EXPLORING THE SOCIAL USE OF SPACE USING PRINCIPLES OF RELATIVITY

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Abstract

Exploring the social use of using principles of relativity

This thesis applies a new application for old scientific principles based on a philosophical extension of Einstein's theory of relativity for Space-Time. With Einstein's physics, space and time are relative to the observer. Comparisons of house floors by relativity is achieved with a mathematically based procedure that places a universal point of observation within all structures based upon the centroid of the structure itself. The data is transformed so that all structures can be placed upon the same axial alignment and sampled for spatial correlations by Principal Components Analysis (PCA), relative to each structure's space. A further method Selective Centric Morphology (SCM) created for this study, places the point of observation as that relative for archaeological interpretations. In this study, the centre of the hearth acts as a centre of social activity and all space is transformed around this point of observation. This enables the ability to apply statistical tests that can be linked to spatial distributions, to compare known quantities against archaeological examples, and to directly make intersite comparisons beyond an anecdotal level.

A test case, Kilpheder House 500, has archaeological distributions of objects related to food storage (pottery) and preparation (flint or unburnt bone) within house floors tested against models of longhouses and round/wheel houses to determine group membership. The longhouses tested against were formed from twelve expert models and a synthesis Cognitive Model. The round/wheel houses tested against were Black Patch (East Sussex, England), Catpund (Shetland, Scotland), Sollas (North Uist, Scotland), Stenness House 1, 3, 6 and 10 (Orkney, Scotland). This thesis found that with transformations by both relativity and SCM, the strongest correlations for Kilpheder House 500 were with the longhouse expert models and has a likely group membership with longhouses. In this study, mathematical transformations allowed intersite cases to be examined directly against each other.

The transformation of space into a universal framework will offer archaeologists the ability to make precise mathematical comparisons between relative spaces. This not only offers the ability to make comparisons of multi-dimensional data-sets as a means of understanding the social use of space in archaeologically recovered buildings but can be applied to any area with clear boundaries where spatial comparisons can aid interpretation. Future work may make it possible to determine archaeological taxonomic memberships with these methods.

Ehren Alexander Milner

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Section 1: Introduction- Relativity

Archaeological investigations are often translated into numerical forms to facilitate the understanding of the use of space. As long ago as the early nineteenth century, the German mathematician Carl Gauss discussed (in his letter to Friedrich Bessel) how it is nearly impossible to describe spatial aspects completely (MacKay 1991: 100). But that has not stopped later scholars trying. Ethereal concepts can be, but are rarely, distilled to the greatest of artificial understandings- mathematics. Spatial relationships can be described, or estimated, through the use of mathematics, but never understood in totality other than through artificial means. The particular domain of interest is mathematical relativity, but until now is an advancement that has not been applied in archaeology and accordingly there is no relevant archaeological literature on the subject. But the application of general relativity, special relativity, as something that goes beyond the field of social, linguistic and temporal relativity, has been a formal aid to spatial interpretations in the physical and theoretical sciences outside of archaeology (*e.g.* Physics: Bertin, Pimentel and Pompeia 2010; Biology: Auffray and Nottale 2008 Mathematics: Cianci 1978). . Archaeological approaches to spatial interpretations have instead focused upon comparative syntax (*e.g.* Cutting 2003), ethnographic analogy (*e.g.* Smith 1994), and uses of descriptive spatial statistics (Smith, Marshall and Parker Pearson 2001; Viklund 1998). Although these methods employed have offered a means for discussion, no mathematical certainties have offered evidences that are self-evident. To this end, an investigation of the application of relativity for the configuration of the coincidence of space will for the basis of this thesis. This will be accomplished through an analysis of the use of space within a structure through applications of general relativity and a further study of invariance by Selective Centric Morphology (SCM) created for this study.

1.1 Recovering past spaces

Current views are that an examination of microassemblages offers the best hope of achieving an understanding of the use of space by finite quantification of material deposition (Metcalfe and Heath 1990; Smith *et al.* 2001; Milek 2001; Milek 2006). Further to this, an examination of geochemical composition and geomorphology are thought to offer linkages to the use of space (Milek 1999, 2006; Matthews *et al.* 1997). With the aid of ethnographic approaches, these uses of space can be more apparent through comparative sampling (*e.g.* Milek 2006; Kent 1984; Smith 1996; Viklund 1998). However, it should be noted that "the principal limitations of micromorphology are that sample sizes are small and the emphasis in analysis is largely on extant visual attributes" (Matthews *et al.* 1997: 285).

Mapping spatial variations in the social use of space is not without its difficulties. Different samples sizes and their different alignments, make direct comparisons between buildings by spatial axioms difficult. Smith (1996) excavated selected areas where the use of space was thought to be known within a recently abandoned farmstead at Schoolhouse Croft on South Uist, Scotland. The characteristic levels of pH, Phosphorus, phytoliths, plant remains, mollusc remains *etc.* were tested for group membership using discriminant functions against midden samples. Smith found that the characteristics of each area within the presumed scheme for the social use of space appeared distinct. The apparent exception was the midden which held the greatest resemblance to the barn features because they were most likely formed of animal husbandry space. This advance offered the ability to characterize potential commonalities between spaces, but did not offer an ability to examine where these spaces occur within a building's floor surface. To counter this, recent excavation at Kilpheder and elsewhere have begun to take systematic samples. This is largely because taphonomic factors have left few artefactual finds within buildings as a consequence of refuse disposal (Smith *et al.* 2001: 251). Indeed, much of the prevailing view within archaeology is that artefact deposition within buildings represents abandonment rather than the use of space during the occupation of the structure (*e.g.* Brooks 1993).

Recent projects have employed extensive sampling to recover information about the use of space within houses (Smith *et al.* 2001; Milek 2006). A typical methodology is to collect samples from within 0.5m x 0.5m (or finer) sample units evenly arranged across whole surfaces interpreted as house floors to provide a grid of data which is then transformed into density or land use plots. Further geomorphological, bulk and geochemical samples are often taken within identified features. At Kilpheder (House 312 in Smith *et al.* 2001) the results of total phosphorus, magnetic susceptibility and the range of fragments per litre for artefact/ecofactual materials within an anthrosol, or human influence soil, were presented (Smith *et al.* 2001: Figures 3-10). Similar methods were also used by Milek (2006) who also linked material distribution to ethnographic examples and included analyses of spatial syntax for and examination of a house at Vatnsfjörður on Iceland.

If samples taken to obtain distributions of geochemical and macro/microbiological remains are too small to constitute enough data to lead to a greater knowledge about the use of space, and the positioning of larger objects cannot be trusted to be disposed of near their place of use, how can the use of spaces be compared? The application of ethnographic examples provides a middle range theory to social relativism. A framework of modern understanding is used to engage with an ethnographic example that can be used to align axioms in three-stage process to understand material depositions as they may be expected in the present, observed in the less distant past and compared to the remote past. It is in this context that Milek (2006) was very successful at examining areas within her archaeological cases against those within ethnographic examples. Indeed, the ethnographic examples pointed to a likely inclusion of objects that are nearby within floors as turf was collected as close as possible to the structure. One aspect that was ignored in the study was the mention of the frequent relaying of turf as a floor in an *ad hoc* manner. This would, in effect, in the context of Iceland, have created major differences in material distributions, as some areas would be swept and others would have the addition of new turf if the roof leaked, producing a puddle in an area. An indicator of this activity was found to be fuel ash which served as a consolidating agent. Thin sectioning of geological column samples would illuminate such activity. However, without regular sampling, it would be had to tell if an individual thin section was representative of an entire floor. With Smith (*et al.* 2001), the presentation of the data has been criticized as being of a 'lower rung' interpretation, following Hawkes (1954) "Ladder of Inference" model (Milek 2001: 276). Although not stated, this is likely because there is no uniform synthesis of a model and merely matches analogical representations to ethnographic examples. Although Milek (2006) provides a fully detailed access analysis (spatial syntax) to archaeological features to compare data between buildings, no such interpretive scheme was provided by Smith (*et al.* 2001). Moreover, the geochemical data presented was likely to have been heavily affected by its proximity to the sea, which is abundant in Phosphorus. The pH of the anthrosol was not stated. It is also possible, as indicated by the high preservation of organic materials, that the pH of the site was between 6.0-7.0 and therefore could have been subject to dephosphatisation. Between these two factors, the distributions of Phosphorus can only be viewed as unreliable. The use of counts of fragments instead of another density indicator, such as mass or volume, could lead to densities indicative of later taphonomy and not primary deposition. That is, further trampling action could further fragment items in areas of high traffic and lead to false 'high density' counts. If a material was more friable than another material, the ratios between the two material types would be unreliable. If unburnt bone was viewed from the ethnographic model as an area of food preparation prior to cooking, and charcoal or burnt bone as area of cooking, it would only become apparent that something was amiss, beyond archaeological expectations, if densities for both were high in the same area. It could just be that charcoal and burnt bone are more friable than unburnt bone and really they should appear in different proportions as has resulted in archaeological examples but not in more time restricted ethnographic examples. The lack of inclusion of large artefacts, on theoretical grounds, was also discordant with all prior archaeological excavations.

Despite similar methods of collection, and similar adaptations of middle range theory using ethnographic examples, the sites themselves are not comparable by means other than old analogous method of 'that looks like this' so let's test that discrete space and test for similarities. It would be useful if all observed spatial characteristics, the space between samples, and known discrete features, were examined. The difficulty is in how best to compare the sites. It is possible to determine architecturally that two areas, at two different sites, may hold similarities in form but their uses may be entirely different (Sabean 1990). The examination of samples within these areas would require the exact scale and size, and positioning of samples, to truly look at the distribution of materials within a set of buildings to determine if they hold similar, testable, patternization. If however, it was possible to take a building of a similar, but slightly different shape and compare it in the same shape, with all archaeological distributions juxtaposed into the same shape, it would be safe to describe the distributions mathematically or analogically as the same or not. That is, if the floors of several different buildings could all be placed within the space of one building, with all spatial relationships of ratio distances between features and finds intact, any examination of the placement of items could be treated as if examining the phasing within a singular structure. The application of relativistic frames can make this step possible.

1.2 Research aim

The aim of this research shall be to develop and test a mathematically based procedure for the comparison of multi-dimensional data-sets as a means of understanding the social use of space in archaeologically recovered buildings.

1.2.1 Objectives and how they each will be achieved

The focus of this study is upon testing relativistic methodologies. The applications of the methodologies contained herein will be focused to make the aim attainable. It is for this reason that below is a brief description of how each of these objectives will be achieved.

1.2.1.1 To apply statistical tests that can be linked to spatial distributions.

In order to implement tests that are more spatially accurate, it will be necessary to analyze archaeological materials that have been recorded spatially. For example, when dealing with discriminant analysis of materials found inside of a building, it has often been the case that the materials in their entirety have been compared between houses. Although this does take into account the differences to be found between buildings in terms of possible activities, it does not give an indication of how activities may have coincided. If A, B, and C are found in association in two houses, it does not mean that the use of space within that house is identical. In one house, A, B, and C may have been recovered from a shared use of space but in another building they may have never overlapped in their distributions. It is these relationships between the placement of items, and not just their presence and absence that will be examined. This will be done using a series of techniques that will perform image analysis on raster data and distribution analysis on vector placements. The results of this data will then be tested probabilistically to see if the distribution of materials is alike between sites.

1.2.1.2 To create simplistic and relativistic methodologies for comparing samples between sites.

Several techniques are being borrowed from a new application of special relativity. Through the use of linear algebraic transformations, each area will be understood relative to a set perspective. Once hypothetical and real world models are configured to a set artificial space, spatial measurements of distributions will be understood from a shared perspective.

1.2.1.3 To compare known quantities against archaeological examples.

The best and most practical way to create a model that is entirely known is to create a Cognitive Model, a form of interpretative policy capture. A survey was used to gain an understanding of what would be expected for a longhouse. This idealised use of space and material distribution should give an indication of what thoughts are brought to bear on a site prior to its excavation. This will be linked to data recovered to another known quantity – a recreated site where activities and the use of space are known. This will be accomplished through the comparison of thirteen hypothetical Norse period tripartite test models against an archaeological example, Kilpheder House 500, speculated to be a tripartite Norse house. This will in turn be compared to precursors of this house form in the form of seven round structures: six roundhouses and one wheelhouse.

All of this will occur under the theoretical grounding of relativity. Before the full methodology is unfolded in the following chapters, a greater understanding of the implications of relativity shall be introduced here. This will be in two sections. The first will be a brief introduction of how the term relativity has been adopted into wider anthropological, sociological and linguistic studies. The second shall cover the greater scientific developments of the theory of relativity that have led to the grounding for the application in this study. Included will be a visual study aided by relativity that will introduce archaeological applications.

1.3 Cultural and Linguistic relativity

It would be reticent to discuss relativity without at least a brief mention of how relativity has produced theorems elsewhere in the social sciences. With archaeology, relativity mainly has brief mentions as to the impact of new theories upon science (*e.g.* Schiffer 1996: 648). The literature in the social sciences is rather more extensive and therefore only the key concepts will be covered. The primary aid of relativity to areas of social, linguistic, historic and anthropological is the 'concept of the self'. This is not just concepts discussed by the likes of philosophical heavyweights such as Locke, Rawls and Hume. Instead, it is the acknowledgement that the fundamental basis for discovering or noting an observation that can be said to be relative is that the 'self' is distinct from what is being observed Murray 1993). Here, there is the recognition that the individual has their own internalized 'egocentric' view and a 'sociocetric' view that is formed from the greater society. It is only through these relativistic perspectives of the self, and oneself in one's own society, that the external world may be viewed. Such observations are experiential and are largely substantive only to the self. Despite this, most literature will focus upon how anthropological studies outside the 'West' will be viewed in the framework of this westernized self. This view of the external world therefore would experience different levels of relativistic perspectives.

These very concepts of the self, and the society from which one has been formed, affect different concepts of spaces through the language that we can conceive (Levinson 1998). Levinson (1998:20) notes that orientations and directions are largely restructured to group membership within communities. As such, the perception and description of the world is restricted to the forms of communications and "background computations of a specialized sort that members of other communities may not indulge in at all"(Levinson 1998:20). The relativity of language can go even further in our ability to classify items. The confines of a society, outwith the self, may form the main ability to shape a level of comprehension of levels of understanding. Dougherty (1978:77) notes that what may be basic for some, may not be basic for others. The ability to provide examples of basic types or generalities may only be available to the societies that have a need for this construct. That is linguistic clarity and foreknowledge is only likely to be available based upon the relative need within a society.

Melford (1986: 259) notes that of prime importance in the concept of epistemological relativism in current applications within anthropology. Nothing can truly be objectively described as 'true' or 'false' as all things are a matter of perspective. This same concept extends to historic relativity where views of the past can only be understood through the present. The Type of relativity under discussion in this thesis is that of a set observer within a space. Further arguments could be made the perspective of the observer and the framework in which this work shall proceed.

1.4 Relativity in science

For both special (Einsteinian and Lorentzian) and general (Galilean and Newtonian) relativity, the world is composed of space-time points that can be represented by a quadruple (x, y, z, t) of real numbers in each reference frame and different reference frames can be connected "by rules of transformation of the appropriate theory" (Joseph 1979: 428). For both forms of relativity, space-time can be converged and treated as flat at a point (Misner *et al.* 1973: 386). For the special theory of relativity, Lorentz transformations make provision of different frames of perspective (see Figure 1).

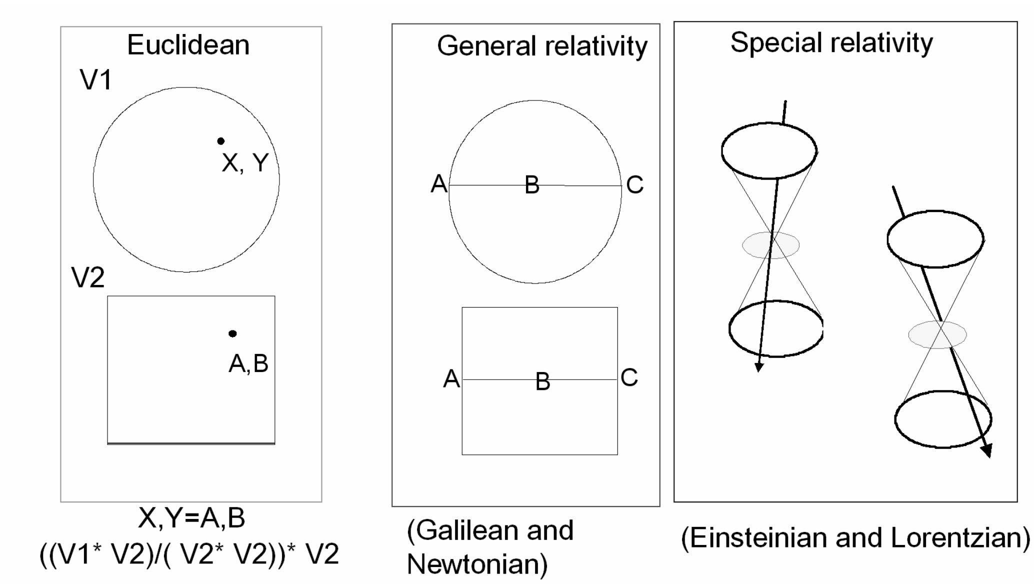


Figure 1. Spatial Transformations

Many of these concepts relied heavily upon the fundamental concepts of equivalence, the equality of effect, whereby the state of an observed force can be transformed to produce the same value through quadratic equations.

Einstein relied heavily upon the tensor calculus of Gregorio Ricci-Curbastro and Tullio Levi-Civita (Walter 1999). In Einstein's view, space detached from a physical concept does not exist, space-time cannot exist on its own but must be linked to greater fields and context, space is never empty and objects are not "in space" but are spatially extended from a point of reference (Westman and Sonego, 2009).

1.4.1 3-D spheres and the 4th-dimension

Moving beyond X, Y, Z, it would be possible to model space as a 3-D sphere with external linkages to further dimensions. Hermann Minkowski (1864–1909), helped to bring four-dimensional applications to theoretical physics through his interpretations of the laws of special relativity in the language of non-Euclidean geometry, that which has dimensions further than conceived by Euclid. Although Henri Poincaré (1854–1912), stated that any geometry realized in physical space is not unambiguous and is in fact not synthetic, a universal metric is best for testing models but his judgment that "Euclidean" geometry shall form the easiest basis for comparison was appropriate (Walter 1999). It took attempts to answer some of the more abstract questions of geometry to provide a need for variational methods. Hertz perhaps first applied "variational methods in an n-dimensional space in which the number of dimensions corresponds to the degrees of freedom of the system under investigation" (Walter 1999: 17). Non-Euclidean geometry was found to provide the best approach to three principal directions: projective geometry, differential geometry and axiomatics.

This allows for the 'slowing' of clocks and the 'contraction/expansion' of metrics such as a yardstick so that "there is no such thing as unique spatial separation of the point-events" (Joseph 1979: 429). Special relativity of space-time allows for congruence of points to be viewed with the same metric unit, much as Euclidian transformations of two-dimensional points can create spatial convergences from one metric (*e.g.* map projection) to another. Special relativity can create a universal frame that all vectors from a case can be 'boosted' into another frame to be understood on the same terms. Reichenbach (1957) maintains that a universal force keeps the length and breadth of bodies preserved in their position by the same factor and to preserve all congruence relations. The addition of special relativistic theory to archaeology would provide a universal metric whereby differences and commonalities could be viewed under the same spatial congruence.

Minkowski was the first to state in the most simple terms that "the world in space and time is, in a certain sense, a four-dimensional non-Euclidean manifold" (Walter 1999: 109). Unlike later scholars, the fourth-dimension was measured as an imaginary dimension. Later works placed further dimensions that matched the conceptions of studies. The methods created what is called a pseudo-hyperspace in a unit of imaginary radius and a counterpart two-sheet hyperboloid which is very much like a bisected sphere where space coincides. This transformed space, unlike that which would be observed in Euclidean space, would transform two parallel lines to a degree that as some point at the extension of their length they would cross-over and intersect. Arnold Sommerfeld (1868–1951) went further and re-wrote the surface of these hemispheres of imaginary radius into known models of hyperbolic geometry to prove greater trigonomic formulae that could be linked to real-world angles and more familiar geometries (Walter 1999).

1.4.2 Spheroid Model

This is where a spheroid model could be introduced. A cross-section of a sphere in space could be represented as circles on a 2-D plane. The method used for relativistic transformations placed a third-dimension point upon a two-dimensional disc. Although this method proves highly useful where items are being considered in plan, it does not consider more than one axial shift or contributing factor. If items are placed within a relativistic sphere, rotational tilt could provide an infinite amount of outside factors that a site could be orientated upon. In most space-time theories, the relationships of topological and differential properties of objects can be viewed on a four-dimensional manifold as M and a group of tensor fields can be presented by differential geometry (Westman and Sonego, 2009). Starting with the bare manifold, it is possibly to add structures independently to this “container” for the purposes of comparison. It is this artificial container, with its set dimension which makes this an application of Special Relativity.

Within GIS, it would be possible to find the 3-D midpoint for an entire set of data points, or, the vertex points of a boundary file. The furthest point from the centre could be rescaled to a value of 100. All other points could be rescaled relative to this maximum. Where P is equal to the point position and C is the centre position, and P-C would be the vector created when taking the data point and subtracting from its centre point, as follows:

100*(P-C) / length (P-*C)

Vectors consist of a distance and a direction. With vectors, there are only 2 important qualities – the length (magnitude) and the direction. The processing of data, together as a body, will change the origin points of all end points to the centre point <0, 0, 0>.

If there are two vectors, V_1=<a,b,c> and V_2=<d,e,f>, let V_1=<5, -3, 2> and V_2=<1, 4, -7>.

By this notion, V_1 starts at <0, 0, 0> and ends at the point (5, -3, 2).

To find the relative position, and angle between V_1 and V_2, it is possible to take the Dot Product of the vectors.

The formula of $V_1*V_2 = a*d+b*e+c*f$. This would result in $V_1*V_2=5*1 + -3*4 + 2*-7 = 5 - 12 - 14 = -21$.

The length of V_1 would be the calculated by taking the square root of (V_1*V_1), or as $\sqrt{a^2 + b^2 + c^2}$.

This would result in $\sqrt{5*5+-3*-3+2*2} = \sqrt{25+9+4} = \sqrt{38} = 6.1644$ units.

To standardize a vector to a set length, (100 / length(V_1)). This would equal (100 / 6.1644)=16.222. The angle would remain the same, but the length would change.

To project one vector system into another would result in a formula like where the projection of V_1 to the projection of V_2 would = $((V_1* V_2)/(V_2* V_2))* V_2$ which would require the Dot Product mentioned earlier (-21) divided by the square of V_2 (66) and then multiplied by V_2.

This would equal $<-21/66, -84/66, 147/66> = <-0.3182, -1.2727, 2.2273>$.

These transformed points would then be set within a new three dimensional projection. The computing power required for such three-dimensional renderings, when processing hundreds of thousands of points at once, is increasing and could be adapted to the tools already available in ArcGIS. A basic script of linear algebra could be adapted to provide multi-layered site models, with contexts in their respective positions. These would essentially be microcosms of a site and could be used as visual aids and to perform statistical tests.

As the use of GIS grows, it will be possible to take further theoretical advances from other areas of the sciences and test their applications within archaeology. This type of research will help us to look beyond the static taxonomies that have formed from the past two hundred years of excavation. With the addition of an idea of Émile Borel (1871–1956) , it is possible to view more than just one frame of reference in terms of that to another. Instead he chose to look at two frames of reference through that of a third inertial observer (Walter 1999: 112). Effectively, instead of performing a Lorentz invariance transformation of one projective set to another, it would be possible to employ a metric within the confines of limits set by an observer that is not in either vector system. There will be two transformation systems explored in this thesis. The first is relativity which effectively creates and observer point at the centroid of each of the case studies that reprojects space to this set observer. The second method will be SCM where the archaeologist acts as an outside observer and can select the co-ordinates to which all others shall transform- the centre of a hearth.

1.5 An application of relativity: landscape and monument visualization

The effect of relativistic applications on two-dimensional datasets can be demonstrated through a simple example of circular objects before moving onward to test distributions within rectangulous archaeological floors. Another area where the use of relativity may have use within archaeology is to test how monumentality may appear to have similar visualizations or orientations in respect to their own spaces. As an example, consider Alexander Thom's (1966) use of the megalithic yard as and explanation of how celestial orientations were sought in the construction megaliths. To test this, the illustrated examples chosen by Thom (Woodhenge, Penmaenmawr, Moel Ty Ucha and Druid Temple) were all digitized and placed on the same orientation (see Figure 2). The orientations and scales were taken directly from Thom's study and the representations in Figure 2 are at different scales.

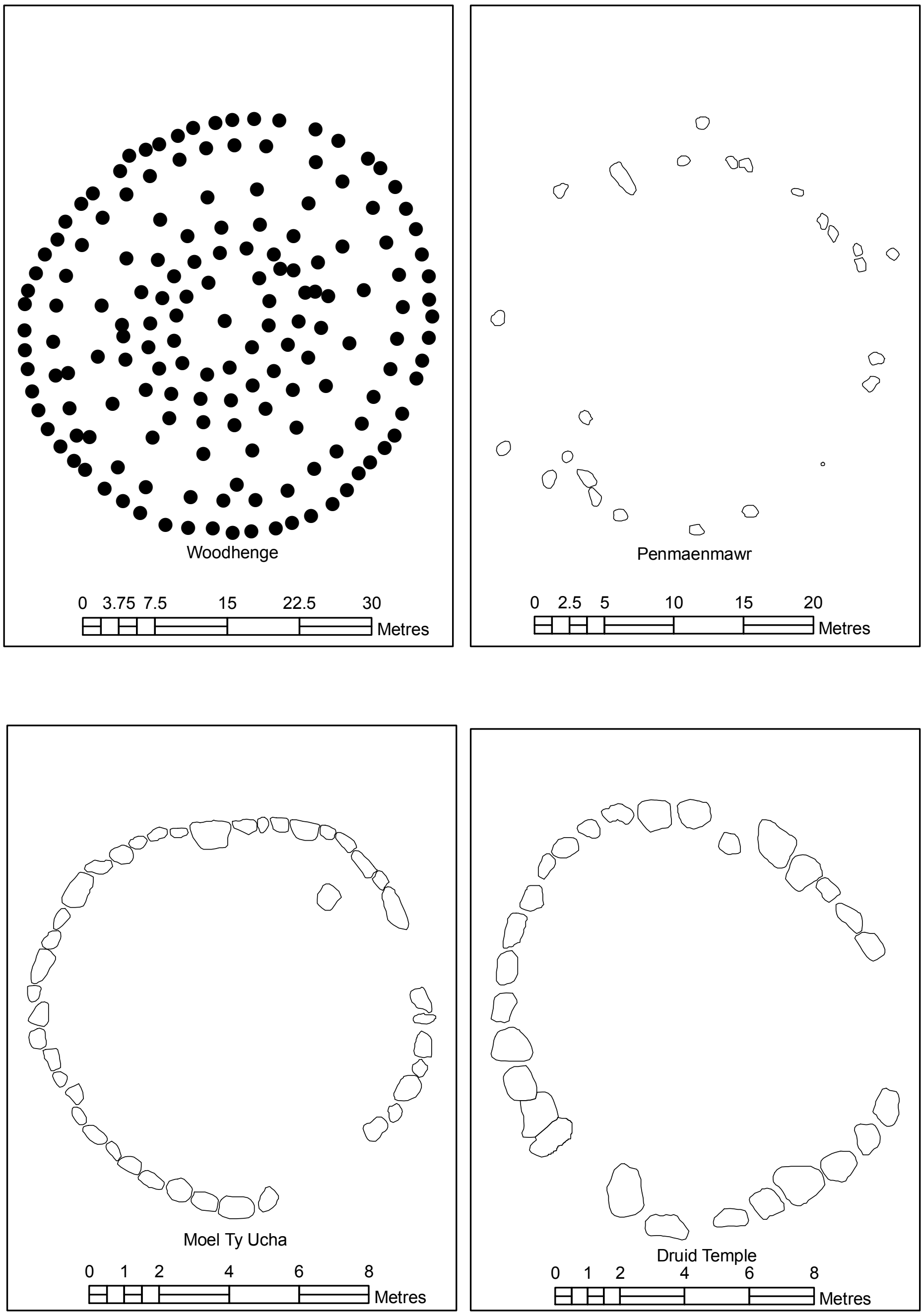


Figure 2. Case studies used by Thom (1966)

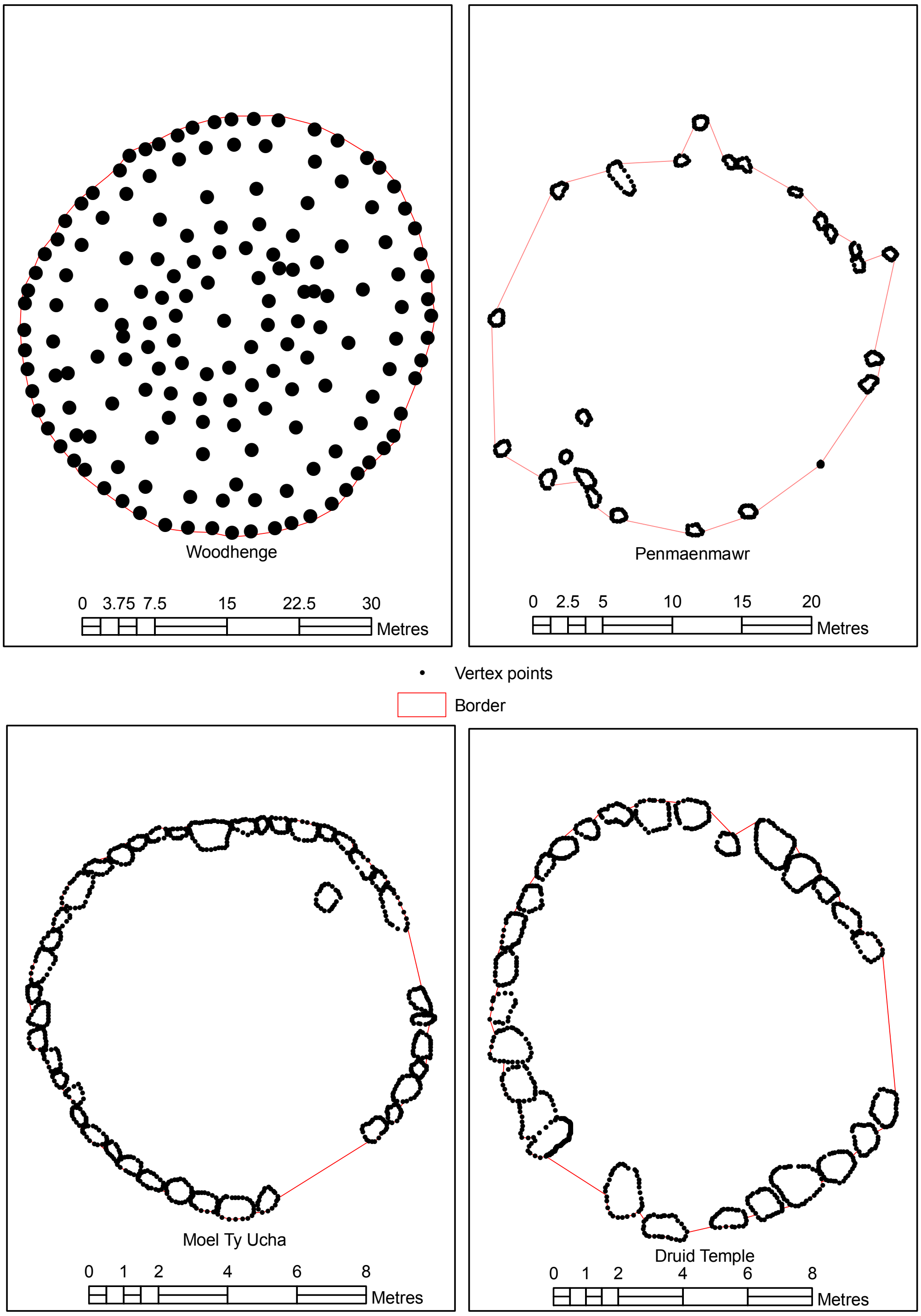


Figure 3. Border surrounding stone circles

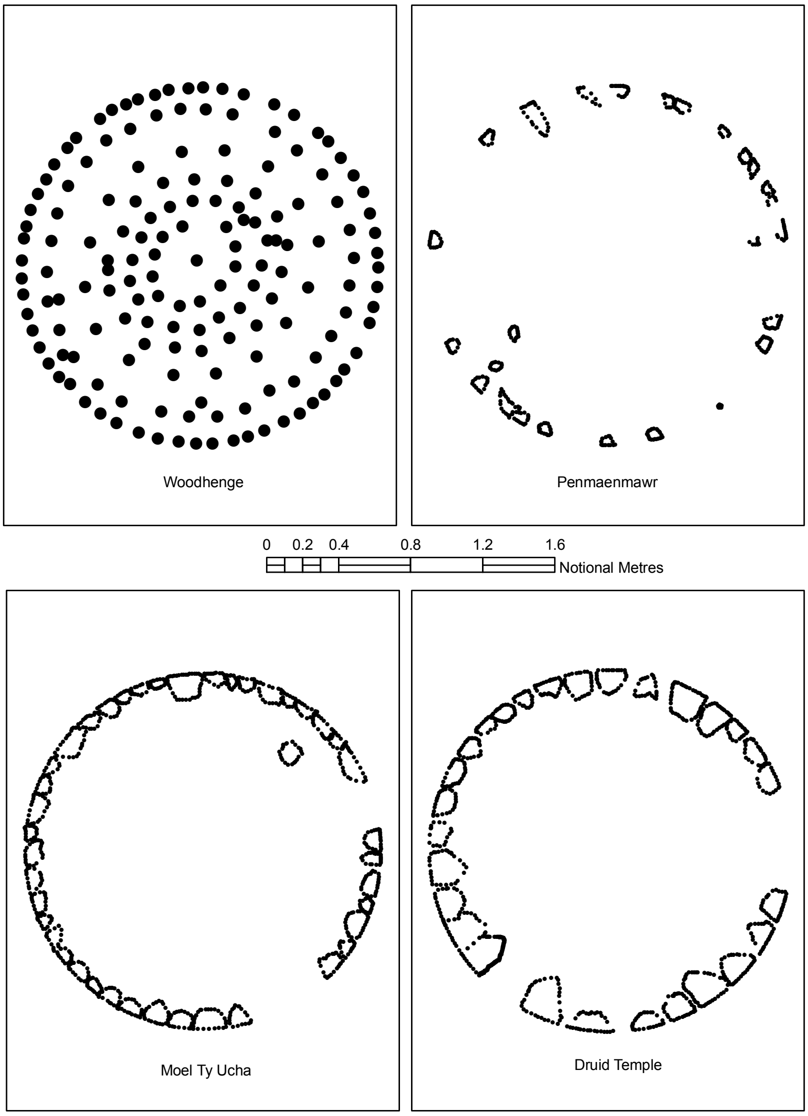


Figure 4. Relativistically transformed stone circles

The vertices of the monuments were surrounded by a border (Figure 3). The vertex points were then moved into relativistic space to see if the monuments do indeed display similar orientations, and therefore could have been created using a common conceptual cosmography (see Figure 4). What becomes clear is that there is some sort of clustering of material upon the north axis. The possible entrances, to the east, also appear to have similar placements. Unlike Thom's study, does not have to be reconfigured to a new number of 3.12 nor does pseudo-mathematics have to be used to explain the structures in relation to each other. It is possible to see each monument as if it were placed within a set boundary on the same site, again, almost as different phases of the same site. An advantage of the method is to draw outliers on the site into relation with the main body of the megaliths to better perceive the conceptions of the past. It is an approach that is not confined to looking at circular structures but can work well with square and rectilinear forms as well.

1.6 The Case studies

Five archaeological sites, including a main test case, were chosen for the study. A further thirteen models of hypothetical space also formed a basis of criteria for selection went beyond just the level of intact archaeology and known taphonomic factors that may have affected the site.

The methods for selecting the case studies focused upon eight criteria. The first criterion is that the site had to have an area of designated or potential occupation space. This was either down to the interpretation of the archaeologist(s) who excavated the site or the likelihood that a structure would have been appropriate in size for domestic activities. The second criterion was that the data has to have been available or published. Some of the data included in this study will have been formed from interim reports or from original site archives. Where this is not possible, the often less detailed publication reports shall inform on the artefact distributions for a site. The third criterion is that items must have been recovered from the defined potential *domus* area. Past excavations have merely presented finds as having come from an excavation as evidence of building function or period of occupation. For example, Doarlish Cashen on the Isle of Man (Gelling 1970) is often described as a Norse longhouse but was most likely just a shieling of rectilinear form. No artefactual, ecofactual or geochemical evidence was recovered from the building that could possibly indicate its function or period of construction. Instead, a typology was made by association with finds from outside of the building. This data would prove insufficient for the methods of this study. The fourth criterion is that the data should have been collected in a uniform or predictable fashion. If sampling has occurred, and it is not stated where the sample came from a site will have to be discounted from this study. The fifth criterion is that, in the least, Easting and Northing co-ordinates must have been recorded or mapped for archaeological materials. The sixth criterion is that to aid reconstructing habitation use, samples that may have been taken should have been taken from potential habitation layers and not just the known layers of destruction. Seventh, the excavation has to have at least partially reached the post-excavation stage so that materials have been quantified across the site. Eighth, materials should have been examined in a way that can be re-created. Through this short list of criteria, it was possible to eliminate most of the previously excavated structures. It appears that most excavations have been feature-driven and not focused upon artefactual evidence. This is particularly true for many prehistoric structures where a lack of extant features can create a situation where it is not possible to know that a structure was being excavated until postholes and pits can be identified in plan view. By this time, it is too late to sieve or attempt to recover what may have been intact floor layers. The methodologies applied for this investigation will seek out how to best make use of old data when possible.

Case 1: Kilpheder House 500

The site of Kilpheder (a.k.a. *Cille Pheadair*) on South Uist (NF 7292 1979) was subject to a rescue excavation before its eventual destruction by the eroding sea between 1996 and 2000 (see Figure 5). The structure included in this study is House 500 which dates roughly from the 10th to 13th centuries and had possible Norse influence in their construction. The site is currently in the process of a re-examination of the post-excavation analysis and therefore the data being used is from an earlier study (Milner 2000) pertaining to just the excavations of 1996 to 1998. Bulk sampling was conducted at every 0.5m and geochemical samples were taken in the corner of every 0.5m grid. Also, at the intersection of 0.25m lines, further samples were taken for later use. Large items within a haphazard placement were not recorded *in situ* as it was assumed that the could not offer as much information as could come from samples of by-products of repeated processing within uses of space (Parker Pearson and Smith, forthcoming).

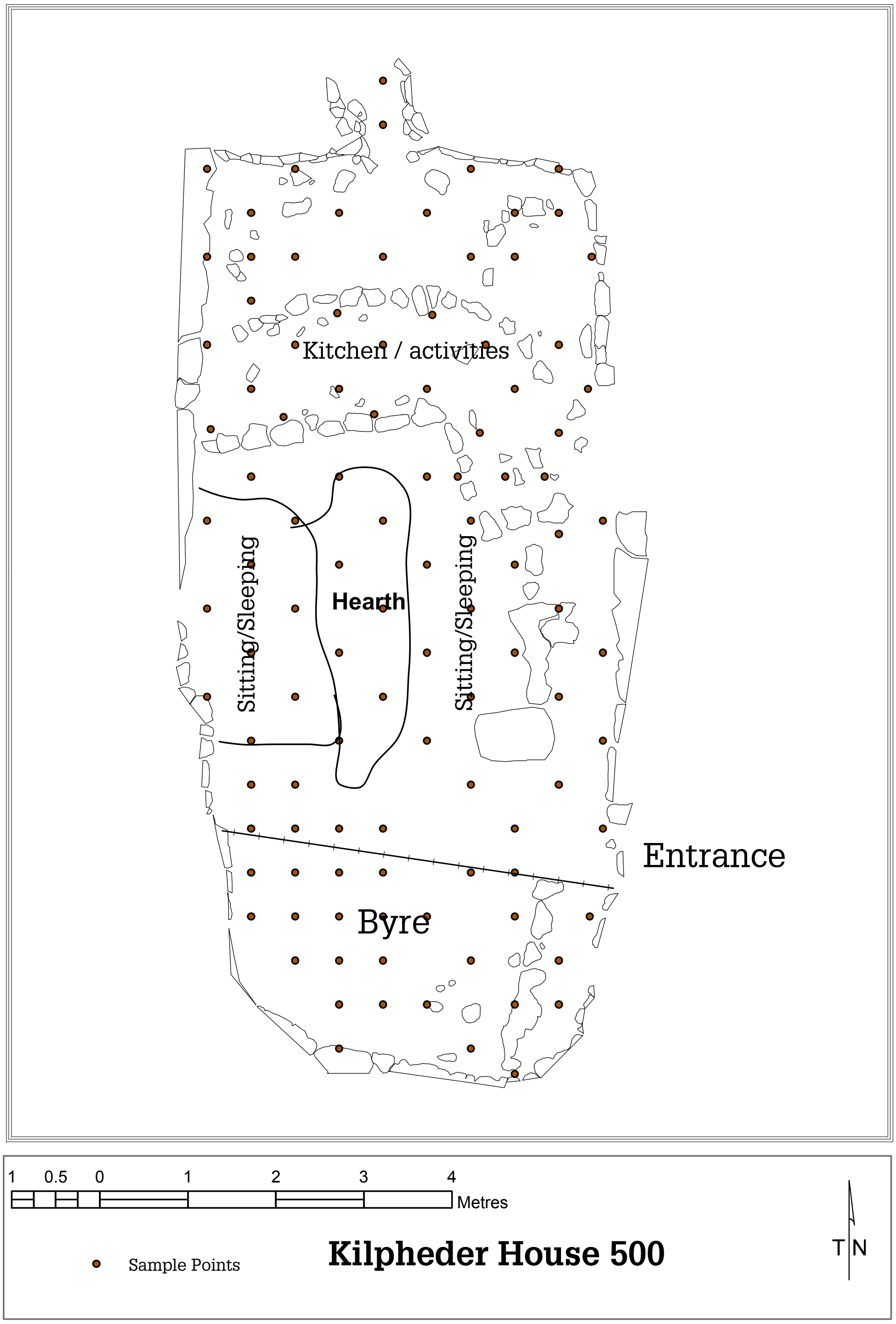


Figure 5. Kilpheder House 500.(after Brennand, Parker Pearson, and Smith 1998:Figure 9)

Cases 2-14: Survey tri-partite models

An expert model (Figure 6), formed of the microscale view of wider thought in regard to Norse longhouses was captured in the form of a survey. This yielded twelve spatial models from experts in the field on the hypothesized use of space within longhouses in the Norse world. Included were material distributions that would be expected to be encountered within the hypothesized uses of space. Each of these models would be formed from the many years of experience and knowledge that come from the excavation of archaeological sites and the digestion of literature on the subject. As each of these formed the perceptions of just one individual, an over-arching Cognitive Model was formed through the conglomeration and synthesis of all of the surveys into one form. Further details on the creation of this testing toll can be found in Section 3. If Kilpheder House 500 is indeed a tripartite longhouse, then the expected distributions hypothesised in these expert models should offer some of the strongest correlations to the use of space as demonstrated through the distributions of finds. As such, each of these expert models is, in a way, being tested themselves to see if they will fit against a 'real world' example. Juxtaposed against this will be the most opposite forms of structures that could be expected-roundhouses. .

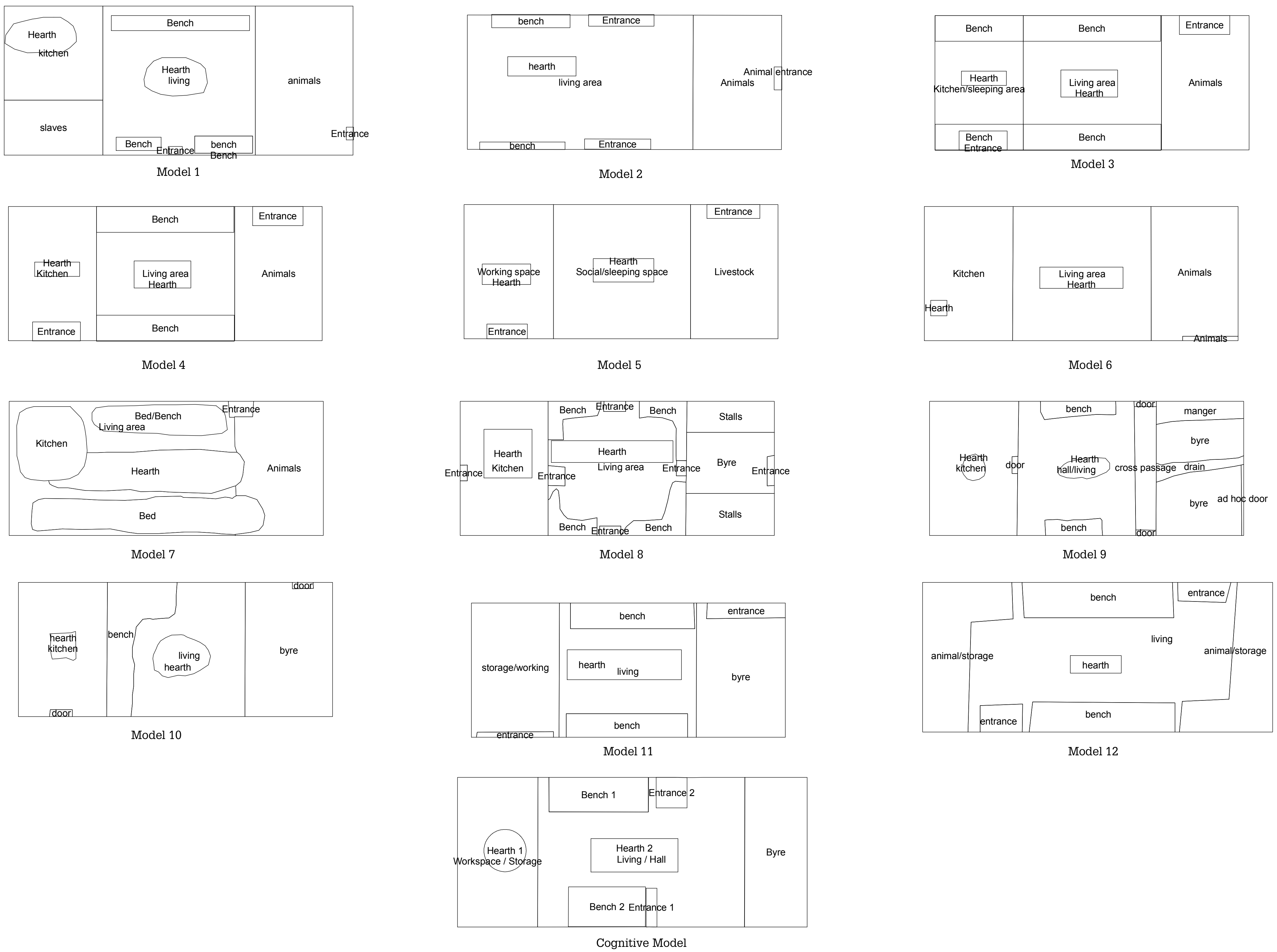


Figure 6. Cases 2-14. The tri-partite models

Case 15 Black Patch Hut 3

Five hut structures were excavated at Black Patch, near Alciston, East Sussex (Drewett 1979). Although at first glance it seems unusual to include a case study that is not a longhouse, Black Patch Hut 3 contains the most comprehensive interpretation of space for a roundhouse with well-plotted finds, features and a radiocarbon date (+/-1060 BC). The hut was some 8m in diameter and cut into a terrace. Finds consisted of bronze, pottery, loom weights, flint flakes and fire cracked flint. The main mass of pottery discovered was in the north-west and north-east of the structure. Within the north-west of the structure area three pits were encountered and this together with the pottery indicated an area of food storage and preparation (Figure 7). The distribution of flint flakes was mainly massed over the middle of the structure from west to east and at the far end of the hut directly opposite the entrance. Expectantly, the fire cracked flint was mainly found hear the hearth area although there was and abundant amount found in the far north-east in the same area where larges amounts of pottery was recovered. Together, this may indicate a secondary food preparation or consumption area. These were used as evidence to show that the hut was roofed, as no full evidence was found of post holes that would indicate construction methods. Moreover, it was thought likely that this indicated the importance of this structure amongst the small nucleated settlement and was thought to have formed the structure where the head individual would be along with most communal social activities. Hut three also had a clearly delineated doorway and a hearth feature. With one side of the hut dedicated to storage, the middle formed of a cooking area; this meant the eastern side was likely to have formed other social activities. It seems highly improbable that strong correlation would be found between this structure and that of Kilpheder 500 but its more rigorous examinations should offer insights into the more local examples described below.

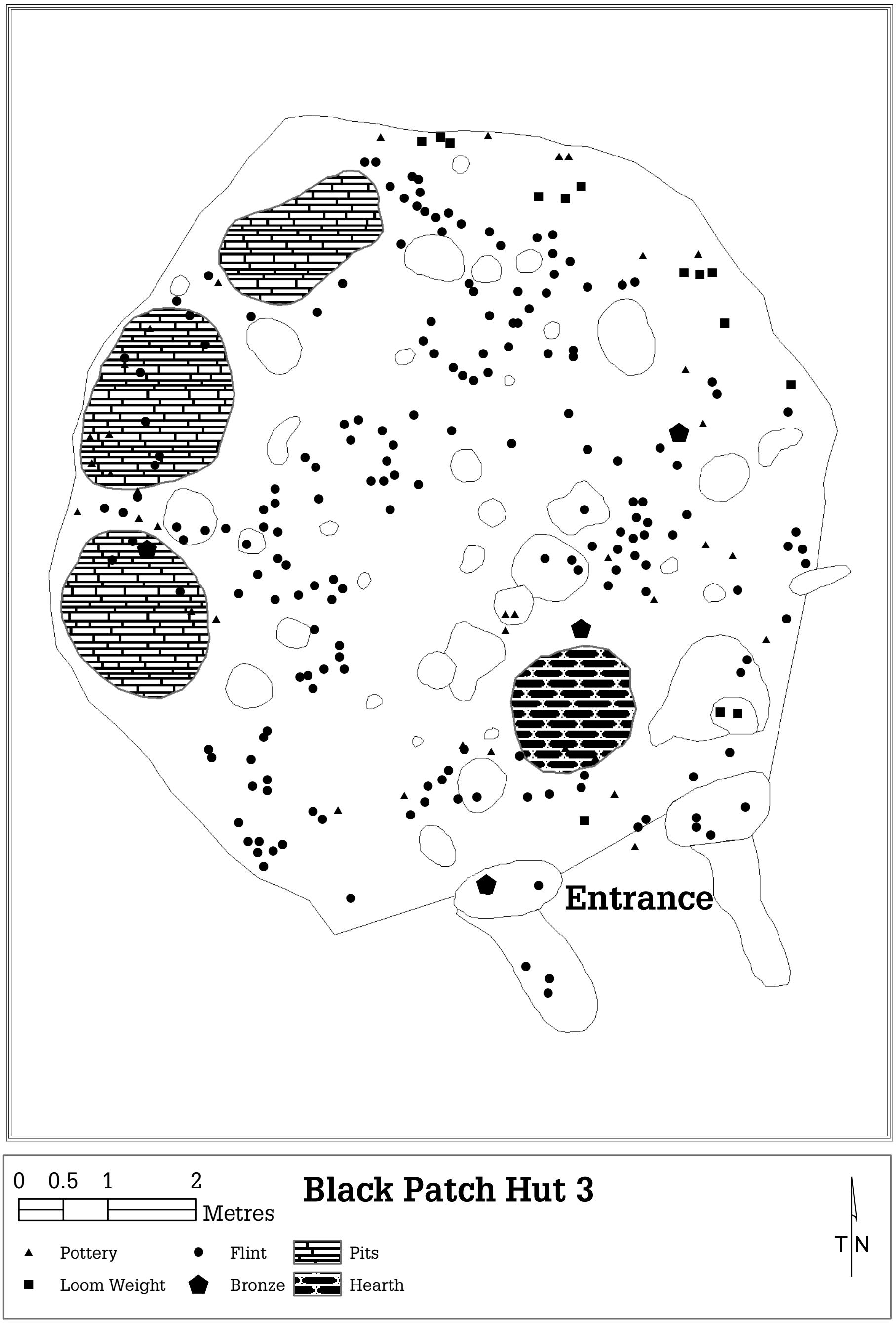


Figure 7. Case 15: Black Patch

Case 16 Catpund

The site of a prehistoric house at Catpund, near Cunningsburgh, Shetland, NGR: HU 4242 2725, was excavated in advance of the potential mining of steatite in 1988 (Ballin Smith 2005). What was found was a roundhouse structure of probable late Bronze Age to early Iron Age date (Figure 8). Recorded in the structure was a stone storage box, hearths, a drain and intact floor deposits. These floor deposits included ard points, various stone tools, stone bars, quartz, steatite and pottery. The focus of the post-excavation programme was upon the function of individual finds and no common linkages were established as "the individual artefacts have produced little information on the function and chronology of the house" (Ballin Smith 2005:42). The size and shape of the house and the nature of the tools were used to establish a date for the structure. However, the research programme was not able to discern the full uses of space of the structure from the evidence encountered.

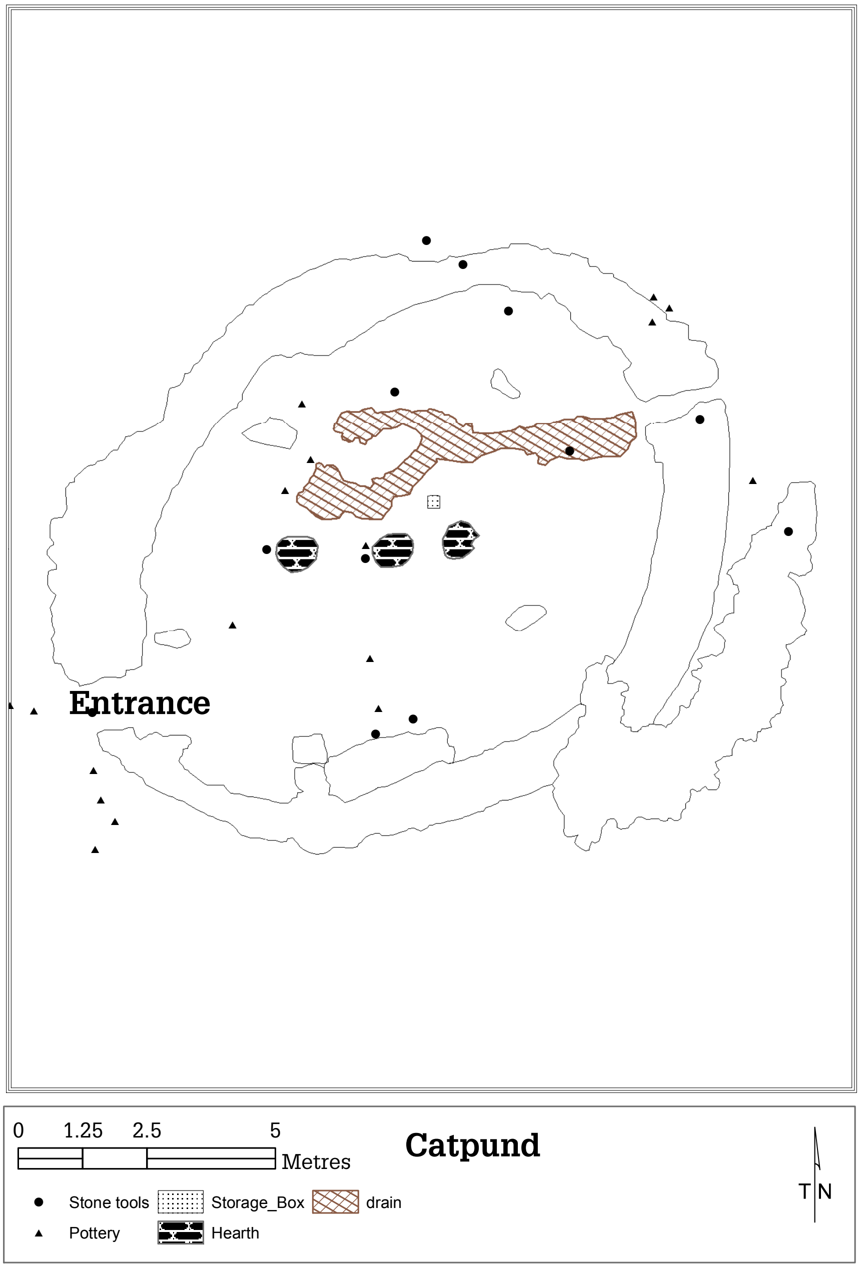


Figure 8. Case 16: Catpund

Case 17 Sollas

Sollas represents an example of another precursor to the longhouse tradition in the north of Scotland- a wheelhouse excavated by R J C Atkinson in 1957(Campbell 1991). With both an abundance of pottery and radiocarbon dates from the first or second century AD, the wheelhouse was firmly dated to the Hebredian Iron Age with a location on North Uist (NGR NF 801 756). Sollas represents the closest structure with true chronological and geographical proximity to Kilpheder House 500 on South Uist. The wheelhouse was formed of 14 cells and the apparent ritualistic deposition of animal burials was linked to some unexplained activity (Figure 9). The locations of bone finds, unburnt animal bone, animal burials, and pottery were recorded mostly around the hearth and in greater densities in cells 8 and 9. Also, there was a hearth near the centre of the structure, located near a well. These two factors alone indicate that this area was likely a place of food preparation. It is thought that prior to the wheelhouse there was a roundhouse on the exact perimeter of the structure.

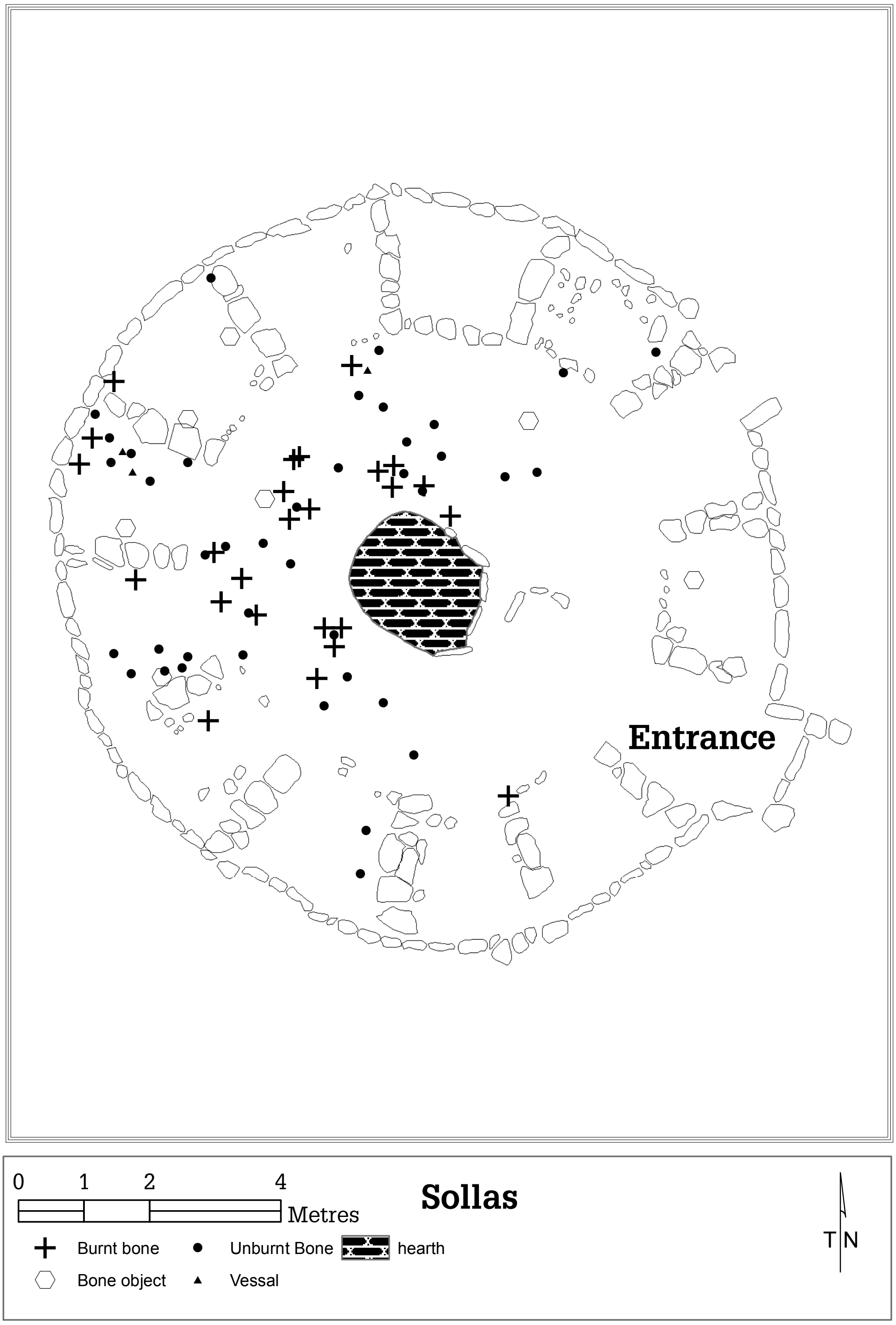


Figure 9. Case 17: Sollas

Cases 18-21 Stenness Houses 1, 3, 6 and 10

A further four examples contribute as comparative examples of non-rectilinear structures in the form roundhouses 1, 3, 6 and 10 from Stenness, Orkney (Richards 2005). These monuments represent just a small part of the larger investigation at the site which was in an area of known monuments from many phases.

For House 1 (Figure 10) all of the lithic material was derived form a single clay context with many of the finds placed around the hearth. The finds were of an apparent event distribution in House 3 (Figure 11) and almost wholly, with one except of a piece of flint, to the east within House 6 (Figure 12). The placement of the finds within House 10 (Figure 13) were almost exclusive to the area around an entrance and the opposite side of the structure.

All of the case studies have two common features with Kilpheder House 500. The first is an entrance and the second is a hearth. These two features will be crucial for testing any uses of space that can be evidenced through the final deposition of finds. Broad classes of material have commonalities in all examples. In order to simplify matters for this demonstration of a tool that can be an aid to archaeology, two classes of material that may have linkages to food preparation were compared. The first is that of food storage or cooking in the form of pottery or steatite. The second that food preparation prior to cooking would be represented by flint tools (Black Patch, Catpund and Stenness) or unburnt bones (Kilpheder House 500, the longhouse models and Sollas). These are things that all of the case studies have in common and it is on this basis that they shall be compared using an application of relativity.

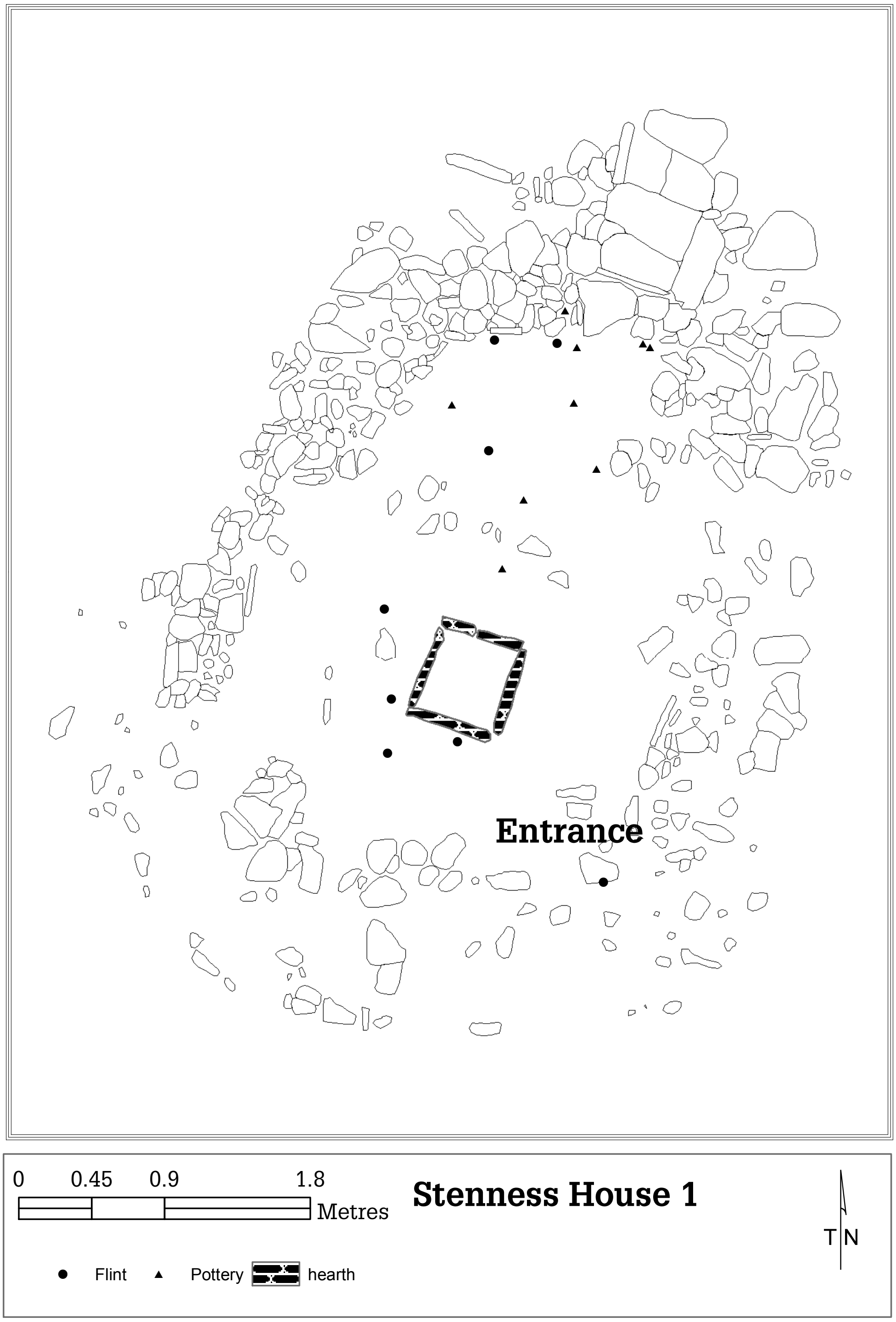


Figure 10. Case 18, Stenness House 1

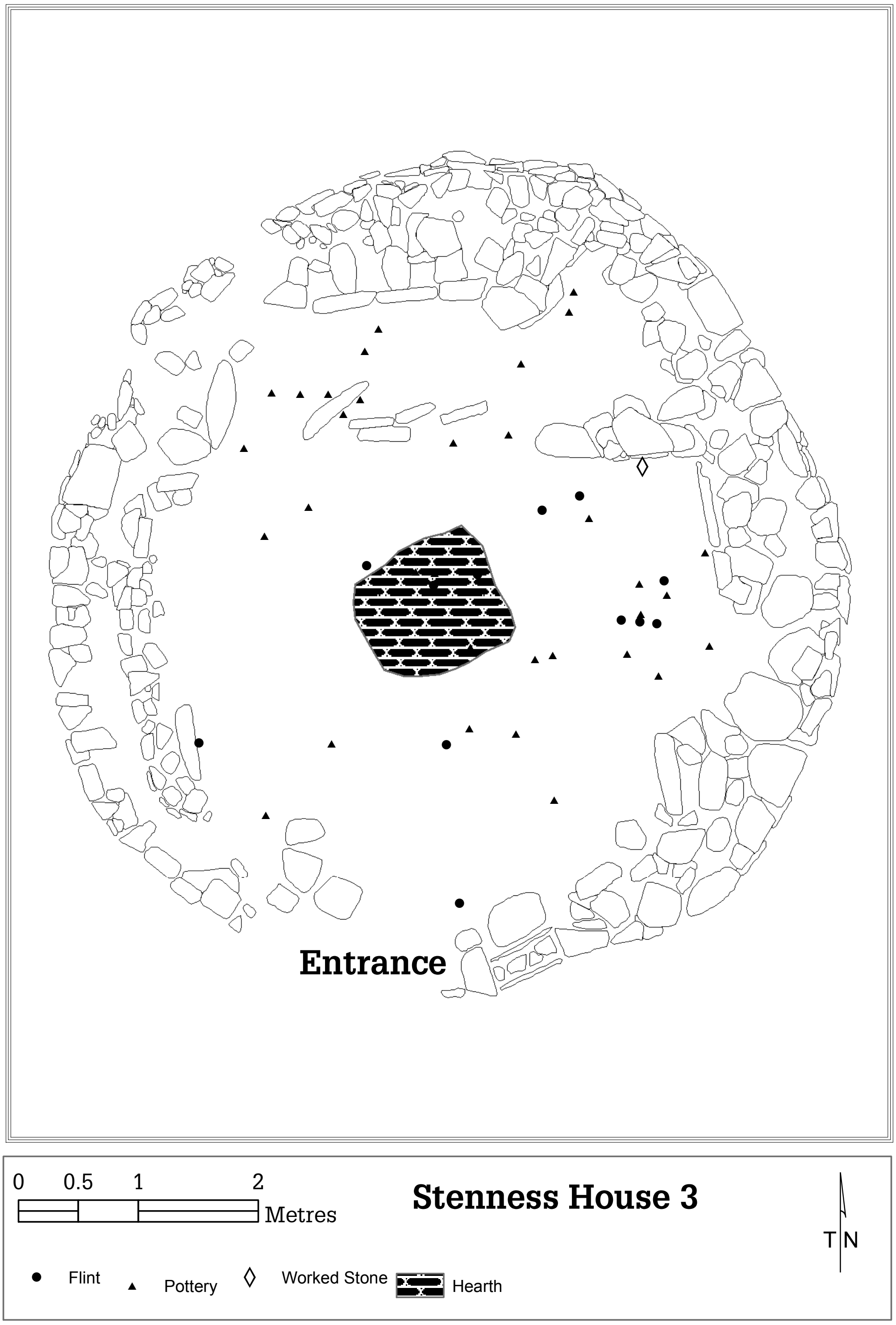


Figure 11. Case 19: Stenness House 3

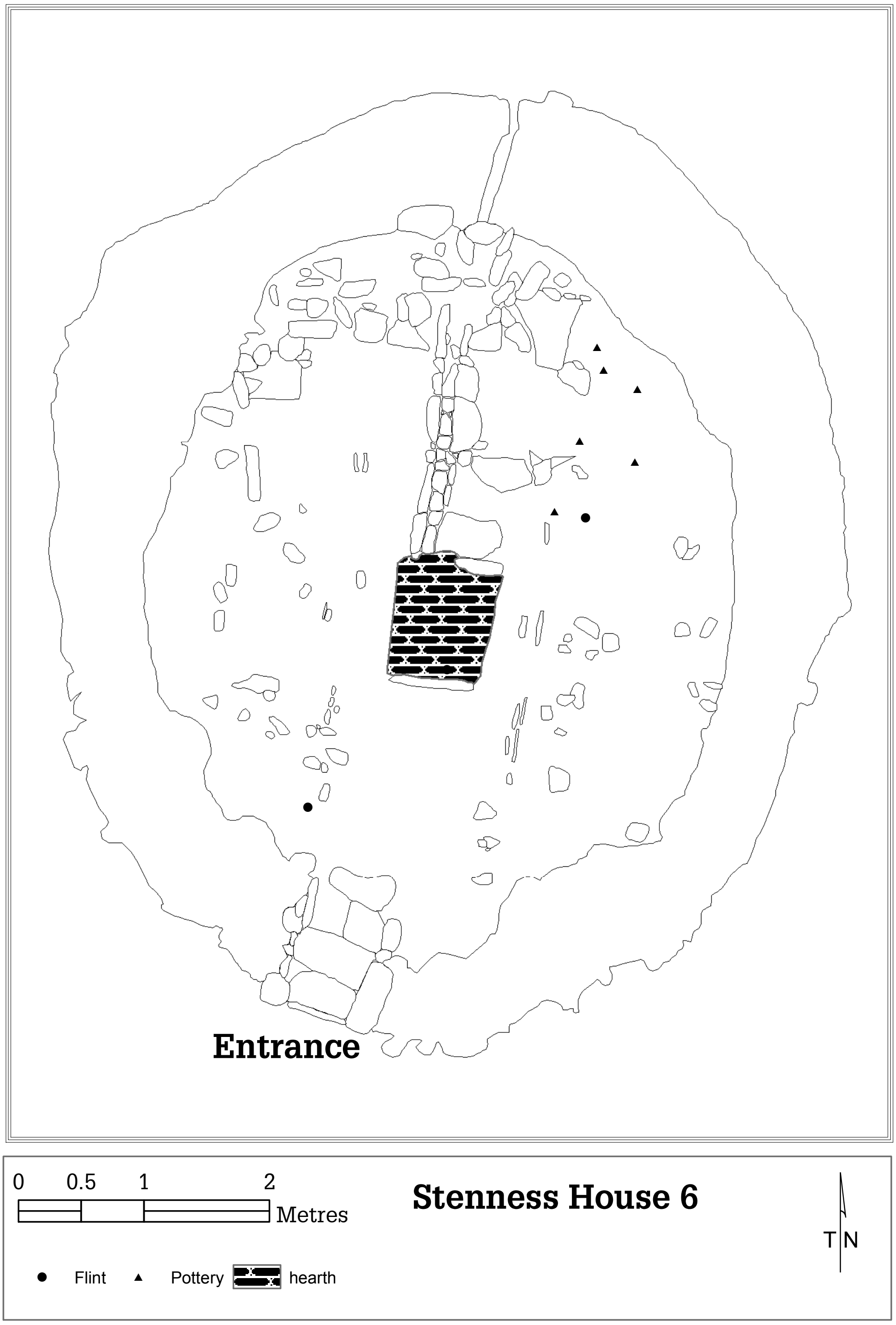


Figure 12. Case 20: Stenness House 6

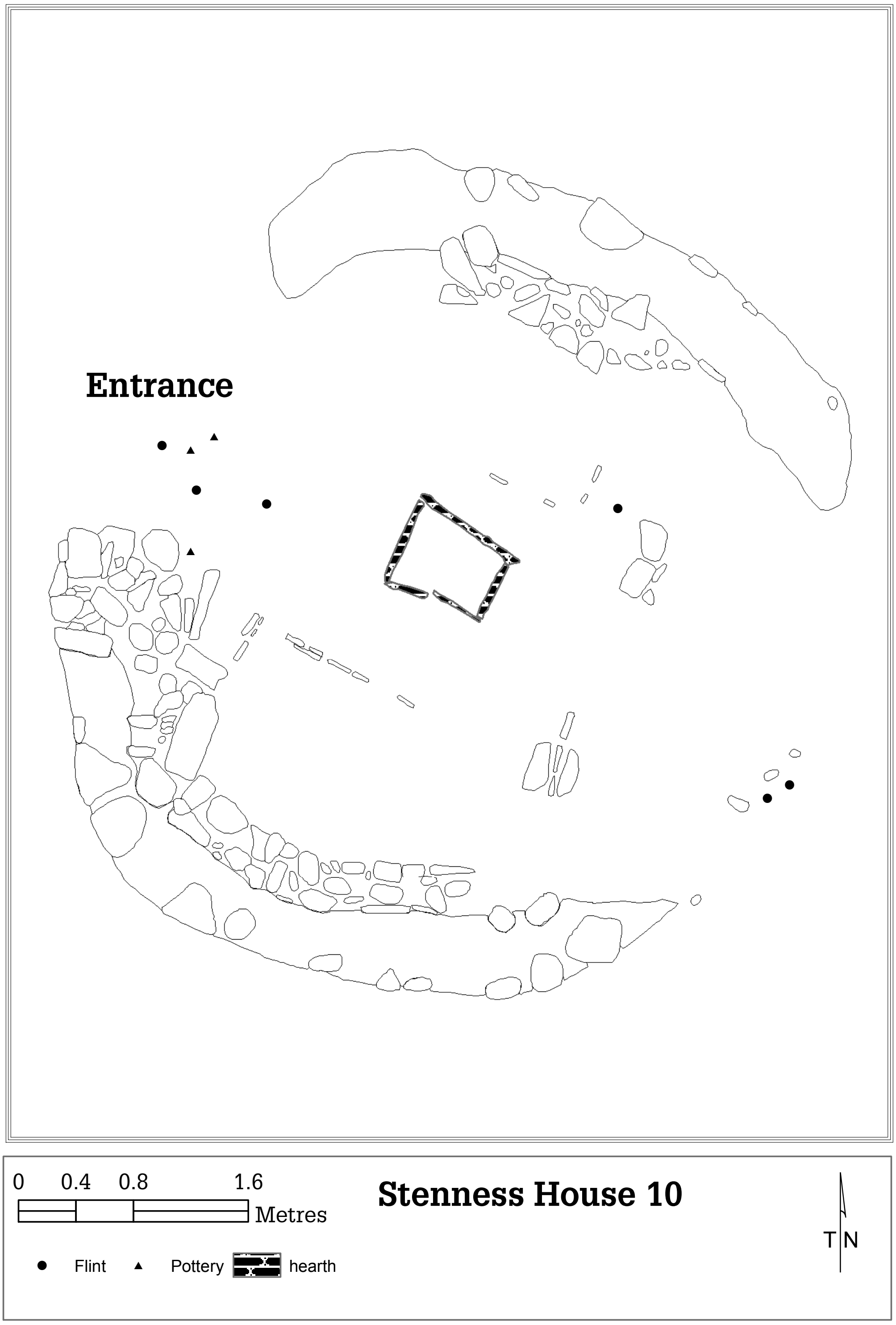


Figure 13. Case 21: Stenness House 10

1.7 Conclusions and thesis structure

The above section has established a new application for old scientific principles based on a philosophical extension of Einstein's theory of relativity for Space-Time. With Einstein's quantum physics, space and time are relative to the observer and any vector on which they may be moving (Russell 1985). A popular explanation is the example Bertrand Russell's gives of how a swarm of bees is in flux so that it is not possible to distinguish a large swarm far away from a small swarm nearby. Space is relative to the observer as visual cues still point to a swarm. Although this was largely used to explain Earth's position within the expanding universe, it introduces the concept that a change in perspective can be used as the basis for the comparison of similarities. As detailed above, other disciplines outside of archaeology have adopted the terminology as a means to understand that which is being observed through the fixed frameworks implicitly tied to the observer. The case studies that will be used to determine group membership of Kilpheder House 500 as a Norse tripartite house were presented above. These include expert models as representatives of what could be expected and, at the opposite end of the spectrum, the inclusion of round structures which have no apparent similarity to the architecture of longhouses.

The following section will detail some of the developments into the study of longhouses and the use of space in general. Thereafter, section three will go through in detail how relativistic methods will be enacted. This will include further details about the survey created to form the models used as Cases 2-14. Moreover, a further technique created for this study, a Selective Centric Morphology, will demonstrate how the transformation of data around theorems of archaeological understanding through mathematical invariance can provide results that can be positively linked to archaeological interpretations. The results will then be presented at the end of this section followed by a discussion of the results in the concluding section of this thesis.

Section 2: Social space and houses

2.1 Introduction

The intent of this section is to provide background to the main case study, Kilpheder House 500. As this is a hypothetical Norse longhouse, the primary focus will be upon longhouses and the study of Norse structures, specifically within Scotland. Much of what has been studied about longhouses within Scotland has focused upon the Norse settlement of the North Atlantic. It is through this medium that much of what we know about the use of space within longhouses has been built-up. As such, the Norse habitation of the North Atlantic will form a great part of this conversation.

It would be hard to discuss longhouse archaeology without at least acknowledging how the methodologies and motivations of excavation have affected what we know about Norse society and associated structures. As much as defining space within a house is important to our current understanding, the motivations of those of the past is also worth understanding for why or how they were attempting to understand the past. To analyse these, excavation/observations have been arranged chronologically between major philosophical movements in society as previously employed by Sherratt (1996: Figure 1) and Darvill (2005).

Table 1 below shows a brief synopsis of research into research of longhouses, and the Norse expansion into the North Atlantic. Perhaps the best way to understand how researchers were influenced by diametrically opposed contemporaneous cultural forces.

Table 1. Diametrically opposed contemporaneous cultural forces and the study or the Norse (after Sherratt 1996).

Renaissance (classical revival) 1400-1700	Sagas published Stefánsson's map of the Viking World Edege excavates Hvalsey (Greenland)	Reformation (Roots of Northern peoples) 1650-1800
Enlightenment (Comparative ethnography) 1750-1850	Scott names Jarlshof Det Kongelige Nordiske Oldskriftselskab begins systematic mapping of Norse sites.	Romanticism (Volkgeist) 1800-1900
Positivism (Biological science) 1890-1960	Recording of Ethnograpic details. Excavation of Stöng and other sites described in the sagas. Excavation of Scottish sites	Nationalism (Siedlungsarchäologie) 1900-1990
Modernism (Processualism) 1960-present	Application of environmental sampling (after Gene) Reapplication of Ethnographic models.	Post-modernism (Post-processualism) 1990-present

A brief visit to Jarlshof by Sir Walter Scott in 1814 not only gave him a chance to name this site but also to describe romantic images of the area's Norse past in his book ***The Pirate*** (1823). There may, however, have been further motivations for Scott to find non-anglicised connections for Shetland. Scott was not only known as the proto-typical Romantic writer but also as the ultimate patriot for Scotland. By creating links to cultures to the north of Scotland, a common past can be found that is not the result of a relationship with the area to the south of Scotland, England.

Soon after the Napoleonic war, the "Royal Society of Northern Antiquaries" (Det Kongelige Nordiske Oldskriftselskab) in Copenhagen, made efforts to map or excavate as many early Norse sites as they could find in Iceland and Greenland (IIA 2002; Scott 1996:322). This was largely a nationalistic act because the outcome of the turbulent late-18th century was that Denmark lost most of its empire (Scott 1996:322; Stummann Hansen 2001). By emphasising the past, Danish researchers were able to hark back to their great empire. This is much as how the Germanic and French speaking states published great histories on the Holy Roman Empire during the same time period. Work by Bruun in 1894 and 1903 demonstrated that the far away territories in Greenland had the Norse as their first permanent settlers. It should be noted that although there may seem to be links to nationalism, the very fact that sites were excavated as "proof" also conforms to the enlightenment principles of seeking the truth. It would have been just as easy to say that sites were Norse without a shred of evidence.

During the latter half of the nineteenth century and the early part of the twentieth century, ethnographers (*e.g.* Vilhjalmur Stefansson) and travel writers (e.g. Fridtjof Nansen) made their greatest efforts to record the disappearing rural life in what can only be viewed as a harsh climate.

The archaeological research leading to the Second World War took a dangerous turn as sites were excavated as ways to legitimise aggressive actions against neighbours (Arnold 1990). It was during these times that the vast majority of Viking sites were excavated (cf. Stuman-Hansen 2001, Sveinbjarmardottir 1975) and links between all of Northern Europe were created/discovered (Shetlig 1937; Roussell 1934). The first three hundred years of investigations into longhouses may appear to be motivated by a need to assume cultural affinity with other peoples or the past but that is really a simplistic view. In a way, this is a form of cultural relativism as the approach to understand longhouses is only through the dogmatisms of a society and age. Each time period seeks to find the longhouse it needs to fulfil its own its own identity. With Kilpheder, the excavation took place clearly in the post-modern era of philosophy.

However, much of the research has focused tend on the Norse introduction of longhouse type when there is actually some evidence that the Norse themselves may have adapted to other house types elsewhere. Although the work of Smith (1994) can be viewed as attempting to learn more about the Norse through recent subsistence strategies, it may be that these recent excavations may focus too much on house form. For example, in Ireland, there appears to be a roundhouse that saw later Norse use (Sheehan *et al*. 2001). There are also many square houses that have a combination of Celtic and Norse finds. The use of space was not clearly defined in these houses.

2.2 How space can be transmitted

Will the distributions within the buildings show a closer relationship between the Norse longhouse models or the roundhouse forms? Much of this may depend on who built the structure- was it built by the descendants of the people who'd previously built roundhouses adopting a new form through mimetic behaviour or was it in-comers?

An example of mimetic behaviour where house forms changes through transmission of memes was when the Senecas in America changed from their traditional longhouses that housed extended families to two-story log cabins with nuclear families (Shoemaker 1991). This development happened after Quaker missionaries created a log cabin in 1798 on the boundaries of a Seneca village. Within five years, seventeen new houses had been built in the same style as the missionaries by the Seneca as display of status. The end result was a change in the use of space within houses and a fundamental shift in the use of longhouses. Other groups, such as the Yakima, start to use the longhouse only for ritual activities. So, although they no longer lived in the longhouses, the cosmogony that was represented in the building structure of the longhouse was preserved as a space for group behaviour that was no longer part of everyday life. As the introduced form was not an evolutionary change but a meme contagion, as the house form spread to the remaining Seneca within a few years, the social behaviour had to remain in the past ritual space. This same could hold true for Kilpheder where activities, such as the apparent ritual burial of animals at sites such as Sollas, could be extended elsewhere and not evident with the house itself.

Ethnographic evidence from other pastoralist and peasant societies in Europe support the idea of "social identification with a named house group [...] and a high degree of ritual elaboration revolving around the house and its members" (Pine 2001: 443). In modern society, house types trace "descent" through the "ideology of the house" (Sabean 1990: 93). As such, there is a distinction between the type of houses between areas and peoples by the ascription of different names to these structures. In Poland, traditional cottages (*chatupa*) are given preference in rural regions to modern brick houses (*dom*) because traditions state that "a wooden house breathes and keeps people well" (Pine 2001: 447). The interaction between the house and its inhabitants went a step further so that once people were no longer born in their homes, the umbilical cord would be taken from the hospital and buried under the house to protect the baby and link it to the health of the house (Pine 2001). Most of these cottages were two room structures - the black room had a hearth (hence the name) and the white room without a hearth. In these rooms, there was a clear cut dichotomy of actions dirty/clean; sacred/profane and small animals were kept in the room with the hearth until they grew large enough to be placed in an outbuilding and food was constantly kept on the boil. All menial tasks and sleeping were done in the black room. Children were born in the black room and sick family members were brought there to die. The black room represents everything normal in life. The white room was used for storage of precious items and for taking of special meals tied to religious feasts. All rituals in the household, whether it be receiving a blessing to get wed or mourning a recently passed family member, take place in the white room. The concept of half a house being dedicated to ritual in a 'hand to mouth' agrarian society either shows the importance to ritual in everyday modern life or that once equal time was given to ritual in the household. In the modern houses in Poland, white rooms, much like the British parlour, are kept as places to put the best furniture to keep it safe from everyday activity. In Poland the basement has replaced the black room and the rest of the house is left empty until another generation gets married. As such, the profane has slowly taken over the sacred architecturally. This has briefly shown how a pastoral society, similar to the Norse in terms of subsistence strategies, has defined areas within a rectilinear domestic structure by the rituals that are performed within the house. Areas of space were transmitted from one house form to another. This leaves the possibility open that the same could occur with seemingly different forms of longhouses. Ritual does not have to be confined to the observations of the sacred given by Pine (2001).

Sites in the hinterlands of the Norse world were not likely to be different in their attitudes to the use of space than those homes in the home countries unless they were an indigenous product. In fact, it appears that settlers tend to formalise the use of space more towards the ideal as a way to separate themselves from other peoples. A clear example of this would be the structure of domestic life for Anglo-Indians during the time of the Raj (Chattopadhyay 2002). A greater abundance of materials and the ability to start a house anew allowed greater planning rather than an *ad hoc* structure that was continually reoccupied in the home country. It therefore seems important to have the use of space inside and the architecture outside to be identifiable as belonging to a culture. If the architecture does not conform, the use of space appears to work its way around that and adapts to new structures.

Sophie Chevalier's (2002) recent study of modern British and French domestic use of space demonstrates that cultures with similar resources and mass produced items available to them will arrange their structures based on cultural constructs and not on architecture or environment. The implications of this are that the use of space is not likely to change if a population moves or takes over a previous dwelling.

Some early examinations of the use of space in Norse buildings employed ethnographic (*cf.* Roussell 1934; Shetelig and Falk 1937), linguistic (Shetelig and Falk 1937) and architectural approaches (Roussell 1934). As the science of archaeology progressed, descriptions about the use of space came largely from narrative descriptions of where artefacts and deposits were found in buildings (*e.g.* Curle 1954, 1935, 1937; Dahl 1970; Gelling 1970). It has been recognised that processes are often explained at the site level, or compared back to the examples from the homelands of Norse settlers (Morris and Rackham 1992). Bigelow (1992) notes cynically that the houses found in rural settings are often the products of failed habitation sites. Those areas where settlers prospered have continued to be built upon to this very age. The houses left can either be viewed as shells of failure or finite time capsules from the past. Quantum leaps in the use of statistical methods, that could be used to compare houses within the hinterlands, have only occurred recently. Smith (1994) used discriminant analysis of material recovered from middens to examine if biota could be used to prove that ethnographic examples were appropriate in their application to our understanding of the past. What was found was that the evidence of subsistence, and the activities that must have related to this, were consistent between the material evidence and the ethnographic reports. Elements have been compared collectively within geographic areas (*e.g.* the eating habits of Greenland or plant cultivation in the Hebrides). Tests have not been performed to understand how local items may still fall within a larger picture (*e.g.* whether bones on a site with no plant evidence have similar placements within a house to plant materials recovered on a site with no bones).

Price (1994) argues that there are links between the hinterland sites and local variances are the product of perceptions of status. The southern Faeroe Isles appear to have more trade contacts with the British Isles (Stummann Hansen 1992) and consequently have house forms that correspond more closely to the Scottish archipelagos. It should, however, be noted that initial settlement on the southern Faeroe Islands and the Hebrides are closer chronologically than Iceland or Greenland (Brøgger 1929).

In Iceland, for the tenth century sites, there appears to be some clear universal uses of space – the tripartite structure (as extensively described by Sveinbjarnardóttir 1975, 1992). This structure in the tenth century is thought to have been divided by wainscoting. There are benches within a hall, a workspace/living area with possibly wider benches and a storage area. These uses of space that Sveinbjarnardóttir (1975) describes appear to be amongst the main things that would be expected in a Norse longhouse.

It appears; however, that byres were usually placed in an outbuilding in Iceland during this period such as was the norm in Viking Age Scandinavia. The evidence for this is debateable because most of the sites from this period were excavated prior to the introduction and adoption of sample taking for chemical analysis although recent work has reinforced this idea for later sites (Milek 2006). The hearths from the tenth century appear to mostly be long-hearths placed along the central axis of the hall area. Pit hearths or small square hearths appear to have been used in the workspace for cooking (*máleldr* or cooking hearth) or heating (*langeldr* or a hearth for heating) of this area where many activities may have occurred. Most sites have only one doorway near a gable end on a long wall (Sveinbjarnardóttir 1975).

For the 11th century sites, an evolution seems to have occurred. The areas of the tripartite longhouse became antechambers that ran 90º to the longest walls and protruded near the gable ends. It appears that the social hall became the emphasis or large structure. The change in architecture may be environmentally related. Sveinbjarnardóttir (1975) notes a great change from larger halls of stone faced turf foundations and turf walls and large hearths to stone foundations with turf walls. It does appear that the longer the Icelanders lived in their new environment, the more they depleted timber resources. There is evidence that after the initial settlement, the environment grew colder (Ogilvie, Barlow and Jennings 2001) and soil erosion resulted from deforestation (Diamond 2005).

How then does this compare to what is known about Kilpheder? The earlier forms of building on Iceland would appear to bear a close resemblance to that of Kilpheder in terms of the hearth, bench and storage areas. However, the archaeology demonstrates that the Norse were not always partial to combining animal husbandry and social activities under one roof (Milek 2006: 90). That is, the early Norse settlers may not have included byres in their longhouses.

2.3 The Scottish Longhouse

The Scottish longhouse has largely been considered an outside introduction from the Norse tradition. There is no contention that Jarlshof (1956) is a Norse longhouse. It is just misfortunate that the artefact distributions in the most intact structures were not sufficiently recorded to address some of the prescient questions about the use of space. Amongst the first questions to be addressed should be why there is consistency in building shape throughout areas of Norse influence. If the Norse were so good at being "invisible peoples" (Hadley 2002), why did they introduce "new" house forms to environments so conspicuously? Was it just that it was of a capacious design or were there more important reasons for the retention of the longhouse design, even into the modern era? The answer to this must either be that the house form was not so foreign to indigenous peoples or that it held cultural significance with the Norse. If, indeed the longhouses assumed to be Norse were merely the product of Norse influence, and there was no technological advantage to making architectural changes, what archaeologists have found may be an example of mimetic behaviour (*cf.* Dawkins 1976; Blackmore 2000). Other sites of rectilinear structures on South Uist, such as Bornais, do not exhibit positive evidence of a byre. It may be that this is an abnormal structure for this area.

In the north of Scotland, these bounds of acceptable societal normality may be confused. Frequent contact between indigenous peoples and incomers, such as the Norse, has left evidence of buildings that don't always fit within the preconceived notions of what a longhouse should look like. For the other houses at Kilpheder, the walls are not bow-sided and hearths do not always appear to be central. This does not match the Icelandic models which are better documented through the sagas (Sveinbjarnardóttir 1975). When attempts are made to pigeon-hole house types, they do not fit neatly into strict typologies. The methodology that will be described in the next section shall seek to find such commonalities.

2.4 Conclusions

Longhouses can be found throughout the world. Their use may vary, but social functions often prevail in this form of structure. Mimetic behaviour may be an influencing force for both the transmission of architecture (Shoemaker 1991). Tradition influences behaviour within buildings, even if the architecture of the *domus* has changed (Pine 2001). These are almost two opposing forces that may influence the deposition of materials within Kilpheder. One consistency should be due to the monumentality of form that provides a communal area around a functional feature- the hearth. As will be discussed in the following section, the methodology applied will make it possible to directly compare aspects of each site against each other. This relativistic approach will make it possible to take material culture and quantitatively define areas where items appear to be in association together. These areas can then be compared against ethnographic correlation. The last step is to then bridge the gap between the cognitive space and the material culture. To this end, the cognitive survey will be used as a means of comparison against archaeological examples. This is just a bridge between past and present by numbers.

Just as Anderson's (1991) model of nationalism may be used to explain how a body may only be bound together as much as it can imagined, or preconceived, the social uses of space can only be applied so far as the imagination is willing to accept links and commonalties. Each house, each farming family as a business enterprise, will make use of space in accordance with their needs or resources.

Ultimately, the material space, social space and cognitive space must be linked together to produce an over-arching model of spatiality (Skre 2001b). Spatiality results from humankind's interaction with natural space to create artificial space. What the examples have shown is that

A method for testing this knowledge shall be outlined in the following section where the full methodologies employed shall be unfolded including the contributions to the spatial models used as the basis for goodness of fit for Kilpheder House 500. These models will have been formed from the previous excavations of other archaeologists. As such, it is important to understand how the excavation of materials will have shaped these perceptions. Moreover, the processing, and analysis of the resultant data must be explored to understand how this information has been transported into the archaeological dialogue. These themes will be explored in the next chapter.

Section 3: Methodology

3.1 Falsifiability

The fundamental basis for any measurement in modern sciences is the ability to falsify an argument (Popper 1968). Therefore "falsifiability, or refutability, is a criterion of the scientific status of a theory" (Popper 1963:37). If a theory or method is such that it can give desired results from any input, that theorem or method falls into the realm if pseudoscience. Most archaeological items do not fall into the realm of the binarial black:white, right:wrong, true:false, statements. Instead, the concepts of probablism should be employed to make arguments on the basis of hypothesised explanations having a low or high probability (Lakatos 1977). The methodology employed in this thesis will be aimed at providing techniques for examining archaeological data through probablism. This chapter will be subdivided into section detailing the data acquisition from the spatial survey, the transformations used on all case studies and the method of test statistics that shall be applied. As this thesis is a demonstration of a technique, the methods applied were kept as simple as possible to provide greater focus and clarity. When technical items are described, simple step-wise terms have been chosen (*e.g*. calculate centroid than can be followed by those familiar with the software involved without having to describe the minutia of the task (*e.g*. a list of the full steps that must be taken to calculate a centroid). The processes undertaken to produce the results presented in Section 4 are detailed below.

3.2 Data Acquisition: The Cognitive Model and testing methodologies to link social space

In order to form an interpretative overlay, an over-arching model, that Kilpheder House 500 could be tested against. To do this, a perception, or

previous notion, expert model was produced through a spatial survey
As direct observation of re-enactment of longhouse spaces did not appear to be a feasible means of understanding how longhouses were likely to have been used in the past a normal method would be to create a spatial model from the archaeological literature. However, what is excavated is only preserved by what an excavator chooses to record (Carver 1990). Data is lost if it is not recorded. That is, the excavator of an archaeological site is making 'conscious or unconscious' decisions about what types of data to record based upon the retrieval methods chosen (Casteel 1972). Excavators and archaeologists choose the methods considered to give the best results based on what they project they will be interpreting. These interpretations are in turn formed from previous literature and there is almost a circular cycle whereby past excavation produce are used to influence thoughts for the collection of data for future excavations which in turn collect data which is many ways predicated on what is known about past data collections. Eventually the different experiences and exposure to past examples produces different interpretations for individuals.

To test these interpretations, it is necessary to extract the thoughts and perceptions of others in a format that can be tested against a body of data. Conversely, bodies of data must also be tested against established perceptions to see if the processes chosen to aid redintegration are capable of achieving similar measurable results. Subconscious manipulation would be likely to lead to a model that would provide the desirable results to match the status quo and provide an easy analysis to only answer established questions. That is, the ideal model created may be too ideal and have no parallels to excavated sites. This means that despite much effort to develop methodologies that will make intersite analysis of intrasite patterns feasible, none of the techniques may work when applied to actual cases.

Working on the assumption that the human brain is perhaps the most powerful tool available to an archaeologist, a comparison of cognitive perception outputs to other individuals seemed prudent. The traditional methods to compare archaeological sites to see if a building matches a "template" of a set type is to survey the literature. The models that result from this type of exploration must take into consideration taphonomy and excavation methods. This would be much like creating an over-arching picture of a similar object from several jigsaw puzzle pieces from different puzzles. A study was conducted to survey the minds of over 100 people in ten countries who have knowledge of longhouses. This was done to create a quantified model of perception for longhouses and escape the trap of relying on limited anecdotal evidence.

The survey that was sent out resulted in a collection of the perceptions of areas of space within a Norse structure in the hinterlands of the Norse world, somewhere like Scotland (see Appendix A). This form of mapping has often been called a cognitive map (Tolman 1948; Kitchin and Blades 2002), cognitive images (Lloyd 1982), and mental images (Pocock 1973). The respondent rate for returning surveys was less than ten percent. This figure is easily explained because the mental demands in creating a spatial model is the highest order spatial task that the mind can perform (Kitchin and Blades 2002). Cognitive maps take a lifetime to be formed (Piaget and Inhelder 1956) so individuals who thought that their own knowledge may not lead to an accurate ratio scale often sent their apologies instead of a completed survey (for completed surveys and related computer files, see Appendix A).

Each participant was sent a blank outlines of a rectilinear tripartite structure and asked to fill in their idealised/expected use of space within such a structure. If the experience of the individuals, their "soma significance" (Bohm 2003: 158) interaction with the physical world and its descriptions, has varied from this template, participants were asked to express their own perceptions. Once each participant had created a use of space from their own machinations, they were asked to fill out corresponding archaeological material distributions that would be expected for the use of space that they have created. This was done by demarcating quartile ranges of contour lines onto participants expected quartile ranges of the density levels as:

1) Negligible;

2) Low;

3) Medium;

4) High.

One of the keys to this exercise is to guide the type of information that would be useful to this study but to also allow for a free flow of information. As such, there were two 'other' houses supplied for the Norse experts to fill in material types that they would expect to find that were not included in the survey.

Although we have no universal model to explain the relationship between material culture and social phenomena (Fletcher, comments in Kolb 1985: 592), participants were asked to make these links and create a relationship between area, activity and archaeological evidence (see Figure 14, Figure 15, and Figure 16).

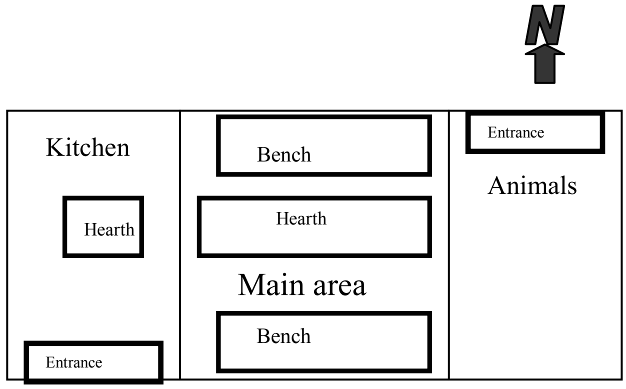


Figure 14. . Example of an idealised uses of space

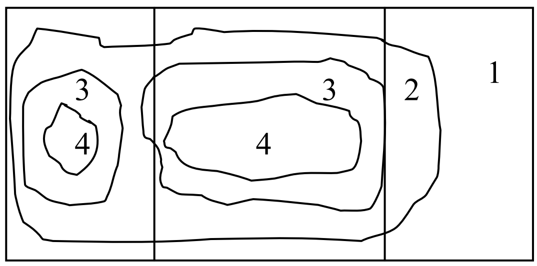


Figure 15. Sample of an idealised charcoal density distribution.

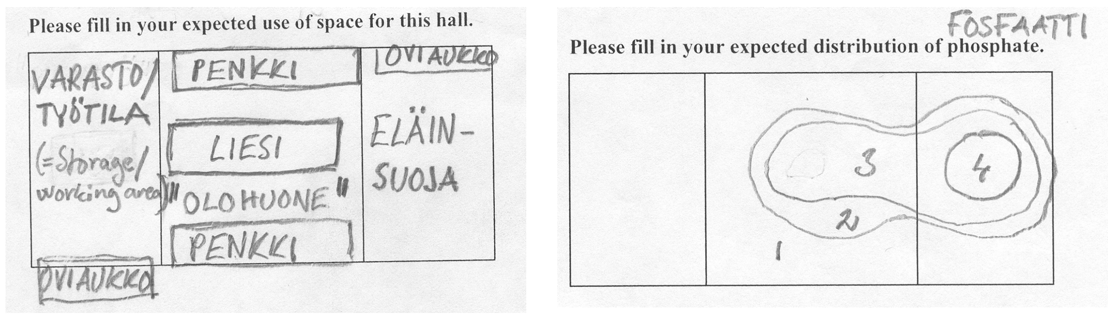


Figure 16. example of a returned cognitive spatial survey.

So, the question would have to remain, what could be gained from this? Surely the arbitrary work of one individual could only have the level of subjectivity magnified when 100 or more individuals asked to create models? This exercise shall create the model that the case studies will be tested against to find conformities to a use of space. Essentially, the process will be more than a mere poll from which to gain perspective but also a mechanism by which we can understand how site data is used to create such models. Another value of such a survey is to encourage scholars to think about what they would expect to find that would indicate a particular use of space. If archaeology as a science is to continue to trade under that logical head, it must first determine what a positive indication of a use of space would be before arriving at any data. Often, we have the data and then try to make a case based upon how some evidence relates to past cases. Although this is a partially a product of the process of not knowing what will be found, the process of data capture should allow some knowledge of what sort of data will is likely to be recovered.

Of the sites chosen, some preliminary models of the use of space have been created by the site excavators. It will be of interest for the general academic archaeological community as a whole to gauge these models against the data collected and the Cognitive Model of what would be expected. The potential of this exercise to bring probabilistic certainty to the association of data with theories about the use of space

The results show the spaces formed within the common psyche of the academic community. Although this does not represent a real site, it shall not only be used as a comparative tool but also as a model that of a single house (microscale) which represents the megascale world of a Scandinavian influenced longhouse. By definition, the megascale view includes the totality of all houses that may have existed, numbering in the unknown millions. The macroscale view includes houses grouped together with their immediate geographic peers, numbering in the thousands, and therefore all of those within Scotland. The microscale view (at the millionths level) is the most intimate view of the world possible - a single household.

3.2.1 Processing the spatial survey

The spatial survey was processed by digitising all of the results from each survey. Essentially, X amount of individual models were formed. Where participants do not feel that their expertise could provide a fair assessment of a material type, they may not provide a distribution map. This would leave a gap in the record.

To overcome this, all of the results will be spatially averaged. The greatest difficulty, from a theoretical standpoint, will come when only one person defines a use of space that no one else does. In response to this, it was necessary to divide the spatially area by the total number of samples to represent that it is only the view of X amount of people. Where cases are in different parts of the house, the centroid of each area in a set group will be spatially averaged to position the area. To determine the area extent, the position of the lines in the drawings was also averaged.

The steps for creating this microscale model were as below:

1. Georectify and digitize all of the surveys
2. Space - centroids and areas averaged as vector files (see Figure 19). Axial rotations determined using Jennrich-Turner axis diagrams calculated to be the separation of use of space repeatable (see Figure 17, below).

Arte/ecofact distributions- Using Principal Component Analysis in GIS 90-95% principal components were represented in a single grid output (see

3. Figure 18). More about Principal Component Analysis shall be discussed later in this thesis.

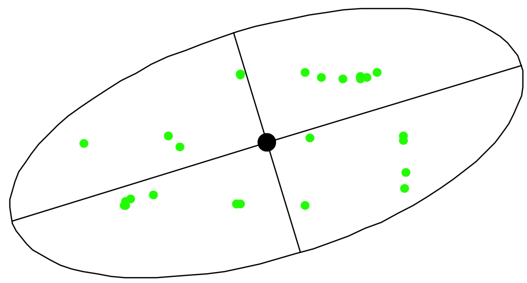


Figure 17.Jennrich-Turner axis diagrams calculated to make the separation of uses of space repeatable.

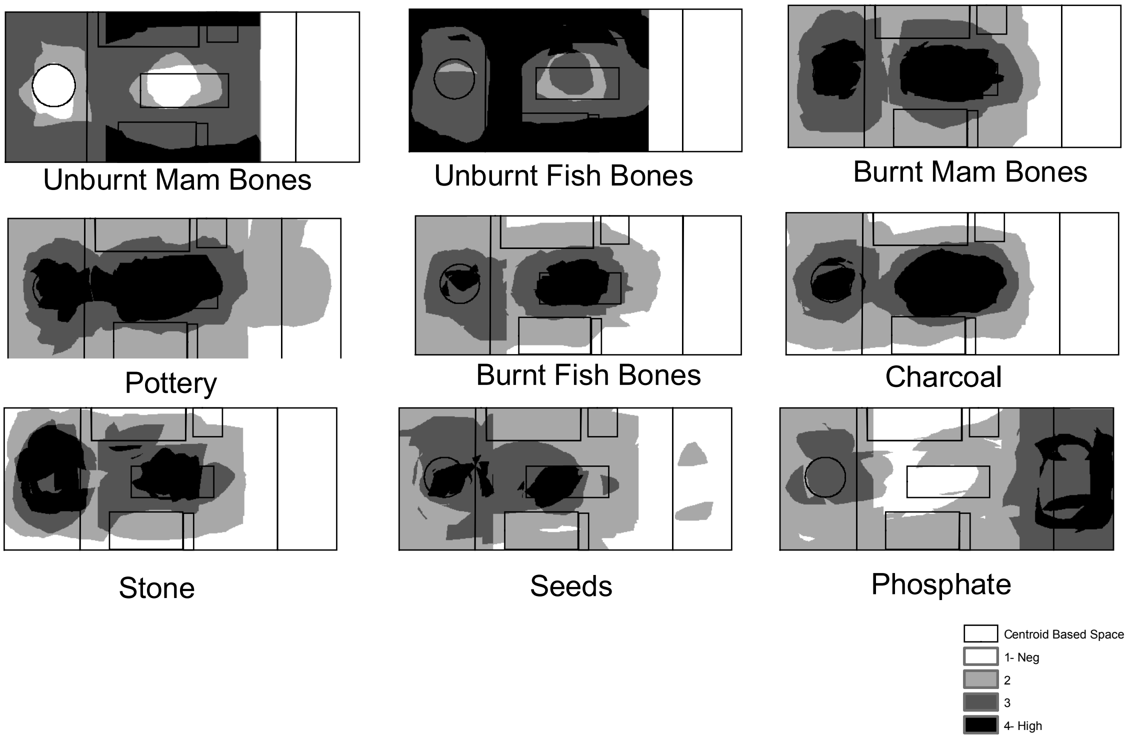


Figure 18. Quartile levels of 'drilled down' distributions from spatial survey formed by PCA

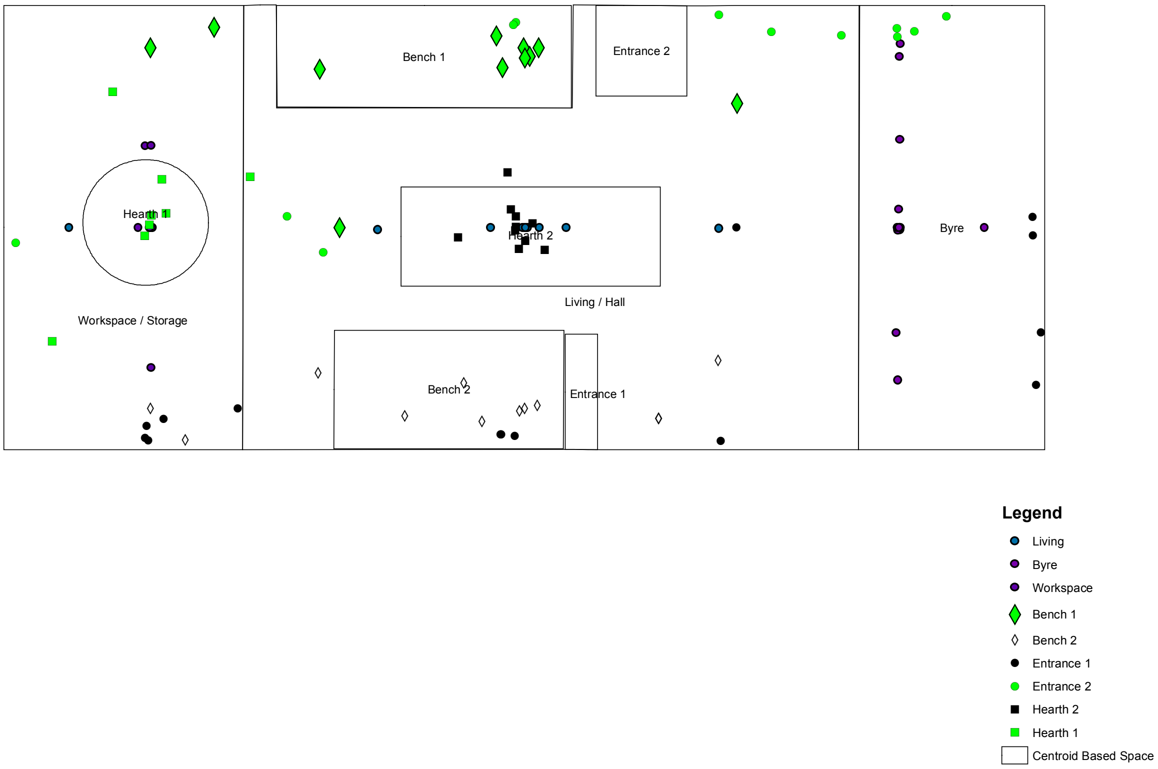


Figure 19. The centroid based space model.

3.2.2 Conclusions on the Spatial Survey

With the Cognitive Model created from a composite of all contributors to the survey, there were then 13 theoretical examples to test against Kilpheder House 500. What was abundantly clear was that nobody truly thought exactly alike. Of the surveys that were returned fully completed, none were identical. Even with the leading suggestion of a tri-partite structure, there was no agreement between the archaeologists surveyed. This led to the creation of twelve individual models. The combination of concepts of several individuals should offer fewer biases. By averaging out the spatial areas, and the expectant values, it was possible to understand more about the archaeological literature and test what archaeologists have learned from past excavations. If there was no relationship shown between any preconceived distributions and reality, the value of what we are learning through excavation must be put into question. It is not just Kilpheder House 500 that is being tested against these models but, in a way, testing to see if what we think we know conforms to a recently excavated archaeological example.

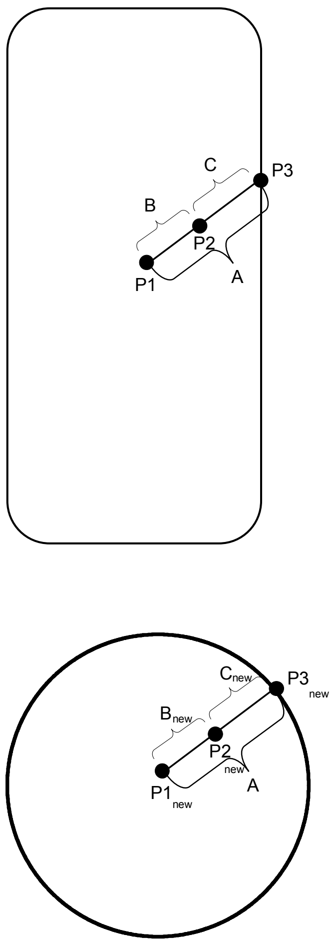
3.3 The Transformation of the Case Studies: Relativity and SCM.

These brief thoughts help guide the direction this study will take. Known architecture will be ignored in favour of the distribution of finds and other attributes for comparisons. As features will not be included as pivotal basis for comparison, it will not be possible to orientate the longhouses upon an axis based upon internal features. When buildings are investigated, much credence is given to the location/orientation of the doorway and its preferred orientation. Discussions often focus upon the rising sun and the light that can be provided within a structure early in the morning such as Fieller and O'Neill's (1982) analysis of Bronze Age houses and Marshal and Marshal's (1994) examination of the location of doorways in Anglo-Saxon houses. As all of the structures have doorways and hearths, these features shall be paramount in transformations. The section below will outline how the transformation of the X, Y, and Z values will not only create a harmonious relativistic transformation but also how it makes orientations to outside factors achievable uniformly.

3.3.1 The methods used to transform X, Y and Z values

After the data has been collected and classified, it has to go through a series of transformations to make the sites cross-comparable. This problem can be solved through the application of an algebraic equation depicted in Figure 20 to bring respective datasets into spatial co-incidence. Forms are altered into a circle because it is possible to make calculations and triangulations based on radians and the constant of π

.



$$P2new = \left(\frac{B}{\sum (B + C)} \right) A$$

$$A = 100$$

Figure 20. Simplified equation of the dot product vector transformations

How the equation operates is to transform all points along a given vector to a new place with an exact relative position within a circle of the same size for all sites. This relies on the relative position of an item from the edge extent, the outer border of a polygon in GIS, the centre of space within the building to a new scaled edge extent. Small nuances of the positions of items within relative space can be discerned. Within GIS, this equation can be extrapolated to gain the initial location through the triangulation of the envelope centroid and its azimuth north and the horizon perpendicular to this vector, of a given point relative to a boundary polygon file (see Appendix B for the script for use in ArcGIS). It was also necessary to make the azimuth of the circle aligned with a characteristic that was on the periphery of the boundaries of all of the cases, the main entrance.

3.3.2 The transformation of Z values

It was chosen to transform the Z values into quartiles after Bachelor's (1997) mapping of Stonehenge. Often, data transformations take the shape of skewing a dataset from an irregular distribution curve on a histogram to a regular distribution so that test statistics can be performed on it (Shennan 1997). This may, however, make it harder to test for differences because skewing one dataset and not another can invalidate results. With spatial data, it is possible to perform a transformation that keeps the three-dimensional relationships between X, Y, and Z values relatively intact.

In the past, quartile ranges have been used as a method to compress the density of archaeological materials in a landscape into categories of High, Medium, and Low (cf. Batchelor 1997). For intrasite analysis, the normal statistical method would be to include all of the sampled population (*i.e.* all of the data from the floors and houses compared).

This would just exacerbate the problems of cross-comparing sites because high levels of one material at one site could skew the results for all of the data even when items are visualized by kriging the results to show a general distribution.

However, if each layer was treated as a select population, then the quartile range of that layer could be calculated on its own. Each occupation layer of a house can be regarded as another house or combined as a general use of the building (both will be tested for differences). Although this may make less statistical sense, it does make archaeological sense. Although taphonomic factors are hard to account for, high levels of a material type at one site could be just a product of local availability (Chartrand 1996).

In the grand scheme, people are likely to have used areas in much the same way but the availability of material types may be most affected by their own spatiotemporal environment. With the aid of ArcGIS, it is possible to use an industry standard algorithm to sort items into quartile ranges so that individual biases could be decreased.

Four quartile ranges can be defined as:

1 = negligible;
2 = low;
3 = medium;
4 = high.

It was thought that this would allow for the comparisons of spatially distinct areas that are similar in form (*e.g.* buildings of the same shape that contain many of the same features). Although this may eliminate outliers, masking some of the variance in the data, four levels make it harder to have purely normalized data as would be possible with an odd amount of variables. The problem with using just this method is that it is only good for demonstrating the distribution of one material type at a time. If the average density of all material types is compared, it will only be good for showing where the most materials have been deposited and may be an indication of site taphonomy and not the use of space. To this end, a method, below, has been considered to show the effect that one material type can have if used as the primary derivative for summarising the distribution of all material types.

The treatment the data commenced as follows for the creation of the relativity models:

1) digitize the locations spots where samples were taken or finds were recovered;
2) create a polygon boundary file that maps the extent of the interior floor surface ;
3) add a value of '0' to the boundary polygon;
4) convert a copy of the polygon into points;
5) copy of all points into new shapefiles, to preserve the original extent, and open in a new project;
6) add the boundary polygon, placed over the top of the points;
7) run the transformation script to produce the points in relative space- this will calculate the above formula with the point (0,0,0) created from the point where the centroid of the envelope of the polygon lay;
8) check to make sure that the boundary polygon has been converted to a circle around the new points and convert this to polygon a polygon file;
9) using the rotate tool, place the centre the door as the northern most point of the new polygon of space;
10) If samples were used to recovered density levels, proceed to step 11. If not add the value of '4' to the point file;

11) create a 3-D TIN (Triangulated Irregular Network) file from the points and polygon with a hard clip to the edge extent;
12) convert the TIN to a raster grid;
13) reclass the values within the grid to levels of 1 to 4, based upon the distributions within a quartile (using the quantile algorithm).

All of the Case studies have been transformed to in this way to relative X, Y and Z values for later spatial comparison. The creation of the Selective Centric Morphology model has a slight variation and used a different script in its execution (see Appendix B for the ArcGIS script). Instead of the script calculating the centroid of the boundary defined as a polygon file, the script requires the user to user to perform the following steps in addition before running the script:

1) Calculate centroids of all polygon shapes of known features, in this case the hearth, and generate a new point file that marks these centroids;
2) Using the selection tool, select the centroid point of the hearth *and* the boundary polygon that contains the points to be reprojected. The polygon must be ordered on top of the point files in the screen view;

An example of this process can be found in Figure 21, below. The selected points used in the calculations for the example here was the centroid of hypothetical storage areas in four different shapes.

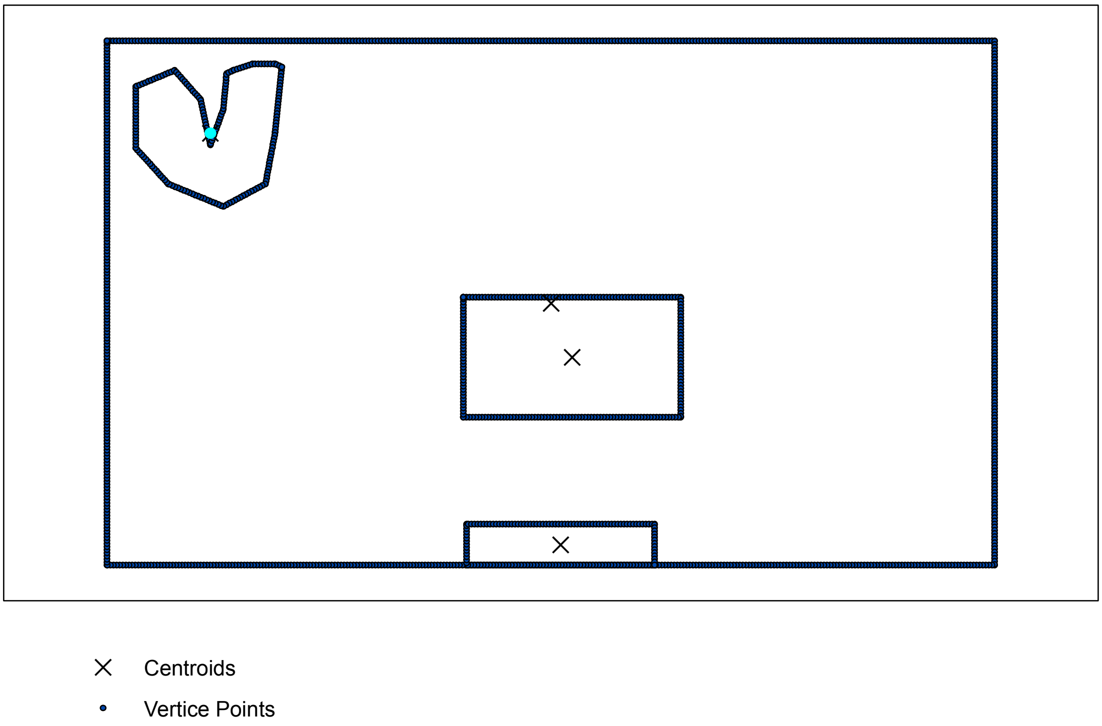


Figure 21. The Centroids of polygons in an example and the selected area for transformation by SCM

This will allow the SCM script to be run so that the selected point is altered to position (0,0,0) and the distance to the edge boundary becomes the new maximum value. How this works in transforming shapes can be view in Figure 22, below. Here, it is possible to see the differences between the two forms of transformations.

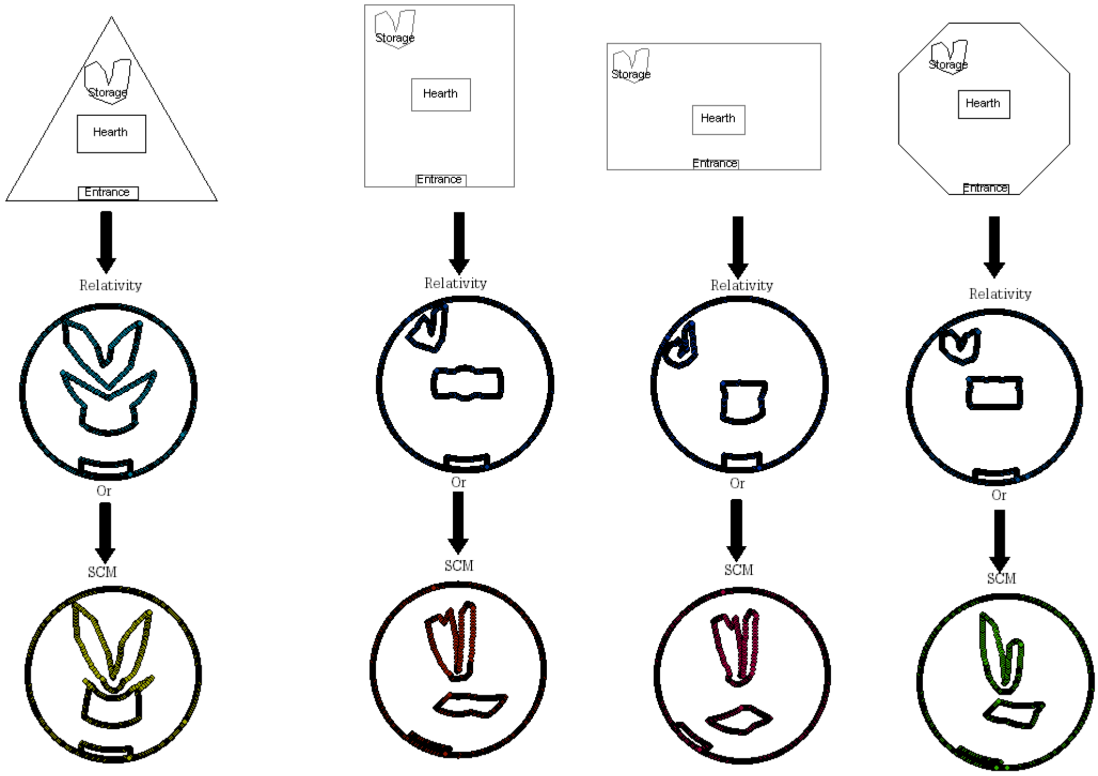


Figure 22. Transformation of shapes by Relativity and SCM scripts

What is most apparent is that with a calculation of relativity, the proportionate representations of the features remain constant in the transformed shape. With SCM models, the new centre of the reprojected space is form from what be characterized as an invariance, rather than strict relativity. Invariance is more similar to reprojecting a map and has the side-effect of stretching areas disproportionately from the edge to the centre (Ma, Soatto, Koˇseck´a and Sastry 2004). The net result in the example give in Figure 22 is that storage areas in four SCM examples gains a higher proportion of importance in any resulting calculations. When testing to see if an area is a focal point of activity, this method gives greater weight to the areas under investigation. This means that the selections in this study, the centroid of known quantity shared between all cases, a hearth, will act as this centre point. For some cases, Kilpheder House 500, Model 4 and the Cognitive Model, the centroid of the hearths were the same as the boundary for the structures. For all other cases, two sends of grids were created for making comparisons in both relative space and SCM space.

3.3.3 Analysing Space

With the distributions transformed into Relative or SCM spaces, the next step is extract data in a uniform fashion. Here, GIS shall be used for the analysis as well. With its myriad of codes and commands, a GIS novice drawn by the gleam of a new tool can soon be lost to confusion (Zubrow 1990) or deluded from practical reality (Miller 1996). Perhaps archaeologists have avoided relying on GIS as a main source of analysis because one could fall into the trap of placing too much emphasis on computers as an "end to themselves" (Henderson 1991 201) without giving enough thought to the proper employment of GIS as a tool. Equally, the use of GIS as a tool is often unnecessary and misleading (Miller and Richards 1995) so it is perhaps best employed in niches where it is the most appropriate tool for the task.

It is for the above reasons that more traditional methods of statistical analysis have often been used. For example, Galanidou (1993, 2000) used cluster and correspondence analysis to compare areas of a site with one another. This largely involves building a model of an area and testing it to see which areas fit with in a certain range. Correspondence or discriminate analysis can then be used to test whether the outcome indeed represents statistically linked groups. The same techniques have also been employed to analyse associated grave goods (*e.g.* Hugget 1995). Some useful methods that have been used with GIS or other programs capable of plotting items is to show displays in ring, sector, trace line, or density analysis. This method is useful for showing occupational patterns within buildings because it is possible to distinguish between areas of a floor visually. Boekschoten and Stapert (1996) explored this technique thoroughly and determined that it is usefully for a qualitative assessment. Smith (2001) also showed that this technique was useful for determining how individual floors may have been used. One problem with this method is that the more data that is included, the harder it can become to distinguish what is going on in the site. Items must be looked at individually as the human eye cannot distinguish what is clustered and which items truly correspond. Examples of this sort can be found almost anywhere as most modern excavations employ some for statistical analysis. All of these methods are acceptable, but they do not answer one important question – how do the areas relate to each other?

Kvamme (1993) has demonstrated that examining the spatial distribution of archaeological materials by attribute can contribute to rigorous interpretation of a site. One tool that can be used to perform forms of spatial analysis of archaeological materials is GIS. Most previous applications have used GIS to investigate larger geographical trends.

3.3.4 Uses of GIS for Intrasite analysis

This is where statistics can set the bounds of high and low probability or determine if one item has a closer relationship to another. In broad terms, prior to the 1960s, the main quantitative method applied in archaeology was seriation (Orton 1992). The use of descriptive statistics as evidence for arguments has increased but probability has largely been ignored. At first, archaeology borrowed statistical methods (*e.g.* cluster analysis; Hodson 1970), that had previously been used to describe biological phenomena. Many archaeologists feared the emphasis that was being placed upon statistics and argued against their use (cf. Hawkes 1968). The 1960s in America and the 1970s in the United Kingdom brought a new acceptance to the use of statistics (cf. Agrawal 1970; Binford 1964; Whallon 1974) as proponents copiously adopted spatial analytical and sampling methods from other dedicated disciplines such as geography (where, for example, statistics had long been used to analyse census data). The early 1980s dawned the age of turbulent statistical theories that pointed to the faults of all of the past methods with their biological assumptions for non-reproducing artefacts (Orton 1980, 2000). This backlash came just at a time when the computing power finally offered archaeologists feasible capability to employ statistical analytical techniques.

Since this time, there have been sporadic phases of applying probabilistic techniques in the popular archaeological literature but most advances have been left to PhD theses (cf. Locke 1984; Viklund 1998) and limited audiences in specialist journals and thematic conferences. However, most archaeological data would be useful for measuring the strength of the patterns with appropriate statistical tests. As described in Section 1, archaeologists often gather data in the form of samples that can be linked to spatial co-ordinates. Yet, not enough is being done do interpret the data in a spatio-probabilistic format when comparing one sample population to another sample population; distributions are interpreted on an intrasite basis. This has largely been because current methodologies have only been adapted to deal with trends in common between sites (such as whether items are clustered) rather than looking at the relationship between the similar placement of objects (such as where items are clustered.

To answer such questions as to the placements of items, Stancic (1995) used GIS as a display tool to overlay settlement types to show visually, with Theissen polygons, the density of objects and centres of importance. GIS has largely been employed to look at larger issues such as site visibility, landscape use, predictive modelling (*e.g.* Chartrand 1996; Kvamme *et al.* 1988; Kohler and Parker 1986) and modelling past environments (*e.g.* Burton, Hitchen and Bryan, 1999; Burton, 2000).

One interesting use was employed by Quesada, Baena and Blasco (1995) to visualise graves associated with certain characteristics. From this, patterns of change for the site were determined by looking at the plots qualitatively. This is much like Massagrande's (1995) overlaying distributions of materials collected to modern roads and towns to determine why pottery has been collected in certain areas. This plotting showed that items just collected where there were more incidences of modern developments, and hence more data collected.

Again, this application is on the intersite level and not as useful for intrasite analysis. This technique could be employed on a site to show whether goods are associated with a type of feature. However, this was a visual display and although it this good for qualitative analysis, it is not sufficient to produce quantitative results that may build a model to compare the sites with elsewhere.

As early as 1993, Kvamme (1993) performed a t-test on lithics distributed within a site using GIS. Kvamme's results showed that unlike the traditional t-test, a t-test performed on a 'graphical database' (or a picture with pixels containing set values in place of values in a table where spatial relations are kept intact visually) would take into account the neighbouring values around a given point.

Lock and Daly (1999) used GIS to perform a Chi-squared test, which indicated whether the quantity of objects recovered in an area were significantly more than expected on a pottery distribution from a field walking survey. The results demonstrated where significant levels of pottery occurred, beyond the amounts that were expected. Such methods are very useful when examining large areas with open spaces and gaps in distribution.

All of these methods could offer ways to examine data spatially. In order to confine the emphasis of this study to the spatial transformations of by

Relativity and SCM, only one form of test statistic will be used: Principle Component Analysis (PCA)

3.3.5 The use of GIS aided PCA

For more complex methods such as Principal Component Analysis (PCA), studies in archaeology have been confined to the realm of the more traditional tools such as statistical packages. Baxter and Beardah (1995) focused on how to display the complex output produced from a PCA. Past work has attempted to differentiate the components, or characteristics of a given artefact type, by displaying objects in multi-dimensional views. The closer given components are to each other mathematically, the more closely they are related. However, this complex series of calculations largely ignores the spatial relation between objects statistical packages outside of GIS.

In the environmental sector, Eastman (1995; 1996) was among the first to use GIS to examine satellite images for vegetation change over time using PCA. The results were that the trends over the years on a site could show where areas of change have occurred and also how they varied from predecessors. Eastman's output showed areas of negative or positive changes for the various values in the imagery. The images of the seasons that corresponded to each other with patterns of vegetation growth spatially had closer relationships in the correlation matrix produced by Eastman's tests.

One thing of note is that Eastman only applied PCA tests over the same area of a site and did to compare differing areas. The literature in this areas has not explored if comparison of two different areas by PCA through GIS will produce useful results. It is this largely unexplored and experimental method which will be the main focus of this thesis. Most likely the reason that the GIS application of PCA is not used in archaeology is because buildings and landscapes are not always conveniently built upon each other and samples are not always taken from the exact same co-ordinates or at the same distance apart from each other as would ordinarily be expected to perform such a Time-series Analysis. The need to make sites cross-comparable by the types of items recovered through the implementation of random samples has left archaeologists with the inability to fully ascertain the spatial patterning of archaeological materials. Although selective sampling might provide a great opportunity to judge a site qualitatively, it curtails some attempts to perform spatial analysis on objects other than those that get classed as 'small finds'. It is the choices about what materials to recover that ultimately shapes the understanding of what can be known about a site after its excavation, and not just the analytical methods chosen.

PCA is a form of data compression that looks at all variables in an image or grid and collectively compares it again of images in a set (Eastman, 1996). The use of PCA works toward achieving the principle of parsimony. After each material type is tranformed and placed into a raster grid, it can be grouped into a stacked grid. If a PCA is run in GIS, it is possible to gain an output table that shows how each layer corresponds to the other layers in a stack. This is useful for comparing a known quantity to several unknown quantities. Those items that are alike will show a closer relationship to each other.

PCA is very useful for showing areas where there are high levels of correspondence between several layers. It can produce a grid that combines three new layers that contain 95% of all constituents. This creates a clear edge but it does not explain the full combinations, ratios of high and low, where items occur together. In the traditional use of PCA, a correlation matrix is created from standardised variables (such as the quartiles or standard deviations used as part data transformation). If this is not possible, a variance/covariance matrix for non-standardised variables may be used instead.

This matrix will give the cosine of the angle between a central line with the vectors indicating how closely related the items are to each other. This line forms the basis of comparison to other characteristics under consideration. To arrive at this angle, it is necessary to take the arccosine or the inverse of the cosine to produce the angle in degrees. For example, if the cosines for three characteristics are 1, .55, and .5, there is a perfect correlation and two items that are closely related to each other at 56 and 60 respectively. Every characteristic is compared to itself and the other characteristics under examination. Components with an inverse correlation will be 180 from each other and uncorrelated variables will be 90 from each other. The figures from these calculations, also called component loadings, can be squared and added together to produce what is called an Eigen value. Once this Eigen value is obtained, it can be divided by the number of variables and subsequently multiplied by 100 to produce a percentage that indicates how much of the variation is accounted for by this principal component.

In archaeology, this is most often applied to the use of artefact and material characteristic studies. Whallon (1984) took the results from a PCA of artefact characteristics and plotted objects in a site to describe the spatial distribution along with some other forms of analysis to say how they were distributed but did not use spatial analysis to evaluate these results further. The use of a PCA for spatial data would be an advancement in data analysis.

3.3.6 How PCA was used in this study

Each ArcGIS grid was compared to the next proceeding grids in a sequence as the first part so that a correlation matrix is produced to show how other images/grids correlate to all of the other grids within a matrix. The percentage of variance of the grids is calculated from Eigen values produced from the correlations or variance / covariance matrices.

If the images/grids are unrelated, it would be expected that the amount of variability would be fairly evenly divided. If two objects were closely related, it would be expected to find that the cosines indicated by the correlation matrix will be less than *c.* 90° and the percent of variance, as it correlates highly with other components, would be likely to account for the major aspect of variance of the principal components. The data was not contoured to fill the gaps between sample locations as the computer programme would interpret this as a larger number of samples and would therefore make any results look more significant (Kvamme, 1993). Such visualisation can show an extensive area where materials burnt beyond the Curie point were charcoalized (see Smith *et al* 2001).

After each of the grids were examined in their entirety, there was no apparent strong overall match for entire structures between Kilpheder House 500 (see Appendix C). This method did not indicate where there were areas of strong correlation or disagreement and could in no way indicate a goodness of fit for Kilpheder House 500. To counter this, a ring sector, such as that employed by Boekschoten and Stapert (1996), was overlain on all of the models. This was not just used to help measure angle vectors and ratio placement (*e.g.* 2/3 of the total length from the centre of the hearth at 45° from a plane of observation). Instead, it formed the basis to extract values at the same positions within Relative and SCM space from the grids. The grid was formed of eight pieces of a pie. Each of these pieces was then, in turn, broken into three to provide 24 ring sector pieces or Pie Segments (see Figure 23). Within each of these pieces values were extracted from the same positions on each of the Relativity and SCM grids using a point shapefile layer in ArcGIS (Appendix D). The values for each of these pieces of the Pie Segments were then compared against each other in SPSS by PCA. The tables and files of this methodology can be found in Appendix E. The results of this analysis will be discussed in the next section.

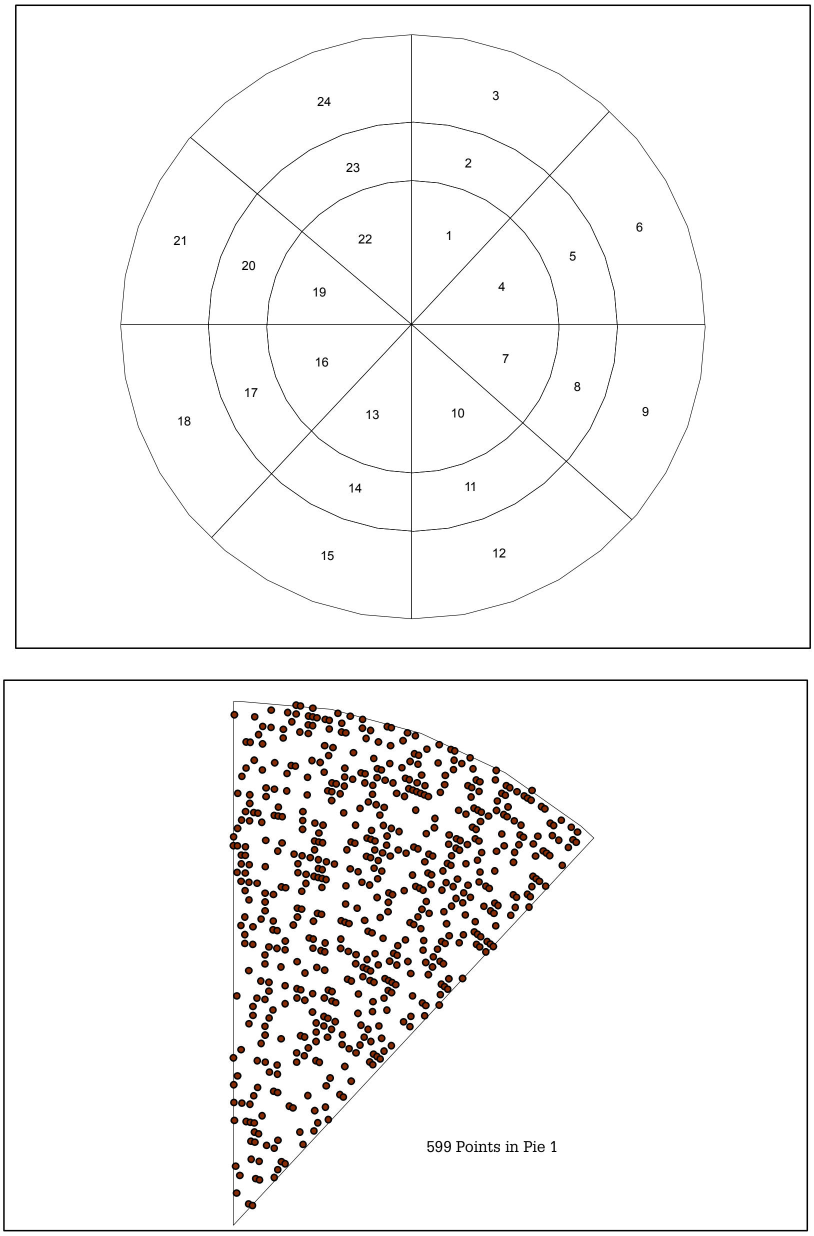


Figure 23. The Ring Sector overlay and an example of the Pie Segment extraction points

3.4 Conclusions on the transformations and analysis methods

The application of the theory of relativity and related projective methods of invariance by SCM provides a basis to compare the distributions of items within different spaces by making space alike in a predictable and repeatable method. The use of PCA spatially will provide indicators of how different discrete areas of finds distributions are between case studies. By focusing on just the kinship of one case study, Kilpheder House 500, against a number of potential lineages, it will be demonstrated in the next section where this case should probabistically be classified. The use of the spatial surveys and the resultant Cognitive Model will offer not only known uses of spaces but expected distributions for materials to be tested against.

Section 4: Results and Conclusions

In a positivist view, the application of statistical techniques to archaeological questions "seek[s] analogies in cultures which manipulate similar environments in similar ways" (Ascher, 1961:319). The methodology in the preceding chapter described a technique for making direct comparisons to see if similarities of space will yield similar results. The results of this analysis will are presented in this section with an emphasis upon the segments where Kilpheder House 500 had strong or negative correlations with the other cases. The full outputs, forming over 96 tables of correlation matrices and related files, can be found in Appendix E.

As mentioned in the previous section, items in correlation will return a value greater than 0 up to an exact correlation if 1. For those items which are opposite to the values represented, a number less than 0 will be returned in the results. Pie Segments that had inverse correlations were recorded as Negative Correlations. Items with a correlation of 0.5 or higher were recorded as having a Strong Correlation. Elsewhere, where variance was not sufficient to compare by PCA or if the result was between 0 and 0.499, a weak correlation was recorded. These results have been simplified so that the emphasis of this study can remain a discussion of the merits of the application of relativistic methods. The results of these tables are given as summative tables in Table 2 and Table 3.

Before examining the results of the statistical analysis by PCA, each of the artefact classes will be described visually. As discussed in Section 1, the application of relativity offers a way to examine sites visually on the same scale.

4.1 Relativity Pottery

A visual inspection of the Relative Pottery (Figure 24) reveals that there were Negligible levels of pottery in Pie Segments 4, 5, 6 and 9. None of the models longhouse models appear to show this same trend for pottery. However, when the densities of all materials were combined to form the cognitive model, the result was high levels moving towards the centre of mass and away from this sector. Consequently, Pie Segments 6, 8 and 9 displayed similar levels on the combine Cognitive Model as in the Test Case. In both the Cognitive Model and Kilpheder House 500, it was hypothesised that this area would form a byre. For all of the roundhouses, the edges of the structures Negligible displayed areas of distribution. The exceptions are areas of Black Patch, Catpund and Stenness House 3 where items were distributed to the edge of the structure. For Black Patch, these areas were known to represent storage pits.

In the immediate entrance way for Kilpheder House 500, there were also Negligible amounts of pottery followed closely by High levels in the majority of the rest of Pie Segment 3. Negligible areas at the entranceway can also be found in the Cognitive Model and all of the roundhouse case studies. Visually, the closest match to Kilpheder is Stenness House 10 and longhouse Model 7.

With Kilpheder, the hearth is in the centre model and encompasses the lower half of Pie Segments 1, 4, 7, 10, 13, 16, 19 and 22. In this area, Medium levels of pottery recovered. Visually, most of the longhouse models and the roundhouse models also had established areas of distribution in these areas as the hearths were near the centre of the models, if not at the very centre. The amounts of pottery in these areas varied greatly with all other models. Models 3, 4, 5, 9 and 12 exhibit a similar morphology in the areas that they encompass. The roundhouses, however, exhibit wider distribution of materials at high levels. The closest match is Model 5. However, what the eye perceives through distribution does not always match statistical comparisons.

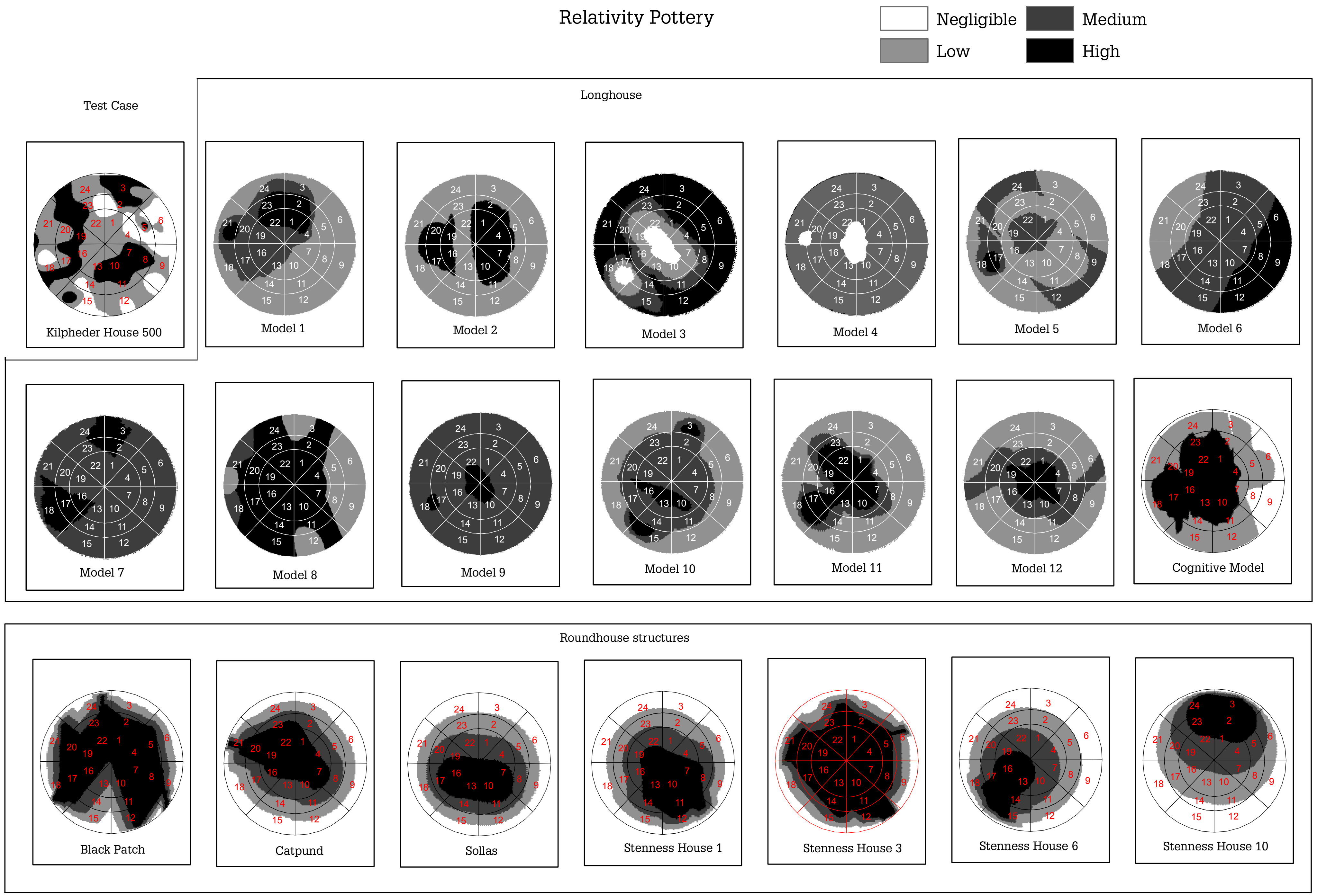


Figure 24. The pottery grids after transformation by relativity

When the case studies are compared directly to Kilpheder House 500, a different picture forms from the sampling of the grids for comparison by PCA (see Figure 25, below). The distribution of pottery which appeared to show areas of similarities with the Cognitive Model in Pie Segments 8 and 9 instead returned Negative Correlations. For ten of the thirteen longhouse models, there was a Negative Correlation for Pie Segments 3 and 24, the areas which represent the entrance to Kilpheder House 500. There were no strong correlations to any of the other case studies with pottery in these segments.

In the area of the hearth, the cases with the most Strong Correlations were Models 3 (with six), 5 (with five) and 12 (with 5). There were Strong Correlations in the areas for nine out of the thirteen longhouse models and five out of the seven roundhouse models.

Relativity Pottery

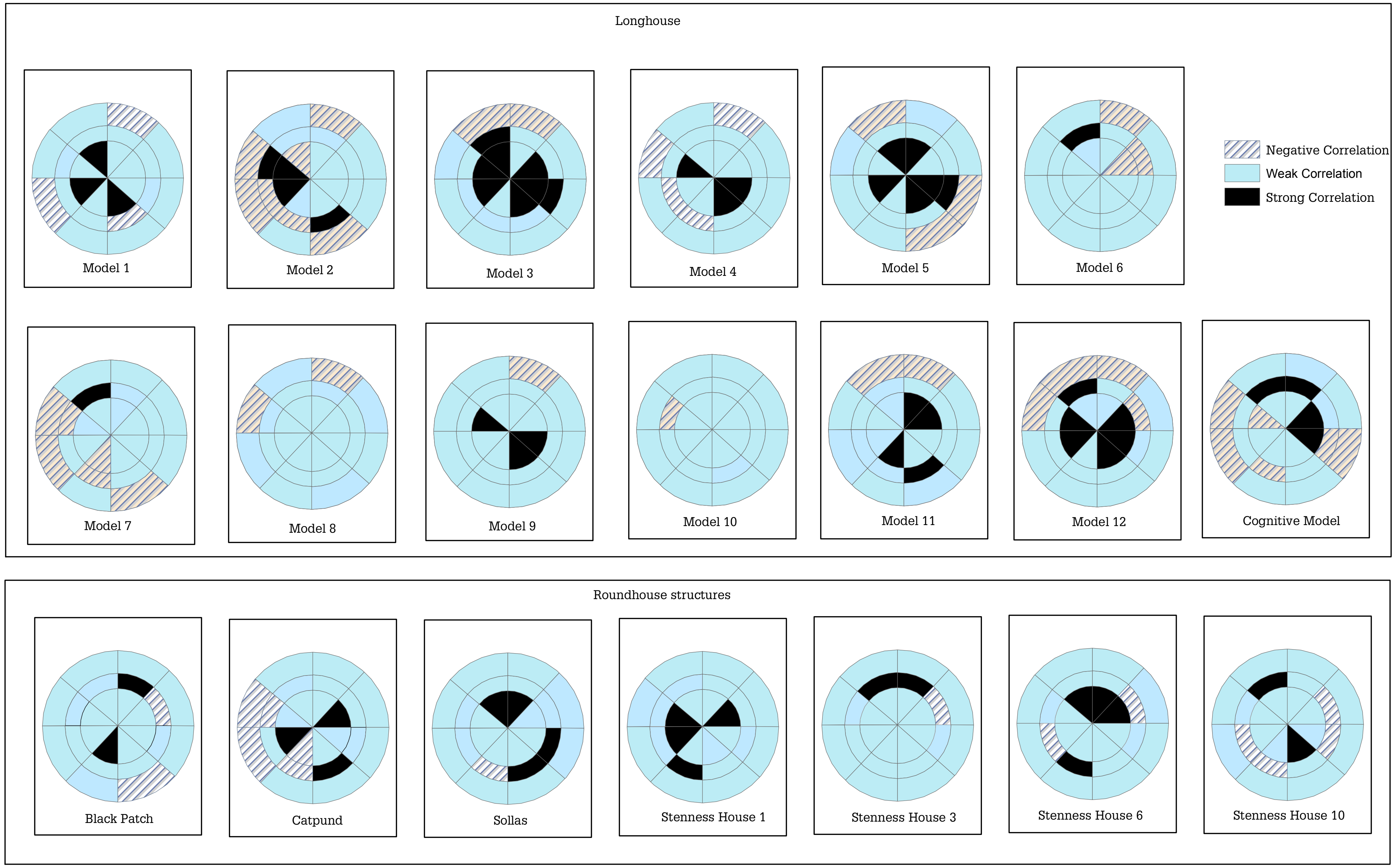


Figure 25. Correlations for pottery transformed by Relativity by Pie Segment

4.2 SCM Pottery

The Selective Centric Morphology models created for this study offer a chance to view the same data from an archaeological framework (Figure 26). For most of the longhouse models the hearth was in the centre of the structures so superficially, there would appear to not be many differences in the final grids presented for analysis. For the Cognitive Model there was no movement in the placement of items because the methodology used to create the location of the main hearth meant the centroid of the hearth was also the centroid of the main boundary of the structure. Likewise, Model 4, which matched distributions to the example in the survey, also had no movement of the centre of mass for recalculations. Lastly, Kilpheder House 500 itself had a perfectly centred hearth.

The changing of the centre of calculation caused slight variation in the distributions in some models and extreme changes elsewhere. A visual inspection shows that slight morphological changes occur in Pie Segments 18 and 21 for Models 7 and 8. Major changes are evident in cases such as Black Patch where the hearth was not in the centre of the structure. For Catpund, the realignment shows a corridor of an area of high distribution of pottery between the hearth and entrance. It would appear that this would make for a more similar distribution of materials between Catpund and Kilpheder. Otherwise, there were no apparent great changes visually that would seem to indicate a strong relationship with Kilpheder and other cases.

When the correlations were considered (Figure 27), again, there were no strong links with Kilpheder and any of the other cases. The areas of the hearth with the greatest Strong Correlations were Models 3 (six correlations), 5 (five correlations), 12 (five correlations) and Model 11(four correlations). There were nine out of thirteen longhouse cases which showed correlations to Kilpheder and four out of seven roundhouse cases which showed correlations. The changes in morphology took away Strong Correlations for Model 7 and changed the areas where there were negative correlations. The case which showed the greatest amount of Strong Correlations was longhouse Model 3.

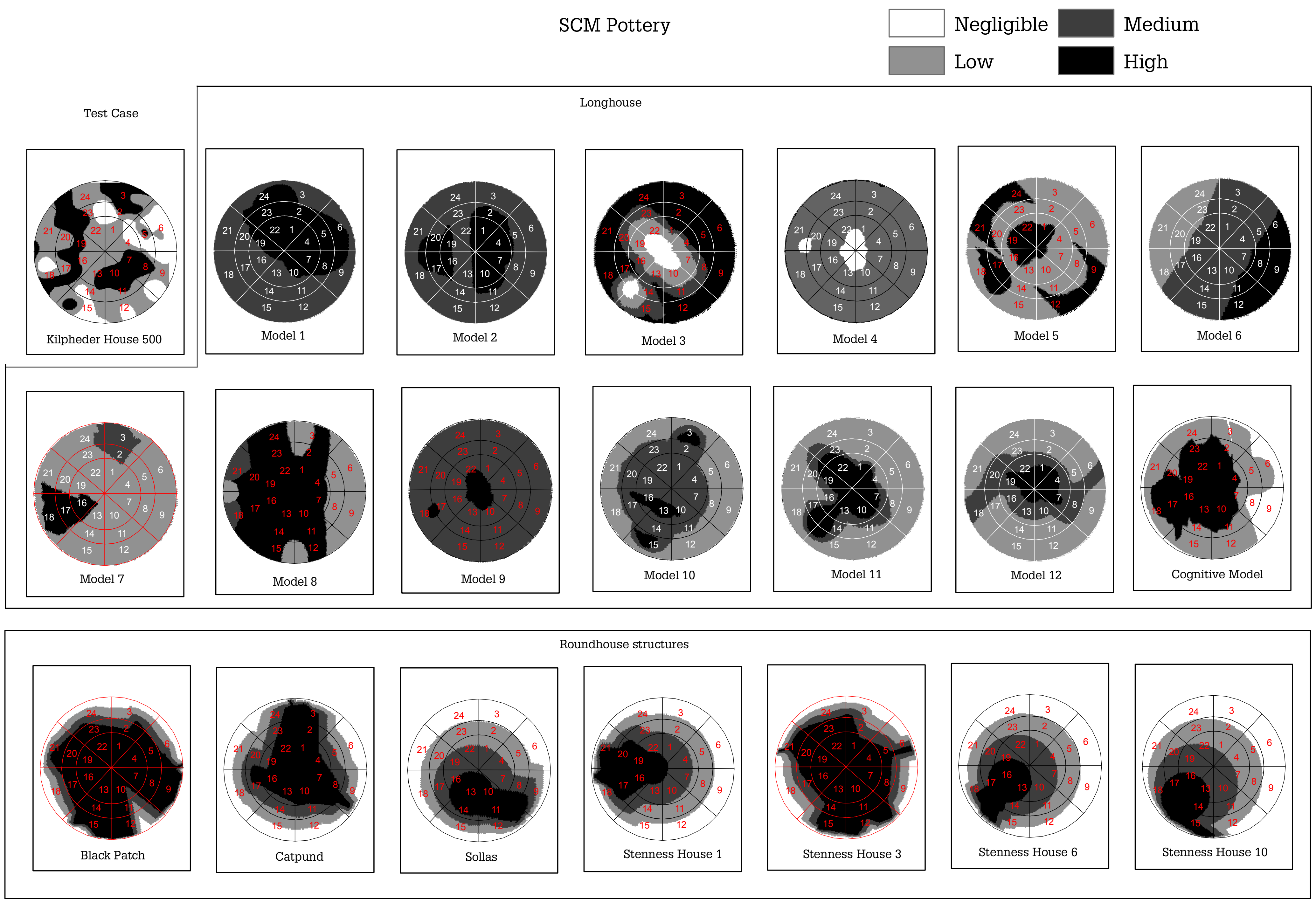


Figure 26. The pottery grids after transformation by SCM

SCM Pottery

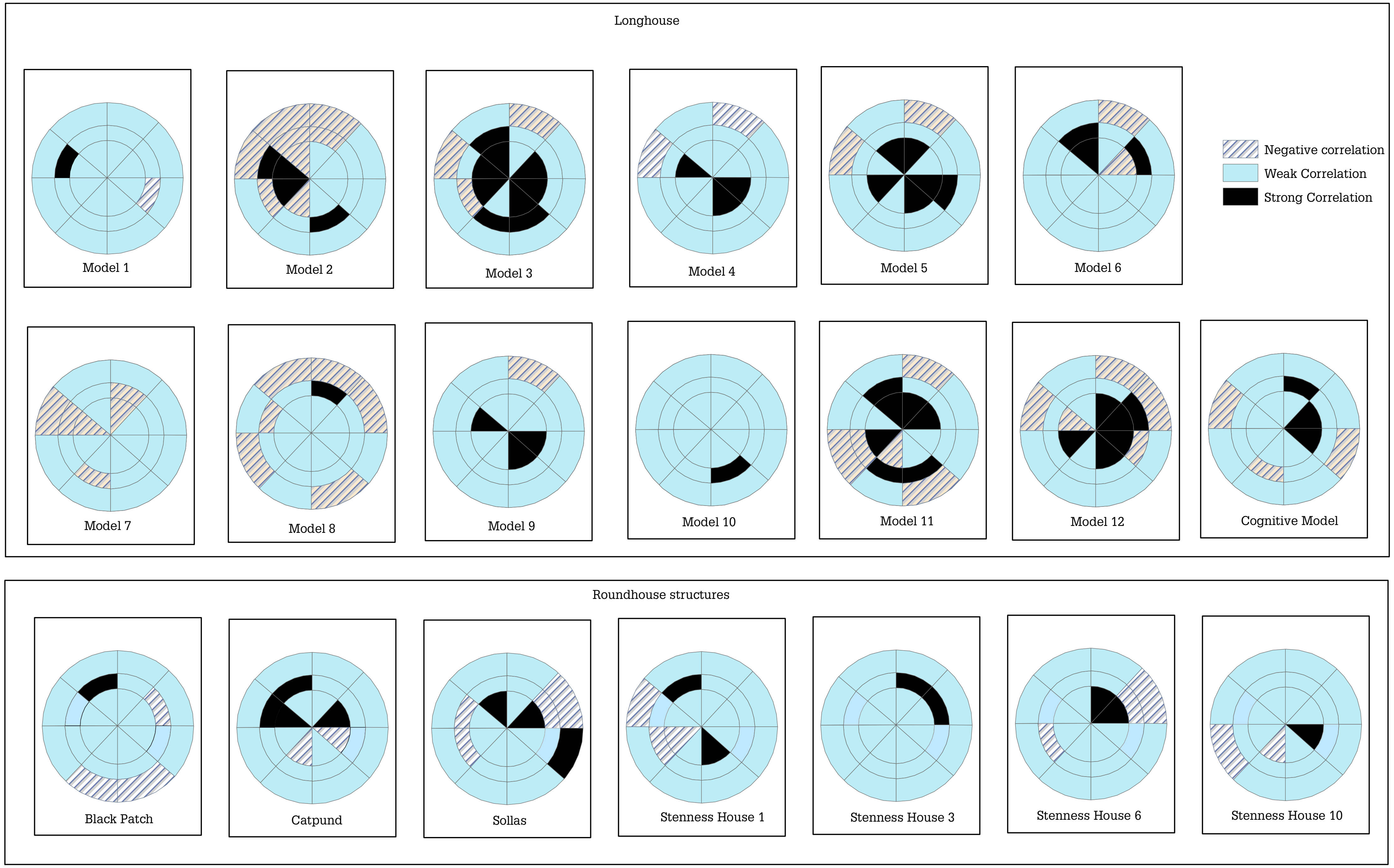


Figure 27. Correlations for pottery transformed by SCM by Pie Segment

4.3 Relativity Bone

The comparisons between Kilpheder and the other models are broader between materials that may be related to an activity type and were not from the same artefact type. For Kilpheder and the longhouse models and Sollas, it was the distribution of unburnt mammal bones which was examined. The remainder of the cases had the distribution of flint tools compared against this. As the majority of the cases involved the disposition of bone, this analysis shall generically be discussed as the distribution of bone. Visually, Kilpheder displayed an areas Negligible distribution surround by an area of low distribution around the areas of the hearth (Figure 28). Model 9 was consistent with this example. Other areas of Negligible amounts were in the hypothesised byre areas. For Pie Segment 6, Models 3, 4, 5, 8, 9 Catpund and Stenness House 1 had similar levels. Where the entrance was, Kilpheder has a discrete area of high distribution. The closest match to this was the distribution displayed by Catpund.

As with the pottery, when examined by correlation (Figure 29), there were not strong relationships with the area of the doorway. In fact, Models 3, 5, 9, 10, Stenness House 1 and Stenness House 6 had Negative Correlations. The model that had the strongest correlations overall was the Cognitive Model with four Strong Correlations in the area of the hearth and two in the area of the hypothesised byre.

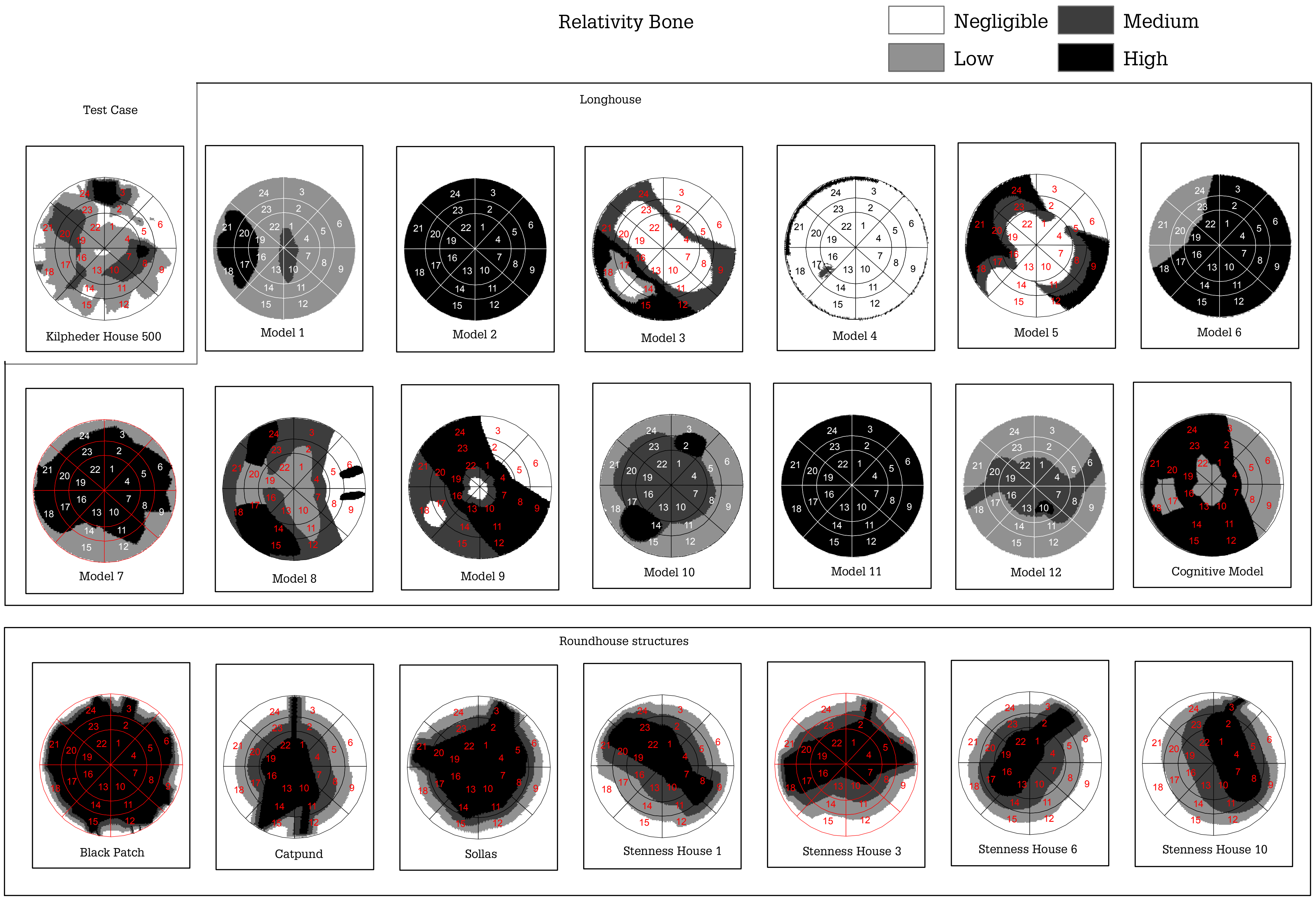


Figure 28. The bone grids after transformation by relativity

Relativity Bone

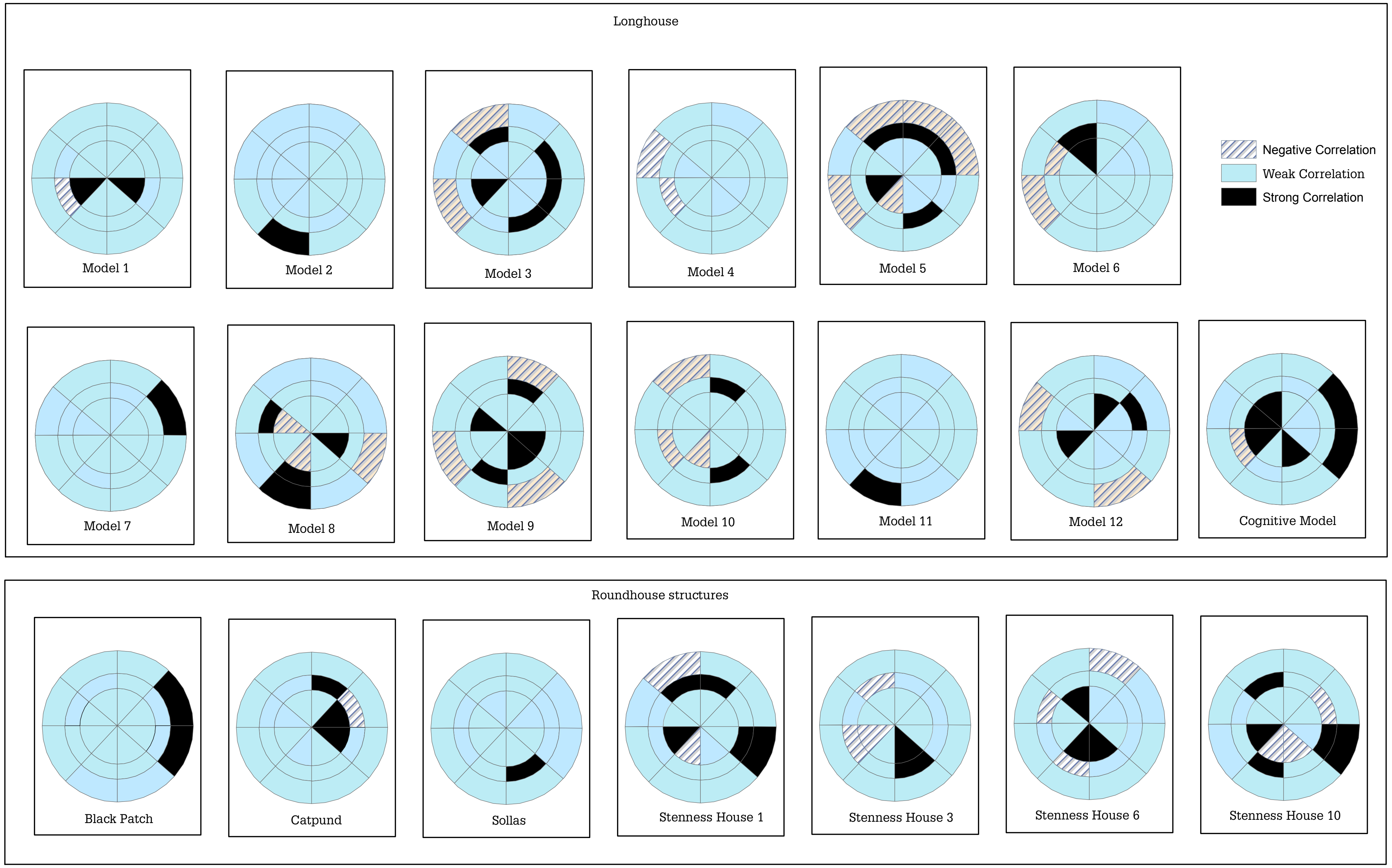


Figure 29. Correlations for bone transformed by Relativity by Pie Segment

4.4 SCM Bone

As with the distribution of pottery, the morphological differences can be seen between the transformations of distributions by relativity and SCM (Figure 30). These changes are more visible for the roundhouse structures where fewer locations contribute to the overall distribution of items. One difference which must have caused a slight shifting of greater weighted cases is Model 3. There were slight shifts in 4 and 13, the area of the hearth and this will have moved items with higher values. The end result was and areas of Low distribution where there was Negligible distribution before. For Catpund, there was no longer link between the centre of the structure and the entrance with high levels.

The areas around Model 8, 9 and the Cognitive Model appeared to have similarities with Kilpheder. Kilpheder Pie Segments 21 and 24 appeared to have similarities with Model 7, Catpund, Sollas, Stenness House 6 and Stenness House 10.

In terms of correlations (Figure 31), none of the cases had strong correlations with the area of the entrance. For six of the thirteen longhouse models and five of the seven roundhouse models there were negative correlations in this area. That which correlated with this area the least was Stenness House 6. However, it was this area that had the strongest correlations with the area of the hearth in Kilpheder. Despite opposite distributions of High and Low for these areas, this contributed to the rest of the immediate environs in both cases having medium distributions. The models with the greatest amount of Strong Correlations were Model 9 (seven), Model 1 (six) the Cognitive Model (six) and Stenness House 6.

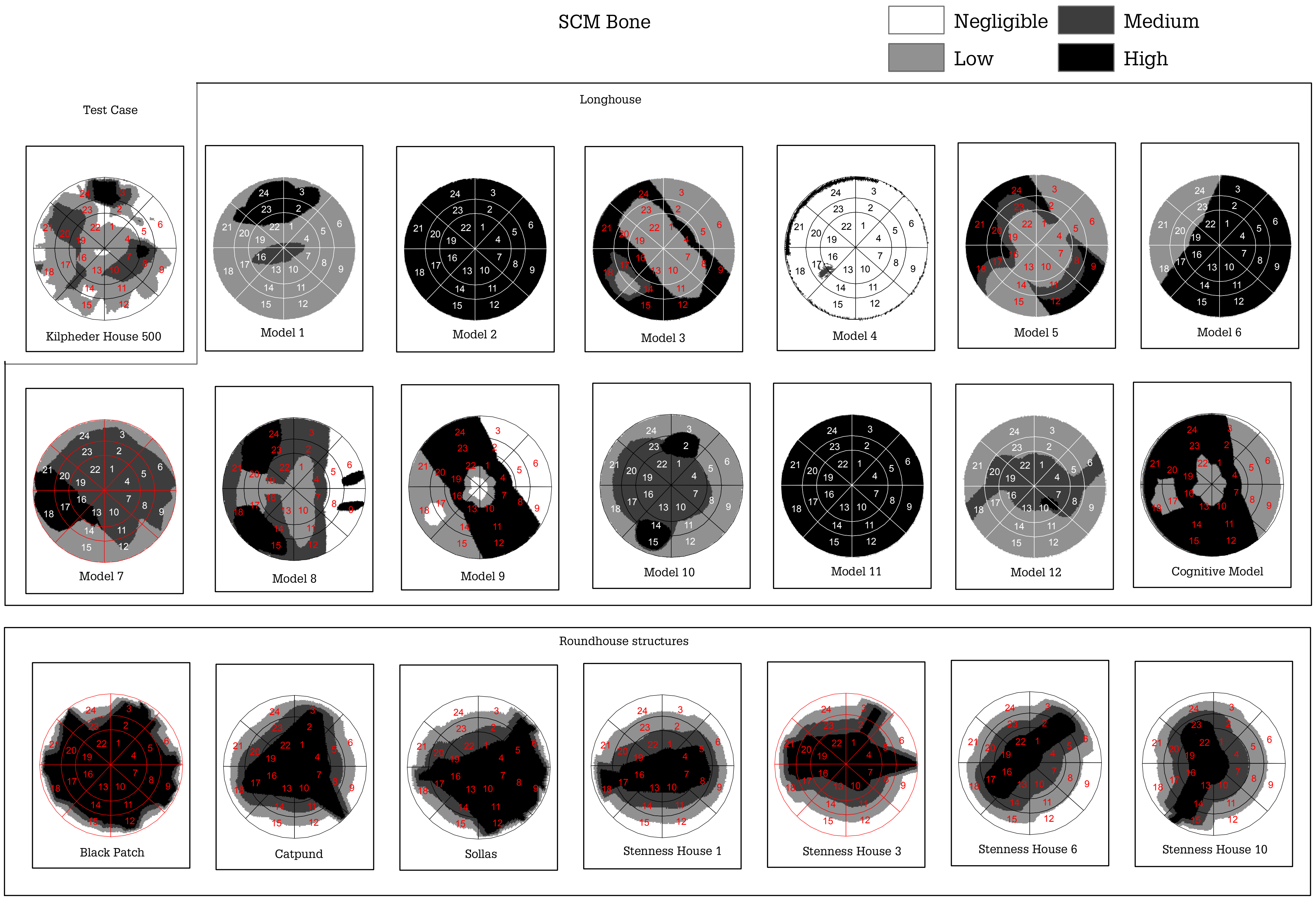


Figure 30. The bone grids after transformation by SCM

SCM Bone

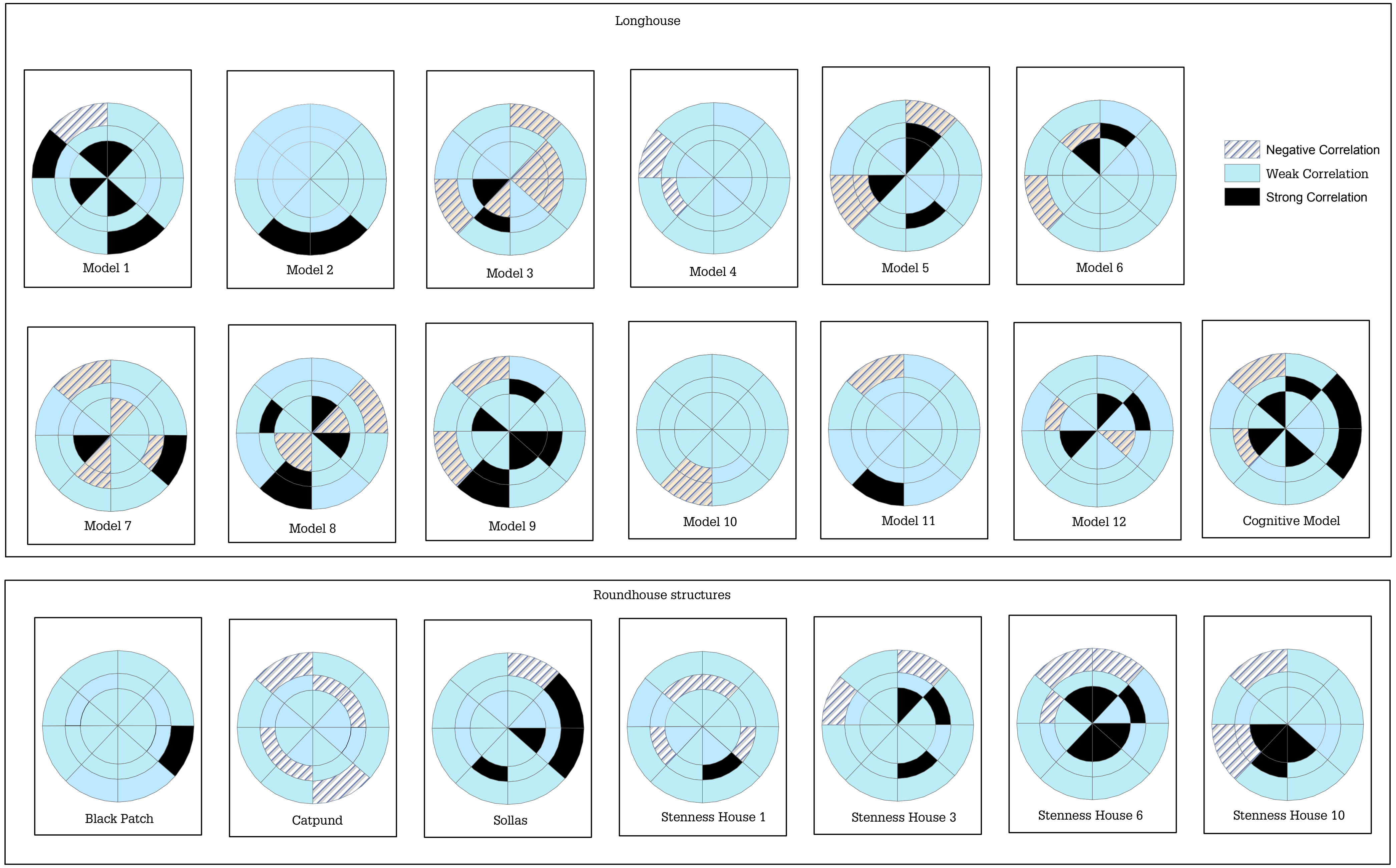


Figure 31. Correlations for bone transformed by SCM by Pie Segment

4.5 Overview of correlations

A synopsis of these mathematical relationships between Kilpheder House 500 and all other cases can be found in Table 2 and Table 3. Here, both the Strong Correlations and Negative Correlations have been presented with equal weight. The Strong Correlations have the Negative Correlations subtracted to yield a net positive or negative integer number that can describe the overall spatiality exhibited through distribution. The results show that two methods do yield different results. When the method of Relativity is applied, the Cognitive Model has the greatest net correlation for Bone (with +5 correlations) and longhouse Model 3 had the greatest net correlation for Pottery (+6 correlations). However, weakest correlations came from Model 4 for Bone (-2 correlations) and Model 7 for Pottery (-5 correlations).

When SCM is applied to the case studies, longhouse Models 1 and 9 had the greatest net correlations for Bone (+5 areas of correlation) and longhouse Model 3 had the greatest overall, net correlation for Pottery. The weakest correlations exhibited in an examination by SCM came from Catpund (-6 correlations) and longhouse Model 7 (-6 correlations). On the basis of these results, it would appear that the strongest correlations can be found with the longhouse models.

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Table 2. Correlations between Kilpheder House 500 and Cases 2-14

	SCM Pottery			Relativity Pottery			SCM Bone			Relativity Bone			
Longhouses	Strong	Negative	+/-	Strong	Negative	+/-	Strong	Negative	+/-	Strong	Negative	+/-	
Model 1	1	1	0	3	3	0	6	1	5	2	1	1	
Model 2	4	8	-4	4	7	-3	2	0	2	1	0	1	
Model 3	9	3	6	8	2	6	2	7	-5	5	2	3	
Model 4	3	2	1	3	4	-1	0	2	-2	0	2	-2	
Model 5	6	2	4	6	3	3	4	3	1	5	5	0	
Model 6	3	2	1	1	3	-2	2	2	0	2	2	0	
Model 7	0	6	-6	1	6	-5	2	4	-2	1	0	1	
Model 8	1	6	-5	0	2	-2	5	3	2	4	3	1	
Model 9	3	1	2	3	1	2	7	2	5	5	3	2	
Model 10	1	0	1	0	1	-1	0	2	-2	2	3	-1	
Model 11	7	5	2	4	2	2	1	1	0	1	0	1	
Model 12	6	5	1	6	4	2	3	2	1	3	2	1	
Cognitive model	3	3	0	4	6	-2	6	2	4	6	1	5	
Total	47	44	3	43	44	-1	40	31		37	24		
Ratio	3.615385	3.384615		3.307692	3.384615		3.076923	2.384615		2.846154	1.846154		Net Ratio
Net Ratio		0.230769			-0.07692			0.692308			1		1.846154

Table 3. Correlations between Kilpheder House 500 and Cases 15-21

Roundhouses	Strong	Negative	+/-	Strong	Negative	+/-	Strong	Negative	+/-	Strong	Negative	+/-	
Black Patch	1	3	-2	2	2	0	1	0	1	2	0	2	
Catpund	4	2	2	3	5	-2	0	6	-6	2	1	1	
Sollas	3	4	-1	4	1	3	4	1	3	1	0	1	
Stenness H1	2	3	-1	4	0	4	1	4	-3	5	2	3	
Stenness H3	2	0	2	2	1	1	3	2	1	2	3	-1	
Stenness H6	2	3	-1	4	2	2	6	3	3	3	3	0	
Stenness H10	1	2	-1	2	4	-2	4	2	2	5	3	2	
Total	15	17	-2	21	15	6	19	18		20	12		
Ratio	2.142857	2.428571		3	2.142857		2.714286	2.571429		2.857143	1.714286		Net ratio
Net Ratio		-0.28571			0.857143			0.142857			1.142857		1.857143

4.6 Discussion and Conclusions

On the surface it would appear that Kilpheder House 500 could clearly be said to belong to the grouping of a longhouse on the basis of the correlation of material distribution. However, if the average values for each of the basic case types are used to calculate ratios of Strong and Negative Correlations, some true differences become apparent between the two methodologies explored. When the method of Relativity is employed to explore the patterns of spatiality of pottery, there is an overall negative ratio for pottery within the longhouse models. For this category, it was clear than many of the models used for comparison do not share many commonalities of distribution. The number of Strong Correlations, as exhibited by the longhouse models was not sufficiently different from the overall correlations that the roundhouse models evidenced. The overall positive Net Ratio of 1.84 for longhouses and 1.85 for roundhouses demonstrates that when both methods are considered together, there is not a clear and significant difference between that case study types.

The methodologies employed have different effects upon the distribution of data. The formula used to calculate the placement of vector points for relativity makes all positioning relative to the structure itself. That is, it is the boundary of the building itself that determines the placement of objects around the centroid of the structure in its entirety.

This method called for no interpretation of the structure other than the axial rotations of a feature on the edge of a structure or an external factor. In the case of this examination, the only interpretation involved the placement of doorways at the northern-most point of the circular ArcGIS grid. This meant that the one commonality that could be tested, where otherwise unknown, was the entrance to the structure. This method created a situation where the Net Ratio for both the Relativity Pottery and Relativity Bone was lower in value for the longhouse models than it was for the roundhouses.

The method chosen to transform the data made it so that broad areas of high values were evident in distribution. That is, by having given items values of four/high on the opposite side of the roundhouse, the TIN structure (Step 11 in the methodology) creates areas of territoriality with items in common. With little morphological changes within a circular structure, and areas that can any commonality will return strong correlations. This is evident with Black Patch where most items were on the periphery of the structure. This creates a large clustering of material that will return weak correlations at the edges and does not have enough variability to be compared fully. The combination of this type of site and this methodology does not create discrete territories. Compression of these territories to more discrete areas occurs when another factor is taken into account in the transformation- the hearth.

With the application of SCM, the longhouse models yielded a higher Net Ratio than the roundhouse models. Because all materials were recalculated with the hearth at the centre, the materials were slightly realigned with two features in common. For example, Black Patch, which did not have a hearth in the very centre, went from a neutral net correlation of 0 to a Negative Net Correlation of -2 for pottery and drop in Net Strong Correlation for bone of +2 to +1. This is even more dramatic for Sollas where pottery went from +3 to -1. However, there is an indication that differences between the distributions of material types may be more apparent in relation to hearths as the Bone in Sollas actually had a Net increase from +1 to +3. The flint of Catpund went from a +1 to a -6 Net Correlation. So, when the sites are transformed around archaeological interpretations by SCM, Kilpheder House 500 has a stronger overall grouping with the longhouse models. When all cases were transformed using relativity, the strongest correlations were still with individual longhouse models. Therefore, Kilpheder House 500 can be said to the best fit with the longhouse models.

When considering the results of the Strong Correlations to the models of the use of space in Figure 6, Model 3 appears to be very similar in the definitions of the use of space perceived by the excavators. The Cognitive Model, which held the closest relationship for the unburnt bone when examined by relativity, also was similar. Models 1 and 9, which had the greatest amount of net correlations for SCM held the basic similarities of most of the tri-partite structures but exhibited archaeological structures not evident in Kilpheder House 500.

By placing the data within the same hypothetical space, it was possible to see how well the distributions correlated as if they'd been deposited within the same household. By these means, it was possible to analyse and directly compare sites as different phases of the same structure. In this way, it was possible read each floor included in this study as if they were merely stratigraphic layers within the same structure. This new method served as a translator of spatiality for Kilpheder House 500.

4.7 Future Applications

The interpretation of sites could benefit greatly from an electronic repository of case studies that could be transformed by relativistic or SCM terms. One of the great hindrances of to the publication of excavations is the task of final interpretation, through analogous cross-comparisons, can prove too taxing for the time pressured resources of researchers. If those who have completed this feat could go one step further from publication

and provide evidence and interpretive overlays in electronic form for other researchers, it could benefit archaeology as a whole.
This could be employed for both transformed data or any data processed into an electronic form. Those who have the time or other resources to make use of the data could do so without having to wait for a full publication to be produced. One of the problems encountered by the SEARCH project at Sheffield, which excavated Kilpheder, was finding analogous sites in Scotland and elsewhere that were recorded as being Norse (Helen Smith, pers. comm.). The archaeological literature is self-fulfilling in that a 'great site' can be one that conforms to widely-held views of archaeology of a type in the published literature.

As such, they would be more likely to attract funding and interest from peer reviewed journals. The sites that are inexplicable must languish in finding individual interpretations. Recent work by Cotswold Archaeology is revealing that many sites, perhaps even the majority, have been ignored as they were not thought to be atypical (Holbrook 2007).

4.7.2 Applying further test statistics

This thesis has been an exploration of the mathematical transformations of archaeological spaces. The statistical method chosen was just one of the many methods on offer and was inspired by the work of Eastman (1995, 1996). One method that offers a combination of correlations and Chi-squared variates is the combined methods of Semblance, "Uniform Gain" and Similarity described by George Dalish at the past four conferences UK chapter of the Computer Applications and Quantitative Methods in Archaeology. Other methods may be to revisit Kvamme's (1993) use of a T-test. In order to carry out these tests on more than just samples of spatial areas, further tools must be created. The application of such spatial transformations as Relativity and SCM should make the analysis of intersite comparisons more accurate than ever before.

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