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Advancing the Archaeology of Architecture: A GIS-Based Approach to the Organization of Built Space in the Castros of Northwest Iberia

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Advancing the Archaeology of Architecture: A GIS-Based Approach to the Organization of Built Space in the Castros of Northwest Iberia

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Abstract

Advancing the Archaeology of Architecture: A GIS-Based Approach to the Organization of Built Space in the Castros of Northwest Iberia

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This thesis is framed as a contribution to the study of spatial organization at the scale of the individual settlement, specifically in the context of the castros of Northwest Iberia. I argue that new approaches to the description and analysis of organizational properties are needed to improve the current state of research on this topic. I propose a new methodology toward this end by applying concepts and methods from spatial statistics in a GIS environment. I demonstrate the potential of my proposition through a preliminary case study involving two castro sites from northwestern Portugal: Cividade de Terroso and Castro de Romariz. I conclude by discussing the implications of my work for the study of architecture and spatial organization in castro settlements, suggesting that there is much to be gained by further pursuit and expansion of this new methodological approach.

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Chapter 1: Introduction

The current work seeks to advance the study of the organization of built space in the castros of Northwest Iberia through the development of a new methodological approach that uses concepts and methods from spatial statistics in a GIS environment. To begin this endeavor, it is necessary to establish some fundamental terms and concepts.

BRIEF OVERVIEW OF THE CASTROS

In the simplest terms, the word *castro* refers to a specific type of hillfort encountered in Northwest Iberia during this region's Iron Age and Early Roman Period (ca. 900 BCE – 200 CE). Castros are most often, but not always, located atop large hills or *montes*. Their placement is clearly influenced by a complex combination of factors, including strategic access to major waterways, defensibility, favorable viewsheds, proximity to various natural resources, and relationships between sites, to name only a few (Dinis 1993; Lemos et al. 2011; Sastre 2008). They typically exhibit substantial fortification in the form of one or more perimeters of thick stone walls or monumental earthworks enclosing the settlement. Also essential to the definition of a castro is their distinctive architecture, which is characterized by extensive stonework and a prevalence of circular forms. In terms of modern political boundaries, the approximate geographic range of the castros encompasses most of northern Portugal (beginning around the Douro River), all of Galicia, and the westernmost portions of Asturias, León, and Zamora. This is what I refer to as Northwest Iberia, or simply "the Northwest." For my purposes, the boundaries of the Northwest are based on a combination of different proposals regarding the geographic extent of the castros (Figure 1). These boundaries are by no means fixed, precise, or widely agreed upon.

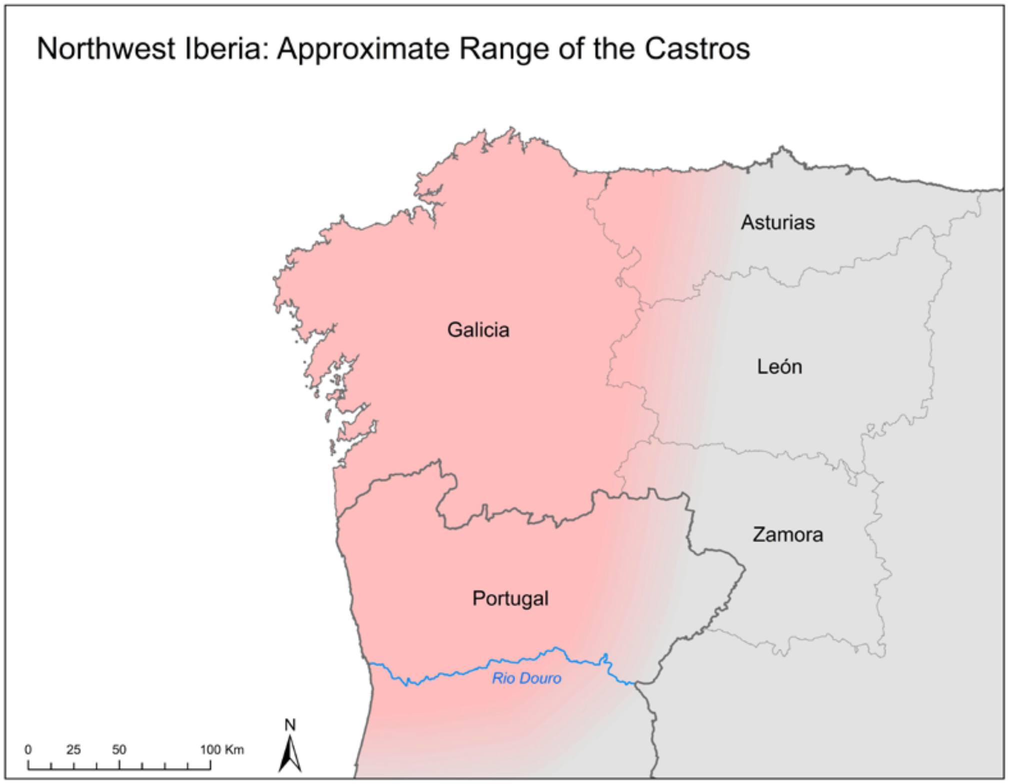

Figure 1: Approximate range of the castros of Northwest Iberia (pink shaded area)

Figure 2: Location of castro sites mentioned in the text

The temporal range provided above is likewise far from concrete. The earliest castro sites may appear as early as 900 BCE with simpler fortifications and perishable structures, as opposed to the monumental stone architecture for which castros are generally known, something which would not appear until sometime from the 4th to the 1st centuries BCE depending on the region in question (Almeida 1984:35-36; Ayán Vila 2008:916-918; González-Ruibal 2006:340-341; Queiroga 2015:266). There is a significant degree of regional variation in both the architectural and artifactual remains of different castro sites across the entire range of the Northwest, despite what this simplistic overview would imply. Yet all such sites are referred to as castros, meaning that a brief explanation of the term must necessarily appeal to broad, anachronistic generalizations. This thesis does not provide a nuanced treatment of the chronology of the castros, nor does it employ explicit terminology in this regard, preferring instead to use vague terms such as “early” and “late.” This was done intentionally so as to avoid making reference to a specific chronological framework. While such imprecision is generally undesirable, the nature of the current work warrants brevity in certain respects, and a fuller treatment of this and many other matters related to the study of the castros can be found in the publications cited throughout.

Early research on castro architecture focused heavily on the development of typologies, such that the identification of structural forms has received much attention. Circular structures are generally ubiquitous at castro sites, and they tend to be the most common form. Other forms are attested at many sites, including oblong, rectangular, and some that evade straightforward description (see Terroso structure 24 in Figure 12). The traditional narrative, based on a typological approach, suggests that castro settlements used only circular structures early in the Iron Age, and that over time there was a progression toward more complex and varied forms. This culminates in the introduction of rectangular structures, which are often interpreted as a direct result of Roman influence, despite some possible examples of rectangular forms in pre-Roman contexts (Carballo Arceo 1996:321). A common feature of both circular and rectangular structures in later sites is the addition of two projecting walls in front of the structure, which enclose an additional space preceding its main entry (see Terroso structures 9 and 14 in Figure 12). These appendages are sometimes referred to as "pincers" due to their shape, and the area they enclose has been given various names in the literature (including *vestíbulo*, *alpendre*, and *átrio* in the Portuguese). These "vestibules" are thought to be a relatively late structural addition, appearing sometime around the 2nd or 1st centuries BCE (Almeida 1984:37; Silva 1986:42). The phenomenon of the vestibule has been interpreted in various ways, for example, as a strategic means of restricting access to the entry (Ayán Vila 2008:957; Mañana Borrazás et al. 2002:81), or as a straightforward indication of which structure is the "main house" within a particular grouping (González-Ruibal 2006b). Nothing on this topic is definitive as of yet: both the timeline of this architectural feature and its sociocultural implications ought to remain a matter of open debate. The same can be said for the phenomenon of rectangular structures, and much else related to the general characteristics of castro architecture.

THE CASTRO CULTURE AND THE CELTS

The issue of how to describe the ethnic and cultural affiliations of the Iron Age inhabitants of Northwest Iberia is fraught with complexity and contention. The debate ultimately begins with the classical references to pre-Roman inhabitants of the region, such as in Strabo and Pliny the Elder (Romero Masiá and Pose Mesura 1987). Ancient references to the presence of Celts in Northwest Iberia are confirmed, some argue, by certain inscriptions and toponyms (García Quintela 2005). Various aspects of the material culture associated with the castros are taken as further indications of a Celtic affinity in this region (Lorrio 2011). Emphasis on the Celtic nature of the castros is well represented by López Cuevillas (1988), whose work can be seen as epitomizing this standpoint. Discourse on the Celtic presence in Northwest Iberia remains vibrant into the present, and new arguments continue to be put forth regarding the relationship between this and other Celtic regions during prehistory, including the theory that Iberia represents the very origin of Celtic traditions (Cunliffe and Koch 2010).

Many have criticized the idea of a Celtic Galicia on the grounds that its underlying narrative is motivated primarily by a legitimization of nationalism. González-Ruibal (2006:37-51) points out that, while nationalism was certainly an essential factor in the historiography of Galicia's Celtic origins, the history of discourse on this topic is long and exceedingly complex, and cannot be satisfactorily understood as solely the result of a nationalist impetus. Some authors have cast into doubt the usefulness of the denomination "Celtic" altogether, pointing out its latent suggestion of widespread cultural homogeneity, the vagueness of its underlying criteria, and its complicity in an implicitly colonialist interpretive framework based on the assumption of cultural replacement through invasion or migration (Collis 2003). Ultimately, the evidence for some sort of Celtic presence in the Northwest prior to Roman conquest is substantial, but the implications of this for castro archaeology remain a matter of open debate, due in part to the fundamental question of what the term "Celtic" entails in the first place.

Another tradition in castro archaeology has tended to distance itself from the Celtic debate, instead conceptualizing the inhabitants of the castros as belonging to their own distinct cultural group, referred to simply as the "Castro Culture." This idea can be traced back to the beginnings of castro scholarship, with Sarmento's early formulation of a *cultura dos castros*. Sarmento's view of the castros was heavily influenced by Strabo's depiction of the inhabitants of Northwest Iberia. In particular, his reading of Strabo had convinced him of the unity of ancient Lusitanian civilization, a unity which he extended to the ancient hillforts he had uncovered in what he saw as the former range of Lusitania (Sarmento 1883-1884). The idea of a distinct culture of the castros quickly solidified following recognition of Sarmento's expeditions in northwestern Portugal (Queiroga 2003:3). The Castro Culture was long viewed as an appropriate means of describing the archaeological reality of the Iron Age in Northwest Iberia, and as a viable alternative to a conceptualization of the castros based on a wider Celtic tradition (Silva 1986, Calo Lourido 1993).

The term "Castro Culture" reflects the cultural-historical tradition of scholarship, wherein the supposed existence of a particular brand of material culture becomes conflated with the existence of a singular, implicitly homogenous human culture. Usage of the term has been subject to criticism following the recognition of significant regional variation in most aspects of the material culture associated with the castros, as well as the acknowledgement that different communities can share specific practices without necessarily sharing a cultural or ethnic identity (González Álvarez 2011). In other words, the castros do share certain features in common, but they are not as uniform across their entire geographic range as was once thought. Furthermore, what they do share in common need not be interpreted as an indication that their inhabitants would have belonged to a singular "culture." The inevitable conclusion is that neither the Castro Culture nor the Celtic paradigm are sufficient to describe the cultural identity of the Iron

Age inhabitants of Northwest Iberia, as the reality these viewpoints have sought to explain is more complex and varied than either is capable of adequately describing. A fuller treatment of this topic is beyond the scope of the current work; suffice it to say that the issue of how to characterize the archaeological reality of the castros in the broadest sense has little bearing on the task at hand.

History of Research on Castro Architecture

The history of archaeological research into the castros of the Northwest begins with Francisco Martins Sarmento in the 19th century, but it is likely that the existence of certain castro sites was known from as early as the medieval period. For example, the Cividade de Bagunte is referenced in documents as early as the 10th and 11th centuries, as the *monte Bogonte* and *civitas Bogonti*, respectively (Almeida and Almeida 2015:50). The Citânia de Santa Luzia, which occupies a prominent position overlooking the modern city of Viana do Castelo, had once been referred to by locals as the “Cidade Velha,” apparently under the presumption that its ruins were built by the citizens’ own predecessors (Viana and Oliveira 1954:40). People have been well aware of the existence of the castros for quite some time, but the true nature of these abandoned settlements was long forgotten. Sarmento, as the first to systematically investigate the castros, discovered that they were far older and more peculiar than had been recognized previously (Martins 1995:132).

Sarmento’s endeavors began in Guimarães, in 1875, with the excavation of Citânia de Briteiros. Thereafter he conducted annual excavations at Briteiros, eventually uncovering a considerable portion of the site. In 1878, he began excavations at Castro de Sabroso, another site in Guimarães very close to Briteiros. Sarmento also traveled throughout northwestern Portugal to observe other castro sites. Neither his work at Sabroso nor his traveling expeditions can be compared in scale to his work at Briteiros, but they played an important role in his conceptualization of the archaeological reality he had begun to uncover.

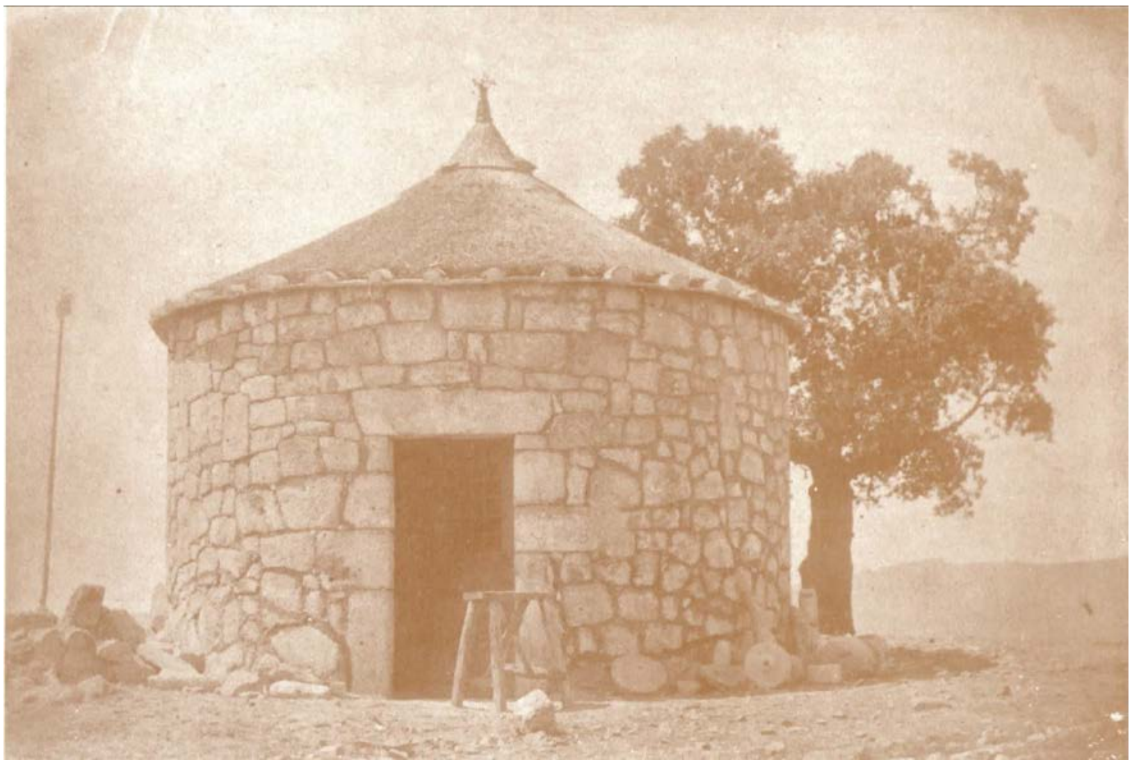

Figure 3: Photograph of the first reconstruction at Briteiros (Sarmento 1992 [1876])

Sarmento’s full reconstructions of two circular structures at Briteiros were influential in the development of a widely held perception of the round houses of the castros as they may have originally appeared (Ayán Vila 2002:138). Sarmento's early investigations at Briteiros sparked a wave of interest in the material remains of the castros, leading to research and excavation at various sites across the Northwest over the coming years. In accordance with standard practices around the turn of the 20th century, many archaeological finds were not thoroughly documented, and what was documented was seldom published. This trend applied as well to the architecture of castro sites, and research documents related to the structural remains mostly consisted of the few isolated reports wherein excavators briefly recounted their activities at a specific site. Thus, scholarship on castro architecture at this time was in a formative period; a body of literature and public discourse on the topic had only just begun to solidify.

Documentation on the archaeology of castro sites remained fragmentary throughout the first half of the 20th century. Excavation results for individual sites were periodically made available through one of several possible avenues of publication, including a number of different research journals, municipal bulletins, and the like. Both the documentary record and the physical remains were scattered, numerous, and incomplete. While generalizations regarding the characteristics of the castros continued to solidify in both public and academic discourse, there still had been no published attempts at establishing a coherent, large-scale synthesis of the evidence that could account for the documentary and material records produced over the last several decades of research (Queiroga 2003:3). The first attempt at a large-scale synthesis of the evidence came in 1953 with a monograph by Florentino López Cuevillas (1988).

Though he focused primarily on the region of Galicia, Cuevillas provided a broad overview, seeking to characterize the ancient “culture” that had been observed through investigation of the castros, which he viewed as decidedly Celtic in nature. Both in this text and in his other works (López Cuevillas 1954), he draws heavily on classical sources to inform his interpretations. His work included assessments of the architecture of castro sites, with a focus on decorative elements and structural forms. By this point in time a generalized notion of the characteristics of castro architecture had emerged, along with a preliminary typology of common forms (López Cuevillas 1947; López Cuevillas and Lorenzo Fernández 1946).

The body of research and literature on the castros continued to steadily expand over the following decades, but methodologies were slow to change. Still at this point, accounts of castro architecture mainly appeared as part of larger assessments of the material culture or in the excavation reports of specific sites, with brief works dedicated specifically to the architecture appearing infrequently (García y Bellido 1971). The first overarching synthesis dedicated to the topic of castro architecture came with a monograph by Ana Romero Masiá (1976). Her typology of common structural forms continues to be frequently cited, a fact which attests to the wide influence of this work as well as to the scarcity of subsequent contributions of a similar nature.

From the 1980s onward, scholarship on the archaeology of the castros increased in both volume and rigor. Methodologies in the Northwest advanced considerably around this time, as stratigraphic profiles and other important categories of evidence began to be recorded and analyzed with greater care than in the past, while the introduction of radiocarbon dating opened new doors for the improvement of chronologies (González-Ruibal 2006:24-37). Theoretical and methodological developments led to the reevaluation of longstanding paradigms and the introduction of new avenues of inquiry and interpretation (Ayán Vila 2002:145-146). One noteworthy outcome is the proliferation of regional studies and the application of landscape archaeology, pursuits which began around this time and remain vibrant into the present (Almeida 2013; Carvalho 2008; Criado Boado and Parcero Oubiña 1997; Delindro 2012; Dinis 1993; Fábrega Álvarez 2005; Fernandes 2010; Lemos et al. 2011; Lopes 2003; Martins 1989, 1996; Parcero Oubiña 1995, 2000, 2006; Parcero Oubiña et al. 2007; Pinho 2009; Silva 2010).

Yet in regard to the study of castro architecture, the situation remained largely the same in that it was seldom approached as a topic in itself, but was frequently alluded to or included as a component of the evidence in various publications. For example, discussions of architecture and settlement patterns played an important role in Armando Coelho Ferreira da Silva's 1986 monograph on the Castro Culture. This work was the first major synthesis of the archaeology of the Northwest since Cuevillas, and it brought together a large body of evidence in order to provide a general overview (Silva 1986). Various studies of large scale or general scope have continued to appear since then (Calo Lourido 1993; González García 2007; González Ruibal 2006; Parcero Oubiña and Cobas Fernández 2004; Queiroga 2003), in addition to the more frequent appearance of thematic essays on the topic of castro architecture (Carballo Arceo 1996). Despite improvements in methodology and documentation over the last few decades, archaeology in the Northwest still suffers from a lack of prompt and thorough publication of excavation results (González-Ruibal 2006:24-37).

The most recent and significant development in the study of castro architecture came around the turn of the current century, as new theoretical approaches related to the general study of architecture had begun to emerge (Ayán Vila et al. 2003:1-6; Mañana Borrazás et al. 2002:14-18). In the Northwest, this culminated in the proposal of a new "Archaeology of Architecture" or *Archaeotecture*, put forth by a group of researchers in affiliation with the Universidade de Santiago de Compostela (Ayán Vila 2001; Ayán Vila et al. 2003, 2009; Mañana Borrazás et al. 2002). Though it also applies to other regions and periods, this constitutes the first formal proposal of an explicit set of methods and approaches for the study of castro architecture. In addition to the founding of a research journal of the same name, *Arqueología de la Arquitectura*, the influence of this new research program can be seen in the adoption of its methods by other scholars (Ruano Posada 2015).

Xurxo Ayán Vila's research on castro architecture takes place largely in the context of this movement, as he is one if its major contributors and proponents. His work on the topic, with frequent publications beginning in the early 2000s (Ayán Vila 2002, 2003, 2005, 2008, 2013; Ayán Vila et al. 2005), constitutes the most extensive approach to castro architecture found in the literature to date. Understanding the current state of research on the topic of castro architecture requires an understanding of Ayán Vila's work, including its context within the framework of *Archaeotecture*.

ARCHAEOLOGY OF ARCHITECTURE: THE CURRENT STATE OF RESEARCH

In the most general sense, Archaeotecture as presented by Ayán Vila and his colleagues seeks to "maximise all of the information which architectonic remains give about past societies" (Ayán Vila et al. 2003:10). Specifically, they place overwhelming emphasis on the need to account for the social and symbolic dimensions of built spaces, which have often been neglected in archaeological investigations of architecture. They propose the following toward this end: "If one plans to maximize the information that the architectonic record can contribute to the understanding of a past social formation, archaeology must develop an approach that uses spatial analysis as a methodology and social theory as an interpretive framework" (Mañana Borrazás et al. 2002:15).[1] The social theory they employ is found to rely in part on the structuralism of Claude Lévi-Strauss.

[1]All direct quotes from publications written in other languages are translations by the author of this thesis.

In particular, they rely on a notion of "rationality" as the basis for explanatory models of human behavior and perception. The following refers to human conceptualizations of space: "This multidimensional space is directly related to the pattern of rationality, which Lévi-Strauss calls thought, of the society which creates it and lives it out; architecture is also the most evident way of giving a physical aspect to the spatial concepts of this rationality" (Ayán Vila et al. 2003:19). As for their methods of spatial analysis, they rely on the toolkit of "space syntax" through application of gamma analysis and visibility analysis (Mañana Borrazás et al. 2002:39). In this way they seek to identify spatially contingent patterns of behavior and perception related to access, circulation, and visibility that can be incorporated within a specific model of "rationality" (Ayán Vila et al. 2003:20). The "ultimate goal" of this approach is to "access the rationality" of a past society by studying the spatial properties of their architectural remains (Mañana Borrazás et al. 2002:27). By formulating this hypothetical model of communal "thought," they seek to establish a concrete basis for informed speculation regarding the socially determined meanings of built spaces.

Approaches from landscape archaeology are fundamental to the theoretical and methodological repertoire of Archaeotecture, and the ideas of Felipe Criado Boado are seen as particularly essential in this regard. The interpretive scheme laid out above relies on the assumption that "activities which take place in relation to space are coherently organised with the ideal representation of the world held by the social group which carries them out" (Criado Boado 1999:10, *apud* Ayán Vila et al. 2003:20). Patterns observed in the built spaces of a particular society are therefore seen as "directly related to specific patterns of rationality," such that by studying the former they seek access to the latter (Ayán Vila et al. 2003:19). In addition to the spatial analyses proposed above, they employ “formal analysis” and “constructive analysis” of the architectural remains so as to capture their full range of physical characteristics (Ayán Vila 2001:31; Ayán Vila et al. 2003:20). They also combine stratigraphic analysis with mensiochronology or the assessment of “vertical stratigraphy” in preserved walls. Through this and other contemporary methods such as radiochronometry, they seek to assess the chronological development of structures through determination of construction events and interpretation of their temporal relationships (Mañana Borrazás et al. 2002:29-30). In combining all of these methods, they seek to provide a descriptive account of the architectural evidence with attention to its structural, formal, and chronological components, which can be applied in tandem with approaches from space syntax to produce a socially relevant interpretation of the remains. While an in-depth assessment of the theoretical frameworks discussed above would exceed the scope of the current work, it is worth mentioning that the concept of rationality proposed in this context warrants critical evaluation, as does the extent to which we are capable of reconstructing the worldviews of a prehistoric community by means of an appeal to this concept.

In accordance with the stated goals of this thesis, the above summary of Archaeotecture focuses on its methods for the maximization of information obtained from the study of architectural remains, specifically as proposed within the context of the castros of Northwest Iberia. The research program of Archaeotecture encompasses more than what is represented in this brief overview. The movement is concerned not only with methods for the study and interpretation of architectural remains, but also with the management and valorization of cultural heritage sites and with the effective dissemination of archaeological information (Mañana Borrazás et al. 2002:19).

APPROACHES TO THE STUDY OF ORGANIZATION IN LATER CASTRO SETTLEMENTS

Architectural evidence at castro sites tends to be very scarce prior to the 2nd century BCE, due in part to the limited extent of excavation at many sites (González-Ruibal 2006:341; Parcero Oubiña and Cobas Fernández 2004:11). This means very little can be said about the organization of castro settlements prior to this time, though attempts have been made using what little evidence is available (Ayán Vila 2001, 2008; González-Ruibal 2006; Parcero Oubiña and Cobas Fernández 2004).

The organization of later castro sites has often been described by means of comparison to the Roman model of the orthogonal city plan, where structures are located in relation to major streets that tend to meet at right angles to divide the settlement into a grid. Castro sites that appear to emulate this model are said to be organized or proto-urban, a phenomenon directly attributed to Roman influence (Silva 1995:519-521). Sites that do not exhibit this phenomenon are generally said to be unorganized or exhibit a lack of urban planning (Queiroga 2003:4). Thus, the organization of castro sites is framed as either unorganized or organized, as lacking urban planning or exhibiting proto-urbanism, with the transition between the two being viewed as a result of Romanization. In this way the assessment of organization is treated as a classificatory endeavor, rather than a descriptive one. That is to say, this approach categorizes the organization of sites into preconceived models, rather than describing their organizational properties on the basis of measurable characteristics. This represents the traditional approach to discussions of castro organization, with precedents as early as López Cuevillas (Ayán Vila 2002:144-145). This viewpoint was largely based on observation of a few well-known "proto-urban" sites from northwestern Portugal and southwestern Galicia, such as San Cibrán de Las, Citânia de Sanfins, and Citânia de Briteiros.

Figure 4: Drone photo showing part of the excavated area of San Cibrán de Las. Note the prevalence of rectangular forms and the impression of an orthogonal grid.

More recent approaches focus on describing the organizational properties of sites using visual assessment. This primarily includes the identification of so-called “domestic compounds,” a common feature in some later sites wherein structures appear to be organized into distinct groupings. Interpretations vary, but these groupings are often assumed to represent family units (Almeida 1984:38; Ayán Vila 2008:954; González-Ruibal 2006b). Compounds consist of multiple structures located in close proximity and facing toward a common outdoor area, which is usually paved with stones. This shared outdoor area is referred to as a “patio” or “courtyard.” Some compounds are clearly delineated by an independent perimeter of walls, a good example of which can be found at Citânia de Santa Luzia (Almeida 2007; Viana 1955; Viana and Oliveira 1954). In the many cases where such a perimeter is not present, the identification of groupings is less straightforward. Despite the attention given to this topic, no explicit procedures or criteria have been proposed for the definition of compounds. Observation of these groupings allows for discussion of organizational schemes beyond the model of Roman urbanism, such that sites can be considered organized without necessarily emulating an urban grid (Parcero Oubiña and Cobas Fernández 2004:41-44). Aside from the existence of compounds, other properties described include the density of the built space, the capacity for circulation between different areas, the sizes of structures, and the directions in which structures tend to face (González-Ruibal 2006:339-391). These properties are interpreted through visual assessment of published plan maps, and are seldom quantified except in simple form (González-Ruibal 2006:371). Recent applications of space syntax to the built space of castros represent an important exception to the conventional reliance on visual assessment. Still, such endeavors have yet to produce a descriptive account of settlement-wide organizational properties beyond the identification of axes and potential paths of circulation (Ayán Vila 2003; González-Ruibal 2006:369-370).

It is a truism that there are many different ways to organize space, and we may not be able to easily recognize subtle organizational patterns through visual assessment alone. This is especially true in cases where we are seeking to detect and comprehend forms of spatial logic with which we are entirely unfamiliar. In such cases, rather than describing the organizational properties of sites by means of comparison to familiar models, it would seem more productive to describe them on account of their own measurable characteristics. Visual assessment is poorly suited for such a task, given that our perception is necessarily biased by what we expect to see, what we have already seen, and other consequences of our inherent subjectivity, not to mention our general inefficacy in intuiting complex spatial or mathematical relationships. This is the reason for implementation of spatial analysis, which stands to aid us in identifying unfamiliar patterns that are not readily detectable through visual assessment alone. Since space syntax is the only form of spatial analysis applied to castro settlements to date, it will be important to understand how it has been applied and what it stands to tell us.

Chapter 2: Space Syntax

GAMMA ANALYSIS

In the framework of Archaeotecture, assessments of access and circulation are achieved through application of “gamma analysis” from the toolkit of space syntax (Ayán Vila 2001:31; Mañana Borrazás et al. 2002:33-39). In this method, which is often called “access analysis” in recent literature, the plan map of a structure (or an area containing multiple structures) is taken as the object of study, with the interior viewed in opposition to the exterior. An access diagram is produced wherein “each unit of space within the building” is represented as a circle, and these circles are connected with lines whenever the structure’s layout permits direct “access between spaces” (Grahame 1997:147). In other words, this method considers a structure or other convex space, typically an area enclosed by walls, and takes the exterior as the starting point. The first unit of space encountered upon entering the structure is the first point of access. This point is connected to the exterior point and to any other units of space within the structure that can be reached directly from this one via passage of a single threshold; the process continues in this manner for every other unit. These units of space, which we can call “rooms” for the sake of simplicity, are distinguished from each other by the presence of dividing walls. Thus, entering or exiting a room means crossing a threshold, defined by a gap in the walls that enclose the room itself (just as an entry to the structure is defined by a gap in the walls that enclose the structure).

The purpose of the diagram is to depict the relationships between every point of access; the connections between these access points determine the path one must take to reach any given portion of the structure. Again, each access point on the diagram is a room; points are connected with a line when passage from one room to the other can take place directly (via passage of a single threshold). The access diagram is then *justified* with respect to some specified point, typically the exterior (Hillier and Hanson 2005:149-151). This involves relocating the points such that all rooms at the first level of depth are placed in a single horizontal row, all points at the next (greater) level of depth are placed in a row above the first, and so on. Here the "level of depth" of a room is simply the number of thresholds that must be crossed in order to reach that room from the exterior.

Creation of this justified access diagram allows for visual assessment of the depicted configuration along axes of *symmetry-asymmetry* and *distributedness-nondistributedness*. In short, a configuration of spaces is considered asymmetric when its rooms tend to be located at different levels of depth with respect to the exterior, while a configuration having many rooms at the same level of depth would be considered a symmetric configuration. A distributed configuration is one where there are multiple possible routes available to reach any given room, while in a nondistributed configuration there is only one possible route available to reach any given room (Hillier and Hanson 2005:94). These are the criteria typically used to characterize an entire configuration based on its justified access diagram. As for the assessment of individual portions of the configuration, gamma analysis calculates values representing the degrees of control and accessibility present for each unit of space within the structure. These values are called the control value and the relative asymmetry value, respectively.

The control value for a particular room is equal to the sum of the reciprocal of the number of neighbors held by each of that room's neighbors, where "neighbors" are any two rooms directly connected by a line in the access diagram (Hillier and Hanson 2005:109). Thus, for a particular room that has two neighboring rooms, with each of these neighbors having three neighbors themselves (including the room in question), the particular room in question will receive a control value of 1/3 + 1/3 = 0.6666. This value, being less than the baseline control value of 1, would indicate that the particular room in question exerts a relatively low degree of control over its neighbors, or in other words that it is a *controlled* space, whereas a value greater than 1 would indicate that it is a *controlling* space (Grahame 1997:147). As we can see, the control value is determined not only by the number of other rooms that can be accessed from a particular room, but also by extent to which entering those other rooms *demands* use of the room in question. The greater the number of spaces that can be reached from a particular room, and the fewer the number of options that exist for reaching those spaces, the more *control* that particular room has. We can see that the use of the term "control" in this context is based on the idea that passage through a particular space is, to a certain extent, obligatory.

The degree of accessibility of a room with respect to the rest of the spaces in the diagram is determined by the number of thresholds one must pass through on average in order to reach that room from any other point (where "any other point" includes every other room as well as the exterior, which in the calculation of values is treated as a unit of space or "room" just like all the others). This accessibility is represented by the relative asymmetry value. To calculate the relative asymmetry value for a particular unit of space, it is first necessary to calculate the "depth" of every other unit of space in the diagram with respect to the unit of space under consideration, which then allows calculation of the "mean depth" of the total configuration of spaces relative to the space under consideration (where the "total configuration of spaces" is the exterior and every room of the structure). The depth of any room with respect to the room under consideration is equal to the number of thresholds that must be crossed in order to reach that room from the room under consideration. For example, any two rooms that are neighbors as defined above will necessarily be at a depth of 1 from each other.

Now, consider a particular configuration of spaces consisting of four rooms and an exterior, for a total of five spaces. Let’s say that, with respect to one particular room, there are two rooms at a depth of 1 from it, one room at a depth of 2 from it, and one room at a depth of 3 from it. To calculate the mean depth of the total configuration of spaces with respect to this particular room, we multiply the number of rooms at each level of depth by their depth value, add the results together, and divide this sum by the total number of spaces minus one. This gives us $(2 \cdot 1 + 1 \cdot 2 + 1 \cdot 3) / (5 - 1) = 1.75$. So, the mean depth of the total configuration of spaces with respect to the room under consideration is 1.75. Now that we know this value, we can utilize the generic formula for calculation of the relative asymmetry value of a room: $2(MD - 1) / (k - 2)$, where “MD” is the mean depth value that we just calculated, and “k” is the total number of spaces (Hillier and Hanson 2005:108). In this scenario, the relative asymmetry value of the room under consideration equals $2(1.75 - 1) / (5 - 2) = 0.5$.

Relative asymmetry values (hereafter, RA values) range from 0 to 1, with low values corresponding to a high degree of accessibility and high values corresponding to a low degree of accessibility. In this scenario, our value falls directly in the middle of the range, indicating a moderate degree of accessibility. However, we are cautioned against such a straightforward interpretation, as the full significance of any given RA value only becomes clear when the RA value of every other room in the total configuration of spaces has been calculated and compared (Grahame 1997:147). This highlights the *relative* nature of RA values.

The procedures outlined above were designed for analysis of a single configuration of spaces, typically a structure or enclosed area containing multiple distinct units of space defined by the presence of internal divisions and accompanying thresholds. It should now be clear that, in a structure without internal divisions, these procedures become extremely limited. This is because in such a scenario there is only the exterior, the entry of the structure (which may or may not be defined as a room in and of itself), and the single room accessed by this entry.

VISIBILITY ANALYSIS

In its simplest form, visibility analysis consists of drawing lines of sight from a particular point of reference to determine which portions of a structure or area are visible from a particular vantage point. In Ayán Vila's application at Castro de Elviña, the point of reference considered is that of the beginning of the entryway (Ayàn Vila 2001:39-40). Drawing lines of sight from this point toward the interior of the structure shows which portions of the interior are visible from the entryway, with the walls of the structure being the determining factor. Ayán Vila (2001:40) interprets the results as follows: the portion of the structure that is visible from the entryway is classified as semi-public space, and the rest of the structure is classified as private space, with the exterior of the structure being classified as public space. While visibility is an important spatial property to model and describe, its interpretation as a straightforward indicator of privacy is problematic. Conceptualizations of "public" and "private" are culturally constructed and historically contingent, and cannot be reduced to a set of universal principles (Grahame 1997:138-145). Still, visibility analysis tells us what can be seen from particular vantage points, and this information can have important implications for the study of built space.

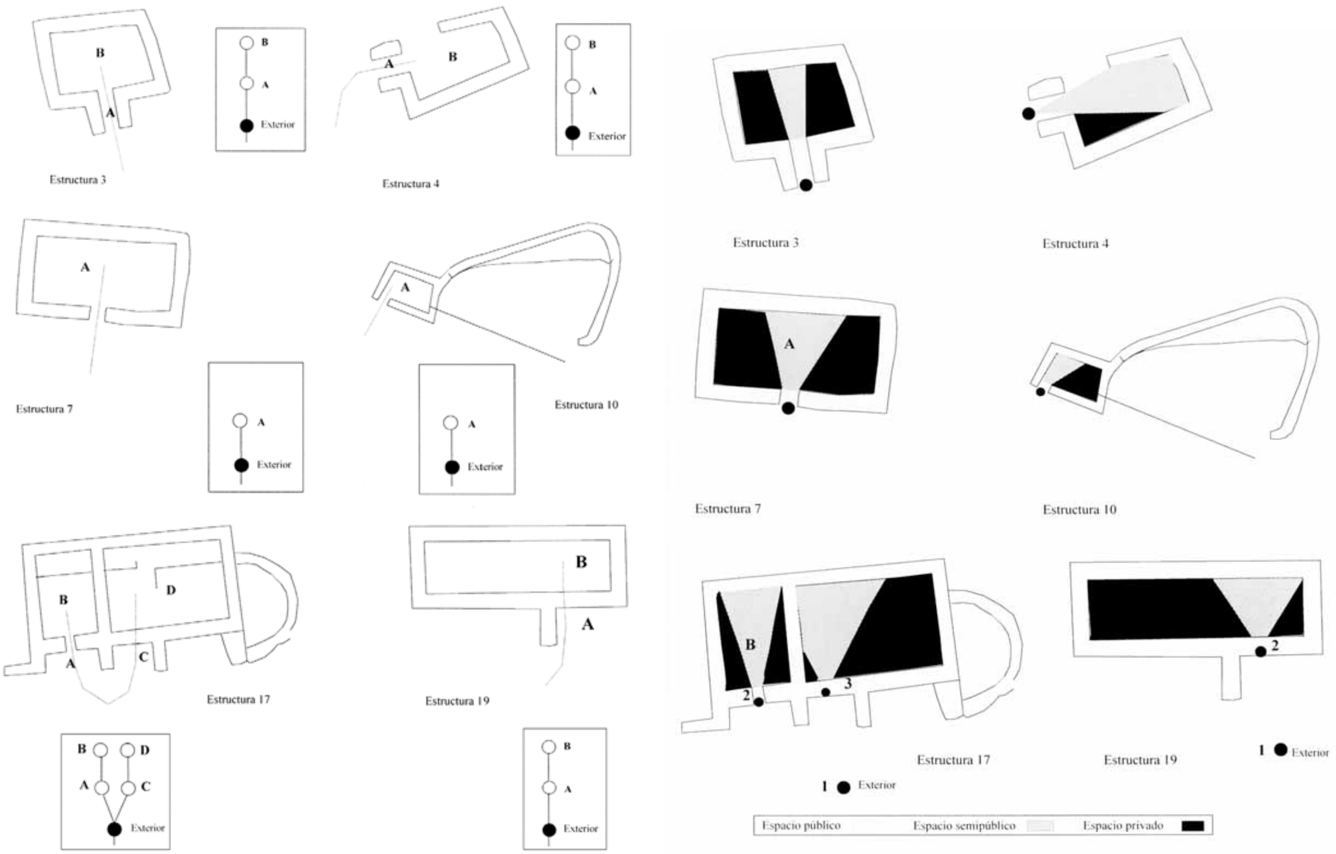

Figure 5: Access diagrams (left) and visibility diagrams (right) for structures at Castro de Elviña (Mañana Borrazás et al. 2002: Figures 40 and 41)

SPACE SYNTAX AT CASTRO DE ELVIÑA

In his presentation of space syntax within the context of Archaeotecture, Ayán Vila (2001) uses Castro de Elviña (in A Coruña, Galicia) as a case study. Assessment of his access diagrams (Figure 5) indicates that half of the configurations are technically asymmetric according to the definition found in Hillier and Hanson (2005:94). The exceptions to this are structures 7 and 10, as any configuration consisting of only two spaces is inherently symmetric. Structure 17 is also fairly symmetric, having an equal number of rooms at each depth level. Meanwhile, all the structures considered are technically nondistributed, which corresponds to an overall pattern of limited access. Ayán Vila's interpretation coincides with this assessment, as he states that the structures observed are characterized by "mostly asymmetric spatial relationships" and "strict control of access," a pattern which he interprets as the "material manifestation of a strategy of impermeabilization of the habitational space" (Ayán Vila 2001:39). Yet assessment of the justified access diagrams is only a preliminary first step; the calculation of control values and relative asymmetry values for each room is considered the more meaningful component of gamma analysis (DiBiasie 2015:46). Ayán Vila does not present these values, which limits our ability to evaluate his interpretation. Below we calculate the values according to the mathematical procedures used in gamma analysis, which are explained above based on the contents of Grahame (1997:147-149) and Hillier and Hanson (2005:108-109).

If the entryway is defined as a room (i.e., treated as its own unit of space), we have two rooms and an exterior, as is the case in Ayán Vila's depiction of structure 3 at Elviña (Figure 5, top left). Following the procedures outlined above, our calculations produce a value of 2 for the control value of structure 3's room A, and 0 for its RA value. This would seem to indicate that room A exerts a high degree of control over neighboring rooms, and that it exhibits the highest possible degree of accessibility. As for room B, the control value is 0.5, and the RA value is 1. This would seem to indicate that this room exercises a small degree of control and exhibits the lowest possible degree of accessibility.

However, the RA values obtained for rooms A and B of structure 3 do not indicate their degree of accessibility in absolute terms, only their degree of accessibility with respect to each other and the exterior. Their degree of accessibility with respect to each other is identical, as these two rooms are neighbors in the sense defined above. The difference in their RA values stems solely from the fact that one room (A) is separated from the exterior by a single threshold, while the other room (B) is separated from the exterior by two thresholds. In other words, we learn that one room is more accessible from the outside than the other, on account of the fact that one room connects directly to the exterior and the other does not. This is a meager conclusion, given that room A is the entryway to the structure. As for the control values, we learn something similar. Room A is seen as a controlling space because passage through room A is obligatory for anyone who wishes to enter room B. What we learn, in effect, is that in order to enter the structure, we must first walk through the entryway. Again, this finding is exceedingly unremarkable.

The access diagrams of structures 4 and 19 are identical to that of structure 3, which means their corresponding values are identical as well. The entryways of structures 7 and 10 are not defined as rooms, which results in a very serious problem: calculation of RA values for these two structures will result in division by zero. This is the case for any spatial configuration consisting of only two units (a single room and an exterior), because the denominator of the equation for relative asymmetry is equal to the total number of units minus 2. In addition, calculation of control values for these two structures results in a value of 1, which is the baseline control value. There are only two units in the entire configuration, and they are each other’s (only) neighbors, such that there is no possibility for exertion of control. In other words, calculation of values for structures 7 and 10 is not just limited; it is largely invalid. Structures 3, 4, and 19 only escape these problems because their entryways are defined as their own units of space. More importantly, while the calculation of values for these three structures is technically valid if we treat their entryways as “rooms,” the results still tell us very little. Given that structures with multiple internal divisions are quite a rare occurrence at most castro sites, gamma analysis appears to be a very limited method of spatial analysis for the study of castro architecture insofar as it involves the calculation of values. It remains technically viable because even the most minimal configurations can be interpreted along the axes of symmetry-asymmetry and distributedness-nondistributedness, albeit with very limited results. The mathematical procedures of gamma analysis, considered to be its more robust contribution, are unable to produce meaningful results in the absence of a sufficient number of rooms for analysis. The theoretical bases and interpretive frameworks associated with space syntax remain valuable insofar as they provide a means of systematically evaluating the social implications of the measurable characteristics of built spaces, but problems arise when such characteristics are unable to be meaningfully quantified.

DISCUSSION

In their formal presentation of Archaeotecture, Mañana Borrazás et al. (2002:79-81) use Elviña as their case study to demonstrate the toolkit of space syntax, mirroring the above assessment by Ayán Vila (2001:38-40). In a separate study at Castro de Viladonga, Ayán Vila’s (2003) application of gamma analysis to individual structures is faced with the same hindrances noted above. In this case he also applies gamma analysis to multiple structures at once, which has been done at other castros as well (González-Ruibal 2006:384; Ruano Posada 2015:72). This slightly expands the capabilities of the procedure, but it also creates a new problem, namely that of how to define the total configuration of spaces in the absence of independent delimiting walls creating clearly bounded convex spaces. Ayán Vila (2003) also expands his application of space syntax to the entire settlement, drawing on the procedures of alpha analysis (Hillier and Hanson 2005:82-142) to produce axial maps and convex maps for the whole site, which allow him to trace paths of circulation through the settlement. In this we see that space syntax has more to contribute to the study of castro architecture, but overall it is still faced with a number of limitations. Even when the forms of spatial analysis encompassed by space syntax can be meaningfully applied, they are only capable of accounting for a particular range of spatial phenomena. For example, quantitative measurements of distance, direction, density, and the dimensions of features are left out of the equation. Interpretation of such factors is mostly left to visual assessment, both in the framework of Archaeotecture as presented above and in the study of castro architecture in general. In order to further increase the information gained from the study of castro architecture, the introduction of new methods of spatial analysis would seem to be a profitable next step.

The layout of Castro de Elviña is said to exhibit an "adaptation to the conditions of the terrain," and to lack any sort of "internal spatial organization based on an urban plan of orthogonal nature, with paths of circulation according to which the habitational units are ordered" (Ayàn Vila 2001:39). This account is not attributed to the results of space syntax; instead it is simply presented as self-evident. While the description itself may very well be true, the problem lies in the assumption that it is sufficient to intuit these properties through visual assessment, without reference to any explicitly defined procedures or criteria. This assumption is pervasive in the literature, and is responsible for the fact that different authors are prone to describe the same site's organization in different terms, interpreting the same body of evidence in contradictory or incompatible ways. For example, Queiroga (2003:4, Figure 13) describes the Cividade de Terroso as having a “lack of organization,” which supposedly reflects a typical “pre-Roman” layout. This seems to be based on a visual assessment of the 1907 plan map of the site, which he shows in the cited figure. Meanwhile, Flores Gomes and Carneiro (2005:113) emphasize that the plan of Terroso clearly reflects a “total urban reorganization” brought about by Roman influence, and Silva (1986:39) likewise concludes that Terroso exhibits an “ordered plan” reminiscent of other “proto-urban” sites. Such inconsistencies between the interpretations of different authors are able to persist because the task of establishing a consistent set of methods for description and analysis of the organization of castro sites has yet to be undertaken in full. In other words, we often lack a concrete basis for evaluation of claims regarding the organization of castro sites, because we lack objective and clearly defined criteria with which to justify and inform our interpretations of this phenomenon. This is the case for any organizational properties that cannot be accounted for through application of space syntax, whose procedures have been shown to exhibit severe limitations when applied to castro settlements.

In accordance with the above, this thesis contends that the organization of built space in later castro settlements has yet to be satisfactorily described, and that our generalizations regarding the spatial arrangement of these sites are consequently dubious. This claim constitutes a fundamental premise of the current work, which seeks to explore new possibilities for description and analysis of the organizational properties of castro settlements. I suggest that, if we wish to move toward social interpretations of the built space as proposed in the research agenda of Archaeotecture, it will be productive to describe the spatial properties of castro settlements more fully. This should involve further pursuit of concepts and methods related to space syntax, as there is room for expansion beyond what has been applied thus far (Cutting 2003; DiBiasie 2015; Laurence

2007; Stöger 2011). I argue that this should also involve the development of entirely new methodological frameworks. Given that there is already a substantial body of literature associated with space syntax, the current work focuses on the task of developing a new approach.

Chapter 3: Methodology

FOUNDATIONS FOR A NEW APPROACH

While GIS has become an essential tool for many archaeologists in recent years, archaeological applications of spatial statistics are mostly regional in scale. The potential of spatial statistics for the analysis of ancient settlements on a micro-scale has not been considered as thoroughly. I seek to explore this potential by applying concepts and methods from spatial statistics to the architectural remains of castro settlements, with the goal of demonstrating that further pursuit of such an approach stands to increase our comprehension of the organizational properties of their built spaces.

The methods I propose are intended to provide new insight on the internal organization of castro sites by detecting patterns in the arrangement of built space at the settlement scale. To acquire the insight we seek, we must establish a set of procedures that can be efficiently applied to a large number of sites. In seeking to compare the spatial properties of many different sites, we face a number of problems, both practical and theoretical. Foremost is the issue of establishing the evidential basis for the data that will come to represent each site.

Of key importance is the acknowledgement that we will not be analyzing the built space itself, but a representation of it. My methodology relies on a representation of the site's layout and architectural remains *as they currently exist*. This entails a fundamental assumption, which is that the remains as they currently exist can serve as an accurate reflection of the built space as it existed at a particular moment in time during the habitation of the settlement. There are three major problems with this assumption.

First, the remains as they currently exist are inherently incomplete. Aside from the passage of millennia causing the destruction and disturbance of architectural remains and the complete disappearance of perishable elements, the extent of excavation is quite limited at most sites. This means we cannot represent the entire settlement, and even the portions that can be represented will exhibit arbitrary gaps.

Second, we cannot always be certain that what does remain is located or oriented precisely where it would have been originally. In many castro sites, partial reconstruction of the walls is undertaken *in situ* as a matter of standard practice. Reconstructions ultimately reflect the excavators' interpretive conclusions regarding the original locations and orientations of structural features. When performed *in situ*, reconstruction partially conceals the underlying remains that formed the evidential basis for said interpretive conclusions. This loss is mitigated by providing thorough documentation of the remains as they existed prior to reconstruction, and by leaving a clear and permanent indication of the threshold between original and reconstructed portions of structures. Problems arise when such a record is not available, as is often the case at castro sites with long histories of excavation.

The third, and perhaps most theoretically complex problem is that of chronology. These settlements did not appear overnight and remain in that state until their abandonment; they emerged gradually and were constantly changing throughout their occupation. We cannot represent *the* site, only the site as it existed at a particular moment in time. Confirming that each structure currently visible in the plan of a settlement belonged to the same precise moment in time is often an impossible task, especially for one seeking to study a large number of sites. This is because for most castro sites, especially those that were fully or partially excavated during the first half of the 20th

century, there is simply not sufficient evidence or documentation for precise dating of every structure. In short, the site as it currently exists is prone to reflect anachronisms, errors, and gaps. It is therefore problematic to assume that the remains as they currently exist can serve as an accurate reflection of the built space as it existed at a particular moment in time during the habitation of the settlement.

Aside from abandoning the endeavor altogether, our only choice in seeking to study the built space of castro sites is to acknowledge these problems and seek to represent the site as meaningfully as possible. This means seeking out the available documentation, including excavation reports and published plan maps, and using them to inform our interpretation of the site's remains as they exist on the ground. We then seek to represent these remains in a spatially precise manner, and use this representation as the basis for our spatial analyses. In doing so we must keep in mind that what we are representing is far from a perfect account of the reality we are seeking to understand, which is the spatial arrangement of the settlement as it existed at a particular moment in time.

The built space of a site is conventionally represented as an illustrated plan map. A premise of the current proposal is that published plan maps cannot be taken at face value or treated as infallible: their spatial veracity must be evaluated if they are to be used as the evidential basis for GIS-based spatial analyses. This means we must explicitly confirm the precision and accuracy of existing representations, or else generate our own. On-the-ground surveys employing a total station, or a digital theodolite and GPS unit, stand to provide the highest degree of precision for this purpose. Yet this process becomes less feasible when seeking to generate or evaluate representations for a large number of sites, due to constraints on time as well as issues of cost and permission. One alternative is to rely on high-resolution orthographic photos of the site, which are easily obtained through use of drone technology. Drone photography is the preferred means of representation for the purposes of the current methodology. Note that structures covered by trees cannot be digitized on the basis of drone photographs, which is a major limitation on this methodology. LiDAR is an effective solution for sites with extensive tree cover, but would require significant funding.

The methodology presented in this work made use of the following tools and technologies: a DJI Phantom 3 drone for aerial photography, a standard camera for supplemental photography, ArcGIS Desktop Advanced with ArcMap for all tasks involving use of GIS, Google Earth Pro for obtaining satellite imagery, Adobe Photoshop for lens correction of drone photos, and the R programming language with RStudio Desktop for statistical analysis of spatial data and creation of customized script tools for ArcMap. Satellite imagery can often provide sufficiently precise coordinates for georeferencing. Strictly speaking, access to drone technology and a capable computer are the minimum requirements in terms of hardware. Viable open-source alternatives exist for all of the proprietary software listed above, such that access to the necessary hardware can be seen as the only strict financial limitation on the proposed methodology. The choice of software will generally be influenced by many factors. For example, Photoshop offers a tool specifically designed for lens correction of images taken by the camera of a DJI Phantom 3, which made it the natural choice for my purposes. My methods will be demonstrated on Cividade de Terroso and Castro de Romariz, two late castro sites from northwestern Portugal. These sites will be discussed later on as part of the case study.

The fundamental objective of the proposed methodology is simply to detect and describe the organizational properties of castro sites more fully. But I would be remiss to exclude any attempt at an interpretation of the results, given that such represents the end goal of descriptive works. I will therefore employ an interpretive framework aimed at discussing associations between structures on the basis of proximity and orientation, so as to identify groupings or “compounds” according to explicitly defined criteria. This demonstrates *one* of the many possible ways in which the proposed descriptive procedures can be applied toward interpretive ends. Drawing on theoretical frameworks employed in the context of space syntax, I acknowledge that built spaces condition the experiences of those who inhabit them, and that they do so in part by determining points of access and paths of circulation. Accordingly, I assume that the arrangement of built space at the sites under study represents a strategic accommodation to factors of circulation and accessibility toward various possible ends, such as facilitating routine activities, maintaining communally held standards of appropriate behavior, or mediating opportunities for desirable encounters while limiting opportunities for the opposite. In other words, I assume that the locations and orientations of structures represent deliberate decisions that were intended, at least in part, to condition the experiences and behaviors of the settlement’s inhabitants and visitors.

Based on this assumption, local trends in the orientations of structures are interpreted as reflections of an underlying organizational logic, wherein certain groups of structures are “associated” by virtue of the relative immediacy of their entries with respect to each other. That is to say, structures located in relatively close proximity and facing toward each other or toward a shared space can be considered associated on the grounds that these conditions promote direct accessibility and ease of travel between the structures in question. If the structures correspond to dwellings, this would necessarily entail frequent encounters between the inhabitants of the associated structures. Thus, structures are said to be associated when their locations and orientations, with respect to each other as well as to other features of the built space, can be seen to promote a preferential relationship between them. This concept will provide the basis for identification of groupings. Understanding this interpretive framework in more depth will require a fuller explanation of the proposed methods, to which the rest of this chapter is dedicated.

GENERATING THE DATA

The first step is data collection in the field, as acquiring aerial photographs with a drone requires that we visit the site in person. After taking drone photos, we walk the site to take photos on the ground, measure the dimensions of structures, and observe the details of the site's remains and topography. A trained eye should look for evidence of reconstruction and seek to determine the apparent extent of excavation. The simplest way to capture as much information as possible during this process is to wear a head-mounted camera. Obtaining this supplemental information on the ground will be useful later on when interpreting the contents of aerial photographs, digitizing the remains, assessing the degree of spatial error in our datasets, and determining the boundaries of the study area. Except at larger sites, the entire visit need not take more than an hour, which makes this an efficient procedure for acquiring data on a large number of sites.

Figure 6: Drone photos of the two sites used for my case study: Cividade de Terroso (top) and Castro de Romariz (bottom)

The next step is to create a georeferenced raster image of the site. For this we require an orthographic base image to be georeferenced, which will come from the drone photographs. We must seek to explicitly confirm the precision and accuracy of the base image, because it is the ultimate source of the data. Images obtained by drone can be orthorectified and corrected for lens distortion through a combination of tools from ArcGIS and Photoshop. The result is an orthographic raster image that can be treated as a reliable representation of the site's remains *as they currently exist*. At smaller sites a single photo may capture the remains at a sufficient resolution; at larger sites multiple photos can be combined into a single "mosaic" raster. The raster is georeferenced in ArcGIS using points in the image with known geographic coordinates. These known points can be obtained by a GPS unit on the ground or by making use of available satellite imagery. The former may allow for more precise georeferencing, but the latter requires less time and investment on the ground. The rasters for Terroso and Romariz were georeferenced using satellite imagery and projected to WGS 1984 UTM Zone 29N.

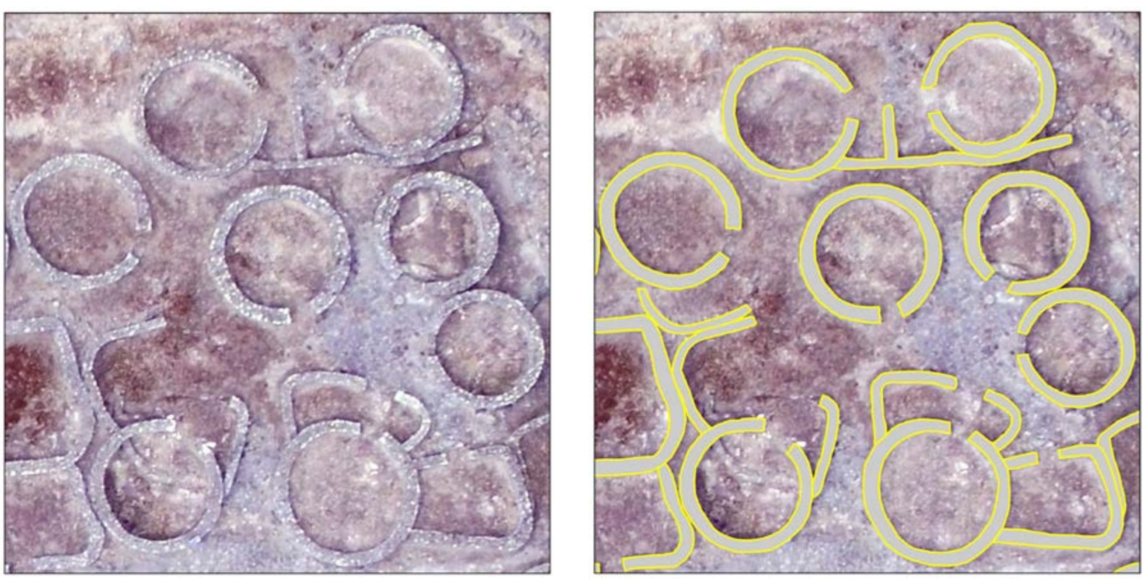

Figure 7: Close-up of the georeferenced raster (left) and wall polygons (right) for Terroso

The next step is the creation of a vector feature class in ArcMap, where the site's full set of structural remains become represented as a series of polygons. At both sites, every wall was manually digitized by carefully tracing over the georeferenced raster, creating polygons one vertex at a time. Great care must be taken to minimize the extent of spatial error between the polygons and the underlying raster, as subsequent data for analysis are derived almost entirely from the wall polygons. The orthorectification and georeferencing of the drone imagery, as well as the subsequent digitization of walls, are therefore seen as the most important steps in the process of data generation. Drone imagery is necessary because the resolution of satellite imagery is too poor for precise digitization to be feasible. Spatial error between objects in the dataset and the corresponding reality on the ground should be minimal, and must not exceed 20 cm for the purposes of the proposed analyses.

On the basis of the wall polygons, new data can be generated: polygons for the interiors of structures, points marking the locations of entries, and lines representing the direction in which entries are facing. First, I identified individual structures subjectively according to my knowledge of the two sites. Note that there are often several different options in this regard: for example, one could conceptualize R-31 and R-52 (Romariz structures 31 and 52) as a single structure. This simple distinction would have a meaningful impact on the outcomes of subsequent analyses. Also note that, purely for the sake of simplicity, appendages such as the vestibule of T-9 (Terroso structure 9) were not treated as part of the structure for my analyses. Future analyses should take into account the role played by these features and strongly consider including them as part of the structure itself, which may involve relocating the entry point of the structure. The unique identifiers for each structure followed the numbering system used in the excavators' publications when possible, and were otherwise completely arbitrary. After identifying structures and assigning unique identifiers, I generated polygons for the interiors and entryways of structures on the basis of the vertices of the wall polygons. The Feature to Point tool was used to determine the centroids of the entryway polygons; these became the “entry points.” Every entry point represents the location of a structure’s entry, and should be placed directly in the center of its entryway. The next step is to generate “entry lines” to represent each structure’s orientation, or the direction in which it is facing.

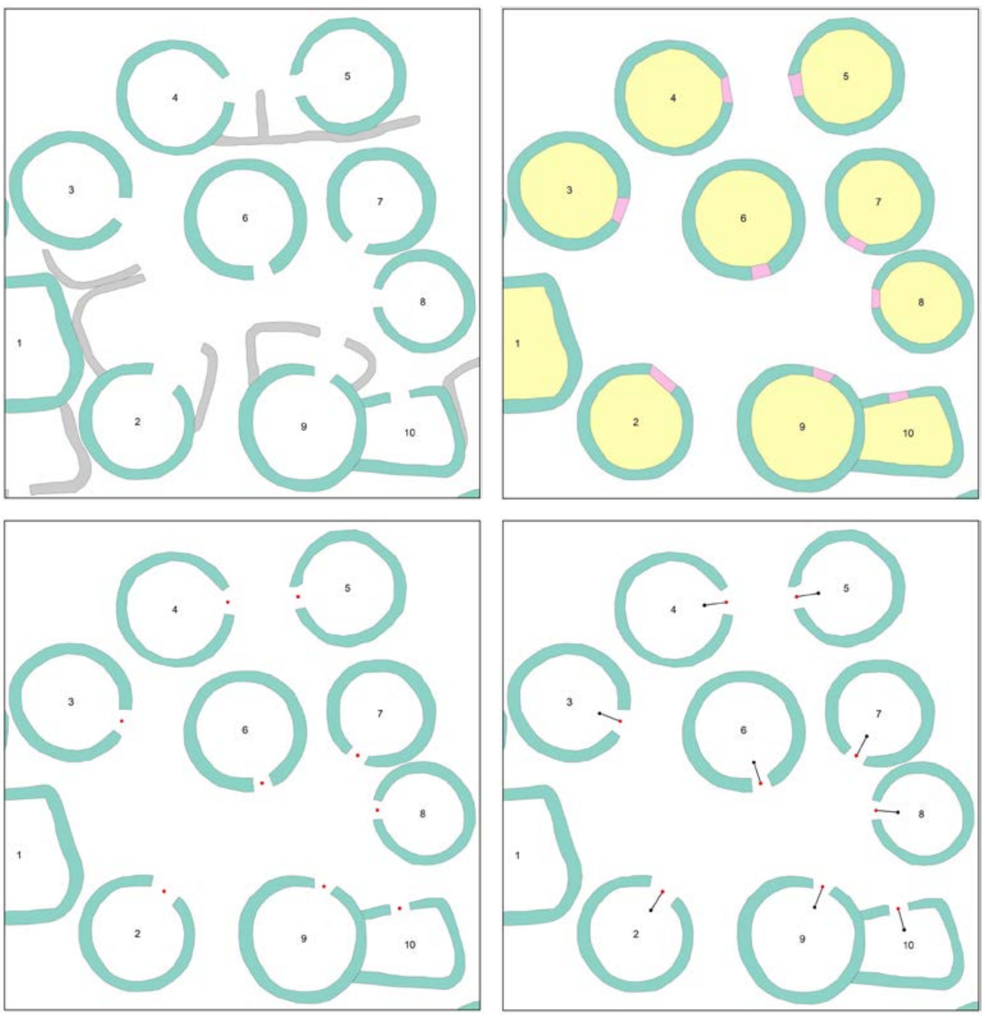

Figure 8: Identifying structures (top-left in green) and generating interior polygons (top-right), entry points (bottom-left), and entry lines (bottom-right)

The entry line must run parallel to the walls that frame the entry and must have its ending vertex coincide directly with the structure's entry point. The length of the entry lines is mostly inconsequential; in my case each entry line was given a length of exactly 1 meter. To calculate the angle value of all entry lines, I generated another feature class called "angle calculation points." These points coincided directly with the starting vertex of each entry line, such that every entry line begins at the angle calculation point and ends at the entry point. I then used the Near tool to generate new fields in the attribute table of the angle calculation points. These new fields indicate the Euclidean distance and the angle between every angle calculation point and the nearest entry point. In other words, these two fields indicate the length and angle value of every entry line, since the entry line is simply a line connecting the angle calculation point to the entry point. I then created a new attribute field for the entry points and populated it with the angle values from the attribute table of the angle calculation points, using a simple Join operation. Every entry point now has attributes indicating the structure to which it belongs and the angle value of that structure's entry line. The angle values are stored by default in ArcMap in degrees, ranging from -180° to 180° with zero at due east. Clockwise rotation corresponds to negative values, and counterclockwise rotation corresponds to positive values.

Figure 9: Defining the study area for Terroso

Figure 10: Defining the study area for Romariz

At this point it is necessary to define the study area, which is another step of critical importance. One should consider the apparent extent of excavation, features of the site's topography, available information about different portions of the architectural remains and their current state, and the suitability of different portions of the site for the intended analyses. At Terroso, this process was fairly straightforward. Beyond the northern boundary of the study area, a modern path cuts through the site and sets a clear limit by disrupting contiguity. The few structures located directly next to this path were excluded. The western boundary of the study area faces another modern path cutting through the site. The structures lying beyond the western boundary of the study area were excluded because their proximity to the modern path makes their relationship to the rest of the site unclear. The structures lying to the west of the modern path itself were not digitized, because they were never considered as candidates for the study area due to the lack of contiguity created by the modern path. The southern boundary of the study area was placed because the structures beyond it lie near the limit of excavations and are partially obscured by tree cover. The eastern boundary of the study area follows the apparent extent of excavation on this side of the site. The single digitized structure lying beyond the eastern boundary was excluded due to its lack of a known entry.

Defining the study area for Romariz required greater deliberation due to the more irregular topography of the site. The eastern boundary of the study area excludes an elevated portion of the site containing few structures, as well as a rectangular structure which faces toward this area. The northern and western boundaries of the study area follow the apparent extent of excavation on these sides. The southern boundary was placed largely for the sake of maintaining simplicity in the simulation of pathways.

As is now clear, the boundaries for the study areas of both sites are subjectively determined and therefore problematic. Each study area represents an arbitrary portion of the site as it currently exists, which is only a fragment of the site as it once was. Neither study area can be considered a meaningful representation of the site as a whole. Experimenting with the effects of different study areas will be essential in subsequent studies of this nature. The problem of establishing a more consistent and robust set of criteria for the determination of study areas is one of the major challenges faced by this methodology. Regardless, a study area must be defined. In this case, the result is that I have defined a contiguous area of each settlement that is suitable for the proposed analyses.

The final step in the process of data generation was to simulate pathways throughout the settlement, which can be accomplished through a simplified version of least-cost analysis. In my case, the entry points determined the source and destination cells, and the cell size of the cost surface raster was 20 x 20 cm. Because the study areas are mostly flat, the cost surface consisted of only two values. All cells that coincide with walls were given a value that marks them as untraversable, while all other cells were given a value that marks them as equally traversable. Small gaps between features were only considered traversable if the width of the gap was at least 40 cm. This simple cost surface was used for the Cost Distance tool, whose outputs were used for the Cost Path as Polyline tool. One structure's entry point would serve as the source cell, while all other entry points were the destination cells. Using the Model Builder feature of ArcMap allowed this process to be repeated iteratively for every structure. The result was the creation of a series of polylines connecting every entry point to every other entry point in the study area. The length of each polyline represents the distance between the two structures connected by that line, as determined in effect by the shortest path one can take to walk from one entry to the other without stepping over any walls. This path-based measure of distance is preferable to more conventional conceptualizations of proximity such as Euclidean distance, as it is a more meaningful approximation of the reality on the ground. It is important to note that the shortest possible path is not necessarily the path that people will tend to follow when traveling from one point to another (Stöger 2011:44-45), but for our purposes it will suffice.

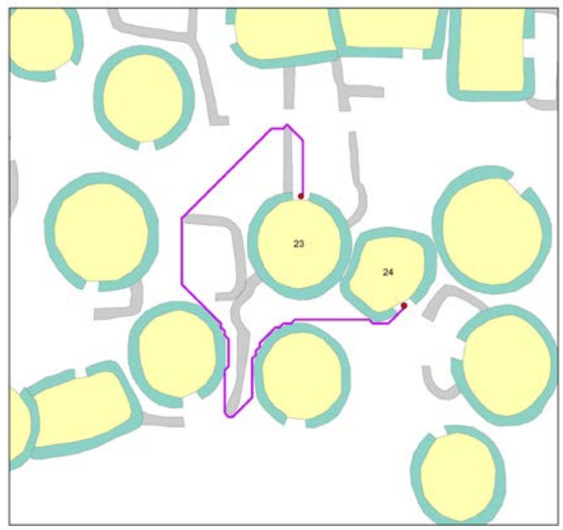

Figure 11: Path connecting T-23 to T-24

The purple line in Figure 11 approximates the shortest possible path between the entry points of T-23 and T-24. The path distance between these two points (35.77 m) is much longer than the Euclidean distance (7.71 m), due to the presence of intervening walls. This demonstrates the value of a path-based conceptualization of distance for our purposes, as it allows us to account for the effect of features of the built space in determining the effective proximity of entry points. Performing all of the above steps for both sites produced the data needed for the proposed analyses: the R scripts will read the attribute table of the entry points to determine the angle value of every structure, and they will read the attribute table of the pathway polylines to determine the path-based distance between any two structures.

Figure 12: Dataset for Terroso

Figure 13: Dataset for Romariz

APPLYING THE DATA

Much can be done with the data obtained thus far. Conventional methods from descriptive statistics can be applied to model global trends in the attributes of different sites, including the dimensions of structures, which can be conceptualized in terms of their interior surface area (easily calculated from the interior polygons), or the density of the built space, which can be conceptualized in terms of features per unit area or average distance between features. My focus is on developing a novel approach to describe local trends in the orientations of structures, something which cannot be done using conventional methods.

At both Terroso and Romariz, the orientation of a structure's entry does not seem to be determined by some communal tradition dictating the particular direction in which buildings ought to face (e.g. "it is best to make your home face toward the rising sun"). If such were the case, we would expect to see consistent global trends in the orientations of structures, such that one or a few angles of entry would prevail across the settlement. In other words, the set of all angle values would exhibit a low circular variance, because values would be concentrated in one or in a few directions (see Fisher [1995] for this and other concepts from circular statistics). Instead, at Terroso we see a circular variance of 0.95, approaching the maximum value of 1, which means the orientations of structures are very evenly dispersed across the range of possible values. The circular variance for Romariz is also fairly high, at 0.87.

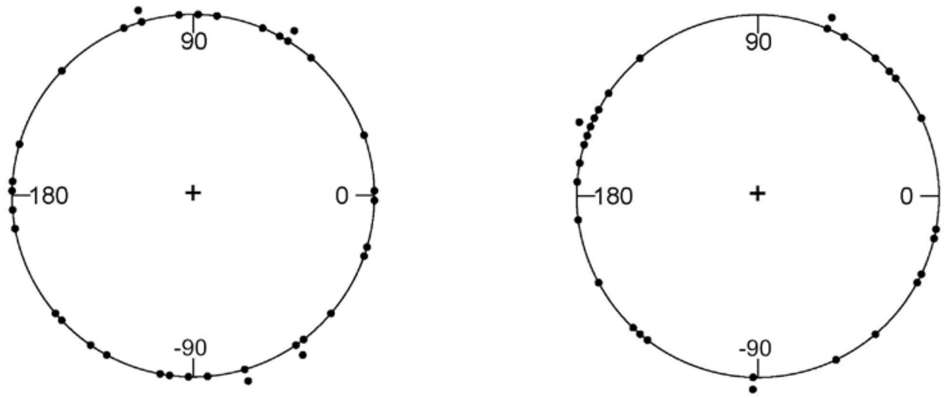

Figure 14: Plot of all angle values for study areas of Terroso (left) and Romariz (right)

I assume that the location of the entry on a structure, and therefore the direction in which a structure faces, must be determined in part by local relationships between features of the built space. In this scenario, we may not expect to find consistent global trends in the angle values of structures. Instead, we would expect to find local trends. One way to test for local trends is to employ a local indicator of spatial association (LISA). Put most simply, conventional LISA operations aim to reveal localized concentrations of high or low values in the variable under study. This is not always appropriate for an assessment of angular values, because circular data do not typically follow a linear scale from low to high. For example, when measuring angles within the familiar range of 0° to 360°, the magnitude of angular difference between 359° and 1° can be described as either 2° or 358°. The latter is the same as the difference between 359 and 1 on a linear scale, but the former is a more meaningful indication of the actual difference between the two angles, particularly when the angle values in question represent the orientations of static objects. In short, using conventional LISA operations to study the orientations of structures would entail treating angle values as linear data, which may lead to erroneous results.

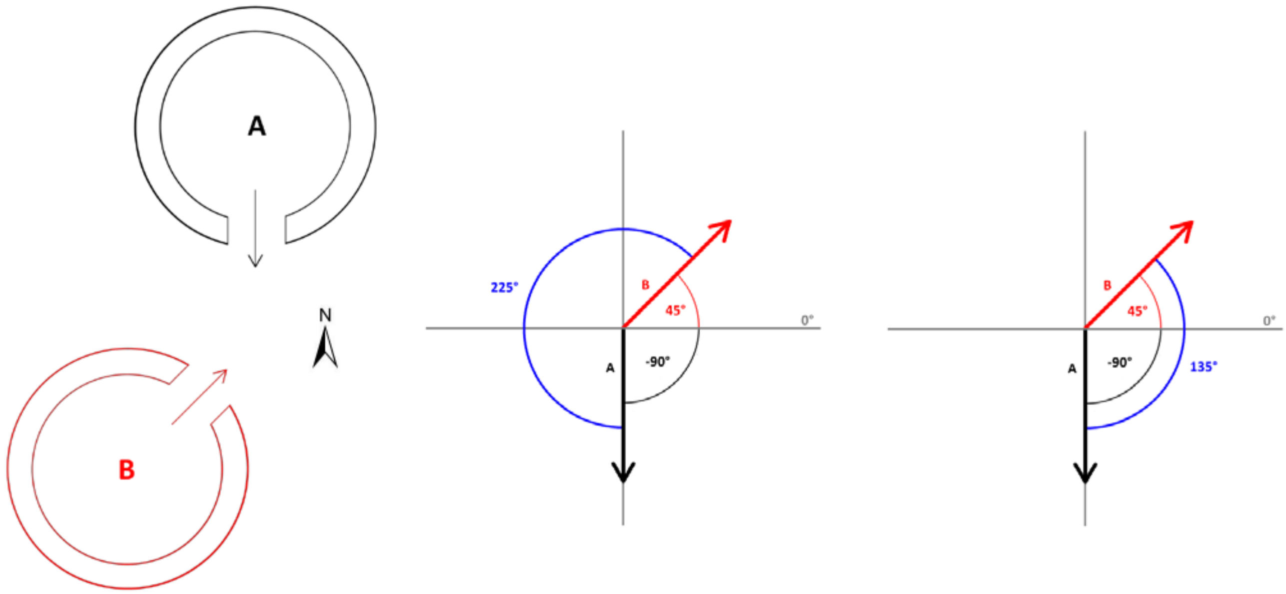

Figure 15: Visualizing magnitude of difference in angle

One solution is to focus on the absolute differences between angles, rather than on the values of the angles themselves, because an absolute difference in angle can be treated as a form of linear data in the sense that it ranges from low to high. In Figure 15 we see two ways of quantifying the magnitude of angular difference between structures A and B. We are interested in the smallest magnitude of angular difference (seen on the right), because this is the most realistic way to quantify the difference in orientation between two structures. This represents what I refer to as the "absolute difference in angle" between two structures, and it can be calculated by subtracting the angle value of one structure from the other, forcing the difference to remain within the range of -180° to 180° by either adding or subtracting 360° if necessary, and then applying absolute value. The resulting value, the absolute difference in angle, will fall within the range of 0° to 180°. This restricted range means the absolute difference in angle can be treated as ranging from low (0°) to high (180°). An adaptation of Local Geary's c designed to work with circular data will allow us to model local trends in the orientations of nearby structures based on their absolute differences in angle. I explain how this works below.

LOCAL ABSOLUTE MEAN DIFFERENCE IN ANGLE AND MODIFIED LOCAL GEARY'S C

For my purposes, two closely related forms of analysis were written as custom script tools through the interface between ArcGIS and the R programming language. The procedures were designed to detect local patterns in the orientations of structures as a factor of their proximity to each other. Both are modeled after univariate Local Geary's c, which measures local spatial autocorrelation on the basis of weighted squared differences (Anselin 2018). I use the angle values of the entry lines as the variable under study and the path distances between entry points as the measure of proximity.

Local Absolute Mean Difference in Angle

The first, more basic form of analysis produces a value that I call Local Absolute Mean Difference in Angle (LAMDA). We calculate LAMDA because we are interested in describing relationships between the orientations of nearby structures. In the simplest terms, LAMDA allows us to quantify the average extent to which nearby structures face in opposite directions (large absolute difference in angle) or face in the same direction (small absolute difference in angle). The extent of difference in orientation, when combined with an assessment of proximity, should prove useful in determining associations between structures.

In the context of this and other applications of spatial statistics, one should make every effort to mentally distance themselves from the typical connotations of the term "neighbor." In the current usage, the neighbors of a structure are simply the structures that fall within a specified distance of the structure in question. For my purposes, the distance between structures is defined as the path-based distance between their entry points. The threshold for neighbor determination or "distance band" will vary depending on user input. The distance between neighbors will thus range from an unspecified minimum (which cannot be zero, but in theory can be quite small) to a clearly defined maximum (equal to the distance threshold for neighbor determination). To calculate LAMDA, the neighbors of a structure are first determined according to a fixed distance band, which is provided as an input to the script tool. The difference in angle value between a specific structure and each of its neighbors is determined, “wrapping” as needed via addition or subtraction of 360° to keep the difference values in the -180° to 180° range. Absolute value is then applied to each of these differences, which are themselves still angle values. The mean angle of these absolute differences is then taken, which is the arctangent of the sum of their sines over the sum of their cosines. The process repeats for every structure, resulting in a single value for each structure that is equal to the mean angle of the absolute differences between the angle of its entry line and those of its neighbors. This LAMDA value is conceptually similar to univariate Local Geary’s c with a fixed distance band and row-standardized weights, except that it utilizes absolute value rather than squaring and produces a mean angle rather than a standard arithmetic mean. It serves as a representation of the average extent of absolute difference between a structure’s orientation and those of its neighbors, depending on the input distance band.

The script is written as an iterative procedure whose output is a table indicating each structure’s LAMDA value and number of neighbors. Like the absolute differences from which it is derived, every LAMDA value is an angle ranging from 0° to 180°. The higher the LAMDA value, the greater the average extent of absolute difference in orientation between a structure and its neighbors. The intuitive format of the output reflects the overall goal of the LAMDA procedure: it is a heuristic and exploratory tool intended to aid in the implementation and interpretation of subsequent, more sophisticated procedures. A table containing LAMDA values for each structure can be referenced during interpretation of subsequent analyses to allow for quick assessment of the role played by angular difference in determining outputs that account for additional factors. Caution should be used when viewing LAMDA values on their own, as the simplicity of the underlying calculations can give rise to a few caveats.

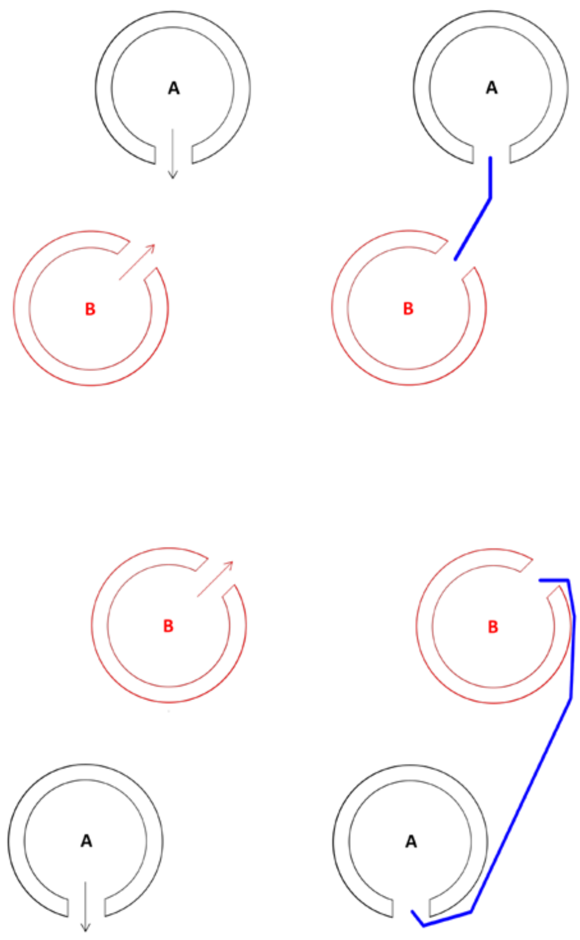

Figure 16: The absolute difference in angle between structures A and B is the same in both the top and bottom scenarios, but the path distance varies.

The absolute difference in angle between two structures with fixed orientations will always be the same, regardless of their locations with respect to each other. This problem demonstrates why absolute difference in angle, and thus LAMDA, is not sufficient by itself as a means of detecting local patterns in the orientations of structures. One way to address this problem is to account more fully for the distances between entry points, because this is a factor that changes depending on the respective locations of structures. The path distance between two entry points will be shorter when two structures are facing toward each other (Figure 16, top) and longer when they are facing away from each other (Figure 16, bottom). Depending on the features of the built space between the two structures, the path distance can become even longer (Figure 11). LAMDA only accounts for distance in a binary manner through neighbor determination, using the fixed distance band provided as an input to the script. LAMDA is therefore limited in its capacity to distinguish between scenarios where a similar difference in angle can be produced by phenomena with entirely different implications (such as when structures face toward each other versus when they face away from each other). This demonstrates the need for a more sophisticated weighting scheme that can account for the path-based distance between entry points beyond the level of neighbor determination.

Modified Local Geary's c

The next form of analysis produces less intuitive outputs because it does not preserve the angular nature of the variable, but it is more effective as a rudimentary local indicator of spatial association. First, just as in the LAMDA procedure, the neighbors of a structure are determined according to the input distance band, and the difference in angle between the structure and each of its neighbors is determined, wrapping the differences as needed. Each difference value is converted to radians, then squared, and then weighted via division by the squared distance between the structure in question and the neighbor in question. Each of these squared, weighted differences is then summed to produce the output value for the structure in question, and the process repeats until each structure receives its own value. In other words, this procedure is a straightforward application of Local Geary's c with inverse squared distance weighting and a cutoff distance for neighbor determination, except that scaling of the output values via division by the variance is not performed. It also differs from standard applications of Local Geary's c in that it includes extra steps (wrapping the angle differences to keep them in their original range, and converting from degrees to radians) as well as the fact that it utilizes path-based distances. I refer to this procedure and the value it produces as Modified Local Geary's c (MLGc), because it is a customized application of Local Geary's c with rigid and highly specific parameters.

The output is a table indicating the MLGc value and number of neighbors for each structure. As in conventional applications of univariate Local Geary's c, the output value ranges from zero to an unspecified value greater than one, and it serves as a measure of spatial autocorrelation by indicating the extent to which the variable differs on account of the spatial relationships between features, with the potential to reveal localized concentrations of similar values. By mapping the output, we can visualize patterns in the orientations of structures as a factor of their proximity to each other. High MLGc values should indicate that structures' entries are located in close proximity without intervening obstacles and that their orientations exhibit a large difference. Ideally, high values should appear when nearby structures tend to face toward each other or toward a common central area, while low values should appear when nearby structures tend to face in the same direction. In practice, interpretation of the outputs will be more nuanced, due in part to the limitations of the procedure itself. This will be shown in the case study below. In this case study, the outputs of MLGc will be interpreted according to a particular notion of “association” in order to suggest potential groupings of structures on the basis of clearly defined mathematical relationships between proximity and orientation. This represents an improvement on traditional approaches to the identification of groupings, but it must be emphasized that this is a preliminary exercise. The following case study is intended to provide an example of what can be accomplished in future pursuits, and does not presume to constitute a worthwhile outcome in and of itself.

Chapter 4: Case Study

In this chapter I apply LAMDA and MLGc to the two sites used for this case study, Cividade de Terroso and Castro de Romariz, and discuss the results. Terroso was chosen because it offers ideal conditions for this preliminary case study: it contains upwards of thirty structures with known points of entry in a contiguous and flat area. The layout of the excavated portion of the site made determination of the study area fairly straightforward, and the uniform topography allowed for least-cost paths to be generated in a simple manner. Romariz mostly presents the same conditions, although the excavated area is slightly more irregular in terms of its contiguity and topography. Due to the number of structures at each site, the datasets are small enough to allow for manual inspection of values, but still large enough to allow for a meager application of statistical methods. Meaningful estimates of statistical significance are out of reach with such a small number of structures. This means the results of my case study are purely exploratory and descriptive in nature, and will be interpreted qualitatively rather than according to standard statistical procedures. As the name suggests, MLGc in its current form does not function as a true LISA operation; it is merely inspired by the principle and adapted from the mathematical structure of Local Geary's c. This is an exercise in generating GIS-based representations of castro settlements and applying concepts and methods from spatial statistics to analyze and describe their properties. It does not accomplish this task in full; it merely seeks to demonstrate that there is value in pursuing it further. Achieving more meaningful results will require that these methods be refined, expanded upon, and applied to a larger number of sites, including those with more structures.

OVERVIEW OF TERROSO

Cividade de Terroso is a castro site located in northwestern Portugal, in the municipality of Póvoa de Varzim. The excavated portion of the site essentially consists of a roughly elliptical platform at the top of Monte da Cividade (Pinto 1932). Rocha Peixoto and José Fortes undertook the earliest excavations at Terroso, from 1906 to 1907 (Peixoto 1908). They uncovered most of the buildings that are now visible, focusing their efforts almost exclusively on the enclosed central platform of the site. Their excavations seem to have been shallow, but they left very little documentation of their work. Gonçalo Cruz provided illustrations, including a rough plan map that depicts the site as it existed immediately following Peixoto and Fortes' excavations. This plan map is still frequently used to represent the site, despite apparent discrepancies between its contents and more recent representations. Though research took place at Terroso (Gonçalves et al. 1964; Pinto 1932), it seems that no major excavations occurred there from the time of Peixoto and Fortes until Armando Coelho Ferreira da Silva's expeditions in the early 1980s (Silva 1981; 1986). Based on available documents, Silva focused primarily on the eastern portion of the central platform. He led expeditions of conservation and restoration in 1986, and he undertook a final series of excavations from 1989 to 1992. José Manuel Flores Gomes was involved in the 1980s excavations, and he undertook further excavations in the early 2000s.

Most of the central platform has been excavated at the surface level, revealing a fairly contiguous plan that is tentatively presumed to represent a single occupational phase. The remains, though incomplete, suggest that a defensive wall originally encircled the entire perimeter of the central platform. Reconstructed portions of this wall can be seen near the western border of the drone photo (Figure 6, top). Flores Gomes and

Carneiro (2005:129-130) suggest that two further sets of defensive walls would have constituted two larger perimeters, built progressively farther from the central platform and thus at successively lower elevations. The site clearly extended beyond the limits of the central platform, but few excavations have taken place beyond it, such that little is known about the rest of the site. Most of the structures in the eastern portion of the central platform have undergone reconstruction, with the threshold between original and reconstructed portions of structures being clearly marked.

The settlement plan currently reflected on the surface of Terroso is interpreted as mostly corresponding to a single occupational phase, likely around the 1st or 2nd century C.E. (Flores Gomes and Carneiro 2005:108-132). This follows from stratigraphic principles and from Roman materials encountered in the upper levels, including those uncovered during the early excavations (Peixoto 1908; Pinto 1932). A few structures from an earlier occupational phase were encountered, for example beneath T-1 and T-2 (Silva 1986:39-40), but excavation at this depth seems to have been very limited across the site in general. Due to the lack of precise chronological information on every structure, the possibility of anachronisms in the plan of the settlement cannot be ruled out. This problem is acknowledged by Silva (1986:39). In other words, I cannot place much confidence in the assumption that the site as it currently exists is an accurate reflection of the site as it existed during a particular moment in time.

Overview of Romariz

Castro de Romariz is another site in northwestern Portugal, located south of the Douro, in the municipality of Santa Maria da Feira. The excavated portion of the site wraps around the western face of Monte Crasto near its peak elevation. The earliest excavations at Monte Crasto took place in the 1840s under the direction of the municipality of Santa Maria da Feira, motivated by the coincidental discovery of a hoard of Roman coins (Centeno 2011:3). At this time, the site's ruins were apparently thought by locals to be of Moorish origin (Santos 1940:20), which seems to have been a common interpretation of castro remains prior to the work of Sarmento. During these early excavations, as many as 16 circular structures were uncovered, in addition to a "column with its capital" and many ceramic tiles (Santos 1940:367). Manuel Fernandes dos Santos undertook further excavations in the 1940s, uncovering most of the structures that are now visible at the site. Santos (1940:369) states that the excavations were "very shallow," not deep enough to reach the level of the floor (*pavimento*) in any of the uncovered structures. Having observed some of the materials collected during this period, Centeno (2011:4) states that most of the finds from the 1940s campaign likely correspond to the final occupational phase of the site. Among the finds from these shallow excavations were numerous pieces of tegula and imbrex (Santos 1940:369). Overall, details from the 1840s and 1940s excavations are very scarce due to lack of thorough documentation.

A more rigorous series of investigations began in 1980, with excavations directed by Rui Centeno and Armando Coelho Ferreira da Silva (Centeno and Silva 1982). Periodic excavations continued into the early 2000s, focusing on an area which had not been uncovered during the excavations of previous decades (Centeno 2011). Just south of the previously excavated portion of the site, they uncovered a large habitational enclosure that they refer to as the *domus* (Centeno 2011:19-28). The settlement certainly extends beyond what has been excavated thus far (Vilarinho 2016:104). Based on my own observations, most of the currently visible structures have undergone reconstruction to some extent, but the threshold between original and reconstructed portions of structures is not always clearly indicated. Modern excavations focused mainly on the area of the domus, such that the rest of the excavated area has only been uncovered at a superficial level, and without proper documentation (as is the case for most of Terroso).

The excavators suggest that the currently visible settlement plan of Romariz dates to the final occupational phase of the site, sometime around the end of the 1st century CE (Centeno 2011:11). For the most part this appears to be a safe assumption, but the possibility of anachronisms remains, owing to the lack of documentation from early excavations. Just as with Terroso, I cannot place a high degree of confidence in the fundamental assumption of the reliability of the current state of the remains in terms of precise chronological coherence between features of the built space.

LAMDA

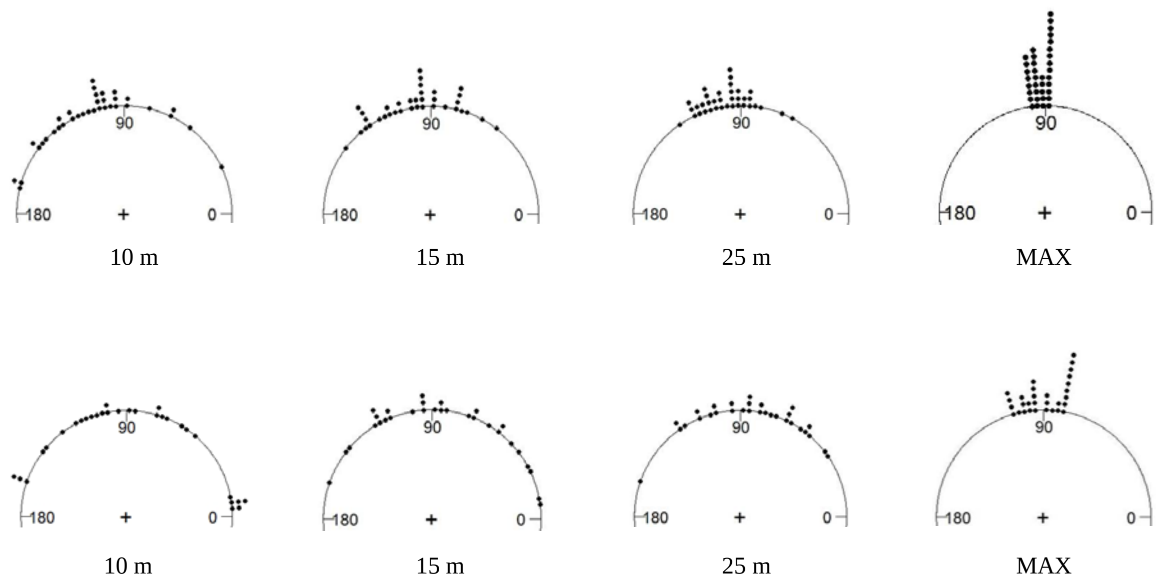

Figure 17: LAMDA plots for Terroso (top) and Romariz (bottom) at various distance bands

Figure 17 shows plots of all LAMDA values for the Terroso and Romariz study areas, at increasing distance bands, to demonstrate a concept that applies to both sites. As the distance threshold for neighbor determination increases, the circular variance of the full set of LAMDA values steadily decreases, with values trending strongly toward the middle of the range. This is seen most dramatically in the extreme case of the maximum distance threshold, where every structure is considered the neighbor of every other structure. This tendency for values to cluster toward the middle of the range as the distance band increases is already evident in the shift from 10 m to 15 m. Smaller distance bands produce greater diversity in the output values because variation in the average extent of absolute difference in angle between structures is a localized phenomenon. In other words, the smaller the distance band, the more meaningfully we can capture local trends in the orientations of structures. At both sites, 10 m is the minimum distance for which every structure has at least one neighbor. Thus, based on the LAMDA outputs and evaluation of neighbor relationships, 10 m was chosen as the distance threshold for subsequent analyses.

Potential differences between the properties of the two sites are already suggested based on apparent differences in the LAMDA outputs. Given the limitations of LAMDA, I will avoid interpretation of these potential differences for the moment. The most important outcome up to this point has been to define the distance band, such that we have now defined the full set of neighbor relationships. Referencing the data tables for neighbor relationships, path distances, and LAMDA values (see Appendix) will prove useful in the interpretation of MLGc outputs for individual structures, as combining this information with a visual representation of neighbor relationships (Figure 18) allows for quick assessment of the underlying factors in each MLGc calculation.

Figure 18: Visualizing neighbor relationships at Terroso (top) and Romariz (bottom), showing only the lines for which path distance is less than or equal to 10 m

MLGc

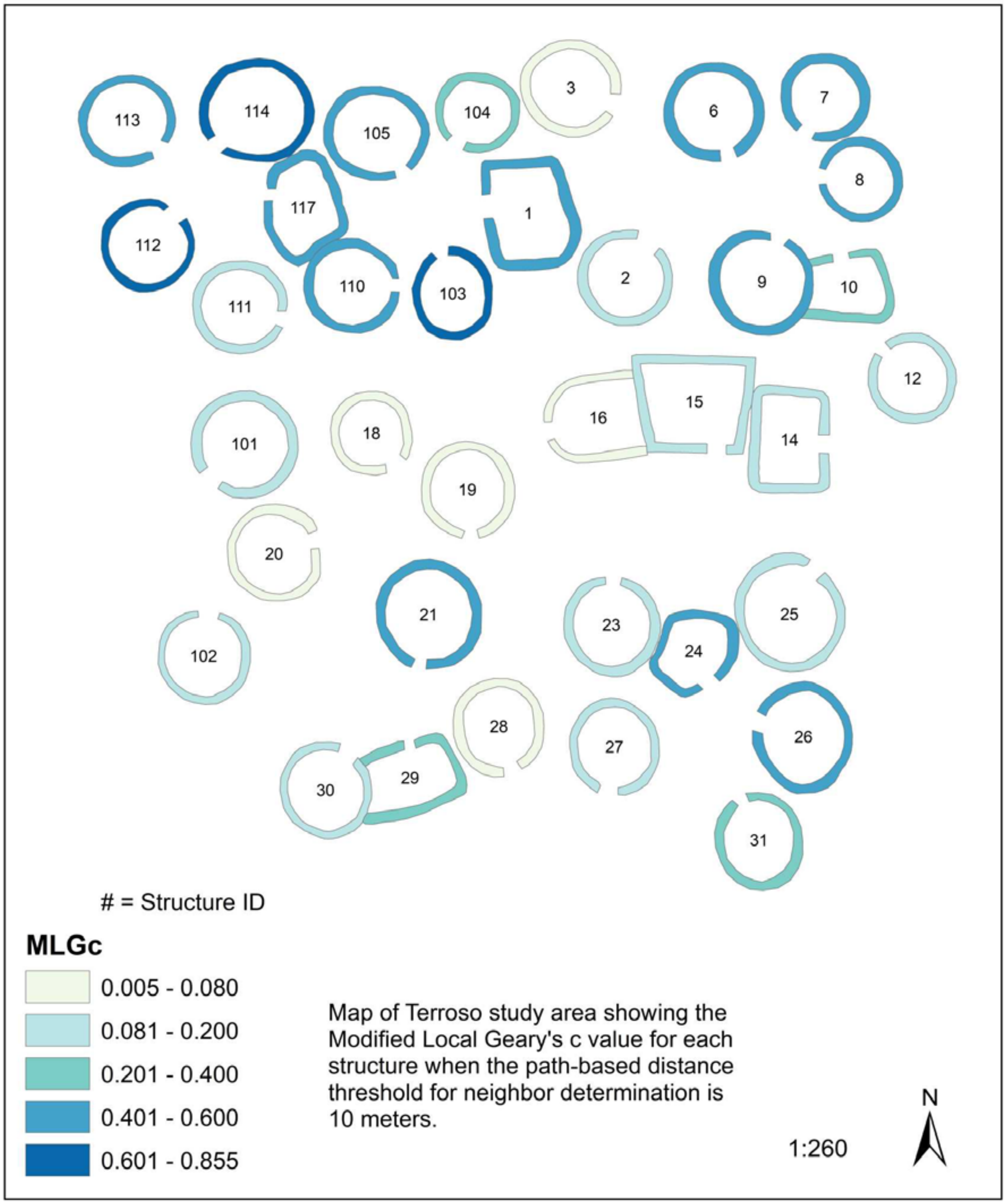

Figure 19: Map of MLGc outputs for Terroso

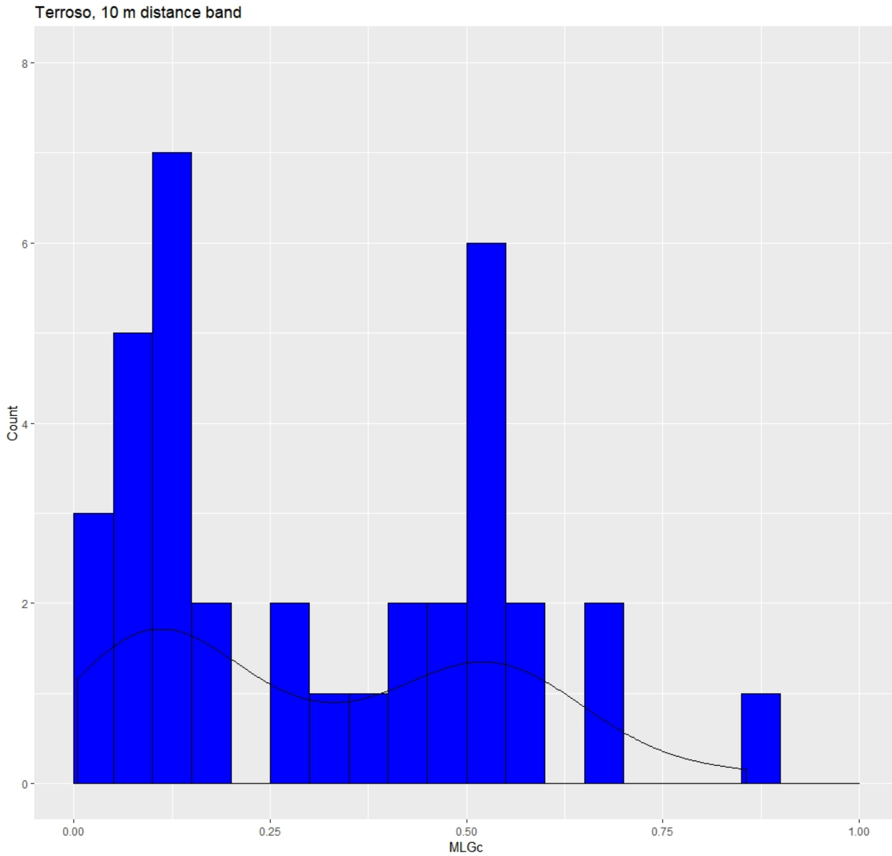

Figure 20: Histogram of MLGc outputs for Terroso

At Terroso, the map (Figure 19) and histogram (Figure 20) depicting output values for MLGc with a 10-meter distance band reveal some potentially meaningful trends. Most of the values fall within one of two categories, composed of relatively low or high values, corresponding to the second and fourth color blocks in the map legend and to the two peaks in the histogram. The fifth color block only applies to three structures, including T-103, which received the highest score. The maps and data tables indicate that T-103 received a high output value because it is located in fairly close proximity to four structures and exhibits a moderate or high degree of angular difference with each of them: conditions which reflect a group of structures facing toward a common area. Most of the structures in the northern portion of the study area exhibit relatively high values due to similar conditions, which indicates that high MLGc outputs can serve as a proxy for associations between structures according to the notion of a preferential relationship created by proximity and orientation. The clustering of relatively high values corresponds to an actual pattern in the organization of built space in the northern portion of the study area, wherein structures located in close proximity tend to face toward each other. In other words, the MLGc procedure has detected the "domestic compound" phenomenon, in that groups of structures with relatively high MLGc values correspond to groups of associated structures facing toward a common "patio" space.

Based on this straightforward interpretation of the values, I can suggest the presence of three compounds in the northern portion of the study area (one consisting of T-112, T-113, T-114, T-117, and possibly T-111; another consisting of T-1, T-103, T-104, T-105, and T-110; and another consisting of T-6, T-7, T-8, T-9, T-10, and possibly T-2 and T-3). I can cautiously suggest the presence of two smaller compounds in the southern portion of the study area (one consisting of T-21, T-29, and T-30; and another consisting of T-24, T-26, and T-31). While this may appear to be a promising result, the reality is that identification of these potential groupings was already possible through mere visual assessment. Yet it has been argued in the context of space syntax that even seemingly obvious spatial relationships are worth quantifying as we seek to comprehend the features of built spaces more fully (DiBiasie 2015:39; Stöger 2011:31). The accomplishment in this case was to provide a means of mathematically describing an organizational mechanism that has already been visually described. While not much of an accomplishment at first glance, this outcome is a promising step toward the fundamental goal of the current work, which is to demonstrate the possibility of mathematically describing organizational mechanisms that have *not* been visually described, in addition to aiding in the identification of those that have been.

T-2 and T-3 have been placed in the same compound as T-6 through T-10 according to conventional visual assessment (Flores Gomes and Carneiro, 2005:114), but the distance between them and the rest of the structures in that area results in a relatively low score for both of them. This reveals another promising outcome, which is the capacity for procedures like MLGc to alter our perception of familiar situations. In conceptualizing the relationships between structures, visual assessment tends to emphasize tangible barriers between spaces, and is prone to overlook subtle differences in proximity. Such subtleties may prove meaningful and, at the very least, ought to be considered as we attempt to determine the relationships between different features of the built space. As for the rest of the relatively low values, they correspond to a variety of different scenarios. For example, T-101 and T-102 are each other's only neighbors, and they are mostly facing toward each other. Their absolute difference in angle is high, but they still received low scores. Rather than indicating minimal difference in orientation, this low score indicates minimal neighbor associations and ample distance between structures. With only one neighbor, there was little opportunity for accumulation of a higher score through summation of the weighted squared differences (since, in fact, no such summation occurs in the case of a single neighbor). Given that the output value is the sum of the weighted squared differences between the angle of a structure and those of its neighbors, the number of neighbors can have a misleading effect on the output value. This effect is easily resolved through row-standardized weighting. Such was not employed in my application of MLGc because observing the effect of the number of neighbors on the output may prove informative as I (or interested readers) seek to refine the procedure further.

A single-neighbor scenario can still produce a high output value if the distance between the structures is extremely small, but such is not the case for T-101 and T-102, which are separated by a 7.85 m pathway. Even though their angular difference was high, the effect of the inverse squared distance weighting and the lack of multiple neighbors resulted in a low output value. Thus, in this and many other scenarios, a low score may indicate not a minimal difference in orientation, but instead a low number of neighbors or a moderate to high extent of distance between neighbors. Rather than a minimal extent of angular difference as one would expect, it is some combination of the factors of proximity and neighbor count that produce most of the low MLGc values seen in Figure 19. In other words, in this case, the relatively low values correspond to a “miscellaneous” category rather than to a single distinct phenomenon. I can at least say that, based on the relationships between proximity and orientation, most of the southern portion of the study area does not appear to follow the same model of the domestic compound found in the northern portion, which is a meaningful observation in itself.

In summary, the results of the MLGc procedure for Terroso are meager, yet promising. They demonstrate the potential for spatial statistics to detect and describe real organizational patterns at the scale of the individual settlement. By discussing the relationships between structures on the basis of explicitly defined criteria and quantitative measurements of distance and orientation, we have already improved on conventional visual assessment. While we have yet to detect any previously unknown organizational mechanisms, we have demonstrated that further pursuits of this kind have the potential to do so, especially with the development of more sophisticated procedures.

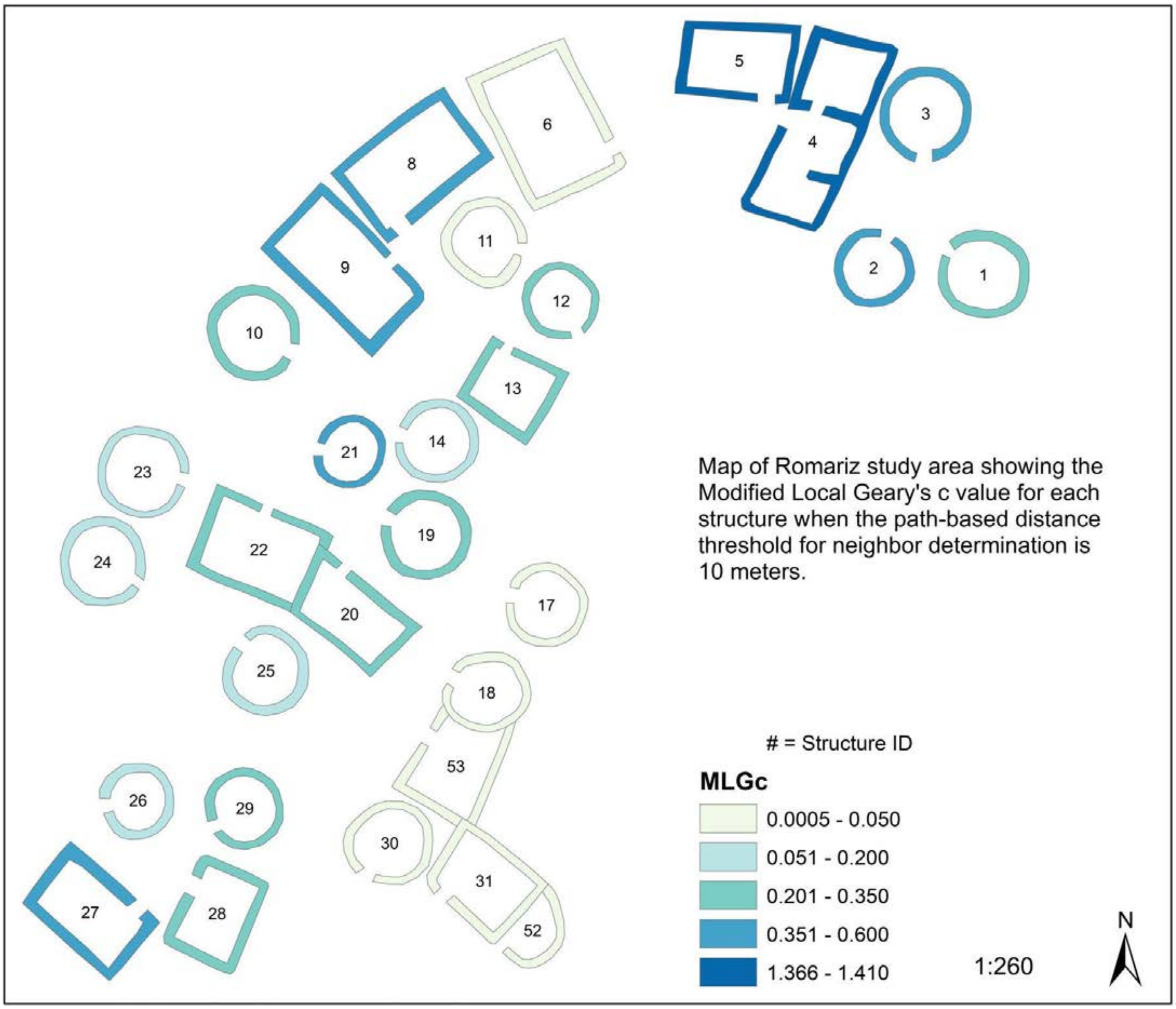

Figure 21: Map of MLGc outputs for Romariz

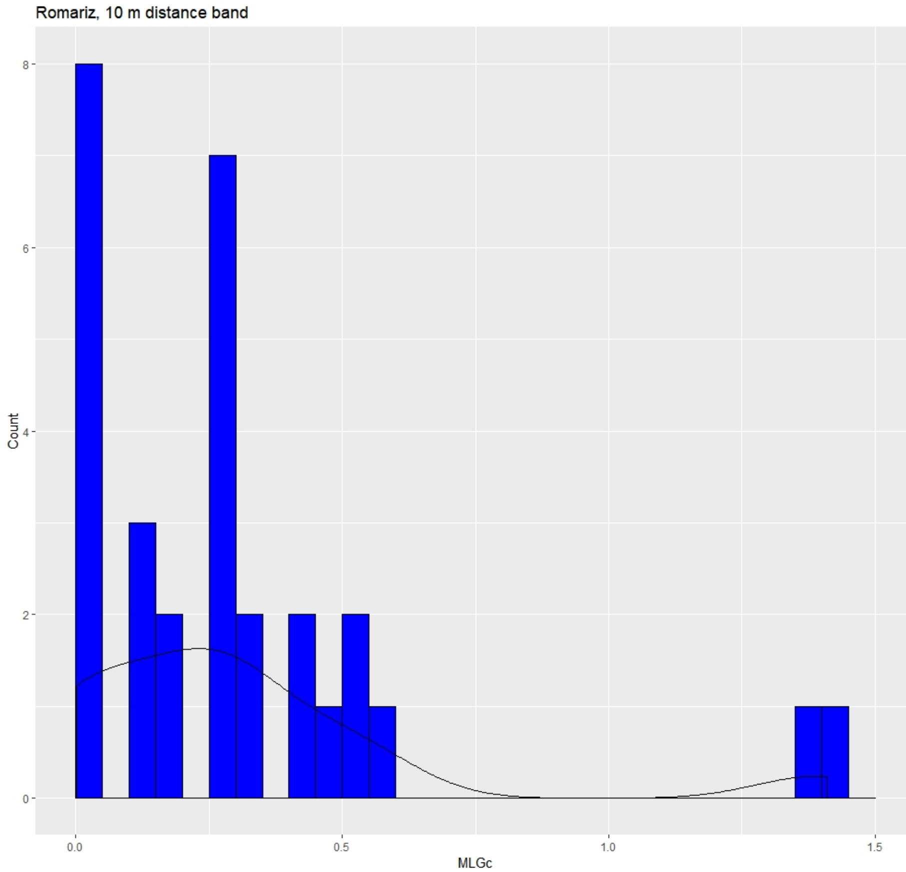

Figure 22: Histogram of MLGc outputs for Romariz

The results for Romariz reveal some of the shortcomings of MLGc in its current form. We see two extreme outliers in R-4 and R-5, whose dramatically high scores demonstrate a quirk of the inverse squared distance weighting scheme: their scores tower above the rest simply because their entry points are exceptionally close to each other. The result is not meaningless if we interpret high values as indicative of an association between structures, as we did at Terroso, since the exceptional proximity of their entries can be said to reflect a close association between the structures. Still, in this instance the weighting scheme appears to have an inordinately strong effect. The most interesting feature of the MLGc outputs for Romariz is the clustering of extremely low values, corresponding to R-17, R-18, R-30, R-31, R-52, and R-53. In this instance, the low values correspond to close proximity and minimal difference in orientation between neighbors. These low MLGc values seem to indicate a different kind of association, wherein structures are located in close proximity but tend to face in the same direction rather than toward each other. In other words, the structures in the southeastern corner of the Romariz study area seem to follow an organizational pattern that differs from the domestic compound model, in that associated structures face toward a common pathway rather than toward an insular "patio."

The rest of the values are more difficult to interpret. They are mostly low or middling, falling in the second or third color blocks. I can suggest an association between R-8 and R-9, whose relationship is similar to that of R-4 and R-5, and I can suggest a compound consisting of R-1, R-2, and R-3. I can very cautiously suggest two more compounds (one consisting of R-27, R-28, R-29, and possibly R-26; and another consisting of R-10, R-19, R-20, R-21, R-22, and possibly R-14 and R-23). In the latter two cases, there is not a very strong tendency toward high values, such that my urge to identify these groupings likely stems from visual assessment more than anything. In short, based purely on the outputs, a clear and consistent pattern does not arise in the correlation between difference in orientation and proximity for much of the study area. I can only conclude that there appears to be more at play than MLGc is capable of accounting for in its current form. So far it has only proven capable of identifying three types of scenarios: one in which nearby structures tend to face toward each other (as seen in the northern portion of the Terroso study area), one in which nearby structures tend to face in the same direction (as seen in the southeastern portion of the Romariz study area), and a "miscellaneous" category in which there does not appear to be a consistent relationship between proximity and difference in orientation (as seen in much of the southern portion of the Terroso study area and most of the Romariz study area).

A few basic conclusions can be drawn based on the results of this case study. The overall extent of proximity between structures differs between the two sites, as suggested by simple assessment of the data tables for neighbor counts and path distances. The overall nature of local angular difference differs between the two sites as well, based on the outputs for both LAMDA and MLGc. This suggests that Terroso and Romariz exhibit organizational differences that are capable of being described quantitatively, which is a promising result. Certain instances of relatively high or exceptionally low MLGc values were interpreted as indications of an association between nearby structures, based on the assumption that the placement of their entries with respect to each other would have intentionally promoted a preferential relationship between them in terms of mutual accessibility to an immediately proximate shared space. This approach allowed for the tentative identification of “compounds” or groupings of associated structures at each site. This case study was not sufficient to describe the organizational properties of either study area in full, but this is to be expected given the rudimentary nature and narrow scope of the analyses employed. The most important outcome of this case study has been to demonstrate the viability of GIS-based approaches for the quantification of spatial properties in castro settlements. I suggest that approaches of this nature can be productively combined with methodological and interpretive frameworks from space syntax to allow for fuller comprehension of the built spaces under study.

Chapter 5: Conclusion

Current Problems, Future Directions

Based on the MLGc outputs, I have cautiously suggested a few local trends in the orientations of structures at both sites, seen for example in the groups of relatively high values at Terroso and the group of extremely low values at Romariz. These are not regarded as statistically significant indications of local spatial autocorrelation, which would be the typical goal of LISA operations. No attempt was made to calculate the significance of the outputs because the small number of structures would render such calculations dubious. Now that it has been developed and tested on a small scale, an important next step is to apply this methodology to larger sites. Increasing the number of structures in the dataset will allow for more meaningful calculations of statistical significance for the outputs. Analysis of larger sites should therefore prove more productive, and evaluation of their outputs should increase our interpretive capabilities at smaller sites by means of comparison and analogy. In this methodology, the meaningfulness of our interpretations stands to increase with every new site included.

Based on visual assessment of their layouts, Citânia de Briteiros and Citânia de Sanfins are often seen as prime examples of the proto-urban castro, which makes them important points of comparison as we seek to understand the layouts of different sites. More importantly, these two sites are among the very few castros with upwards of 100 excavated structures. Briteiros presents difficulties for this methodology because it encompasses a vast area with complex topography and many potential breaks in contiguity. In addition, this site currently exhibits significant tree cover, which means drone photography will not be sufficient for digitization of the remains. While Sanfins avoids most of these problems, many of its structures lack known entries, such that analysis of orientations is less feasible. Thus, two of the sites with the greatest excavated area, for which calculations of statistical significance would be most reliable due to the large number of structures, are incompatible in various ways with the procedures applied in this thesis. This highlights the need for further expansion and improvement of the current methodology, as at the moment it requires fairly ideal conditions in order to be applied.

Expansion of the current methodology will require an alternative means of efficiently generating spatially precise representations, more sophisticated procedures for simulation of pathways and delimitation of study areas, and a more extensive repertoire of spatial analyses encompassing attributes beyond orientation. LiDAR solves the issue of tree cover while also providing high-resolution elevation data, which can allow for more effective representation of sites with complex topography. Photogrammetry is a cheaper alternative for acquisition of elevation data, and can be applied using drone technology. Sophisticated visibility analyses and agent-based modeling, developed in the context of space syntax, are two promising possibilities for improved simulation of pathways (DiBiasie 2015:41-64; Stöger 2011:64-66). Issues related to the delimitation of study areas will need to be explicitly addressed using new procedures. The primary challenge in this regard is that we lack a theoretical framework for conceptualizing the relationships between noncontiguous excavated areas, and the insufficient documentation at many sites can make it difficult to distinguish between unexcavated portions of the site and excavated areas that are simply devoid of architectural remains.

As for expanding the repertoire of spatial analyses, the task will be fairly straightforward, limited only by the types of attributes available for analysis. Thus far, I have identified three fundamental categories of data that can be easily quantified using a GIS-based representation of the remains as they currently exist: the interior surface area of each structure, the orientation of each structure, and the coordinates of each structure's entry. Based on these coordinates, we can generate a path-based measure of distance between any two structures, thereby generating a new category of data from one of the fundamental three. Trends in the path-based distances between structures can be modeled according to conventional statistics, which may provide an interesting point of comparison between sites. Yet the distances between structures and the coordinates from which they are derived cannot serve as attributes in spatial analyses. Instead, such data provide the spatial component, on the basis of which the relationships between attributes are analyzed. Whether sites exhibit any interesting trends in terms of the dimensions of structures remains to be seen, as does whether any such patterns are spatially contingent. Description and analysis of trends in interior surface area, using both conventional statistics and spatial statistics, is therefore a promising line of inquiry for the future. Orientation has been the focus of the current work because, unlike interior surface area, it is a form of circular data for which conventional procedures cannot be applied. Since MLGc scores differ along a linear scale, the outputs themselves can be subjected to further analysis using conventional operations from spatial statistics, such that we now have many options at our disposal, which may allow for a more rigorous assessment of the spatial clustering of outputs. Devising new forms of analysis will be especially important given that the orientations of structures are not always known, as is the case for many of the structures at Sanfins. The form of a structure (circular, oblong, rectangular, etc.) is technically a viable attribute, but its applications are extremely limited given that it is a form of nominal data. In other words, taking into account all of the above, we still only have two promising attributes for spatial analysis: interior surface area and orientation. For the moment I have identified interior surface area as a next step, but it will be necessary moving forward to identify more categories of data, as well as to account for factors such as visibility and elevation.

Thus far, I have argued that the methodology presented in this thesis stands to improve our understanding of the spatial properties of castro sites, albeit only to a modest degree in its current form. I suggest that we stand to gain more by expanding the analyses to account for different attributes, and by incorporating more and larger sites. Incorporating as many sites as possible may require new procedures for the generation of representations, and developing new types of analysis may require new procedures for the extraction of data from said representations. It is also important to note that there are many different ways to employ spatial statistics, both within and beyond the framework of LISA operations. I have focused on assigning attributes to each structure and searching for local trends in the value and spatial distribution of attributes. While I suggest that much can be gained through further pursuit of this approach, many other forms of spatial analysis are available in a GIS environment.

Most of the problems faced by the current methodology are shared with previous approaches. Alpha analysis and visibility analysis, like the rest of the space syntax toolkit, operate in two dimensions, such that sites with complex topography cannot be adequately represented. My methodology fares no better in its current form, since my implementation of drone photography does not provide elevation data. Yet, unlike space syntax, a GIS-based framework is well equipped to account for the third dimension once elevation data are introduced. Adapting the principles of alpha analysis and visibility analysis to work within a GIS environment may allow for improved results at sites such as Briteiros, where assessments of axes and lines of visibility are complicated by significant variations in elevation across the site.

Another problem with space syntax is that gamma analysis simplifies a complex reality: understanding factors of access and circulation may not be sufficient to understand the full range of social interactions, culturally informed meanings, and daily experiences mediated by the built spaces under study. This is not to mention the role that archaeological materials encountered within the settlement could play in such an understanding. This critique is raised by Taylor (2002) in response to Grahame's (1997) application of gamma analysis to a Roman house in Pompeii. All of these problems apply to my methodology as well, since it essentially represents built spaces on the basis of structural foundations, excluding the possibility of a more nuanced treatment of the sociocultural and material realities within which these spaces once existed. In cases where we have access to precise documentation of the archaeological materials encountered within the settlement, such that the locations of finds within different areas can be attested, this information could be productively incorporated into GIS-based analyses. Unfortunately, such documentation is seldom available at castro sites, owing to a combination of methodological deficiencies in previous decades and a lack of thorough publication in more recent ones. In this context, my methodology's limitations largely reflect the limitations of the available evidence. Given the severe limitations of the available evidence, it is even more important to extract as much information as possible from the remains. This is the goal of my current proposal in the simplest terms.

The issue of chronology in the representation of settlements is one that must be dealt with in any approach, whether one is relying on plan maps or aerial photographs. This is particularly troublesome in the context of castro archaeology, where the possibility of anachronisms in the plan of a settlement is a problem at most sites as a result of excavation methodologies as well as publication practices. Any analysis of the organization of a castro site must seek to account for this problem, but a framework for this purpose does not currently exist. It will be essential for future studies of this kind to establish a framework wherein one's confidence in the reliability and chronological coherence of the current state of the remains can be accounted for as part of the interpretive process.

FINAL CONSIDERATIONS

The justification for the current line of inquiry relies on two fundamental premises. First, interpretations of the organizational properties of castro settlements have played a vital role in conceptualizations of social structure and cultural change over time in the Iron Age communities of the Northwest (Ayán Vila 2013; Carballo Arceo 1996; González-Ruibal 2006b; Silva 1995). Second, current approaches to the description of spatial properties in castro settlements leave ample room for improvement, as was discussed at length in previous chapters. An insufficient grasp on methods of spatial analysis has been named as a contributing factor in the overall tendency toward methodological and interpretive stagnation in the history of research on castro architecture (González-Ruibal 2006:340). I agree with this assessment, and argue that the problem has not yet been resolved in full. Archaeotecture points out that excessive emphasis on description can pose a hindrance to research progress, with the idea that we ought to move toward culturally relevant interpretations of the evidence rather than merely recording it. I agree with this assessment as well, but point out that in the case of settlement organization, the task of describing and comprehending the evidence has yet to be satisfactorily completed. This means new methods of description are needed, and the current work has sought to pave the way in that regard. Description of a site's spatial properties forms the evidential basis for interpretations of that site's organization, such that by increasing our capacity for description we improve the substance and reliability of our interpretations. Further pursuit of a GIS-based approach to the description and analysis of settlement organization stands to provide the tools needed to reconcile the inconsistencies found in previous interpretations as well as to establish the basis for new interpretive frameworks.

In adapting LISA operations to analyze circular data according to a path-based conceptualization of distance, and in applying such operations to analyze the organizational properties of individual settlements, my case study represents an innovative, perhaps unprecedented line of inquiry. Even so, this work represents the minimum of what can be accomplished by generating GIS-based representations of sites and applying concepts and methods from spatial statistics to analyze and describe the properties of their built spaces. The primary goal was to demonstrate that such an approach represents a valuable addition to the toolkit employed thus far to study the organization of castro settlements. Until now this toolkit has involved a combination of visual assessment and space syntax. Combining these methods with GIS-based approaches of the sort demonstrated here stands to improve our ability to detect previously unrecognized organizational mechanisms and increase our overall comprehension of the spatial properties of castro sites. While still in its infancy, the current line of inquiry has promising implications for the study of built space in the castros of Northwest Iberia, as well as for the archaeology of architecture in general.

Appendix: Data Tables

Table 1: Base data for Terroso

Structure ID	Angle (°)	Interior Surface Area (m^2)	Form
1	-175.28	19.08	Rounded-rectangular
2	58.00	14.42	Circular / vestibule(?)
3	-20.58	15.23	Circular
6	-72.28	15.49	Circular
7	-118.23	11.68	Circular
8	175.12	11.08	Circular
9	68.84	18.02	Circular / vestibule
10	105.39	11.20	Rounded-rectangular / attached
12	136.30	12.58	Circular
14	-0.44	16.01	Rectangular / vestibule
15	-90.84	22.99	Rectangular / partial vestibule(?)
16	-170.25	17.70	Other / attached
18	-52.03	10.54	Circular
19	-85.74	14.50	Circular
20	19.01	14.93	Circular / vestibule
21	-100.22	19.05	Circular / partial vestibule
23	87.68	15.27	Circular
24	-55.69	11.14	Other
25	60.88	21.48	Circular
26	162.23	17.93	Circular / vestibule
27	-98.17	14.39	Circular
28	-73.57	14.02	Circular
29	93.34	13.73	Rounded-rectangular / attached
30	58.91	14.78	Circular
31	113.61	13.65	Circular
101	-135.13	18.20	Circular / partial vestibule
102	83.03	15.02	Circular
103	105.49	11.98	Circular
104	-123.33	10.65	Circular
105	-55.72	16.56	Circular
110	1.20	14.61	Circular
111	-16.04	14.32	Circular
112	48.19	14.45	Circular
113	-41.34	14.50	Circular
114	-140.00	20.68	Circular
117	179.14	13.93	Other

Table 2: LAMDA values and neighbor relationships for Terroso (10 m distance band)

Structure ID	LAMDA	Number of Neighbors	Neighbors
1	104.29	4	104, 105, 103, 110
2	104.43	2	3, 6
3	65.14	2	6, 2
6	111.16	6	3, 7, 8, 9, 2, 10
7	104.31	4	6, 8, 9, 10
8	88.80	4	7, 6, 9, 10
9	118.42	4	7, 6, 8, 10
10	104.21	4	7, 6, 8, 9
12	136.74	1	14
14	99.03	2	12, 25
15	165.12	2	25, 23
16	93.29	2	19, 23
18	52.38	2	19, 20
19	75.03	3	16, 18, 20
20	87.90	2	18, 19
21	162.78	2	29, 30
23	140.30	2	16, 15
24	125.02	3	26, 27, 31
25	106.52	2	14, 15
26	95.35	2	24, 31
27	63.80	3	24, 28, 31
28	24.61	1	27
29	100.43	2	21, 30
30	96.78	2	21, 29
31	128.69	3	24, 26, 27
101	141.84	1	102
102	141.84	1	101
103	118.82	4	104, 105, 1, 110
104	93.97	4	105, 1, 103, 110
105	99.86	4	104, 1, 103, 110
110	115.19	4	104, 105, 1, 103
111	164.82	1	117
112	130.78	3	114, 113, 117
113	108.90	3	114, 117, 112
114	102.14	3	113, 117, 112
117	125.00	4	114, 113, 112, 111

Table 3:
Path distances between neighbors for Terroso (10 m distance band)

Structure ID	Structure ID	Path Distance (m)
1	103	3.59
1	104	4.35
1	105	5.63
1	110	6.94
2	3	8.63
2	6	6.82
3	6	8.17
6	7	5.06
6	8	5.90
6	9	6.08
6	10	9.27
7	8	2.81
7	9	6.66
7	10	7.83
8	9	4.68
8	10	5.35
9	10	6.33
12	14	7.46
14	25	9.61
15	23	9.52
15	25	8.84
16	19	9.63
16	23	9.86
18	19	6.81
18	20	6.69
19	20	8.97
21	29	4.85
21	30	6.66
24	26	3.79
24	27	9.82
24	31	7.35
26	31	6.15
27	28	6.23
27	31	7.65
29	30	3.90
101	102	7.85
103	104	6.33
103	105	5.31
103	110	3.35
104	105	3.66
104	110	9.21
105	110	6.37
111	117	8.08
112	113	4.13
112	114	4.99
112	117	5.70
113	114	3.28
113	117	7.08
114	117	4.19

Table 4: MLGc values for Terroso (10 m distance band)

Structure ID	MLGc
1	0.5260
2	0.1363
3	0.0375
6	0.5355
7	0.4936
8	0.4911
9	0.5370
10	0.2663
12	0.1023
14	0.1147
15	0.1969
16	0.0561
18	0.0418
19	0.0725
20	0.0759
21	0.5330
23	0.1398
24	0.5947
25	0.1022
26	0.4463
27	0.1248
28	0.0048
29	0.3827
30	0.1979
31	0.2953
101	0.0995
102	0.0995
103	0.8554
104	0.3338
105	0.5462
110	0.5731
111	0.1269
112	0.6645
113	0.5366
114	0.6646
117	0.4351

Table 5: Base data for Romariz

Structure ID	Angle (°)	Interior Surface Area (m^2)	Form
1	144.79	12.79	Circular
2	67.19	9.48	Circular
3	-91.77	13.79	Circular
4	159.98	34.48	Rectangular / multiple rooms
5	-91.94	18.37	Rectangular
6	25.03	34.61	Rectangular
8	-49.82	26.65	Rectangular
9	39.99	29.25	Rectangular
10	-26.10	13.75	Circular / vestibule
11	-12.83	10.89	Circular
12	-63.35	9.35	Circular
13	61.35	12.77	Rectangular
14	169.64	10.87	Circular
17	163.28	10.88	Circular
18	156.06	11.16	Circular
19	156.40	12.39	Circular
20	50.75	16.38	Rectangular
21	175.37	8.03	Circular
22	68.48	23.71	Rectangular
23	-10.06	14.41	Circular
24	-29.26	12.17	Circular
25	130.95	11.27	Circular
26	-171.66	7.94	Circular
27	43.65	17.60	Rectangular
28	153.24	14.45	Rectangular
29	-150.11	9.86	Circular
30	-126.40	11.95	Circular
31	-130.40	16.59	Rectangular
52	-134.74	6.80	Other / attached
53	151.95	17.49	Rectangular / attached

Table 6: LAMDA values and neighbor relationships for Romariz (10 m distance band)

Structure ID	LAMDA	Number of Neighbors	Neighbors
1	100.52	2	3, 2
2	118.28	2	3, 1
3	141.20	2	2, 1
4	108.08	1	5
5	112.52	2	4, 6
6	116.97	1	5
8	100.49	2	9, 13
9	55.58	2	8, 13
10	161.40	2	14, 21
11	50.52	1	12
12	87.61	2	11, 13
13	95.82	4	8, 9, 12, 14
14	102.02	3	13, 10, 21
17	9.27	2	18, 53
18	5.66	2	17, 53
19	72.70	3	21, 22, 20
20	86.86	3	21, 22, 19
21	107.57	6	10, 14, 23, 22, 19, 20
22	74.53	4	21, 23, 19, 20
23	126.56	2	21, 22
24	160.21	1	25
25	160.21	1	24
26	58.48	3	29, 28, 27
27	140.37	3	26, 29, 28
28	66.30	3	26, 29, 27
29	70.55	3	26, 28, 27
30	6.17	2	31, 52
31	4.17	2	30, 52
52	6.34	2	30, 31
53	7.72	2	17, 18

Table 7: Path distances between neighbors for Romariz (10 m distance band)

Structure ID	Structure ID	Path Distance (m)
1	2	3.73
1	3	5.78
2	3	5.23
4	5	1.61
5	6	9.68
8	9	2.25
8	13	9.49
9	13	8.79
10	14	8.11
10	21	7.03
11	12	9.01
12	13	4.33
13	14	9.52
14	21	6.68
17	18	6.09
17	53	9.91
18	53	4.10
19	20	3.99
19	21	6.64
19	22	7.13
20	21	7.71
20	22	6.79
21	22	4.64
21	23	8.26
22	23	5.46
24	25	7.41
26	27	6.79
26	28	7.66
26	29	8.28
27	28	3.78
27	29	6.62
28	29	4.06
30	31	4.90
30	52	9.26
31	52	4.59

Table 8: MLGc values for Romariz (10 m distance band)

Structure ID	MLGc
1	0.2707
2	0.4133
3	0.4205
4	1.3656
5	1.4101
6	0.0445
8	0.5278
9	0.4877
10	0.2801
11	0.0096
12	0.2621
13	0.3356
14	0.1647
17	0.0008
18	0.0007
19	0.2619
20	0.2948
21	0.5347
22	0.2728
23	0.1989
24	0.1425
25	0.1425
26	0.1466
27	0.5862
28	0.3217
29	0.2532
30	0.0005
31	0.0005
52	0.0005
53	0.0007

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