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Reconstructing and testing neighborhoods at the Maya city of Caracol, Belize

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A R T I C L E I N F O

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A B S T R A C T

Present theory suggests that neighborhoods form through frequent, repeated face-to-face interactions among people in groups of spatially co-located residences. Over time, layered interactions create relational identities (through face-to-face contact) and categorical identities (through perceived similarities). Neighborhood identity, when present, indicates a union of both relational and categorical identities generated through shared social experiences. Unfortunately, we cannot directly ask the deceased about their neighbors; however, we can reconstruct likely zones of frequent, repeated face-to-face interaction and then test those assumptions using archaeological data. This analysis reconstructs neighborhoods at Caracol, Belize through the application of least cost analysis and k-means clustering. This spatial reconstruction relies on interpretations of interactions occurring near residences, in adjacent terraced agricultural fields, at public plazas in districts, and on the way to and from service-providing district architecture. Reconstructed neighborhoods, based on relational identity, are then tested archaeologically with excavated material from contexts related to categorical identity. Inter- and intra-neighborhood comparisons of ritual deposits from cache and burial deposits within 59 excavated residential *plazuela* housemound groups situated among eight sampled neighborhoods test and validate these reconstructed neighborhoods at Caracol, Belize by demonstrating, with statistical significance, more similarities within than between reconstructed neighborhoods.

1. Introduction

Neighborhoods, if present, provide an essential level for understanding society through the daily interactions and relationships of a city's residents. In urban and semi-urban contexts, they exist as an intermediary social unit between the administrative district that provides urban services and the residential household. All three of these social levels impact how urbanites live in their cities; however, the identification and testing of archaeological neighborhoods presents even greater challenges than those for modern neighborhoods and requires additional operationalization. In this article, disparate models and theories of neighborhoods from multiple fields are both used and contextualized with archaeological data from Caracol – a large Classic Period Maya city in modern Belize – to provide a reproducible and testable method of neighborhood reconstruction and verification that can be implemented in other regions, time periods, and contexts.

Neighborhoods appear to be ubiquitous in historic urban contexts (Mumford, 1954), and remain a pertinent topic of research today (Talen, 2019). Within archaeology, neighborhoods frequently serve as an intra-urban social unit for analysis (e.g., Arnauld et al., 2012; Burham, 2022; Hutson, 2016; Landau, 2020; Manzanilla, 2012; Pacifico and Truex, 2019b; Prufer and Thompson, 2014; Smith, 2010, 2011; Smith et al., 2015; Thompson et al., 2018; Thompson et al., 2022), but the identified units demonstrate significant variation based on the researcher and their research questions. Neighborhood research builds on prior archaeological investigations of communities from multiple scalar perspectives (see for example Canuto and Yaeger, 2000; Smith, 2003). However, focusing specifically on neighborhoods provides unique insights on the inherent tensions between top-down and bottom-up urban processes in the past with working towards a more emic perspective (Pacifico and Truex, 2019a:7–8).

Ambiguity also exists in the variety of entities called a "neighborhood." Neighborhoods range from a "cluster" of about 50 people (Bullard, 1960:355) to modern "neighborhoods" housing up to 10,000 people (Mann, 1958:96). These two contemporaneous publications highlight the fundamental issue for comparative analysis of neighborhoods between cities; this range of 50 to 10,000 inhabitants hides multiple social entities under the same label. While this may not seem

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significant, it crosses observable organizational boundaries around 500-people from ethnographic analyses (Kosse, 1990, 2000), and the dynamics of interaction at the top and the bottom of this range exhibit very different social processes.

Differences between ancient and modern neighborhoods may also be due to a variety of factors including advances in modern communication infrastructure and transportation technology that have minimized the importance of distance in moderating frequent, repeated human interactions. Communities (the superset of closely interacting groups of people that includes neighborhoods – i.e., *all neighborhoods are communities but not all communities are neighborhoods*) no longer need to be spatially co-located to communicate frequently online. Even so, physically contiguous neighborhoods still persist and thrive in many cities today, as long as groups of individuals living in spatially co-located residences engage in frequent face-to-face interactions. Neighborhoods also can provide a unique intra-urban spatial level in ancient cities (see also Chase, 2023a) for viewing more inherently collective interactions and governance among urban residents (e.g., Blanton and Fargher, 2012; Chase, 2023b; Fargher et al., 2019; Landau, 2020).

As described archaeologically, neighborhoods form through frequent, repeated face-to-face interactions among people in spatially co-located residences (see both Smith, 2010:139 and Hutson, 2016:70–73) follow a more bottom-up, social definition than a top-down, administrative one. Due to this more localized farming, neighborhoods are a special type of community that uniquely exhibits a union of both relational identity – the physical interactions between residents leading to strong person-to-person social bonds – and categorical identity – the perceived similarities among residents created through participation and engagement in shared practices – that would be difficult or impossible to maintain in neighborhoods of several thousand individuals.

Today, categorical identity can relate to a group of individuals with a shared profession, religion, ethnicity, class, nationality, age, or other identifying factors that those people see, share, and perceive in common – for example even the clothing of a sports team or *alma mater* can signal a categorical identity – and neighborhoods of self-similar individuals cluster in ancient, historic, and modern cities through a variety of social processes (York et al., 2011). As used here, this distinction between relational and categorical identity is based on the operationalization of these concepts for archaeological research by Peeples (2018:25–28), who in turn built them on the foundation of broader usage within the social sciences by Nexon (2009:48) and Tilly (1978:63). Archaeologists tend to measure relational identity through the spatial co-location of residences and assumptions of movement and interaction in urban spaces, but they can also observe categorical identity through the identification of shared items within material assemblages from excavations of interacting household contexts.

In this article, I use the relational identity exhibited through the physical location of residences to reconstruct neighborhoods based on models of likely movement and social interaction. I then test that reconstruction against the categorical identity exhibited by material at residences within and between neighborhoods, which would have been a visible part of local community interactions. This method, as well as the processes and ideas present in this article, may also be applied to other urban contexts globally, hopefully providing a meaningful social framework for comparative discussions of neighborhoods.

2. Caracol, Belize

The ancient Maya city of Caracol exists in what is now modern Belize and Guatemala and thrived for over one thousand years on an elevated plateau between the Mopan/Chiquibul and Macal rivers. At its apogee around 700 CE, more than 100,000 people were spread over some 200 square kilometers and called Caracol home (see overviews in Chase et al., 2020b, 2024c; Chase and Chase, 2017). However, unlike a modern city with distinct and separate urban and agricultural areas, Caracol was a “garden city” (e.g., Barthel and Isendahl, 2013; Chase and Chase, 1998; Graham, 1999) – a city where infield agriculture predominated with overall settlement inter-mixing fields and residences (see Fisher, 2014). Caracol’s residents dedicated nearly eighty percent of their urban landscape to agricultural terracing (see Chase and Weishampel, 2016), and the construction of these features still promotes the growth of vegetation today despite 1000 years without maintenance (Hightower, 2012). In fact, the aggregated results of residential labor can be seen through the reduced slope of the landscape in Fig. 1 (the brighter areas correlate with increased terracing in valleys, on hillslopes, and on hilltops; however, even the shaded areas indicating higher slopes still contain many agricultural terraces in the valley bottoms).

The ancient Maya had both infield and outfield focused agricultural cities (see Chase and Chase, 2016a), and infield urbanism also existed within other ancient cities of the tropics in Southeast Asia (Coningham et al., 2007; Evans and Fletcher, 2015) and Africa (Kusimba et al., 2006). This infield urban form of agriculture ensured that households were situated near their agricultural fields while still facilitating access to urban services and infrastructure, at least at Caracol (see Chase, 2016; 2021:116–196, 253–260). Both the large population and the spatial extent of Caracol the city resulted from its dispersed form of settlement combined with a dispersed network of district nodes that ensured short travel times to and from marketplaces, formal ritual activities, and social spaces across the city (Chase et al., 2020b; Chase and Chase, 2020; Chase et al., 2020c). Taken together, the design of this ancient city focused on conjoining agricultural terraces with nearby focal nodes of social interaction (within district centers) for its residents, thereby allowing its population to thrive in their garden city and facilitating distinctive patterns of urban interactions within its districts and neighborhoods.

Some difficulties exist in identifying neighborhoods at Caracol. Its Late Classic Period (roughly 550 CE to 800 CE) urban landscape exhibits no clear architectural feature(s) indicative of neighborhood community buildings that would facilitate neighborhood identification (Chase, 2016:17), something has been argued for other Maya settlements (Burham, 2022; e.g., Manzanilla, 2012:59–64; Walden et al., 2019:4). During the Late Classic era, the city also exhibited a widespread, shared categorical identify based among similarities in the use of material and ritual goods, in shared ritual practices associated with eastern shrine buildings, in similar tomb and burial practices, and in ritual caching (see Chase and Chase, 2009; Chase and Chase, 2017:213–217). However, these similarities disintegrated in the last hundred years of occupation (roughly 800–900 CE) into the haves and the have-nots as the overall system of governance changed (Chase and Chase, 2021; Chase et al., 2024c). In the time-period under analysis, the overarching city-wide categorical identity existed in parallel with localized neighborhood categorical identities, other community identities, and market distributions at Caracol.

Distinct from the neighborhood level of analysis, prior research at Caracol (see Chase, 2016, 2021, 2023a) has identified districts that provisioned urban services – similar to “administrative districts” from Smith (2010:140) and “wards” from Hutson (2016:70–73) – centered around nodes of monumental architecture consisting of public plazas, ballcourts, large and monumental reservoirs, E groups, and other large architectural features. People would have interacted in these public settings in various ways (e.g., Inomata, 2006; Ossa et al., 2017; Tsukamoto and Inomata, 2014) and may have shared a district-level categorical identity. District reconstructions were defined and operationalized by focusing on their potential for provisioning specific urban services (see Chase, 2016; following Stanley et al., 2016). Given the larger populations, spatial scales, and the focus on public activities the social interactions occurring within districts would have had a different form and character to those that occurred within neighborhoods and echoes Bullard’s (1960) “minor centers.” Districts at Caracol provided services for populations that ranged from roughly 2,000 to 10,000 people with an average around 4,500 people per district – assuming a citywide population around 100,000 (Chase, 2021:146-150;

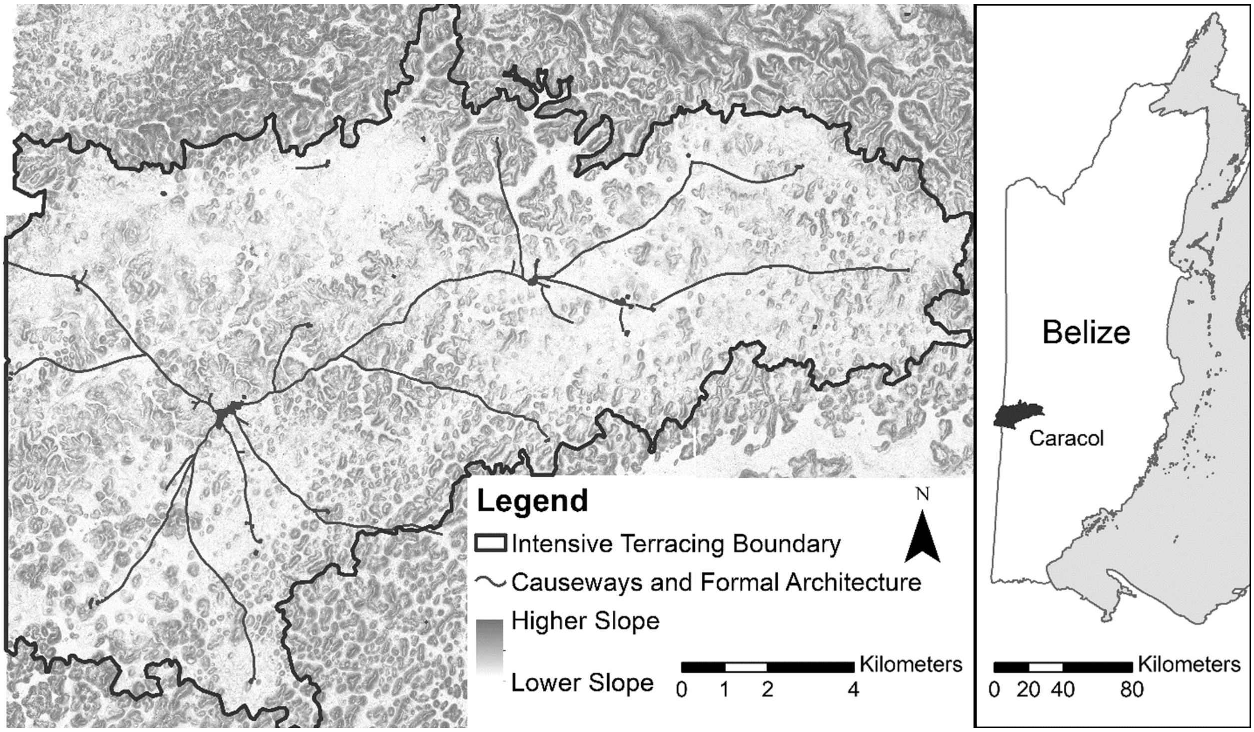

Fig. 1. Map of Caracol in modern Belize showing the city with areas of intensive agricultural terracing in valleys, on hillsides, and on hilltops denoted by reduced slopes (based on Chase et al., 2020a:Fig. 1).

Chase et al., 2024a) – which aligns with the population of modern US census tracks and modern "neighborhoods" defined by service provisioning instead of social interactions.

Preliminary laboratory analysis of adjacent residences during several field seasons (Chase and Chase, 2012, 2013, 2018; Chase et al., 2019) provided the impetus to investigate local variations within this pan-Caracol categorical identity that – based on the analysis that follows in this article – indicates the existence of unique neighborhood-level categorical identities. I use a material dataset of ritual and burial items within eastern residential shrine structures to check and test the results of the spatial analysis used to reconstruct neighborhoods. The geospatially reconstructed neighborhoods (that do not incorporate excavated materials) possess material similarities among their artifacts that demonstrate neighborhood identities which intersected with the more widespread city-wide identity in a way consistent with the properties of neighborhoods as communities of collocated, frequently and repeatedly interacting individuals.

Both burials and caches within residential eastern shrine structures held items with special significance which were revisited by ancient residents (Chase and Chase, 1996) and also demonstrate acts of generational remembrance (Ashmore, 2015; Chase and Chase, 2011) that likely entailed specific ritual and locally embedded social gatherings during their deposition. The spatial analysis used to identify neighborhoods focuses on the ancient residents of Caracol and their engagement in social interactions occurring near residences, in their adjacent terraced agricultural fields, at public plazas among Caracol's distributed district nodes, and on the way to and from those public plazas – each of which provided some of the social benefits of urban life.

3. Understanding neighborhoods

Operationalizing neighborhoods requires an underlying set of theories embedded in existing geography, social network analysis, and cognitive science literature. Spatial autocorrelation (geography) indicates that closer residences should be more similar, creating sprawling, fuzzy neighborhoods. Triadic closure (social network analysis) introduces the social distinction between strong and weak ties that could create hard neighborhood boundaries among more homophilous (and more frequently interacting) residents. Finally, cognitive limits (cognitive science) suggest an upper limit around 500 people in a neighborhood, based on re-analysis by Lindenfors et al. (2021) of the 150-person group size suggested by Dunbar (1998, 2009, 2010) and identified separately and robustly in ethnographic datasets by Kosse (1990, 2000). Together, these three disparate disciplines provide concepts that reinforce the spatial congregation, social boundaries, and interactions that would have facilitated neighborhood formation and, crucially, neighborhood maintenance over time. While the existence of neighborhoods has often been taken as a given in cities, these ideas provide a firmer foundation for how and why neighborhoods could emerge and persist. Additionally, these ideas provide concepts for how to think about neighborhoods as places of frequent, repeated face-to-face interaction embedded in physical and social landscapes.

The first law of geography states that closer things are more similar to each other (Tobler, 2004); however, other scholars have investigated similarities based on space and distance before Tobler coined the phrase (see for example Sahlins, 1965:Fig. 1 on kinship distance). This closer proximity increases the likelihood of frequent and repeated interactions, and modern theories of urban interaction rely on the dichotomy between push and pull factors for interaction along with the additive effects for city life (see for example Bettencourt Luís, 2021; Stier et al., 2022; Strumsky et al., 2023). The concept that closer things are more related and become more similar (i.e., homophily, see Asikainen et al., 2020; Feld and Grofman, 2009; Kandler and Caccioli, 2016) can also be considered a form of spatial autocorrelation. When applied to residences, it suggests that neighborhoods would be "groups" of more similar residences based on the recursive interplay of desired interaction, physical proximity, and initial and resulting homophily. On its own, this process would generate fuzzy neighborhoods that could have any given population size and may not suggest any clearcut divisions within a settlement. Sprawling "neighborhoods" could even have residences in the same group but so far apart that may not interact on a regular basis – an issue that contrasts with the definition of frequent face-to-face interaction used here. As such, this law from geography alone does not account for the sometimes-sharp boundaries that can exist between neighborhoods, but it does provide the inherent logic supporting a least-cost-path analysis approach – as distance increases, the cost for travelling increases and the likelihood of frequent, regularized interaction decreases. This concept also strongly suggests that population density could exhibit a fundamental effect on differences in neighborhood form between cities.

The issue of boundary identification can be mitigated through lessons gained from social network analysis (SNA) due to the intertwined concepts of triadic closure and homophily. The principle of triadic closure (also called cognitive balance) provides a framework for understanding social bonds and how they are likely to change or persist over time, making it a good choice for considering neighborhood formation through accumulated interactions and increasing categorical similarities among residents (see Asikainen et al., 2020). The fundamental idea is that individuals prefer interacting together among sets of people with shared strong bonds; as such, if one individual has strong social bonds with two others, then those two other individuals are expected to either form a new strong bond or see one of the original strong bonds become a weak bond over time (see Granovetter, 1973; Peeples, 2019:458). Put mathematically, individual T in time 1 (represented as T_1) has two strong ties to individuals U and V (who are not currently connected by a social tie), and the passage of time will result in either one of two outcomes (T_{2A} or T_{2B}). Either T_{2A} will maintain both strong bonds and a new strong tie will form between individuals U and V, or T_{2B} will experience the deterioration of one strong bond into a weak bond (e.g., either the tie between T_{2B} to U or T_{2B} to V). As cognitive balance, this concept represents the pattern of forming (e.g., closing) triadic cliques of strongly interconnected individuals and represents a fundamental unit of social networks.

For neighborhoods, the expectation would be for weak ties to exist between neighbors in different neighborhoods and strong ties to exist between neighbors in the same neighborhood due to the accumulated effects of both triadic closure and homophily (building on Asikainen et al., 2020). In addition, social network analysis has shown that persistent ties are more likely to form between more similar individuals. These individuals would be those with additional shared and overlapping categorical identities. This concept, called homophily in social network analysis, simply indicates that like tends to interact with like (see Feld and Grofman, 2009). Within a neighborhood context, homophily suggests that strong ties will persist over time more often when the two linked residents possess more inherent similarities. However, in combination with the first law of geography, this principle would still permit neighborhoods of 50 to coexist next to neighborhoods of 10,000 with some sharp breaks between neighborhoods.

Cognitive science provides additional parameters by placing potential limits on neighborhood size based on underlying limits on peoples' abilities to frequently interact. A strong empirical threshold limiting group size below 500 ($\pm$100) people has been observed in ethnographic data (Kosse, 1990), and suggests nested layers of complexity in human social organization (Kosse, 2000). More contentiously, this research trajectory has also focused on the "Dunbar number" that originally represented 150 people as a common limit on frequent interaction and group size (Dunbar, 2009, 2010; Dunbar and Sosis, 2018). It has had both supporters (e.g., Casari and Tagliapietra, 2018; Gonçalves et al., 2011; Zhou et al., 2005), and detractors (e.g., McCarty et al., 2001; Wellman, 2012) in equal measure. However, recent research has potentially resolved the potential discrepancy between Kosse (1990, 2000) and Dunbar (1992, 1998). Reanalysis of Dunbar's initial data has demonstrated that average group sizes vary from, roughly, 2–520 people at a 95 % confidence interval (Lindenfors et al., 2021). As such, this suggests that groups of individuals who interact frequently and face-to-face should be below this roughly 500-person-odd threshold. This reconciliation captures the variation observed by all of the research listed above and it provides a means for neighborhoods of various sizes to exist in different settlements (e.g., Chase, 2021 and; Thompson et al., 2022: table 2). This also suggests that much larger modern "neighborhoods" represent a very different type of social and administrative entity than these archaeologically defined neighborhoods, at least based on the concept of neighborhoods as groups of spatially adjacent residences with residents who engaged in frequent and repeated face-to-face interactions.

This roughly 500-person threshold is far smaller than the five-thousand person "neighborhoods" sometimes used in modern cities For example, Howard (1902) designed his garden cities to contain 32,000 people with 2,000 people living around a city comprised of six equal sectors of 5,000 each – with the sectors designed for incremental construction and service provisioning as the city grew. In contrast, Mumford (1961:501) credits Clarence Perry with propagating the 5,000-person neighborhood concept in urban planning (again focusing on the requisite population to provide a tax base for service provisioning); and, both values are similar to the US Census Tract which contains on average around 4,000 people but range from 1,200 to 8,000 per tract (USCB, 2022). By focusing on smaller group sizes with frequent interaction, the cognitive limit around 500 captures the difficulty in maintaining larger "neighborhoods" like these, and aligns with the robust ethnographic analyses of Kosse (1990) and recent statistical analyses by Lindenfors et al. (2021).

If neighborhoods are defined and identified through the frequent, repeated interactions of people in spatially adjacent residences (e.g., both Smith 2010:139 and Hutson 2016:70-73), then this suggests that modern "neighborhoods" of five thousand people represent a fundamentally different organizational entity more similar to administrative districts than social neighborhoods. Especially given the focus on urban service provisioning over social interaction. These population numbers align instead with those of the administrative districts at Caracol, which similarly provisioned urban services to urban residents (Chase, 2016; 2021:146–150). Again, this is apt since both Howard (1902) and Mumford (1961:501) focus on their socio-spatial units in terms of urban service provisioning for schools and parks more-so than on processes of social interaction for these populations. In other words, there are multiple, distinct spatial and social levels within cities that have been called "neighborhoods" by different researchers including archaeologists, but these social units have differing and implicit assumptions about the nature and frequency of human interaction given the population and area entailed within them yet still lead to obfuscation in comparative urban analyses.

Integrating these three different disciplinary perspectives (geography, social network analysis, and cognitive science) on space and interaction provides a testable model for neighborhood size and structure. Spatial autocorrelation highlights both the importance and rationale for spatial co-location of residences in a neighborhood based on proximity but creates fuzzy neighborhoods. Cognitive balance provides the potential basis for sharp delineations between neighborhoods but creates the potential for neighborhoods of drastically uneven sizes. Finally, cognitive limits on interaction yield the "optimal" maximum neighborhood size up to roughly 500 people but also suggests that modern "neighborhoods" of several thousand represent a fundamentally different organizational entity due to mental limitations on frequent and repeated face-to-face interaction, which lines up with past discussion of service provisioning for groups of around 5000 people (i.e., they would be administrative districts instead of neighborhoods).

4. Neighborhood reconstruction method

Reconstructions of neighborhoods in ancient cities often rely on unique architectural features associated with those neighborhoods (Burham, 2022; Manzanilla, 2012:59–64; Walden et al., 2019:4) or k-means clustering of flat, *x-y* data (e.g., Robertson et al., 2005; Robin, 2003:330–331; Smith and Novic, 2012:11–12). Caracol neither has those architectural features nor a flat topography. Instead, the rugged and hilly landscape of Caracol requires a way to integrate elevation (*z*) with latitude (*y*) and longitude (*x*). As such, to operationalize interaction and use *x-y-z* data, I used least cost analysis (following White, 2015) from the residences to the districts' public plazas and back again. Represented in hours of travel, neighbors would possess similar travel times to each focal node of energized crowding (e.g., Hutson and Welch, 2021; Smith, 2019) with the overarching overlaps in travel times acting as a proxy for the ease of frequent interaction among neighbors in the past. However, this relatively simple approach generates a table of over 128,744 cells – 5852 household rows and 22 district columns – for clustering analysis. These residences have been previously identified (see Chase, 2017, 2021) within the lidar dataset for Caracol (see Chase et al., 2014; Chase et al., 2012; Chase et al., 2011) and represent a sample of residences present in this city (see Chase et al., 2024a,b). Following prior uses of k-means clustering (e.g., Robertson et al., 2005; Robin, 2003:330–331; Smith and Novic, 2012:11–12), I applied R's k-means analysis ("kmeans" in RStudio version 1.2.5042 and version 3.6.3 of the R programming language) to this dataset of time between residences and districts to identify potential clusters up to one-thousand clusters (Fig. 2). However, the size of the dataset created issues for that implementation of the algorithm. Multiple runs could produce slightly divergent results and some did not always run to completion.

By nature, k-means always produces a cluster for a given value of *k*, which means that this method will always generate clustered groups for any given input. In order to identify likely neighborhoods out of this larger dataset of several thousand runs, I looked for the "kink" (Shennan, 1997:253) in aggregated k-means clustering analyses. I ran ten sets of k-means clustering results for k-values from one to one-thousand and selected those with more than two standard deviations of "acceleration" between results (i.e., the second order derivative, f'') to produce the graph in Fig. 2. Each value there represents a significant f'' (f-double-prime here represents the acceleration in k-value errors or a mathematical way to describe the visible "kink" in the graph) in the clustering results.

This meta-analysis of k-means results showcases interesting f'' values for k-values of 8 and 373. However, the value of eight is below than the number of districts at Caracol (see Chase, 2016, 2021) and does not correlate with any division of districts or urban service provisioning presently identified. This value also produces clusters that would have been too large to have facilitated face-to-face interactions among all residents. Instead the 373 value represents reconstructed neighborhoods at Caracol with caveats including both the potential effects of residential *plazuelas* housemound groups (see Chase and Chase, 2014a for a detailed overview of these residential groups) missed during lidar digitization and of additional Caracol districts and settlement in modern Guatemala beyond the current lidar dataset (Chase et al., 2024b).

In other words, these results represents the number of neighborhoods visible in the current data, but the effects of missing data would either increase the number of neighborhoods (up to 637 while keeping the mean of 157), increase the number of residents within these

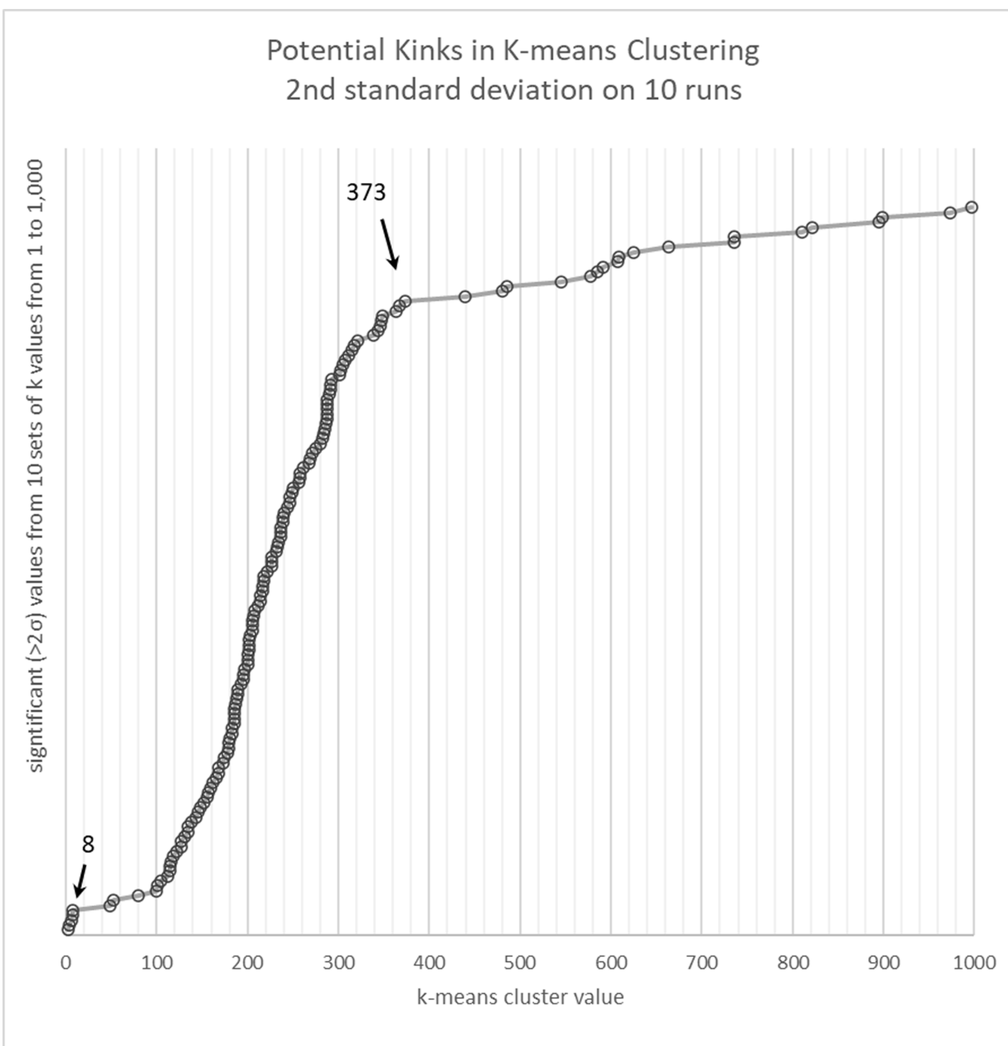

Fig. 2. A graph of the f'' "kinks" above 2σ after 10 runs of k from 1 to 1,000 showing at 373 value of k representing neighborhoods along with another value at 8.

neighborhoods (up to a mean of 269), or some combination of both (see Chase, 2021: figure 7.6 and table 7.2). Neither change creates a neighborhood with over 500 individuals. The 10 to 40 square kilometers of ancient Caracol in modern Guatemala would also increase the total number of neighborhoods above 373. As such, this 373-value provides a baseline – and not an absolute – number of neighborhoods during Caracol's apogee for multiple reasons.

Running the same least cost area allocation method to apportion raster cells to shapefiles used to create the district boundaries at Caracol (Chase, 2016:24) generates a map of the 373 reconstructed neighborhoods (both are shown in Fig. 3). While depicted with hard boundary lines here, in the past both these districts and the neighborhoods would have possessed fuzzier boundaries. At any given time, individual actions of residents across generations could have varied and affected the actual neighborhood boundaries based on the residents themselves and their unique patterns of social interactions. However, the similar nature of access to district nodes, agricultural fields, and residential adjacency would likely have facilitate the formation of neighborhoods similar to those depicted. The social processes of frequent, repeated face-to-face interaction among residents suggests that these reconstructed neighborhoods would likely form, persist, and potentially re-form over time, even with variation due to individual actions.

5. Excavation datasets

To test these spatially reconstructed neighborhoods with archaeological materials, I used a sample of eight neighborhoods selected from three districts so that half of the sample exists near downtown Caracol and the other half exists near the outlying district nodes of Puchituk and Monterey as shown in Fig. 4. Not every residential *plazuela* in each neighborhood has been sampled, but a sample of 59 *plazuelas* – excavated over four decades by the Caracol Archaeological Project – provides a reasonable representation of all eight neighborhoods. Those neighborhoods near downtown Caracol consist of the arbitrarily named Alta Vista to the west, Dos Aguadas to the east, Machete to the southeast, and Rebel to the northeast. The Puchituk District has neighborhoods on each of its three major hills with Ace to the southeast, Chak to the west, and Sage to the northeast. Finally, Monterey possesses a single neighborhood called Boulder that includes both adjacent hillsides. The nature of this sample allows for a comparison of neighborhood similarities and differences while also factoring out the role of market distribution between the downtown and outlying districts.

This analysis of neighborhoods used *plazuelas* as the fundamental residential unit. These residential features would have housed extended family groups in the past. Each *plazuela* has three to eighteen structures, with an approximate average of four, around a central residential plaza (see Bullard, 1960:Fig. 2; Chase and Chase, 2014a; Chase et al., 2024b). In addition, prior excavation has shown that these residences participated in a shared "pan-Caracol" categorical identity that includes a focus on an eastern shrine in about 75 % of residences and a system of ritual deposits in burials, tombs, and caches with relatively similar material remains (Chase and Chase, 2009; Chase and Chase, 2017:213–216). The excavation samples used here usually represent two-meter-wide trenches over eastern structures in the *plazuela* group that were usually sampled to bedrock (see Fig. 5).

In this research, to better capture categorical identity, I focused on the special deposit (cache and burial) materials instead of the general fill contexts from these excavations. This ensured that the focus of this analysis remained on intentionally deposited material that held special significance to the residents themselves. The ancient Maya revisited these deposits in acts of remembrance (e.g., Mills and Walker, 2008) and persisted in these acts through cyclical patterns of access where items were added, moved, or even removed over the course of generations (Chase and Chase, 1996, 2011, 2023). As such, these materials represent intentional deposition within residences among these neighborhoods. In addition, in selecting these samples I believe that these formalized, ritual deposits included an intentional choice of materials and potentially included a publicly visible display of them before or during their

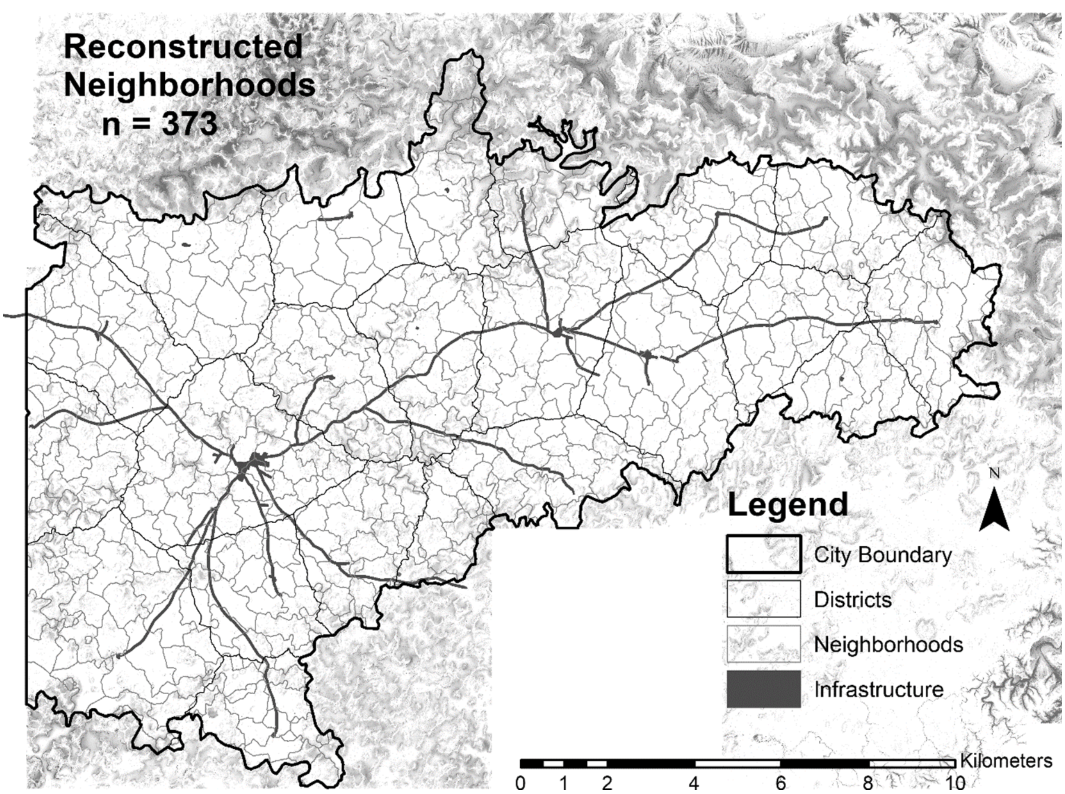

Fig. 3. 373 reconstructed neighborhoods at Caracol generated through k-means clustering on travel times shown with the overlapping city and district boundaries. Actual neighborhood boundaries in the past were likely fuzzier.

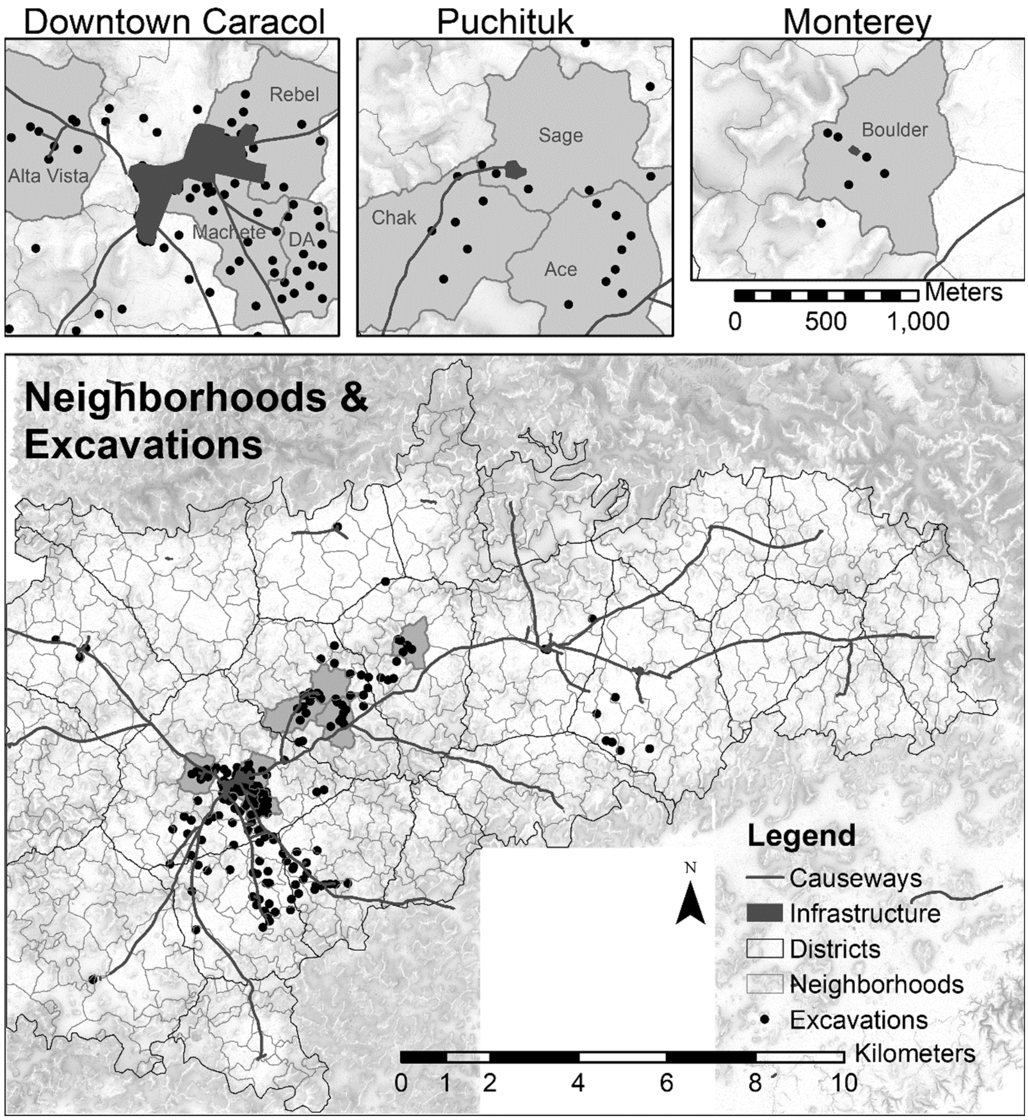

Fig. 4. Excavations at Caracol shown along with sampled neighborhoods representing 59 plazuela groups among 8 neighborhoods in 3 districts.

ceremonial deposition or re-deposition. This assumption is embedded in the idea of a neighborhood categorical identity resulting from shared and perceived similarities, in this case of caching and burial practices and associated social events including both family members and neighbors. While this may initially suggest an ethnic or religious identity, the expectation is that the layered nature of social interactions over generations of witnessing and participating in these events instead created and perpetuated local neighborhood identities of shared ritual practice separate from the polythetic religious or ethnic identities of household residents.

For each of the 59 *plazuela* groups, I aggregated the provenience information from lot cards, illustrations, and season reports (see https://www.Caracol.org's "season reports" tab for accessible summaries of these contexts and materials and ASZ Chase 2021:325–330 for data tables) for the relevant lots and deposits associated with each group's eastern ritual structures, *chultuns* (limestone cysts generally interpreted as places for storage following Dahlin and Litzinger, 1986; but contain burials at Caracol instead following Hunter-Tate, 1994), and plaza excavations in front of eastern structures. This analysis required reviewing 345 special deposits for a few broad categories of artifactual materials. I focused specifically on materials more related to likely categorical identity than material wealth (since walking cities like Caracol exhibit social mixing with diverse incomes co-existing side-by-side Chase and Chase, 2016b:365; Hutson and Welch, 2021; Storey, 2006:9–10), including two types of dental modification (Fig. 6) – both inlays and filing – and fourteen general ceramic forms (Fig. 7) – all broadly defined to avoid issues of diachronic change (but future research will further tease apart these patterns).

Current evidence shows that dental modification practices among the ancient Maya related to, "personal or family choice more than social requirements" (Tiesler, 2020:114), and recent evidence for dentistry in public plazas suggests that modification need occur locally, within neighborhoods (Schnell and Scherer, 2021). This complements the ubiquity of both dental modification and the ceramic forms in Fig. 7 in residences at Caracol, at least during the period of the city's apogee and widespread wealth sharing (see Chase et al., 2015; Chase and Chase, 2014b; Chase and Chase, 2020). Both ceramic form and dental modification had been observed to possess unique patterns within neighborhoods in prior field seasons through laboratory analysis. For example, three of the sampled neighborhoods – Boulder, Chak, and Sage – include no dental modification and others show different ratios of various ceramic forms. The results of this preliminary analysis support future neighborhood research incorporating additional materials and additional analyses of these materials and their distributions.

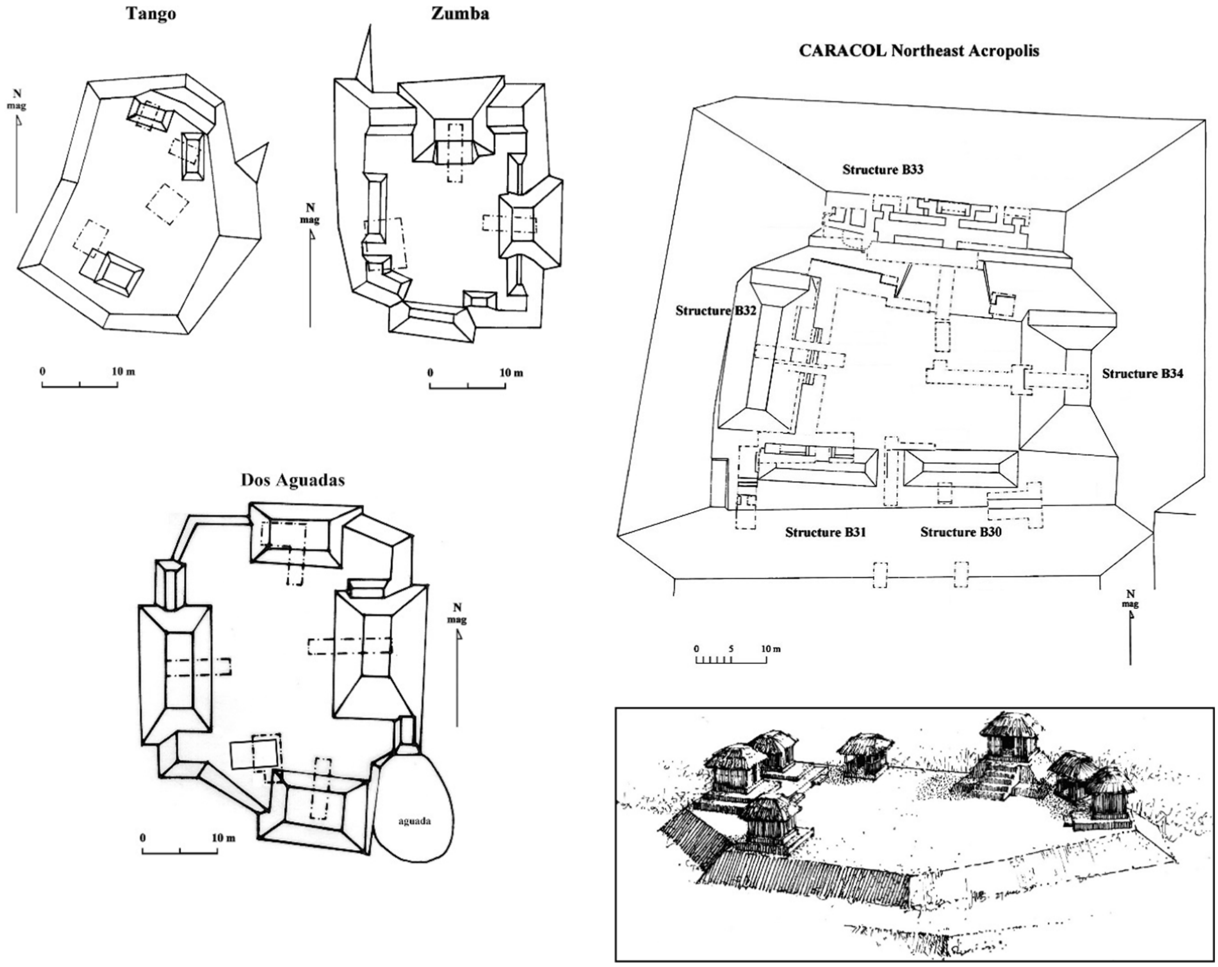

Fig. 5. Excavations at one acropolis (top) and three *plazuela* groups (middle) with an artistic *plazuela* reconstruction (bottom). In each residential excavation, the two-meter-wide trench through the eastern structure can be seen along with additional excavations (Illustrations are reproduced with permission from Chase and Chase, 2014a:Figs. 1 and 2).

Fig. 6. Examples of teeth with dental modification. Jadeite inlays are shown (top) and two styles of filing are shown (bottom). For this analysis all modified teeth were recorded as inlayed or filed without specifying form, type, or tooth.

6. Testing reconstructed neighborhoods

This analysis produced a dataset with many empty cells or a "sparse table" in the computer science sense of the term. This created a special instance of understanding similarity that moves the problem space closer to that of biologists and ecologists studying species diversity and population dynamics (Horn, 1966; Morisita, 1959; Wolda, 1981). This method resolves the issue of comparing species similarity between two environments with both more commonly and more rarely observed species, and, while artifacts differ from animals, the idea of rare and common types remains similar along with issues of sampling and sample size. In archaeology, Watts and Ossa (2016:638–639) have successfully used these analyses to investigate market distributions within ceramic data via this Morisita similarity index (Morisita, 1959), which handles sparse data particularly well.

Similarity indices range from zero to one with zero represent two completely divergent datasets while values of one indicate complete overlap between datasets. In the reverse, dissimilarity indices flip this relationship with zero representing overlap and one representing divergence, which is more suitable for considering differences between neighborhoods. Following this, I calculated dissimilarity indices of the sixteen materials (indicated visually in Figs. 6 and 7) between and within neighborhoods to test these reconstructed neighborhoods (using R's vegdist method). The results show an intra-neighborhood index of 0.5638 and an inter-neighborhood index of 0.6003 thereby showing more dissimilarities between than within neighborhoods. Additionally,

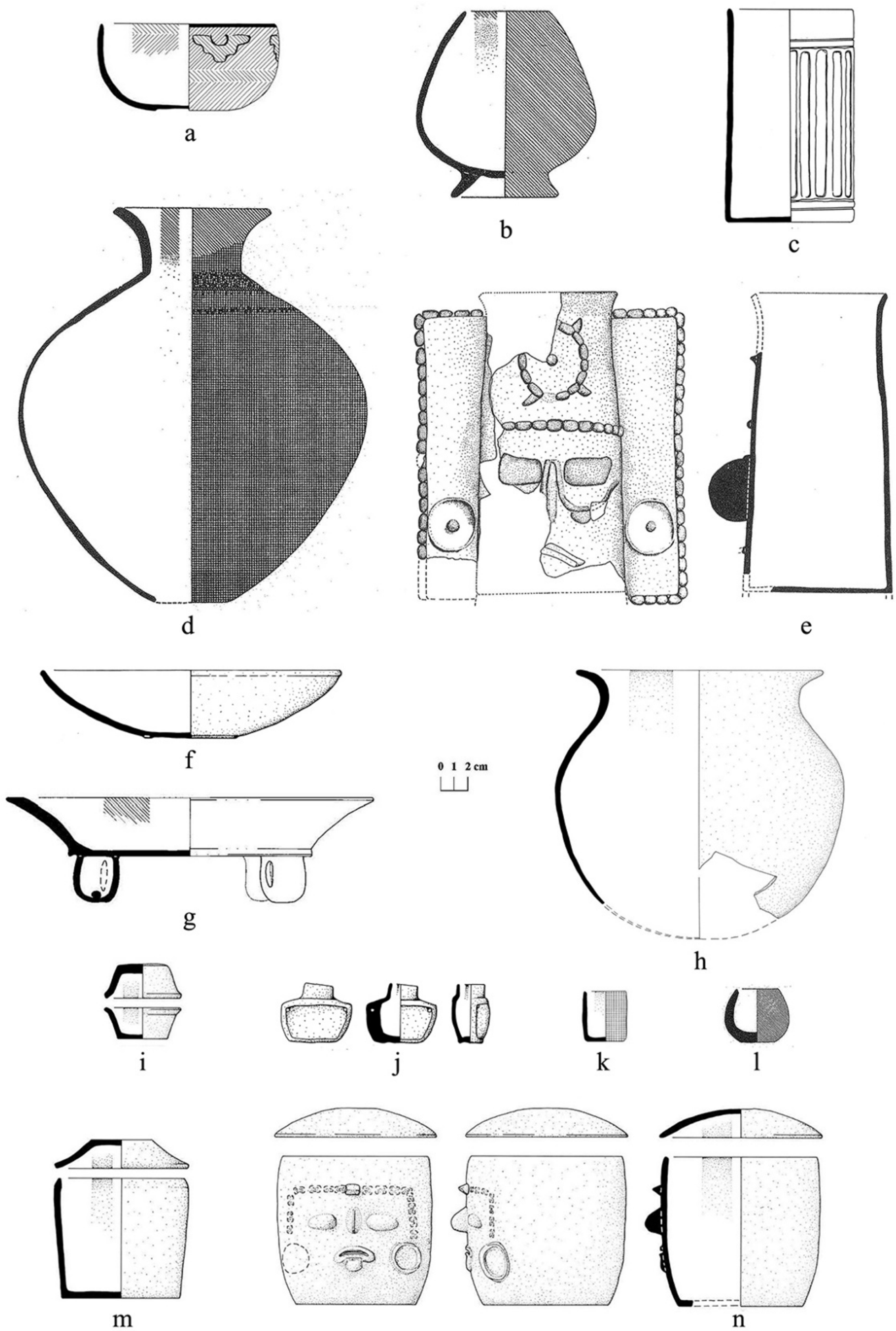

Fig. 7. The generalized vessel forms used in this analysis: (a) bowl, (b), cup, (c), cylinder, (d) jar, (e) incensario, (f) dish, (g), tripod plate, (h) olla, (i) lip-to-lip cache, (j) medicine bottle, (k) paint pot, (l) miniature vessel, (m) barrel/urn, and (n) face cache.

while these values might initially seem similar, they represent a statistically significant difference that takes advantage of the dissimilarity index's ability to identify dissimilarities despite the presence of both rare and common types (see Watts and Ossa, 2016:638–639) and avoids the issue of false similarities from empty cells in the dataset.

To test the significance of these values without assuming a normal distribution (Shennan, 1997:87), I used a one-sided, non-parametric Wilcox Test (using R's wilcox.test method; see also Bauer, 1972) on the dataset of inter- and intra-neighborhood dissimilarities. The results yield an incredibly low p-value of 0.03785, indicating a statistically significant finding. In other words, *plazuelas* within neighborhoods have more similarities in their dental modification practices and these ceramic forms within their ritualized caching and burial deposits than they do with *plazuelas* located in different neighborhoods. This accords with the interpretation that these materials were visible and intended to signal categorical identity at the neighborhood level.

7. Conclusions

Operationalizing neighborhoods through social interaction in archaeological contexts requires invoking research from parallel fields that include the concepts of first law of geography, the principle of triadic closure from social network analysis, and cognitive limits from cognitive science. Together these ideas provide a logic for internally similar and spatially autocorrelated neighborhoods, sharp boundaries in identity between neighborhoods, and a threshold of about 500 people for identifying neighborhoods. While most archaeological researchers use a definition of neighborhoods rooted in ideas of frequent, repeated face-to-face interactions among people in spatially co-located residences, specific methods of identification differ between urban contexts. Some use built environmental features as neighborhood proxies (e.g., Burham, 2022; Manzanilla, 2012:59–64; Walden et al., 2019:4); others use k-means spatial clustering to identify neighborhoods (e.g., Robertson et al., 2005; Robin, 2003:330–331; Smith and Novic, 2012:11–12); and, still others use kernel density and manual digitization (e.g., Prufer and Thompson, 2014:285; Thompson et al., 2018:3–6; Thompson et al., 2022). However, these other methods proved to be insufficient for the rugged and hilly landscape of Caracol. Instead, the method of neighborhood reconstruction presented here focuses on individuals and the nature of their movement and interactions situated on the urban landscape to build a model for geospatially reconstructing and testing neighborhoods. By focusing on household travel times to each district node, this research elucidates aspects of mobility and social interactions in the past through interpreted interactions of residents at public plazas (e.g., Smith, 2019), on the way to district nodes (e.g., Richards-Rissetto, 2012), or near the *plazuela* residences and their agricultural terrace fields themselves.

The least-cost neighborhood method employed in this research reconstructed ancient neighborhoods at Caracol through spatial analysis designed to identify likely relational identity in the past (i.e., reconstructed areas likely to have frequent, repeated face-to-face interaction). Additionally, archaeological data representing likely categorical identity (i.e., the fourteen ceramic forms and two types of dental modification related to intentional and visible deposits) reinforced and supported these spatially reconstructed neighborhoods; testing the reconstructed neighborhoods with archaeological data. Like other ancient, historic, and modern cities (York et al., 2011), the ancient Maya city of Caracol had self-similar neighborhoods with shared categorical identities. This union of relational and categorical identities into a neighborhood identity based on dental, caching, and burial practices yielded statistically significant results with more intra-neighborhood similarity and inter-neighborhood dissimilarity. These results occurred despite the overall similarities and shared practices from a pan-Caracol identity previously identified (Chase and Chase, 2004). In all residential contexts analyzed here, reconstructed neighborhoods still possessed their own local variations on these citywide patterns even if minor.

Importantly, these results indicate neighborhood-level categorical identity existed in addition to the broader pan-Caracol categorical identity. In fact, this analysis could not have succeeded without the data garnered from research designed to investigate the latter. These results also suggest additional avenues of research. It appears that the urban markets at Caracol facilitated the distribution of all goods relatively evenly throughout the city because neighborhoods within the same district that used the same markets still exhibited inter-neighborhood diversity; however, this will require additional analysis (and excavation) to test and verify. This analysis also focuses on the Late Classic Period and the diachronic changes in form within these deposits could also constitute a significant avenue of research to add more temporal depth to this analysis. There is also a question of kinship and how interrelated the individuals within each neighborhood might have been (following the idea from Ur, 2014:258) that can be tested through future aDNA investigations. Regardless, the research presented here demonstrates that neighborhoods at Caracol exhibited a union of both relational and categorical aspects of identity, and – despite the absence of neighborhood architectural features – ancient neighborhoods can be reconstructed through consideration of likely individual face-to-face social interactions in the past and successfully tested with archaeological data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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