THE EVOLUTION OF ORTHOGONALITY IN BUILT SPACE:
an argument from space syntax

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Abstract

We present here a discussion on why there is a predominance of rectangularity in the buildings of our contemporary environment. We begin by noting relevant findings in two areas of inquiry. Morphological studies of buildings show that rectangularity is closely associated with close-packing of rooms. A comparison between cross-cultural ethnographic studies and the archaeological investigation of societies progressing towards sedentism reveals that rectangularity is not a pervasive feature of societies in all periods, but occurs predominantly in cases where dwellings are multi-roomed. With the latter, emergence of rectangularity is strongly associated with a change in social organization, and almost invariably with the emergence of autonomous households. We use theoretical ideas from space syntax to show why this should be the case, arguing that rectangularity offers several advantages to societies organized in terms of economically and socially competitive autonomous households. Such households require dwellings that are varied in their size and spatial requirements, but require a consistent syntactical structure. Our proposition is that rectangularity is a resource that societies utilize as a way of organizing space that simultaneously allows appropriate variations in the spatial organization while preserving its socially relevant characteristics. Creating dwellings with spatial organizations that have specific socially relevant structural properties is also a means for creating social solidarity that is necessary to hold dense settlements together.

1.

Our purpose here is to contribute to a debate in several disciplines on the preponderance of rectangular geometry in the planning of buildings. The predominance of rectangularity in architecture is essentially an empirical phenomenon. Enough exceptions exist to it, as we will describe later, for there to be an essential factor behind it. In other words, there is no definite reason, mathematical, cultural, or technological, that prevents us from building otherwise, but the fact remains that we do so almost invariably.

Steadman (1983, p. 173) offers a good summary of the issue. He refers to Kruger (1979), who, studying building stock in Reading (Berkshire, UK) found that over 98% of buildings were rectangular in

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plan and to Bemis and Burchard (1933-36) who statistically computed that 88.5% of all American building followed an orthogonal geometry in their volume. More recently, Steadman (2006) has offered both a good background to the issue, as well as a persuasive argument on at least one of the reasons why we would favor using rectangular geometry in our buildings. Steadman observes that rectangularity often tends to occur in buildings (or in parts of them) where rooms need to be closely packed together. He goes on to show that under the condition of close-packing, rectangularity offers a particular advantage; it gives designers an unlimited choice of dimensions of the individual rooms that are closely packed without disturbing their mutual adjacencies (Figure 1a). If a similar exercise is tried using triangular geometry, one finds that varying the individual dimensions of the regulating grid, or grating, independently while still preserving the mutual adjacencies necessarily distorts the shapes of the component individual rooms (Figure 1b). For a given set rooms with mutual adjacencies, orthogonal geometry, thus, offers flexibility of dimensional variation that other geometries do not. Flexibility is a desired property because it allows more variations and creates more opportunities for creative design solutions. These arguments are made largely in the context of contemporary architecture and it is worth asking how well they may be generalized to the built environment of other societies, past and present. Do the conditions that require close-packing and greater flexibility hold in other cases as well?

Figure 1:

Diagram illustrating Steadman's (2006) argument that varying the individual dimensions of rooms preserves both the shape and the mutual adjacencies of rooms on a rectangular grating, whereas it does not do so for rooms organized on a triangular grating
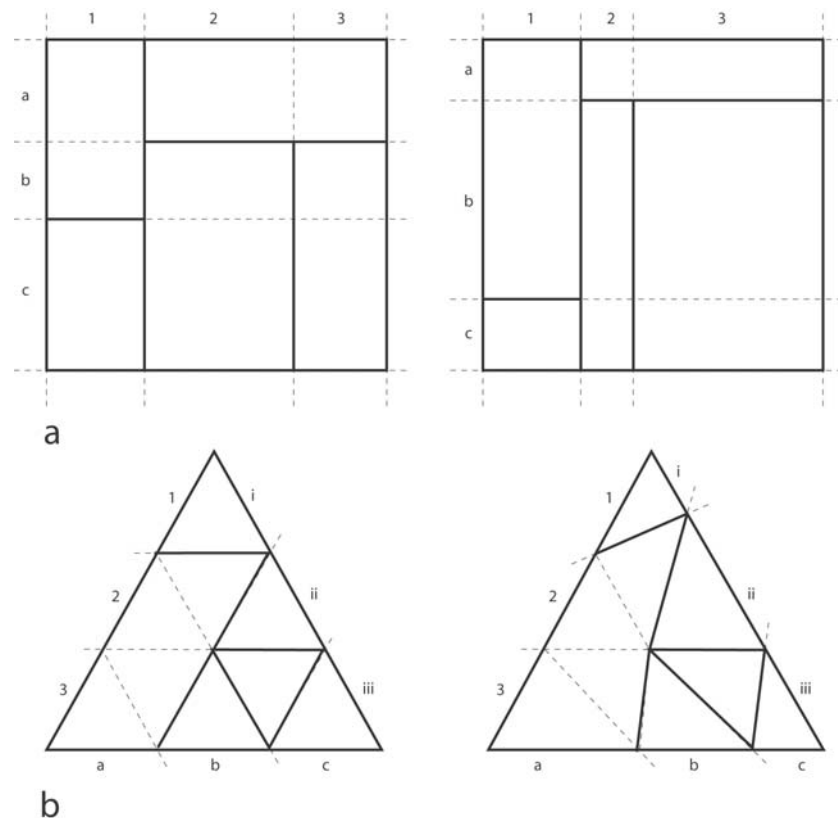
2.

Cross-cultural studies have shown that the predominance of rectangularity is not characteristic of a great number of vernacular building traditions. Drawing on ethnographic data from 136 cultures, Whiting and Ayres (1968) made an attempt to see what social features could be predicted from the shape of the typical house in any particular culture. Their initial approach was to classify the sample of houses into six types of shapes, but they found that an overwhelming

majority of dwellings was either rectilinear or circular (Whiting and Ayres 1968, p. 121). Their study, then, turned effectively into a comparison between the social, ecological, and technological correlates of circular and rectangular houses. They were able to establish several key points. The median size of rectilinear houses was much larger—300 square feet—as compared to the 100 square feet median size of circular ones (Whiting and Ayres 1968, p. 122) and the larger rectangular buildings also tended to have more rooms. This partly supports Steadman's point about the association of rectangularity with close-packing. However, the actual numbers confound the issue somewhat. In their sample, although several rectilinear houses had more than one room (12 rectilinear houses had two rooms, and 14 rectilinear houses had more than two rooms), many (31) had only one room. In comparison, 23 circular houses had only one room, while there was only one example of a circular house with two rooms; no circular house had more than two rooms (Whiting and Ayres 1968, p. 121-122).

Their most conclusive result was regarding the relationship between the degree to which the society was settled and rectangularity:

"Eighty percent of the cultures with rectilinear floor plans are sedentary, and seventy-eight percent of the societies with both curvilinear and rectilinear floor plans are semi-nomadic…. Although slightly more (65 percent) of the houses with circular floor plans are found in nomadic societies, a substantial number are found among sedentary peoples, and no good prediction can be made about the permanence of settlements where curvilinear plans are in use." (Whiting and Ayres 1968, p. 124-125).

However, the relationship between sedentism and rectilinearity was associated neither with environmental conditions nor with construction technology. Sedentary societies in treeless environments, they found, build rectilinear houses even when heavy building materials are not available; and all sedentary societies that construct curvilinear houses do so despite the availability of materials for rectilinear architecture. "Thus ecology does not influence predictions… about the permanence of settlement for societies with rectilinear floor plans only or for those having both rectilinear and curvilinear houses" (Whiting and Ayres 1968, p. 126).

Whiting and Ayres did find that rectilinear floor plans are much better predictors for social organization than circular plans. Multi-roomed rectangular dwellings were associated with extended families and with status distinction, usually with both, as were dwellings larger than 200 sq ft. In contrast, the presence of circular architecture was not a good predictor of these qualities in the cultures studied (Whiting and Ayres 1968, p. 123). Their conclusion, about these findings, was that, "[c]urvilinear floor plan is a better predictor of the structure of the house itself", since it predicts flexible materials and single roomed buildings, whereas, "[f]or predicting from floor plan to social organization, rectilinear architecture is more effective" (Whiting and Ayres 1968, p. 126). The predicted features included status distinctions, extended families, or both, and sedentism. However, there was one feature of social organization that circular plan did predict: "[c]hances are three to one that the society practices a polygymous form of marriage." (Whiting and Ayres 1968, p. 130).

In sum then, the Whiting and Ayres study demonstrated that no predictable association exists between the ecology of a site, or the technology available and the shape of houses built there, particularly where rectangular buildings are concerned. Moreover, their results also disprove a simple and direct association between sedentism and rectangularity. Rectangularity may or may not feature in societies that

are nomadic, but the shapes of dwellings in sedentary societies are predominantly rectangular, although a few exceptions exist. The only features of the social structure of cultures that rectangularity was able to predict relate to social organization, and that too only under the condition of multi-cellularity.

Whiting and Ayres' results were intended for archaeologists who were interested in making inferences about social organization through the analysis material remains, in this case architecture. Being entirely empirical, their study does not give us any explanation for the mechanisms by which multi-cellular rectangular buildings hold implications for aspects of social organization. For this, we would need to turn to anthropological models that explain social changes associated with the transition to multi-cellular, rectangular structures, a phenomenon that has been archaeologically documented in many different areas of the world.

3.

A very pertinent example of this is in a seminal paper by Flannery (1972), which presents a model for the transition in settlement strategy from one based on groups of irregularly-sized, roughly circular dwelling structures to one of nucleated villages with rectangular structures. Flannery's account is based largely on the archaeological record of the Near East, within the southern Levant, beginning from the Late Natufian (12,000-12,500 B.P.) through the Pre-Pottery Neolithic A (PPNA) (11,700-10,500 B.P.) and into the Pre-Pottery Neolithic B (PPNB) (10,500-8250 B.P.) (All calibrated radiocarbon dates; Kuijt and Goring-Morris 2002, p. 366).

In the Levantine case, Flannery points out, the earlier settlement type shares similarities with ethnographically-documented central African compounds, featuring a collection of circular dwellings that likely housed a single person, an adult with a child or two, or, in rare cases, a couple (Flannery 1972, p. 30-38; also see Flannery 2002, p. 418-420). The interior of these houses are simple, relatively undifferentiated physically, and all storage of subsistence items is placed in shared buildings. Sometime between the Late Natufian and the PPNB, villages replace these compounds and one increasingly sees rectangular houses which are multi-roomed and have specific internal areas devoted to storage. The privatization of storage, in Flannery's model, is evidence for the emergence of relatively autonomous households operating within a society. The emergence of autonomous households, Flannery elaborates later (1993, 2002), corresponds to a shift from societies where resources are pooled and shared within the entire community settled in a single location, and risk is therefore assumed at the level of the group, to those where risk is managed by individual households and nuclear families become the basic units for production and consumption (see Wiessner 1982). The advantage of this shift to autonomous households, Flannery (1972) argues, is that it creates conditions where households have a greater incentive to overproduce and may engage in competitive behaviors leading to an intensification of production beyond the demands of subsistence (see Sahlins 1972). Household competition would result in increased wealth and status differences.

Now, it is important to stress that Flannery's model does not deal directly with the matter of rectangularity of houses in village societies. In his 1972 paper, he refers to rectangularity as an empirical observation, but not one necessary to his explanation of socioeconomic change—in the way, for instance, that the presence of storage inside the houses does. There is a passing suggestion that, when compared to circular structures, rectangular houses are better suited to accommodating families, particularly as household

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composition changes over time (with births or marriages, for example), and the need to add or remove rooms arises (Flannery 1972, p. 30-31, 39). In later papers, however, Flannery (1993, 2002) plays down the significance of this point, arguing that a change in building shape is not the critical variable for the rise of autonomous households or the privatization of storage. The fact remains, however, that the second type of society that he describes, is characterized by larger, multi-roomed rectilinear houses. In that context, what makes Flannery's model of value to us is its description of the emergence of the autonomous household as a critical variable.

Recent findings from the Levantine site of Beidha have slightly modified our understanding of Flannery's model. Byrd (1994, 2005) points out that during Beidha's early PPNB occupation (phases A and B), the roughly circular, single-roomed dwellings show strong evidence for housing small nuclear families, rather than individuals as Flannery had initially predicted. Despite this demonstration by Byrd, Flannery's larger proposition that these societies were characterized by risk-sharing at the level of the group still holds. What Byrd's demonstration does is disassociate the transition from smaller, circular structures (phases A and B) to larger, rectangular structures (phase C) from the idea of a corresponding change in the number of inhabitants of a dwelling. Instead, Byrd relates the change in size of phase C dwellings directly to increasing autonomy of the management of production and consumption by households (Byrd 2005, p. 121-122). His claim is based on two observations. First, the increase in size is accompanied by an increase in the internal partitioning of space within dwellings, a partitioning that also includes the development of two-storied houses. Second, there is evidence that indicates domestic and productive activities, which had earlier been conducted in outside open spaces, were now brought increasingly within the dwelling. He argues, in fact, that the ground floors of phase C houses were almost entirely devoted to production and storage, thus testifying to the emerging condition of the household as a unit of production. Byrd, in other words, endorses Flannery's idea that the emergence of nucleated villages of rectangular structures is associated with the emergence of autonomous households.

4.

The Levantine case, thus, furthers the point that aspects of social organization will offer the most fruitful link to the emergence of predominant rectangularity. The key constitutive aspect of social organization associated with rectangularity seems to be the individual household that had increasing autonomy over the production, storage, and consumption of food and other goods. The reasoning that ties the autonomous household with rectangularity is not articulated specifically in either of these writers, but it may be reconstructed as follows: as households begin to emerge with degrees of social and economic autonomy and, perhaps, a condition in which they compete with other households for status, prestige, and power, they produce certain spatial requirements (compare, for instance, with Byrd 2005, p. 122). With increasing autonomy, households begin to show increasing amounts of internal labor differentiation—not just between the sexes, but also between age groups and, perhaps, according to the degrees of kinship, if extended households are considered. Autonomous households will have increased requirements for relatively private areas in which goods can be stored and production and consumption activities can be carried out without disturbance and removed from prying eyes. There may also be a demand for larger areas to accommodate these activities, moderated over time by changes in the household size and other social factors. One way to satisfy these demands would be to create domestic buildings that are multi-roomed,

housing activities with different kinds of requirements in different spaces. And multi-cellularity links naturally to the issue of rectangularity. All this sounds reasonable, and is probably correct, but it carries assumptions that may not be universally valid; in fact, counter-examples may be suggested for some of them.

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A similar puzzle is associated with the assumed relationship between complexity in social organization and spatial segmentation. This relationship has been investigated by a number of writers, particularly by Kent (1990, 1991), who reports that, in general, increased organizational complexity in society corresponds with increased segmentation in the use of space. However, in the account discussed above, there is an assumption that increased segmentation would naturally imply a multi-celled building. But this need not be so. As Kent (1991, p. 438) herself recognizes, internal segmentation of space may be created without physical barriers, by either notional or conceptual boundaries, or habitual association of particular spatial locations with specific activities. In other words, spatial differentiation can happen in single roomed dwellings. In fact, this is observed in several cases, as for instance in the case of the pit-houses of the American Southwest. But more tellingly, this happens in the Levantine case itself.

To see what we mean, we should return to Flannery's original model. An important corollary of his argument is that the emergence of autonomous households coincides with the emergence of a single building—that is, a spatial entity localized in space—associated with the household. In Flannery's preliminary assessment of the model for the Near East, the shift from single-celled circular dwellings to multi-celled rectangular dwellings appears to map neatly, and reasonably, onto this shift. Byrd's findings at Beidha however show that this mapping is not quite so neat: individual buildings associated with individual households (which may have some degree of economic autonomy) appear earlier during phases A and B of the PPNB occupation, when dwellings are still single-celled and circular. There is actually a good indication of segmentation in phase A and phase B houses, but the segmentation is largely notional and based on localization of specific activities, not boundaries. The shift to rectangularity, and to multi-cellularity, occurs later with increased autonomy, implying that the relationship between social forms and rectangularity is a matter of degree and not of a kind of shift in social organization. One puzzle, then, is how we can specify the point of social change at which multi-cellularity may emerge.

Note that in the shift discussed here, rectangularity seems to coincide with multi-cellularity. This is the other puzzle regarding rectangularity which the anthropological accounts described above typically do not address. The general inclination in such writings seem to say that it is comparatively easier to add rooms to, and subtract from, rectangular buildings (Flannery 1972, p. 30, ultimately attributing this to a personal communication by R. Ascher to M. C. Robbins 1966). This is not quite satisfactory, for there is no property inherent to shape that would give it such an advantage. The fact that something is easy to modify needs to be a property of the construction method or materials. Actually, an argument has been made which explains the shift from circular to rectangular architecture as a matter of changing construction techniques. McGuire and Schiffer (1983) assume that circular buildings would be built of light-weight materials and are built to have short use-spans, whereas rectangular buildings would be constructed of longer lasting materials. Using this assumption they argue that the shift to rectangularity is associated with a shift in building economy from a primary emphasis on maximizing production goals to maximizing maintenance goals, which happens in societies moving from semi-nomadic to sedentary lifestyles. But, in fact, there is no

reason for the shape of plans in buildings to be beholden either to particular building techniques, or to particular planning strategies.

In short, increased spatial differentiation may not necessarily imply multi-cellularity, and neither does the demand for multi-cellularity necessarily demand rectangularity. A theory that tries to explain the shift to predominantly rectangular architecture as nucleated villages emerged in the Neolithic Levantine would then would have to explain the following two questions: 1) Why, in the context of the emergence of village-based societies, did spatial differentiation manifest itself as multi-cellular buildings? And, 2) why, in the same context, did multi-cellularity come in the form of rectilinear buildings? Further, with respect to the first question, the particular task would be to show not just why, but also when multi-cellularity emerges within a society in which households are getting increasingly autonomous.

We attempt to do this in what follows; that is, we will try to give an account for why the shift to rectangularity occurs in the Levantine case, with an intention of drawing more general conclusions later. We also want to note that our account, at this stage, is speculative—an outline of a theory, rather than a fully fledged theory—part of the purpose being to cast some light on the general question of how aspects of geometry of buildings interact with cultural phenomena. As our survey above shows, theory on this issue is conspicuously lacking in both architecture and anthropology. We will end with a quick discussion of Beidha, where such a transition has been very elaborately documented, to see how well our theory does against an actual case.

5.

We begin by thinking a little more elaborately about how the consolidation of the household into a single spatial location necessitates spatial segmentation. Our argument derives primarily from ideas articulated in Hillier, Hanson, and Peponis (1984), and elaborated in Hillier and Hanson (1984, p.143-147). According to Hillier and Hanson, buildings function socially by acting as interfaces between different groups of people—between the sexes, between the core and extraneous members of a household, between members and guests, and so on. In creating interfaces, buildings become depositories of implicit social knowledge, which is knowledge of status differences, norms, and behavioral rules associated with particular settings and concerning interaction with members of different social categories. In fact, at times, much of that social knowledge would be difficult to construct, and to maintain, if it were not hitched onto space. It is important to keep in mind that it is not the specific environmental qualities of the internal space of the house that are associated with the mapping of this social knowledge, but rather it is the structural qualities of the spaces—that is, how the spaces connect with each other—that come into play. Such social knowledge is embedded in the building by two operations: the first operation is to create spatial settings, that is, particular areas where specific activities may happen, where specific encounters/interactions may be located, or where specific behaviors may be defined; the second is to create an appropriate system of control between these settings, the control being established by a combination of physical means, such as partitions allowing selective vision and access, and non-physical means by norms of practice and behavior. The association of increased internal differentiation within the domestic buildings with the increasingly differentiated autonomous household is thus not simply a matter of satisfying the individual spatial and environmental requirements associated with the activities of the household, but rather of creating an appropriate structure to accommodate the day-to-day dynamics of life within it.

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Now, re-examining the case of the emergence of nucleated villages in the Levant, we can see that as the household consolidates itself into a particular location, say within a building, such a structured space will begin to emerge. In cases where the household is small and relatively fixed in its composition, and activities performed within the building relatively limited, the kind of social knowledge needed to function within the household will be relatively easy to pre-specify. In such cases, non-physical means for spatial segmentation may suffice. But as household composition becomes more complex, or as activities inside the house proliferate, the kind of social knowledge needed by the inhabitants to negotiate interactions becomes much more difficult to pre-specify; it would help in such conditions to create more elaborate and physical means of control such as partitions that restrict either vision or access, or both. It follows that as autonomous households emerge we will see a gradual transition in which there is an initial emergence of relatively simple buildings, perhaps single-celled, but with some indications of internal segmentation (e.g., a fire-place or areas set aside for storage); later these will become more elaborate giving way, very likely, to multi-cellular spaces. So far, our account seems to predict what others have said. There is however, a necessary corollary to our case: when multi-cellularity emerges, it cannot be just as a collection of rooms within a building. The collection of rooms must have an internal spatial structure that corresponds to the categorization and control of the deployment of activities within the household.

There is an additional constraint on the graphs that comes from the relationship between households and the wider community. With social obligations to share reduced, and opportunities for jealously and conflict increased, economically-autonomous households within village societies will require supra-household level mechanisms to keep the community integrated (see Byrd 1994:643).

Now, because the spatial structure of the house carries with it a mapping of aspects of social knowledge, its spatial structure is implicated in the working of the society more broadly. More precisely, the structure of the house helps to create solidarity that is not directly concerned with any pre-established social relation such as kinship. It does so at two levels—one spatial and the other trans-spatial. At the spatial level, the house contributes to the maintenance of social knowledge by virtue of modulating activities and behavior through its spatial structure. Guests may be kept to certain areas of the house, but given selective visibilities to others. Certain activities may be kept private, others performed in full visibility and accessibility of people not associated with the house. Each house thus helps create and maintain aspects of regular social transaction of life in its locality, and the sum of all houses (as well as other buildings) is the sum of the social life in the entire settlement. But at another level, the house is also a microcosm in itself, containing social transactions and norms of behavior that only concern members of a particular household. Children may be required to follow certain spatial practices which are tied in with their coming of age. Women or men may dress and behave differently in different parts of the house. But such norms, however private, may also be typical, in that most households would observe them. In embedding aspects of such norms, behavioral practices, and social transactions in space, the household creates a trans-spatial solidarity with other households. All of them are similar in selected ways.

We are suggesting therefore, that in addition to supra-household organization, the very arrangement of the domestic interior will help create solidarity within the community. In other words, it is the interactions of the households—their internal competition, if present,

and their ability to organize themselves in cliques and so form supra-household organizational forms—that helps settlements maintain larger sizes. This role of households puts additional constraints on the spatial structure of domestic buildings.

What then, can we say about these restrictions on the spatial structure? The actual structure of the buildings is naturally a matter of the specific forms the households take, and so cannot be described in general, but we can describe some of the general requirements that this structure should have. This includes, first, that it be non-trivially repeatable; that is, it have enough structural complexity that it can create appropriate interfaces between members of the household as well as between the household and the rest of the community. Secondly, this calls for a structure that can be modified without disturbing the structural properties of the whole. Aspects of this structure are best described through the properties of accessibility graphs of the houses. One significant property of these graphs produced under these requirements is that the connectivity values of their nodes have a power distribution: a few nodes connect directly to a large number of spaces, and several nodes to a few—often one—space(s). This property results directly from the structuring of the graph itself. The graphs are often tree-like, with one or two nodes leading to several; for larger buildings, the graphs tend to be either of recursive trees (that is multi-branched trees, some of whose branches lead to other multi-branched trees), or to have rings some of whose components further link to trees or small loops. Certain modifications to these graphs, such as adding nodes directly to the high connectivity nodes, or replacing a single branch by a tree, preserves the structure of the graph. Another advantage of these graphs is that their diameter remains small even with increasing number of spaces.

6.

It is these kinds of a demand on the spatial structure of domestic buildings that rectangular geometry helps satisfy. But before we address this, we need reformulate the issue on two points.

The first point is that the issue in the emergence of predominant rectangularity in societies moving towards increasingly sociopolitically complex, sedentary lifestyles is not really that of a shift from circular to rectangular buildings; that is, it is not an issue of selecting between two dwelling shapes. This framing may been a result of the Whiting and Ayres' (1968) study, which redefined the larger issue of the relationship between building shape and social organization in terms of an opposition between circular and rectangular architecture. For Whiting and Ayres, this redefinition of the issue as a circular versus rectilinear choice was merely a matter of acknowledging the nature of their empirical data—their samples showed statistically much fewer examples of buildings that were neither circular nor rectilinear, leading them to subsume these alternatives within the two dominant categories. But in the writing of several writers (see, in particular, McGuire and Schiffer 1983) who have followed, this issue leads to complexities that may simply be an artifact of the framing.

We believe that the issue is much better clarified if the shift is seen instead as a move from modes of social organization which are shape-indifferent to ones which are not. Another way of saying this is that as societies acquire complexity in sociopolitical organization, they find it profitable to add geometric restrictions to the making of their domestic buildings; their domestic buildings begin to be defined in a Euclidean geometric, rather than a topological, space. This is not an either/or phenomenon, but rather a gradual transformation. Put in this way, our attention immediately shifts from the problem of explaining the superiority, or the efficacy, of rectilinearity over other shapes, to

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that of explaining the why shape, as such, would begin to matter in the planning of buildings.

The second point can also be traced back to the Whiting and Ayres' study. In the way that they formulated the relationship between the shape of buildings and culture, the shape of the buildings was an outcome of cultural decisions. As they put it, it is a dependent factor, and "causation flows from culture to house type to plan" (Whiting and Ayres 1968, p. 117). The implication is a general understanding of the shape of building plans as a consequence of certain conditions. Our proposal, instead, is to treat shape as a cognitive resource that designers or builders in a society exploit when developing its architecture. There are certain advantages in thinking about shape in this manner: first, it recognizes that shapes are a cognitive phenomenon, not merely a geometric one. Second, it explains the peculiar statistics of the correlations between space and social factors. Under our formulation, social factors by themselves do not necessarily lead to particular shapes; rather designers/builders would selectively deploy particular shapes under specific social or technological concerns. This need not be a necessary condition; shapes of artifacts and buildings can, of course, emerge unintended under certain physical or technical considerations, but the possibility of intentional use of shape must be admitted. Third, this way of thinking about shape creates a different (and this specific case, we think, better) relationship between shape of building and social conditions. In several theories about the relationship between building shape and society, the relationship between shape and society broadly speaking is mediated by functional or technical criteria; social factors influence the conditions under which functional or technical criteria become selectively advantageous, and particular functional or technical criteria are associated with particular shapes. Thus, for McGuire and Schiffer (1983), under social conditions that require greater mobility, functional/technical criteria such as the relative benefits of the cost of production versus the cost of maintenance drive the decision to adopt dome-shaped construction for their houses. In such an argument, shape is entailed circumstantially, in that a particular shape happened to be associated with a particular building technique available to the builders in that society. In the formulation that we will suggest, the mediating element between shape and social conditions will be the designers.

In proposing to think of shape as a resource, we have been speaking of the designers' active utilization of shape. A more correct way to speak—and one that acknowledges the point made earlier—would have been to say that the designers operate in a space in which shape is recognized. In other words, in using shape as a resource, designers will not so much choose between alternative shapes (rectangles versus circles), but rather work within a medium that acknowledges the shape qualities of their creations. This is not always a given, and as we have proposed earlier, in some societies, shape may not be exploited in organizing space for sociopolitical ends; but we want to argue that the possibility exists and the predominance of rectangularity attests to the fact that most traditions take advantage of it.

How exactly, then, does this active engagement with shape enter into the argument here? And, why does this engagement actually result in predominant orthogonality? We have already noted that rectangularity is strongly associated, in sedentary societies, with multi-cellularity; this association, in fact, is the very issue we are attempting to resolve in this section. What we have also seen, in the previous section, is that multi-cellularity is structural, and that this structure needs to meet particular conditions; it must allow variation in composition and size,

and still leave some structural parameters unaltered. We offer below two suggestions on why this should be so:

1. Steadman has shown that rectangularity becomes advantageous under specific conditions: a close-packing of rooms is required, and certain flexibility desired, which allows arbitrary variation in the dimensioning of the individual rooms while keeping their mutual adjacencies intact. For Steadman, looking at the issue from the point of view of a designer, the advantage of geometry would lie in its ability to offer variety and choice. In our case, however, the need is for greater restriction in choice. Folk builders do not work with graphs, mostly not even with drawings, but with general procedures for construction and modification of buildings. But there is a premise in Steadman's demonstration that is very consequential to our purpose. His demonstration is based on the fact that the significance of geometry, or awareness of shape, lies in the fact that it constrains the spatial embedding of topological arrangements. Moreover, different geometries constrain the embedding to a different extent, with a rectangular grid offering far more constraints than a triangular one, but at the same time offering far more choice of dimensional variation. It must be noted that while Steadman describes this in terms of adjacency graphs, our argument is based on accessibility graphs so it is not all that obvious that this reasoning should hold through. Still, we can posit that following an orthogonal geometry restricts the chance that in making any design choices; builders might disturb the graph of buildings.

2. There are other advantages of rectangularity as well, and these have to do with our cognitive capacities. Researchers working on spatial cognition (Shepard and Hurwitz 1984) have shown that we tend to cognize our visual environment in terms of an egocentric frame of reference which has a primary axis oriented forward, and a secondary axis oriented orthogonally to it. Sadalla and Montello (1989) and Montello (1991) show further that that our perception and memory of angular changes of direction is biased towards these two axes. Rectangularity in buildings restricts key elements that define the building's topological structure—the layout of internal passages or corridors, the location of successive doorways, the relative locations of different rooms, or larger zones of the house—into relationships whose mental representations are cognitively easier to make and manipulate, as compared to a relationship between these elements in buildings that are based either on no particular geometry (and thus are amorphous) or on alternative geometries.

On both these points, then, the advantage of bringing rectangular geometry to bear upon the structuring of the internal space of a house essentially lies in its capacity to create restrictions on possibilities of embedding. We need to reiterate, finally, that our position is only articulated in outline here and is suggestive in intent rather than demonstrative; much more work does remain on the several issues raised above.

7.

We conclude by revisiting Beidha to show how our proposal bears out in an actual case. To recall, the emergence of rectangularity there was not just a matter of changing the shape of buildings but the development of a new building type—the type implying not just a formal characteristic, but also patterns of use, modification, and construction technique. Buildings in phase C: (1) are larger; (2) show a greater variation in their size; but (3) are uniform in their internal structure. They also: (4) are more densely packed than in earlier

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settlement phases; and (5) show a pattern of modification and change which is starkly different from those of phases A and B (Figure 2). In phases A and B, structures were not all co-terminus and had shorter lifespans, and buildings built over the same location did not always follow the boundaries or orientations of earlier ones. In contrast, structures in phase C show signs of continued habitation over a longer period, with successive buildings being rebuilt over the foundations of earlier ones, and often not replacing them completely but modifying them, either by sealing parts of them shut, opening new entrances, or extending them (Figure 3).
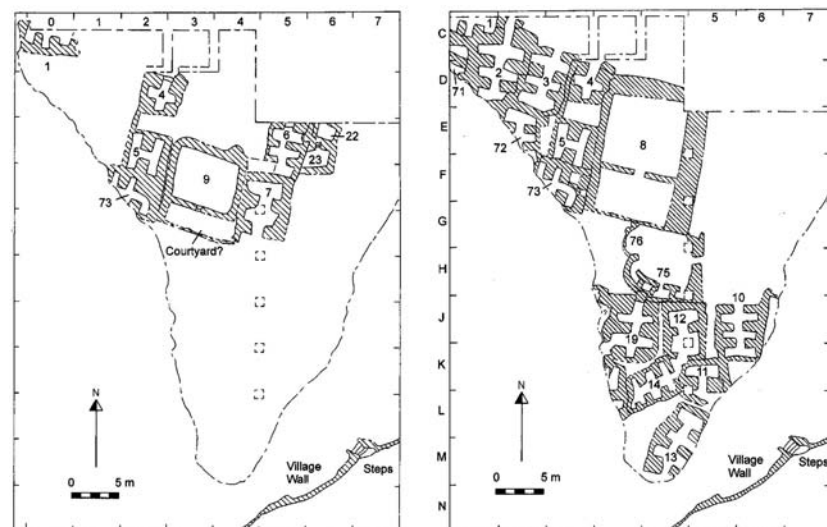
Figure 2:

Site-plans of phases A and C (lower stories only) of the excavated PPNB settlement at Beidha, Jordan. (reproduced from Byrd, 2005b)
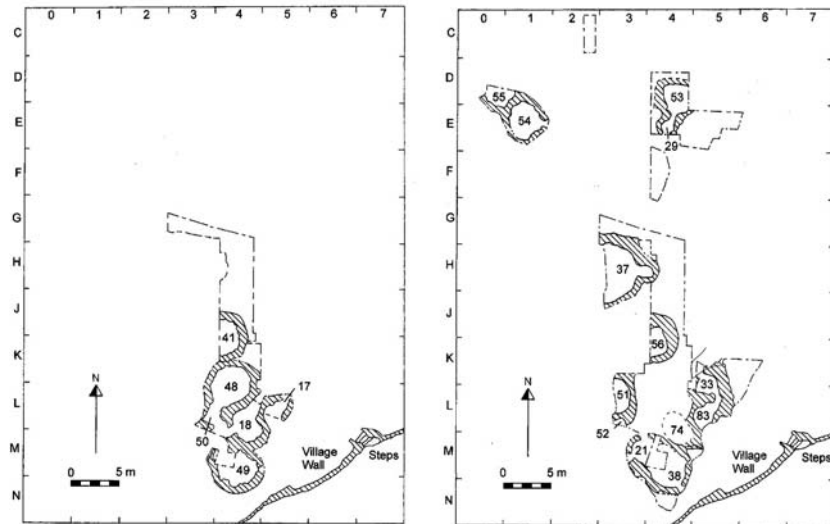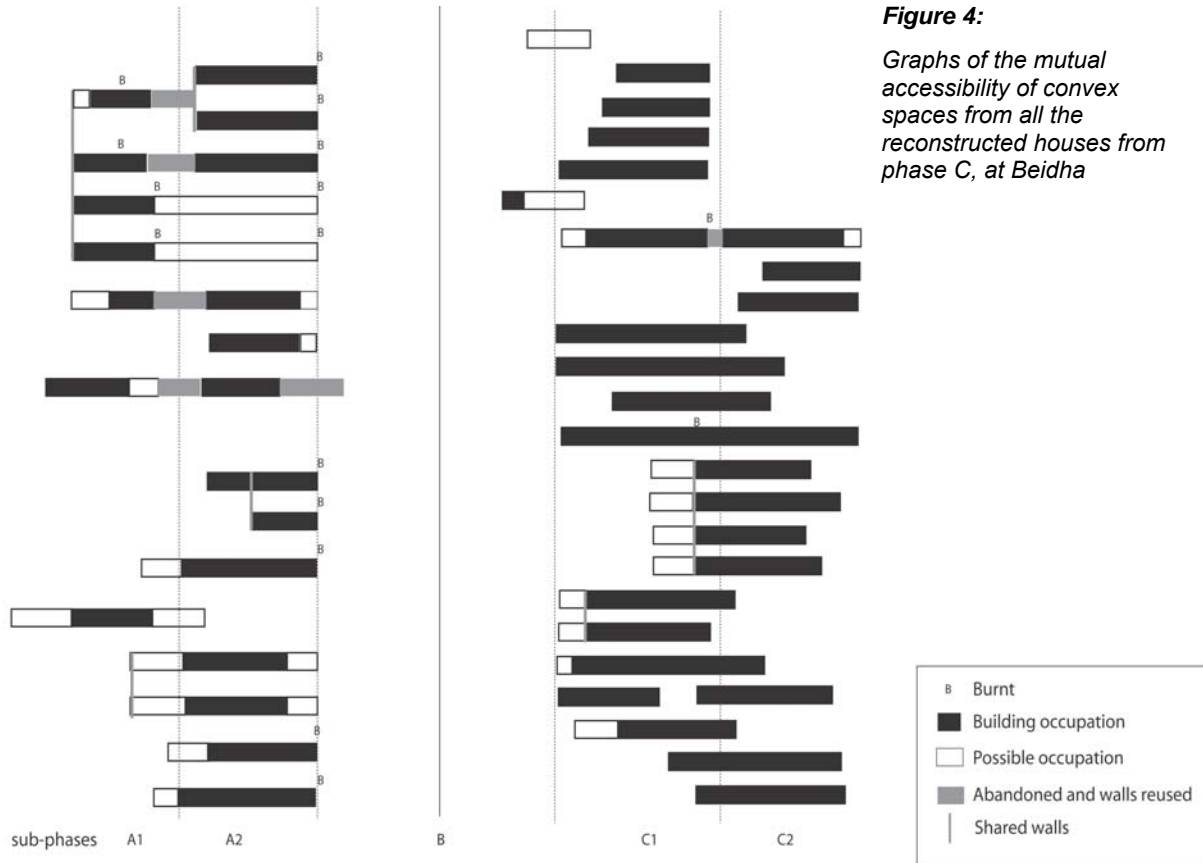

Figure 3:

Byrd's reconstruction of the use life-spans of individual buildings in phase A (left) and phase C (right) at Beidha (modified from Byrd, 2005b)

The buildings of phase C were all built to a specific model, which Byrd calls the corridor type. This consists of a semi-basement with a single long corridor accompanied by tiny rooms on both sides. Our knowledge of the upper story is conjectural, but it very likely consisted of two large rooms. The inside space, thus, is structured enough to support the complexity of social interaction within the house, as well as that between the household members and the wider members of the settlement community. Rectangularity, in this particular case, is not exploited to generate buildings with rooms of varying dimensions. But we can see how it creates a strong restriction in the variation of topological arrangements (Figure 4). Given the geometry of the building type, acts of modifications that were the most commonly employed—sealing-off areas or extending the buildings—did not disturb syntactic characteristics of the building. For instance, because

of the corridor-type geometry of the buildings, the substantial variation of internal sizes (as in buildings 3, 4, 5, and 11), does not create a corresponding variation in depth from the carrier space (the public space outside the house). Moreover, this way of using buildings over a long period and rebuilding precisely over the foundations of the earlier ones created and helped preserve a street structure, which is not present in previous settlement patterns—there is thus a close-packing of the buildings within the settlement as much as there is close-packing of rooms within the building.

Figure 4:

Graphs of the mutual accessibility of convex spaces from all the reconstructed houses from phase C, at Beidha

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The intent of this paper has been to clarify the social conditions under which a choice of rectangularity in domestic buildings would have been an advantage in very early human settlements. On the issue of establishing the actual advantages of rectangularity, our effort remains suggestive rather than demonstrative. But we are persuaded that these advantages lie not so much in the functional implications of rectangular structures as in the role rectangularity plays as a medium of conceptual design.

References

Bemis, A.F., Burchard, J., 1933-36, *The Evolving House,* 3 vols, Technology Press, Cambridge MA.

Byrd, B.F., 1994, "Public and Private, Domestic and Corporate: The Emergence of the Southwest Asian Village", *American Antiquity*, vol. 59, no. 4, pp. 639-666.

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Byrd, B.F., 2005, *Early Village Life at Beidha, Jordan: Neolithic Spatial Organization and Vernacular Architecture: The Excavations of Mrs Diana Kirkbride-HelbÃ¦k*, British Academy monographs in archaeology, no. 14, Beidha excavations, no. 2, Oxford University Press, Oxford.

Hillier, B., Hanson, J., Peponis, J., 1984, "What do we Mean by Building Function?', J.A. Powell, I. Cooper, S. Lera (Eds), *Designing for Building Utilization*, E & F N Spon Ltd, London, pp. 61-72.

Hillier, B., Hanson, J., 1984, *The Social Logic of Space*, University of Cambridge Press, Cambridge.

Flannery, K.V., 1972, "The Origins of the Village as a Settlement Type in Mesoamerica and the Near East', P.J. Ucko, R. Tringham, G.W. Dimbleby (Eds), *Man, Settlement and Urbanism*, Duckworth, London, pp. 23-53.

Flannery, K.V., 1993, "Will the Real Model Please Stand up?: Comments on Saidel's Round House or Square", *Journal of Mediterranean Archaeology*, vol. 6, no. 1, pp. 109–117.

Flannery, K.V., 2002, "The Origins of the Village Revisited", *American Antiquity,* vol. 67, pp. 417-433.

Kent, S., 1990, "Segmentation, Architecture, and the Use of Space: A Cross-cultural Model", S. Kent (Ed), *Domestic Architecture and the Use of Space: An Interdisciplinary Study*, Cambridge University Press, Cambridge, pp. 127-152.

Kent, S., 1991, "Partitioning Space: Cross-cultural Factors Influencing Domestic Spatial Segmentation", *Environment and Behavior*, vol. 23, no. 4, pp. 438-473.

Krüger, M.J.T., 1979, "An Approach to Built-form Connectivity at an Urban Scale: System Description and its Representation", *Environment and Planning B: Planning and Design*, vol. 6, pp. 67-88.

Kuijt, I., Goring-Morris, N., 2002, "Foraging, Farming, and Social Complexity in the Pre-Pottery Neolithic of the Southern Levant: A Review and Synthesis", *Journal of World Prehistory*, vol. 16, no. 4, pp. 361-440.

McGuire, R.H., Schiffer, M.B., 1983, "A Theory of Architectural Design", *Journal of Anthropological Archaeology*, vol. 2, no. 3, pp. 277-303.

Montello, D.R., 1991, "Spatial Orientation and the Angularity of Urban Routes: A Field Study", *Environment and Behavior*, vol. 23, no.1, pp. 47-69.

Robbins, M.C., 1966, "House Types and Settlement Patterns", *Minnesota Archaeologist*, vol. 28, no. 1, pp. 2–26.

Sadalla, E.K., Montello, D.R., 1989, "Remembering Changes in Direction", *Environment and Behavior*, vol. 21, no. 3, pp. 346-363.

Sahlins, M.D., 1972, *Stone Age Economics*, Aldine-Atherton, Chicago.

Shepard, R.N., Hurwitz, S., 1984, "Upward Direction, Mental Rotation, and Discrimination of Left and Right Turns in Maps", *Cognition*, vol. 108, pp. 161-193.

Steadman, J.P., 1983, *Architectural Morphology*, Pion, London.

Steadman, J.P., 2006, "Why are most Buildings Rectangular?", *Architectural Research Quarterly*, Vol. 10, pp. 119-130.

Wiessner, P., 1982, "Beyond Willow Smoke and Dogs Tails: A Comment on Binford's Analysis of Hunter-Gatherer Settlement Systems", *American Antiquity* vol. 47, no. 1, pp.171-178.

Whiting, J.W.M., Ayres, B., 1968, "Inferences from the Shape of Dwellings", K.C. Chang (Ed), *Settlement Archeology*, National Press Books, Palo Alto, CA, pp. 117–133.