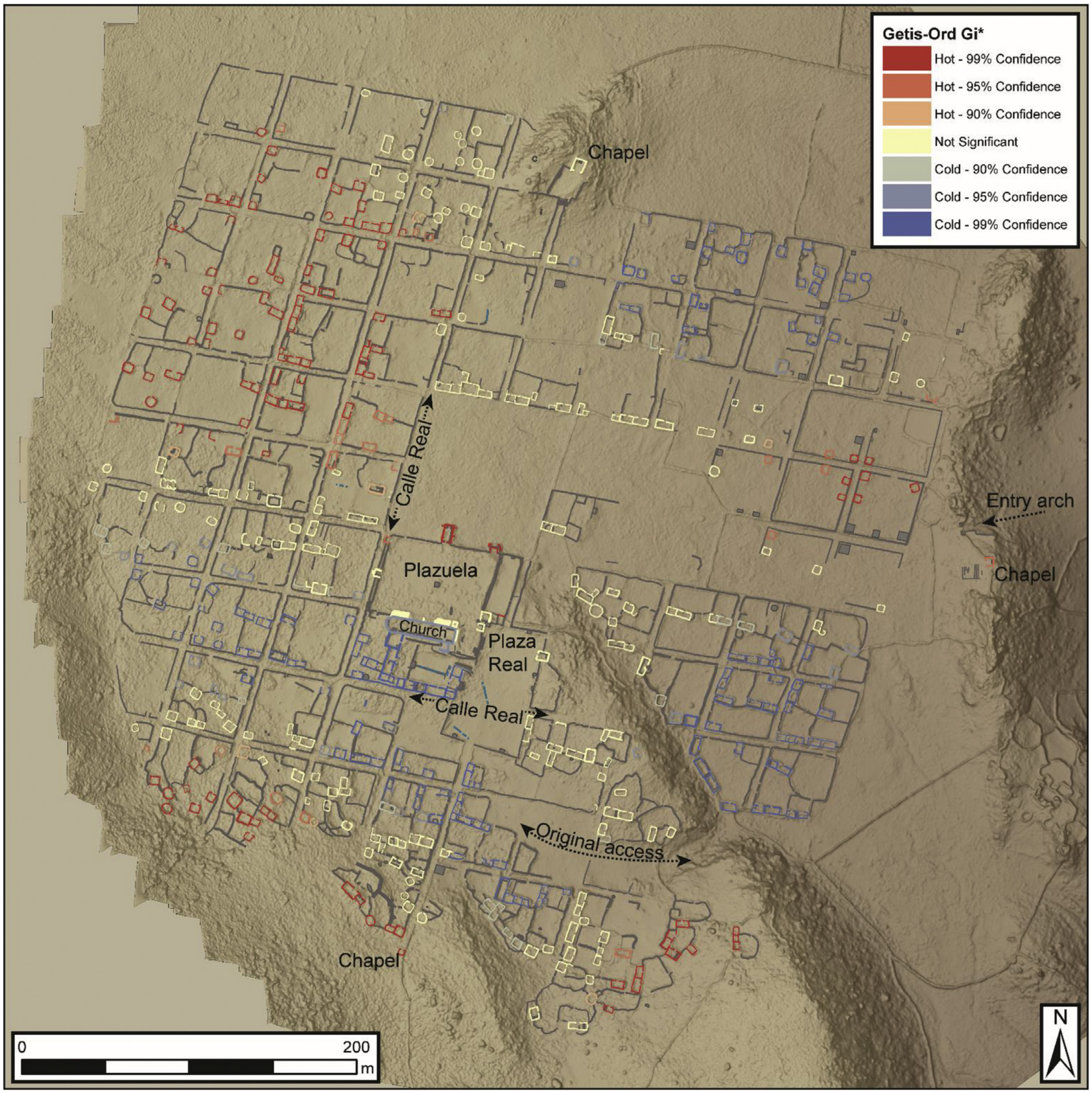

Fig. 13. Hotspot analysis of maximum visibility values of buildings in transit density-weighted cumulative viewshed with unrestricted viewing radius.

likely the higher-ranking Hanansaya moiety, which included the paramount ayllu making up nearly half of the village population. This is consistent with what we would expect, as Hanansaya (literally, upper moiety) in Andean highland communities is associated with high topography (Albó 1972; Bouysse-Cassagne 1986). Houses in the higher elevation areas of the northwest quadrant were also significantly more visible than would be the case if observers were distributed randomly. This is where the bulk of the population of Urinsaya resided, as occupation in the northeast quadrant is much sparser, owing to the presence of the marshy bofedal. However, the bodedal itself continues to retain high visibility, most likely owing to its adjacency to the heavily-transited Calle Real running along its western margin. Of note here is that the chapel at the extreme eastern margin is situated adjacent to the entry arch to the reducción. The center of this arch is collapsed today, but the two massive buttressed pillars that formed the clear span of the arch remain standing. Of the rest of the central area, only the chapels on the north side of the Plazuela form a visibility hotspot. The large chapel in the center of the north side of the Plazuela, opposite the main church, is especially prominent. This chapel is specifically referred to as a funerary chapel (miserere chapel) in the parish inventories.

The nave of the main church and the buildings of the parish, however, actually make up a visibility coldspot in this unrestricted viewshed simulation. This is probably due to the fact that the nearest neighbors to the church are the buildings of the parish, which have especially low visibility values in this simulation. This is especially interesting because it shows how the parish is relatively secluded when considering the overall visual impact of the built environment of the site, producing a cloistered effect for the priest who resided there.

6. Discussion and conclusion

By simulating movement from every house to every other building, and combining the aggregate patterns of transit with cumulative viewshed analyses, we have attempted to characterize the basic parameters of movement and visual experience—that is, the affordances of walking and visibility—within the built environment of this planned colonial town. With minimal assumptions about how the people of Santa Cruz de Tuti may or may not have moved through their town, and instead simulating nearly every combination of possible movement between the buildings of the town, this analysis shows how its built environment fostered certain propinquities of transit and visual experience; the latter was also sensitive to whether the viewer focused more on the proximate visual field or also looked out beyond it.

On the one hand, the manner in which the reducción materialized and enacted an ideology of imposition, eradication, and replacement to inculcate new rhythms of interaction and experience is readily apparent. In aggregate, transit would have been heaviest thorough the central plazas and past the main church and plazas, lest walkers take a more circuitous route than necessary to reach their destination. Likewise, in aggregate, the church, the plazas, and the central corral at the site were most visually prominent as one moved through the site, lest one focused beyond the proximate visual field (that is, beyond 50 m), in which case, the prominent households of the Hanansaya and Urinsaya in the higher elevation margins were generally more prominent. Moving through these spaces and seeing them was “baked in the cake” of the built environment itself. In this sense, we can now see in a quantitative, probabilistic, and reproducible fashion, how these affordances served colonizing ends: that is, to inculcate new habits in the bodies of the people of Santa Cruz de Tuti. This aspect is quite in line with Viceroy Toledo's stated goals for rebuilding Andean communities from the ground up to form “proper” civil and religious communities in an ideal Mediterranean image of urban order.

However, recalling the previous discussion, neither was the built environment of the reducción *only* an imposition. The entire colonial settlement was oriented by the former focal ceremonial complex of the Inka center that preceded the reducción. Stated differently, the imposition of a new colonial spatial order had to contend with the building blocks of its Inkaic precursor. The Plaza Real—the central stage for Inka-era commensal rituals—retained its central role and visual prominence as the people of Santa Cruz de Tuti went about their daily routines and (now Catholic) ritual cycles. It also likely continued to act as the boundary between the two moieties of the town—both a place of convergence and division between two halves of a community split between pastoralist and agriculturalist households.

These insights point to how the Plaza Real, and the reducción as a whole, might be understood as a doubly colonized and colonizing space as new patterns of practice, sensory experience, and surveillance both mapped onto and overwrote Inkaic precedents. The construction of this reducción in this particular place, and in this particular manner, minimized disruption to the elite residents of the former settlement and drew upon the practices associated with its most central public spaces. Conversely, its particular configuration must have resonated with its residents by means of its recycling of space, thereby substantially impacting the reception and significance of movement and visual experience while living in it. Are these spaces—those areas of high visual prominence and aggregate transit, such as the plazas, the church, the chapels, and so on—“lovely” in the relational affordance sense articulated above? At one level, the built environment seems to be structured to foster propinquities of movement through these spaces and to dominate visual experience in aggregate. But this place was far from a tabula rasa. Given the specific history of this place and its people, it seems equally clear that the effects and significance of these experiences would have been far more ambiguous than colonial administrators or clerics would have it. There could be no unmediated relation here between built environment and “ability”. Indeed, by building the reducción in the location of a former Inka administrative center, and by reusing its central ritual space, the Spanish made their urban model analogically intelligible, but in so doing likely unwittingly also fostered precisely the kinds of continuity of belief and practice they sought to eradicate.

In sum, this paper explored how GIS modeling can be used heuristically and interpretively, but equally importantly, in a manner that is measurable, reproducible, and robust. The results of these combined models of movement and visual experience at the site represent the beginning of a research process rather than an end. As a simulation, the results are suggestive and productive for framing future research questions as well as more diverse network and visibility simulations. In this sense, our GIS-based simulations of movement and visual experience in Mawchu Llacta are themselves an act of placemaking.

Acknowledgements

Research at Mawchu Llacta was funded by a Vanderbilt University Discovery Grant and a Vanderbilt University Chancellor's Faculty Fellowship. Photogrammetry and spatial analysis was supported by the facilities of the Vanderbilt University Spatial Analysis Research Laboratory (SARL). Gabriela Oré made significant contributions the basemap editing phase. Logistical support was provided by the the Parish of Santa Cruz de Tuti and the Municipality of the District of Tuti. Special thanks to Mr. Jesús Quispe and the community of Tuti for their support and hospitality. Investigations at Mawchu Llacta were conducted with the authorization of Resoluciones Directorales 431–2012 (Viviana Siveroni, co-director), 007–2013 (Gabriela Oré, co-director), and 227–2016 (Gabriela de los Ríos, co-director) of the Ministry of Culture of Peru.

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