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ON SPACE SYNTAX AS A CONFIGURATIONAL THEORY OF ARCHITECTURE FROM A SITUATED OBSERVER'S VIEWPOINT

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Abstract. A configurational theory of architecture (CTA) from a situated observer's viewpoint (SOV) is discussed. It includes the levels of description-proper, representation, and interpretation. It takes a bottom-up approach because a situated observer, who is on the ground with a building, typically builds her understanding of the building using immediately available elements, called perceptual primitives. Evidence from geometry, psychology/cognition, and spatial reasoning suggests that the level of description-proper of a CTA from a SOV must include unambiguously defined perceptual primitives and their perceivable elementary topological and projective relations. Subsequently, in the levels of representation and interpretation any complex relational properties of buildings must be constructed and their meanings must be explained using these perceptual primitives. Early space syntax (SS), with its foundations defined using such perceptual primitives as convex space and axial lines, helps capture the structure of visual experience of buildings but has limitations regarding a CTA from a SOV. More recently, SS theorists have revised the foundations of SS using much simpler perceptual primitives in an attempt to integrate the apparently disparate techniques of SS into a coherent mathematical system. As a result, they have eliminated many limitations of early SS regarding a CTA from a SOV. However, in order to become a CTA from a SOV, SS will still need to explain the importance of these newly defined perceptual primitives, and - provide a framework for configurational studies using the mathematical system developed based on these primitives.

Keywords. Space Syntax. Configurational Theory. Situated Observer.

INTRODUCTION

Space syntax (SS) theorists often use structure and order distinguishing perceptual from conceptual in architecture (Hanson, 1989; Hillier, 1996). They suggest that architecture becomes intelligible in two ways. In one way, we grasp a building all at once if we are in a position to see it as a whole from high above or in the form of a plan diagram. In such cases, the order of the building, as defined by its repetitive elements and relations, determines how well the composition of the building would reveal itself to us. It is suggested that we tend to associate the concept of order with the rational, formal, and the logical constructive activity of human mind.

The other, more natural way to grasp a building happens 'on the ground' over time through movement. In this mode of understanding, the order of building may have very little or no role to play. In fact, repetitions of elements and relations may even be harmful to this mode of understanding, for they may confuse the observer on the ground. SS theorists argue that what is important in this mode of understanding is the structure of the experience of architecture. This structure of experience often depends on how local perceptual characters of buildings are identified and differentiated and how these characters are related to the global form. Hence, "an apparently disorderly layout may turn out to be well-structured and intelligible to its users, whereas a highly-ordered architectural composition may in fact be unstructured when we experience it as a built form" (Hanson, 1989:22).

SS theorists often claim that their theories and techniques are better at describing the structure of experience of buildings (e.g., Peponis, 1993a, 1993b, Hanson, 1994). The earlier SS literature suggests that order and structure are different, and that these concepts are not related to each other because a plan or a bird's eye view represents buildings and places with an order or a conceptual unity, which cannot be duplicated on the ground because architecture is not experienced in this way (Hanson, 1989). In contrast, the more recent literature suggests that our experience of buildings may vary along a continuum defined by the amount of order and structure they possess; and that some buildings may be highly structured but poorly ordered, others may be poorly structured but highly ordered, yet others may provide a good balance between order and structure, and there may still be others that are neither ordered nor structured (Psarra, 2009).

While dualities such as composition and configuration or order and structure in the SS literature are interesting, does SS really provide ways to construct logically any global compositional traits of buildings from a SOV, such as geometric symmetry, as claimed by some space syntax theorists? The strongest argument in support of the claim can probably be made based on many empirical studies showing that people tend to gravitate toward the most integrated spaces in a building (e.g., Hillier et al., 1993). Therefore, one can potentially claim that when the most integrated spaces occupy the axis of symmetry of a building a situated observer may get a stronger sense of symmetry than when the most integrated spaces do not occupy the axis of symmetry (e.g., Psarra, 2009). This potential claim, however, would be susceptible to immediate questioning because many buildings with strong geometric symmetry do not have the most integrated spaces along the axis of symmetry. What really transpires in this discussion on order and structure, or conceptual and perceptual in the SS literature is this: If architecture is rarely available as a whole to a situated observer, then how does the observer know the whole based on the glimpses of its parts and their relations from any number of positions she may occupy during her stay in and outside the building?

THREE LEVELS OF A CONFIGURATIONAL THEORY OF ARCHITECTURE

To answer the above question, the paper proposes a configurational theory of architecture (CTA) with three interrelated levels. At the lowest level of the theory is "description-proper," where materially anchored perceptual primitives are identified. At the next higher level is "representation," where one or more formal schemes to construct more complex relational patterns of architecture are defined. The traditional axial map of SS representing a skeleton of movement is an example of such a representation. At the last level of the theory is "interpretation," where the meaning of architecture within a given "context" is discussed. For example, a traditional axial map may be interpreted as an embedded system of spatial relationships to explain wayfinding issues (e.g., Haq, 2003; Peponis, Zimring and Choi, 1990).

The above separation, however, is not permanent. Since a theory of configuration operates within a defined context, the same object may have several definitions in relation to its contexts. Thus, the subject of description-proper of architecture in one context may become the subject of representation in a different context. In SS, Figueiredo and Amorim (2005) link several axial lines to represent a continuity element analogous to an extended street, which then becomes the unit of analysis. In doing so, the axial map, which is a representation in its own right, becomes an object of description-proper to be used for another higher-level representation (also see for Peponis et al. 2008 for a similar use of the axial map).

Any approach taken to study the configuration of architecture in a defined context already endows it with an implicit meaning. This implicit meaning is embedded in the ways certain elements rather than certain other elements of architecture are selected in the process of description, and is engendered by the ways in which these elements are related to one another in the process of representation. At a more explicit level of interpretation, aspects of architecture are frequently mapped onto other knowledge domains to study correspondences. Through these correspondences, architecture acquires meanings that are implanted into it.

It is possible to clarify the differences among these three types of meanings using examples from SS. SS theorists often use the convex map of a building layout to study how functions are put together. In contrast, they use the axial map of a building layout to study how people move in the building. They even suggest that convex organization relates to buildings experienced in repose, and axial organization relates to buildings experienced through movement (Hanson, 1994). Hillier (1996) articulates the importance of these techniques in the following way: "Convex and axial structures, built on the basis of the metric geometry of space, are the fundamental means through which we make the structure of space intelligible, and pretty well the only means" (Hillier, 1996: 175). These two techniques thus provide good examples of the meaning that is already embedded in the way these theorists conduct their studies of buildings.

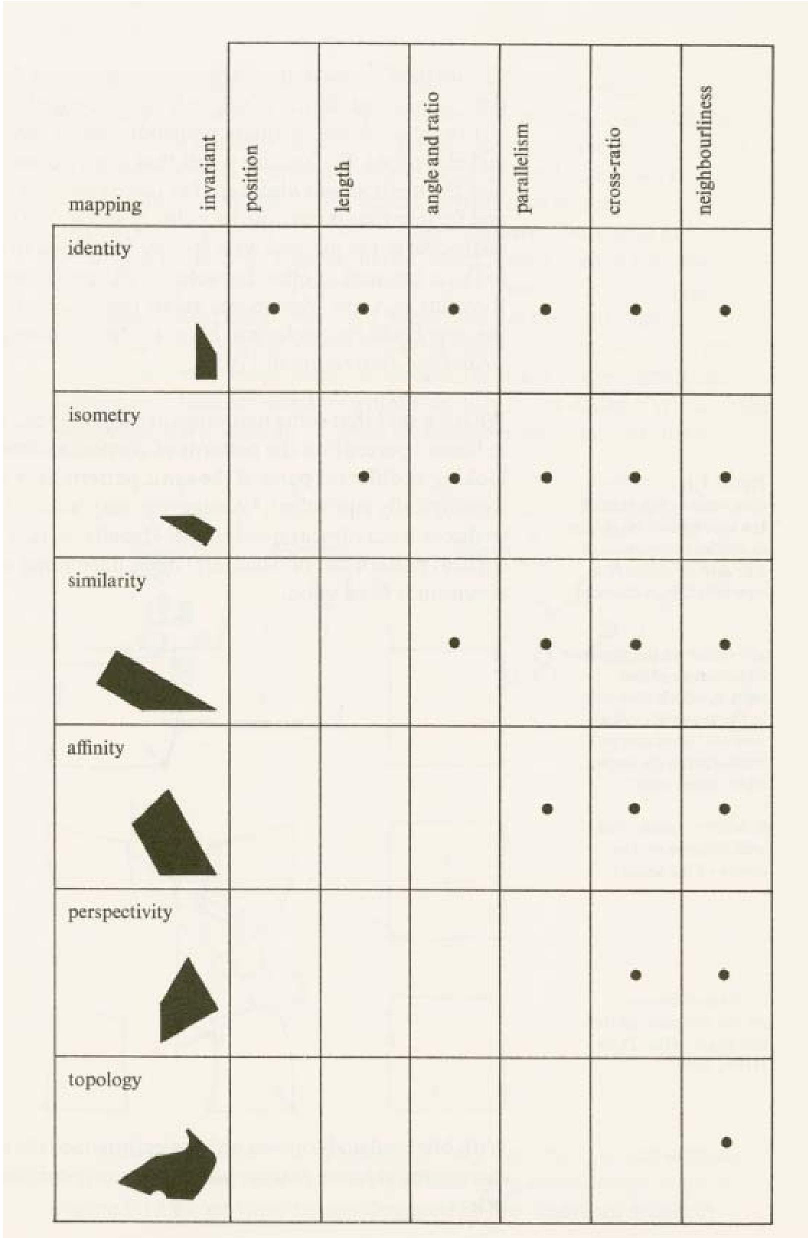
To illustrate what might be the engendered meaning, we can use the access graph of a building (i.e., a graph that shows how spaces are connected to each other) that SS uses to study such constructs as depth, ringiness, and control (e.g., Hillier et al., 1987). These graph-theoretic constructs, then, help us show how meanings can be engendered in the way one chooses to describe the relational patterns of spaces. However, for both embedded and engendered meanings, there is no need to map the structure of the study object onto that of another object; thus, no meaning is implanted. To understand what the implanted meaning is, consider the following example from SS.

SS researchers often study movement densities on paths defined by the axial map of a layout, and then they correlate syntactic values of these paths—values that describe how connected each of these paths are to all other paths in the system—with observed movement densities on these paths. Through numerous studies they reveal that there exists a strong correlation between syntactic values and movement densities. Therefore, they propose 'the theory of natural movement' suggesting spatial configuration as a strong predictor of movement (Hillier et al., 1993). Thus, they are able to implant meaning on the axial map via its mapping on movement densities. Hillier (1996) further categorizes the implanted meaning into instrumental and symbolic meanings. This paper deals with all three levels of a theory of configuration referring to the fact that our ability to recognize, discuss, and describe formal properties of architecture, which are the subject matter of description-proper and representation, arises from an interaction between perception and conception. As a result, there is always a need to involve meanings in the process.

THE FORMAL CONTENT OF A CTA FROM A SOV

In order to define the formal content of a CTA, this paper uses a bottom-up approach. Geometry, psychology/cognition, and the ways we perform spatial reasoning using natural language already suggest a common way to define this approach. In trying to find out how geometry fits within a CTA from a SOV, it is interesting to go back to the history and philosophy of geometry. In 1872, Felix Klein gave a lecture at the University of Erlangen (translated in Klein, 1893), now known as the Erlanger Program, where he proposed a unifying principle for classifying various geometries based on automorphisms, i.e., one-to-one transformations of objects in the space onto itself preserving the basic relations among the objects. As a result, he created a hierarchy of geometries with topology at the root. All other geometries can be obtained by adding axioms to topology and, therefore, one class of geometry can be seen as a more specialized case of another class. Properties that are preserved in a certain group of transformations are called invariants. In general, a certain group of transformations is strictly contained in the preceding group of transformations: for example, all affine transformations are also projective transformations and therefore preserve projective invariants. March and Steadman (1971) provide a table showing how by relaxing various invariants—position, lengths, angles, ratios, parallelism, cross-ratios—it is possible to make a smooth transition from Euclidean geometry to topology where only neighborliness is preserved (Figure 1). An understanding of invariants of each class of geometry in the hierarchy, thus, seems to be important for describing a building from the viewpoint of a situated observer.

Like geometry, humans also follow a similar process in the representation of cognitive space (i.e., the representational space). The groundwork on the topic was done by Piaget with his colleague Inhelder (Piaget, 1969, 1970; Piaget & Inhelder, 1967). In Piaget's opinion, the representational space is different from the perceptual space. The perceptual space may be assumed the same for all humans, but the representational space is different for children at different stages of the development of the intelligence. To be able to represent space, the child must learn to coordinate spatial relationships mentally through a process that proceeds from the more elementary to the more complicated aspects of space. In this regard, Piaget's experiments show that fundamental spatial notions are not the basic elements of the Euclidean geometry (such as lines and angles), but topological



mapping \ invariant	position	length	angle and ratio	parallelism	cross-ratio	neighbourliness
identity	•	•	•	•	•	•
isometry		•	•	•	•	•
similarity			•	•	•	•
affinity				•	•	•
perspectivity					•	•
topology						•

Figure 1. A table showing how by relaxing various invariants—position, lengths, angles, ratios, parallelism, cross-ratios—it is possible to make a smooth transition from Euclidean geometry to topology where only neighborliness is preserved (from March and Steadman, 1971)

concepts (such as connectedness, inclusion and order). The conclusion of Piaget's work is that the representational space of the child starts with elementary topological intuitions before becoming at the same time projective and Euclidean. A psychological process transforms the topological notion of order to the projective straight line after the discovering of points of view, and to a Euclidean system when the child becomes able to understand distances and movements.

Based on the Erlanger Program and Piaget's ideas, it is possible to imagine a framework of configurational studies of buildings based on topological, projective, and metric properties. Through topology, information about neighborliness, connections, and the presence/absence of holes of the object will be provided for these studies. Through projective geometry, information about convexity/concavity of the object will be provided. Finally, through metrics or Euclidean geometry, information about compactness, symmetry, and so on will be provided. The problem of parsing among the topological, projective, and metric properties of buildings for such a framework can be solved based on how we perform everyday spatial reasoning using natural language. It would seem that in everyday spatial reasoning, we depend more on topology and projective geometry and less on Euclidean geometry. As observers we are not very good at using exact metric and global properties to describe the environment, whereas we can very easily perform context-dependent comparisons, or understand relational properties. Naturally then, both architecture and cognitive science have frequently focused on projective relations in conjunction with topology to build the early phases of a model explaining our perception and and understanding of the physical environment. Therefore, in the next two sections, the relevant cognitive science and architecture literature is reviewed keeping in mind the needs of a CTA from a SOV.

COGNITIVE SCIENCE AND A CTA FROM A SOV

Our mental representations of space are different from the external representations of space. These mental representations may include, but are not limited to, the space around the face, that around the hand, that of the body, that around the body, that of navigation, and that of graphics (Gross & Graziano, 1995; Tversky, 2003, 2000). For a CTA from a SOV, the space of navigation seems most relevant. Typically, this space is considered large-scale space for its relevant structure is at a scale larger than the sensory horizon, so knowledge of it must be acquired from exploration within it (Kuipers, 2008).

Physical, developmental, physiological and computational or information processing perspectives are among the theoretical perspectives taken to explain how we gain knowledge of large-scale spaces. Developed based on Lynch (1960), the physical perspective suggests that our mental representation of large-scale spaces is determined largely by the arrangement of the critical environmental elements, such as paths, edges, districts, nodes, and landmarks (e.g., Evans, 1980; Evans et al., 1982). Mainly derived from Piagetian theory (see above), the developmental perspective presents a view that we actively construct the mental representations of large-scale space from the data we acquire about them (e.g., Moore, 1979; Pick, 1976). The physiological perspective examines the basis of spatial cognition in large-scale space in the brain (e.g., Kritchevsky, 1988; Lieblich & Arbib, 1982; O’Keefe & Nadel, 1974, 1978). Finally, the computation or information processing perspective includes formal models that simulate the processes by which we create mental representations of large-scale spaces (see below). Theorists taking this last perspective often integrate ideas developed within any one or all the other theoretical perspectives. For a CTA from a SOV, the computational theory of cognitive robot mapping (CRM) seems relevant because it takes a bottom-up approach integrating all the theoretical perspectives mentioned above.

In CRM human knowledge of large-scale space is represented using a number of distinct cognitive modules related to different aspects of the space. Some consist of procedural, “how-to” knowledge about getting from one place to another. Some consist of topological connections between places and travel paths. And some consist of metrical layouts approximately analogous to the environment itself or to a printed map. For many several of these modules may work well together, while for many others even fewer of these modules may not work together so well. Therefore, an adequate computation theory of CRM assumes that there is an ‘ideal’ structure complete with all the modules working well together, and that all the variants--with individual style, developmental stage, or amount of experience in a particular environment--are modified or restricted version of the ideal (Kuipers, 2008).

With the above in mind, Kuipers and his colleagues provide the Hybrid Spatial Semantic Hierarchy (Hybrid SSH) model of CRM with multiple levels of spatial representations, each one grounded in the ones below (Kuipers et al., 2004). They provide this model based on their earlier TOUR and SSH models (Kuipers, 2000; Kuipers, 1978; Remolina & Kuipers, 2004). Part of the original motivation for the TOUR model was that humans do not typically create an accurate global metrical map from observations during travel. Whereas SSH and Hybrid SSH take into account the fact that with increasing experience in the environment, humans can create cognitive maps that are increasingly faithful to the Euclidean representation of the world. In the end, the goal of their models is to "build a correct global metrical map on the skeleton provided by an accurate topological map, using observations from experience in the local perceptual map" (Kuipers, 2008: 257).

Like the Hybrid SSH model, the CRM approach of Franz and colleagues also uses multiple levels of spatial representation created based on place and view graphs (Franz et al., 2008; Franz and Wiener, 2008). These levels include route navigation, topological navigation, and survey navigation. In the place graph, nodes correspond to single places or positions within an environment, and edges describe the connectivity between nodes. In the view graph, each node corresponds to a pictorial snapshot of the environment as seen while walking through the environment. Nodes are connected by edges if the corresponding views occur in immediate sequence while walking. They are labeled with local navigation rules. The basic idea of the view or place graph is to generalize route memories to a more flexible representation of space (Franz, Mallot, & Wiener, 2005). In survey navigation, a metrical map with a single frame of reference is then constructed based on the place and view graphs.

The computational theories of CRM may enable a robot to build accurate global metrical maps based on local information, but they possess several limitations regarding a CTA from a SOV. The first limitation is related to the fact that the basic aim of a computational theory of CRM is to find an economic way to describe the environment exhaustively and accurately. While economy in the description of architecture is an important goal as well, most architectural descriptions are often motivated by one or more specific purposes. Traditionally, architectural theorists have been less interested in exhaustive and accurate representations of their knowledge of space, if their descriptions or representations helped explain these purposes sufficiently.

The second limitation is related to the fact that the description of human commonsense knowledge of the physical environment has been the end purpose of any computational theory of CRM, whereas it is only the beginning for a CTA from a SOV. Unlike robots, humans navigate space with a higher purpose in mind. They do not passively receive, sort, compare, and learn spatial knowledge. As they navigate, they constantly interact with space in their own way and, as a result, create new spatial knowledge. For example, they find some spaces useful; some spaces interesting; some spaces quiet; some spaces friendly; and so on. As humans create new spatial knowledge, they also apply this knowledge to the process of spatial navigation. In other words, humans' spatial navigation involves a process of emergence, which is hard to define before the fact.

The third limitation is related to the fact that architecture is both an object and a process—a view Hillier presents in his book Space is the Machine (1996). According to Hillier, physical and spatial form alone cannot define architecture. If this were to be true, then we could easily copy the work of a great architect and claim an equal status for the copy. We cannot do this because the definition of architecture is intrinsically related to the intention of the architect. To understand the intention of an architect, an observer may need to attribute some meanings to the building. So far, no computational theory of CRM deals with how meanings can be attributed to the environment. Therefore, for all of the above reasons, at least for now we will have to accept the fact that the computational theories of CRM are not suitable for a CTA from a SOV.

SS AND A CTA FROM A SOV

In architecture, SS is a good candidate for a CTA from a SOV. It already includes the three levels of a theory of configuration. At the level of description-proper, SS uses the convex unit and the axial line as the perceptual primitives. SS also uses the 360-degree visual polygon available from a point, called an isovist (Benedikt, 1979), as a perceptual primitive. At the level of representation, the convex and axial maps of SS are the two most important representations used for describing the visual experience of buildings. In addition, a well-defined set of visual polygons is also used as a way to represent the visual experience of a building (Turner et al., 2001). Once plans are represented as convex maps, axial maps, or visual polygons, the topological relationships among the spatial units in these representations are described using graph-theoretic techniques. Taken together, the convex map, the axial map, and visual polygons and their graph-theoretic measures are able to provide a

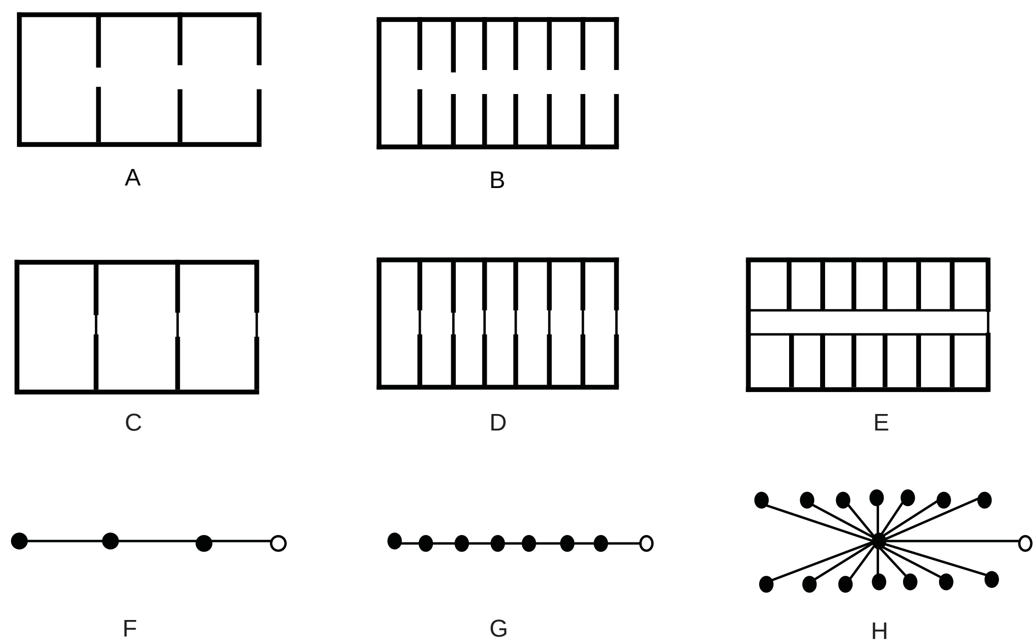


Figure 2. For Plan A the convex partition C appears meaningful. However, for Plan B the convex partition D appears less meaningful than the convex partition E. Not only does D have less spaces than E, it also has a significantly different access graph (G) than its counterpart (H).

rich description of the visual experience in buildings.

Concerning meaning, the literature on SS shows that convex maps are relevant to studies concerning how buildings, through spatialization of functions and social categories, embody and represent social knowledge. Likewise, axial maps are found to be relevant to studies concerning how buildings create different conditions for movement, interaction, and co-presence. In the literature, visual polygons are often used in conjunction with convex maps in studies concerning spatialization of functions and social categories, and in conjunction with axial maps in studies related to movement, interaction and copresence (for an excellent survey of the SS literature see Peponis and Wineman, 2002).

For a CTA from a SOV, SS thus appear particularly promising. Its techniques provide an efficient representation of the environment at a wide range of scales. At the same time, they are capable and flexible enough to retain a substantial amount of psychologically and behaviorally relevant information of the environment. However, concerning a CTA from a SOV, the formalism of early SS (Hillier and Hanson, 1984; Hiller, 1996) had a number of shortcomings that have been the subject of many subsequent SS studies, which are discussed below.

Problem 1: The early definition of convex map as the fewest number of fattest convex spaces that cover a spatial system was not mathematically well-defined (Figure 2).

Since this is an intractable problem, SS theorists have suggested other ways to define convex maps. Hillier (1996) provides a method to identify a set of overlapping convex spaces instead of a unique convex partition. The method extends all the extendible surfaces within a plan, which, of course, produces a very large number of overlapping convex spaces (Figure 3). For his overlapping set, Hillier (1996) selects only those spaces each side of which has at least one wall surface partially or fully covering the side (Peponis et al., 1997).

In contrast, Peponis and colleagues (1997) provide at least three different types of convex partitions. One of these is called a minimum partition because it uses a minimum number of convex spaces to cover a plan. This partition, however, may not always contain the fattest possible convex space as required by the early definition. In addition, a minimum partition is not uniquely defined because a plan may have more than one

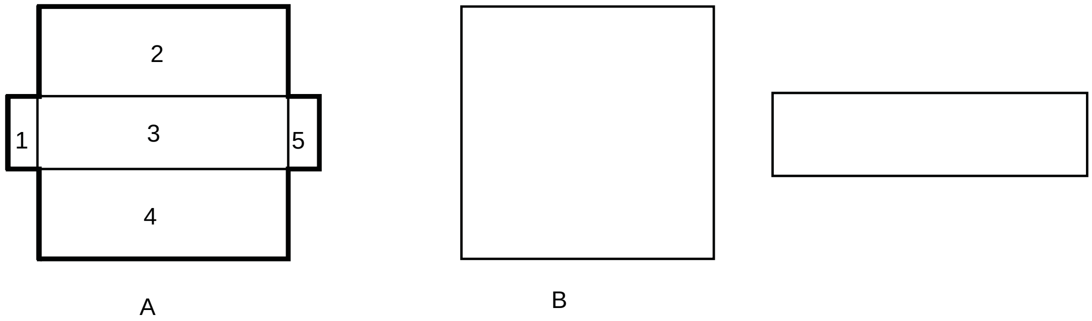


Figure 3. In Hillier's overlapping convex space modeling, the convex partition is defined by the extension of all extendible surfaces, as shown in A. However, Hillier (1996) does not discuss the way in which the spaces in the partition can be coalesced into larger units of analysis. The solution to this problem as suggested by Peponis et al. (1997) is shown in B.

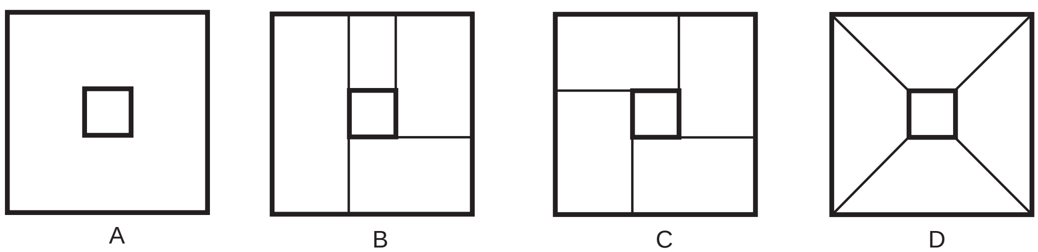


Figure 4. B, C, and D are three different minimum partitions of Plan A (drawn based on Peponis et al., 1997).

such partition, each with a different configuration, if the rules used for generating these partitions are different (Figure 4).

More important for the purpose of this paper, however, are the other two partitions provided by Peponis and colleagues (1997). Like Hillier's overlapping partition, Peponis and colleagues use walls of a plan and their surfaces to generate their partitions. They use walls and s-lines (i.e., the extensions of extendible walls or surfaces) to define the s-partition composed of discrete s-spaces; and walls and e-lines (i.e., the extensions of extendible walls and diagonals) to define the e-partition composed of discrete e-spaces (Figure 5).

The s-partition of a plan is important, because each time an observer crosses an s-line an entire surface either appears into or disappears from her visual field. However, while within an s-space one or more surfaces can go out or come into the view of the observer. Thus, s-spaces are not informationally stable. In contrast, each e-line in an e-partition demarcates a change in the visibility of the endpoint/s of wall/s. They are also informationally stable because from any point within an e-space the number of visible endpoints remains unchanged. Since the e-partition is significantly more sensitive to the metric properties of walls than the s-partition of a configuration (Figure 6), it may be less useful than the s-partition in the studies related to the generic properties of building plans from the viewpoint of a situated observer.

In addition to s- and e-partitions, walls and surfaces of a plan also help define the d-partition, which is composed of all the d-spaces generated by the diagonals in a plan (Figure 5). This partition represents all possible triangulations of visibility between the endpoints of the plan. Triangulation is important because it represents the most elementary structure of visual relations defined by the endpoints of a plan (Rashid, 1998).

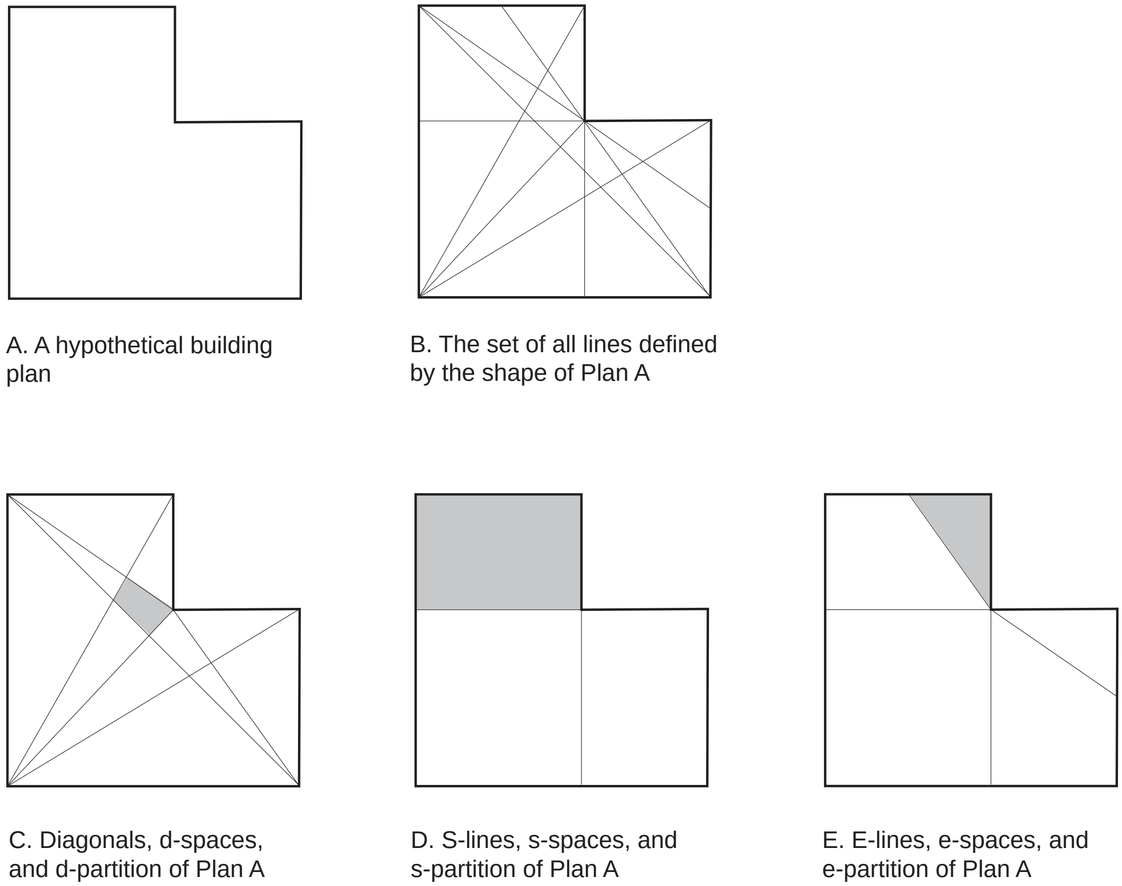


Figure 5. The d-partition, s-partition and e-partition of a hypothetical building plan.

Problem 2: The early definition of axial map as the fewest number of longest axial lines that cover a spatial system also was not mathematically well-defined (Figure 7).
To solve the problem, Peponis and his colleagues (1998a) generate linear representations of building plans based on the above partitions. The traditional axial map, which is one of the three different linear representations presented by these authors, is defined here as the minimum set of lines needed to cross all s-lines (as opposed to "cover all convex spaces" of the traditional definition) and to complete all movement rings of a configuration. The techniques used by Peponis and his colleagues to generate linear representations are somewhat related to an "all lines map" used by Hillier (1996) (Figure 8). Hillier's "all lines map" includes all diagonals, e-lines and s-lines (Peponis et al., 1997), but does not provide any method to extract a more economic linear representation as did Peponis and his colleagues (1998a). Later, some of these ideas were applied to automate the generation of axial representations (Turner et al., 2005).

Batty and Rana (2004), however, suggest a different method for solving the problem. Their method starts by generating a set of isovists on a raster defined at a suitable scale of resolution. It then uses an algorithm for sorting these isovists according to their maximum diameters. The algorithm finds the isovist with the longest diameter, selects this as the first axial line, and reduces the isovists to be considered in the next step by subtracting the isovists associated with this first line. It then repeats these steps until all spaces have been covered by one or more of these axial lines. This method is interesting for it provides an unambiguous way to generate an axial representation based on isovists. However, the method sometimes generates axial lines that are not always connected in the way they would be connected in a traditional axial map ensuring continuity in movement. Additionally, the method identifies several well-defined processes to determine the scale of resolution at which

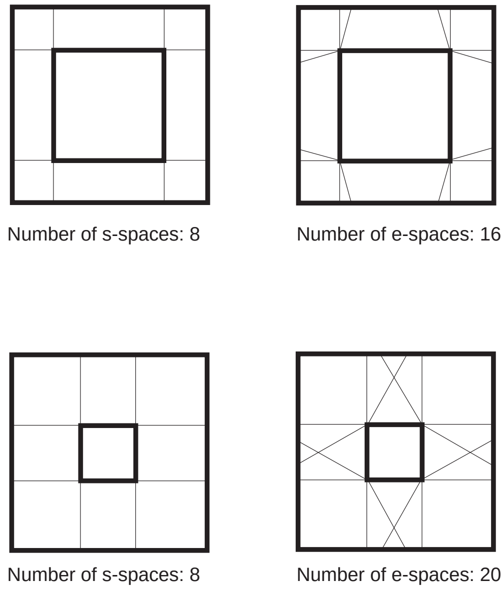


Figure 6. The s- and e-partitions of two simple hypothetical plans. They help illustrate the fact that e-partitions are more sensitive to metric properties than s-partitions.

isovists must be drawn, but all these processes involve rules unrelated to the situated observer and the environment it describes.

Turner (2007) uses angular segment analysis (ASA) (Dalton 2001; Turner, 2001) to provide yet another solution for the problem. ASA breaks the lines of a linear representation of a spatial system into segments at their intersections, and then finds the sum of the angles turned from the starting segment to any other segment with the system. This angular sum is treated as the ‘cost’ one pays as one takes a trip from one segment of the representation to another. It is generally assumed that the higher the angular sum the more one pays for a trip. Turner (2007) as well as Hillier and Iida (2005) show that ASA measures of a linear representation are excellent predictors of movement patterns. ASA also is more grounded in cognitive science studies that have long suggested that route angles affect spatial navigation and cognition (Hochmair and Frank, 2002; Montello, 1991; Sadalla and Montello, 1989). Other SS studies have also shown that when programmable agents use least-angular strategies for reaching their goals their patterns of movement correlate well with patterns of pedestrian movement (Penn and Dalton 1994); and that people tend to minimize angle towards their destination (Conroy Dalton, 2003).

ASA helps eliminate a long-standing problem of the early axial representation related to the fact that sometimes one axial line may suddenly become many axial lines due to minor changes in the environment. As a result, SS produces significantly different analyses (Ratti, 2004). ASA does not suffer this problem because when one axial line gets broken into multiple axial lines due to minor changes, these axial lines always are at small angle to each other and do not change the sum weight significantly. However, when considered for a CTA from a SOV two basic problems with ASA applied to road-center lines are: 1) road-center lines are rarely available to a situated observer as a perceptual primitive of the environment; and 2) regardless of whether one chooses road-center lines or the traditional axial maps, ASA breaks these lines into segments that have very little meaning for the situated observer. In other words, ASA does not fix the foundational problem related to the outside interference in linear representations and their analysis.

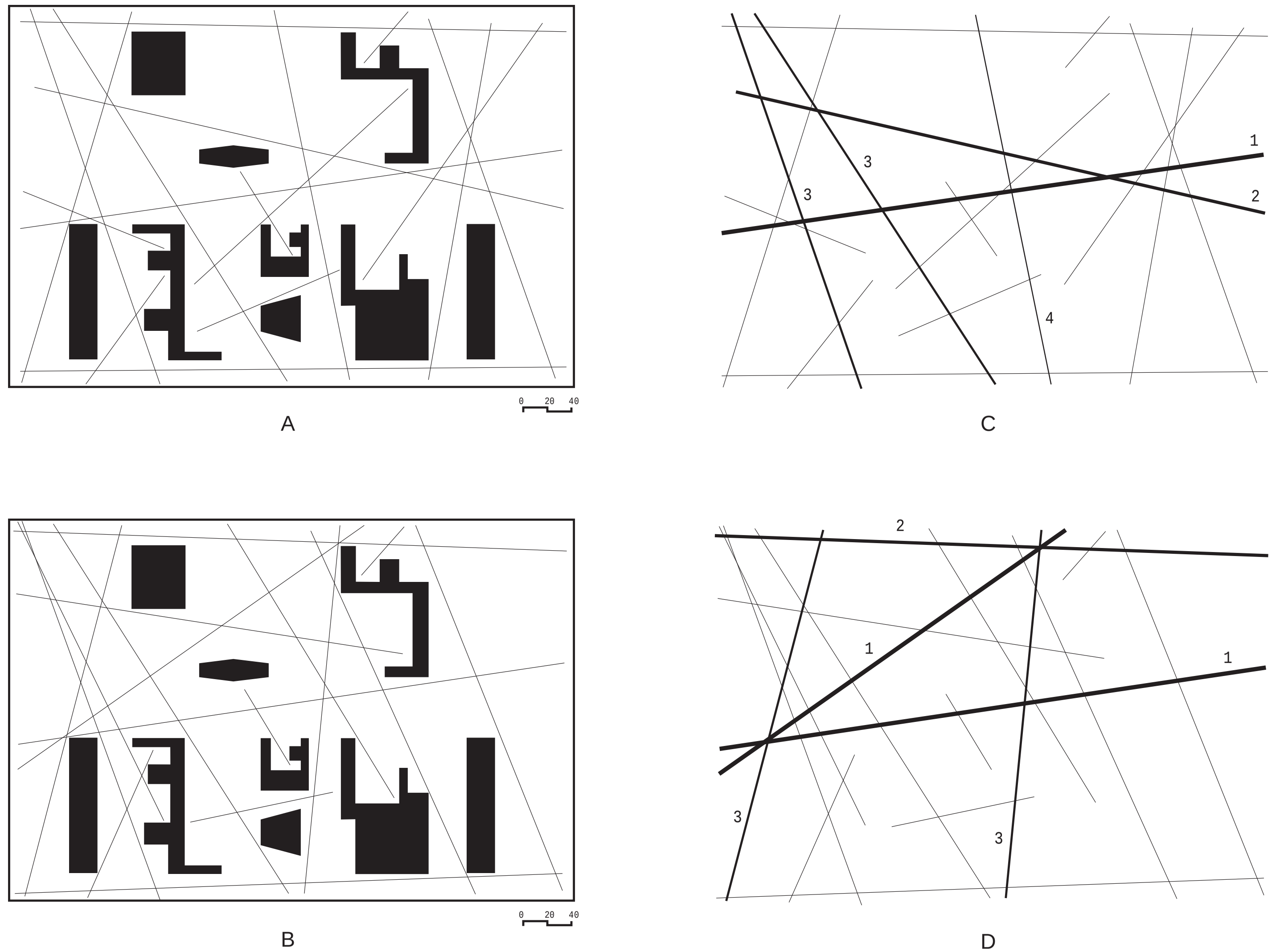


Figure 7. A and B are two different axial maps of the same layout, and C and D show their integration cores.These diagrams help illustrate the fact that the early definition of axial map as the fewest number of longest axial lines that cover a spatial system was not mathematically well-defined.

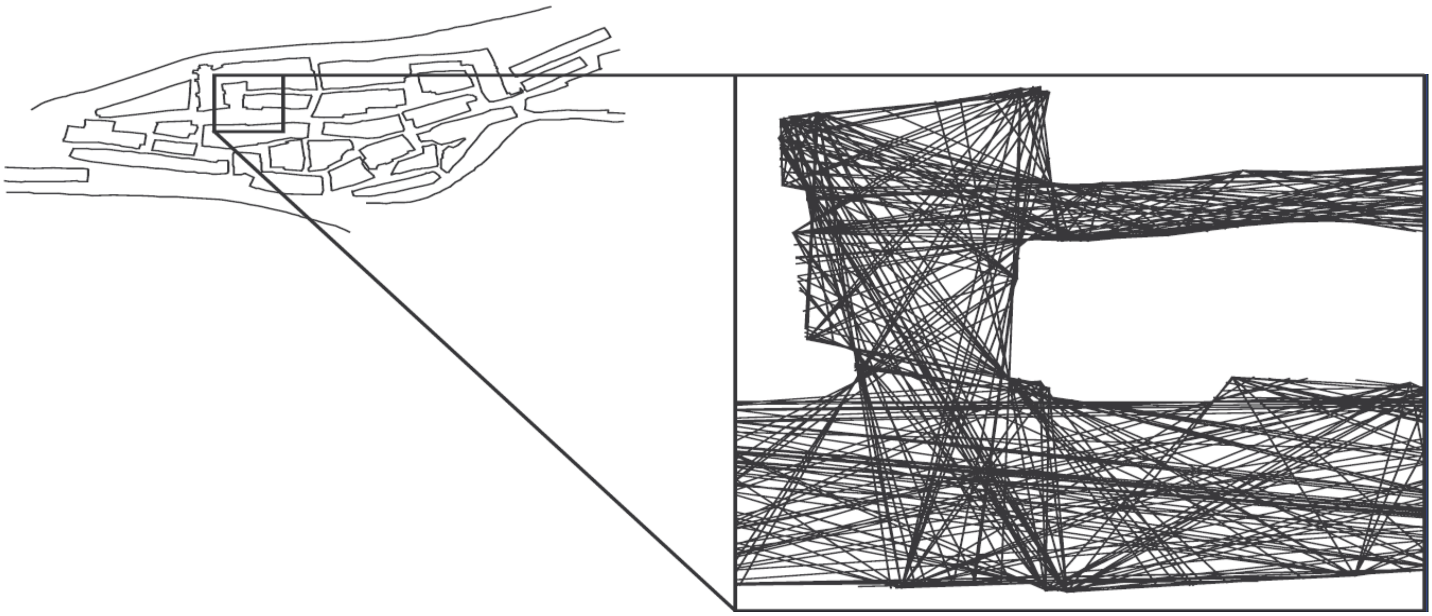


Figure 8. Detail of the all-line map generated from a vectorised version of a settlement layout (from Turner et al., 2005).

Problem 3: Isovist has been a useful technique in SS since its early days, but early SS did not include mathematically well-defined techniques to specify a sufficient set of isovists needed to describe any given environment (Figure 9).

During the last decade or so, different techniques have been suggested to describe the environment using isovists (e.g., Batty, 2001; Batty and Rana, 2004; Turner et al., 2001). These techniques generally use a raster to approximate viewpoints, and define the isovist by relating the raster points within the isovist to the viewpoint. Even though the raster makes computation easy, a major limitation of these techniques is related to the scale of resolution of the raster, which ultimately determines how many isovists must be drawn for a sufficient description of the environment. Concerning this limitation, the pragmatic considerations that often take priority are the amount of computing power available to do the job and the definition of what a sufficient description of the environment is. In other words, all these techniques of isovist analysis require some outside interference to determine the scale of resolution of the raster.

In contrast, Peponis and his colleagues (1998b) use the e-partition of a plan to limit the number of isovists needed to describe an environment sufficiently. Since e-spaces of a plan are 'informationally stable' (Peponis et al., 1997), isovists that can be drawn from all possible points within a plan can be usefully grouped according to sets which correspond to all the points within e-spaces. In other words, the e-partition of a plan provides at least one mathematically well-defined way to limit the number of isovists in the plan without involving outside interference. Peponis and his colleagues used this technique to describe the patterns of covisibility of surfaces discussed below in relation to the fourth problem of early SS.

Problem 4: The early SS techniques were not sufficiently shape-sensitive.

In simple words, if the axial or convex representations of spatial systems with different shapes have the same graph SS analysis of these spatial systems does not differ (Figure 10). March and Steadman (1971) Illustrates the problem vividly by showing how F L Wright embedded the same access graph in three house plans with remarkably different shapes (Figure 11). Hillier (1996) proposed 'overlapping convex spaces' and 'all line maps' (discussed above) to bring shape within the purview of SS. However, he did not explain how these techniques are related to the traditional convex and axial maps. Hillier (1996) also applied graph theoretic measures to

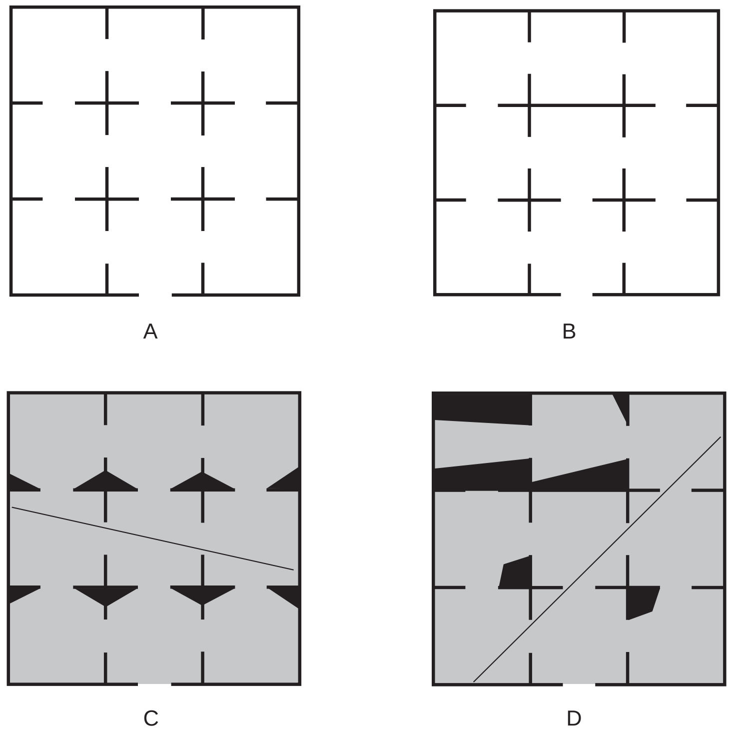
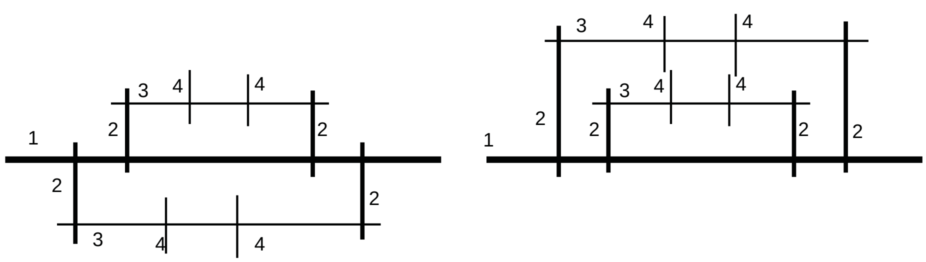
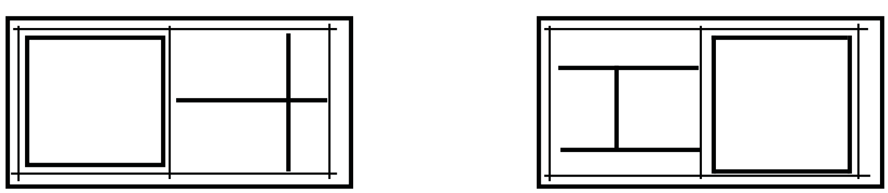


Figure 9. Early space syntax theorists have often used isovists drawn from the most integrated axial lines of building plans to describe how visual experience along these lines may vary. A and B are two hypothetical building plans with similar shape and geometric properties. C and D show the isovists drawn from the most integrated axial lines of these plans. They help illustrate the fact that the most integrated axial lines may reveal very different information about building plans even when they have similar shape and geometric properties.



Two axial maps with the same configuration: While in one case the most integrated line lies in the center; in the other it lies on the periphery. These examples help show that the concept of centrality in topology is significantly different from that in metric geometry.



It is almost impossible to guess the shape of a plan from its axial map, because the same axial map may be embedded in plans which are different not only in shape and metric properties but also in their convex partitions. Note that each map contains the fewest set of longest lines necessary to cross all s-lines and complete all circulation rings following one of the three defintions of linear representations provided by Peponis and his colleagues (1998).

Figure 10. If the axial representations of spatial systems with different shapes have the same graph the analysis of these spatial systems using space syntax techniques do not differ.

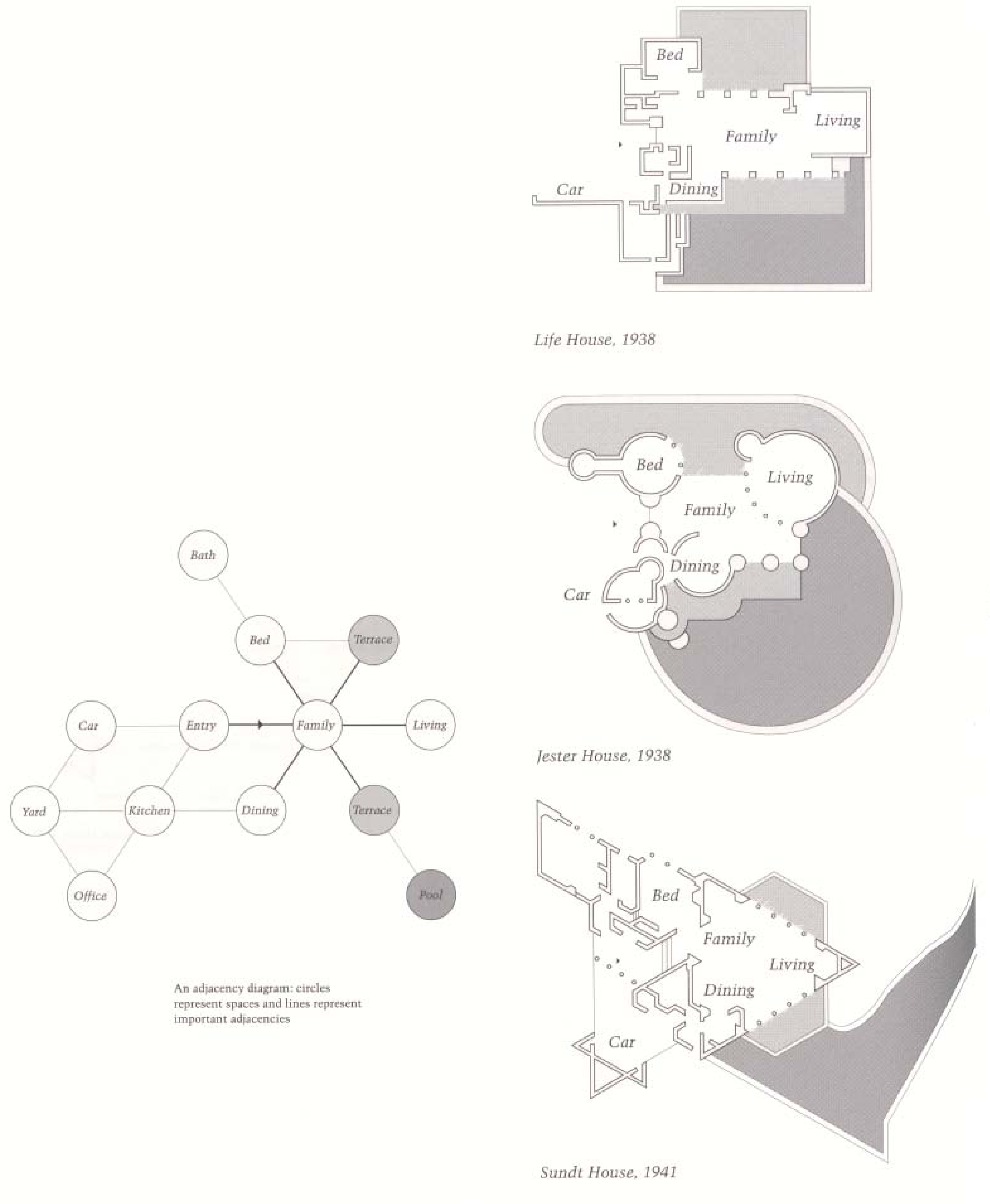


Figure 11. Three F L Wright house plans that have the same access graph embedded in different shapes. (Source: March and Steadman, 1971)

rectangular tessellations embedded in different shapes to show how these measures could help pick up shape differences. Again, these rectangular tessellations were not intrinsically related to the shapes they helped describe (Figure 12).

The s-partition, e-partition and d-partition developed by Peponis and his colleagues recognize the fact that there are objective ways to describe visual experience using the shape of building plans (Peponis et al., 1997; Rashid 1998). They make the synthesis between form and space stronger by providing a process to determine the smallest number of positions on the e-partition of a plan from which all surfaces of the plan become

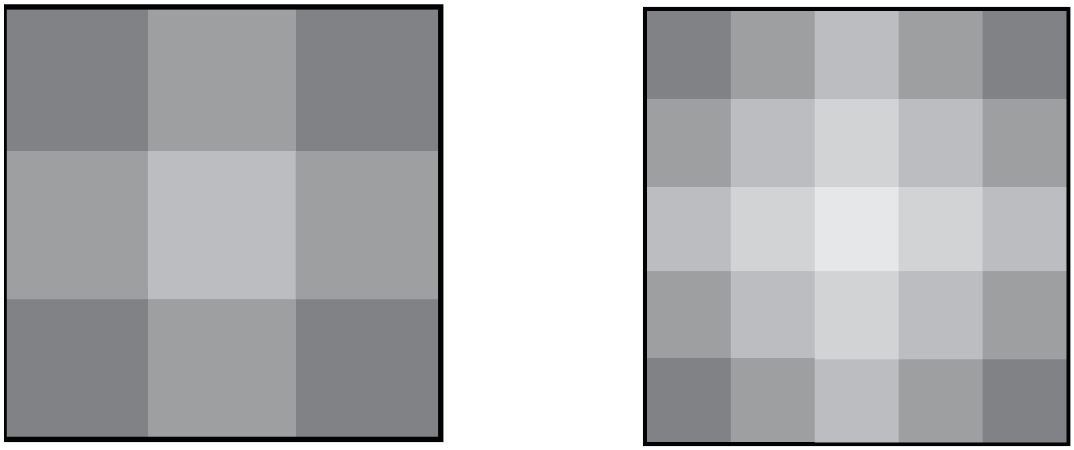


Figure 12. A shape may have different degrees of spatial differentiation depending on the size of the tessellation used ny Hillier (1996).

visible (1998b). They argue that establishing such a set of positions is a step forward toward describing complicated shapes of building plans according to a more economical pattern.

More recently, Rashid (2011) provides techniques to characterize building plans based on mutual visibility of the points defined by the walls and surfaces within a plan. He applies the techniques to three sets of artificial building plans representing the cellular, deformed, and free plan types. With the help of these techniques, Rashid is able to describe several elusive properties of these plans highlighting their similarities and differences. In sum, Peponis and his colleagues have been able to clarify different aspects of the interaction between shape and space from a SOV within a mathematical framework that also unambiguously defines convex partitions, generates linear representations with minimum outside interference, and provides a well-defined way to group all possible isovists that can be drawn within a plan. It is to this mathematical framework we turn next in our discussion on SS as a CTA from a SOV.

Problem 5: Convex maps, axial maps, and isovists were not explicitly integrated into a single framework in the early SS theories and techniques.

The early SS theorists did not consider convex representations, axial representations, and visual fields to be mathematically related concepts. Neither did they consider properties of shape when describing space. Such concerns did not bother the theorists for whom describing space independent of shape was important to understand and explain the social logic of space (e.g., Hillier and Hanson, 1984). The problem of integration became important when the SS community needed to automate SS techniques and analysis. Early attempts to describe space taking into account the shape of plan using overlapping convex spaces and all-lines map did not help establish a systematic relationship between convex space and axial line. Batty and Rana (2004) provide techniques to generate axial representations using isovists, but do not provide a mathematical system to integrate various techniques of SS (see above). Yet another partial attempt is made by Turner and his colleagues (2001). They define the 'permeability graph' (also known as access graph in the SS literature) of a convex map as a special case of a visibility graph, which is a graph of mutually visible locations in a spatial system. As a result, using the visibility graph analysis the structure of movement and the structure of visual fields can be compared more readily. However, in order to develop the visibility graph Turner and his colleagues (2001) use an arbitrarily defined grid. They also do not discuss if a visibility graph of a plan has any mathematical relations to the axial representation of the plan. More recently, Turner (2007) suggests that when guided by the occluding edges derived from isovists constructed throughout the system simulation agents create lines of movement which align well with axial lines.

In contrast, the mathematical system provided by Peponis and his colleagues is somewhat complete for a CTA from a SOV (see above). Their system, which is based on the shape of a plan, helps redefine convex representations, axial representations, and visual fields. This mathematical system also helps establish systematic relationships between space and shape from a SOV. However, Peponis and his colleagues do not explore the full potential of their system. They provide only a few examples for the kind of investigations that are possible using their mathematical system. A more systematic exposition of their system concerning a CTA from a SOV is still needed. They also do not explain why they use shape as the basis for their mathematical system. This is a problem related to the cognitive foundation of SS, to which we turn next.

Problem 6: How individuals contribute to creating patterns of spatial behaviors that SS described so vividly remained unexplained in the early literature of SS.
If the problems of early SS mentioned above are related to description-proper and representation, then this problem is related to interpretation. It can be assumed that if the meaning of the basic elements of a CTA can be explained logically and cognitively, then any representations created using a formalism defined based on these elements should also be logically and cognitively meaningful. For SS, then, the problem is to find the logical and cognitive meanings of its basic elements, which include the convex space, the axial line, and the isovist. Although quite a few research studies involve the axial map of SS and navigation in large-scale space, direct evidence establishing the cognitive importance of axial lines is rare (e.g., Conroy Dalton et al., eds., 2007; Zimring & Conroy Dalton, eds., 2003; Kim & Penn, 2004; Penn, 2003). Typically, these studies use a correlational study design, and use good correlations to argue that SS measures provide access to underlying cognitive processes and representations without explaining individual mechanisms underlying any observable statistical patterns. More recently, Hillier and Iida (2005) and Turner (2007) try to establish cognitive importance of SS measures in a more direct way. While Hillier and Iida do so at the level of the network, Turner does so at the level of the units of the network.

In order to isolate network effects from individual effects, Hillier and Iida (2005) use topological, geometrical, and metric distances to compute different network measures of four areas of London (also see Hillier 2007). They correlate these measures with observed movements, and find topological and geometrical measures to be better predictors of movements than metric measures. Since the networks are not changed in this study, Hillier and Iida argue, the observed differences in correlations can only be due to the differences in the degree to which each mathematical concept of distance coincides with the interpretations individuals make while moving in the system. It is however interesting to note that while this study establishes the importance of topology and geometry of street networks for navigation, it does not say how the findings validate the cognitive importance of an axial representation. It would appear, as though, the study reported by Hillier and Iida (2005) is more about graph measures than axial representations.

As opposed to Hillier and Iida (2005), Turner (2007) uses agent-based models to explore the relationship between the axial representation and movement. He reports that when the agents follow a path defined by the occlusion points derived from isovists constructed throughout the system, their movement patterns corresponds to an axial representation of the system. Since the occlusion points in a spatial system are also used in generating the axial representation, Turner argues that his finding suggests “an innate association between the axial map and the embodied process of agent movement in the environment” (Turner, 2007: 166). Turner points out two unresolved issues regarding the relationship between an axial representation and human cognition. First, it cannot be shown that humans actually use occlusion points to define movement. Second, even if they were to use occlusion points, it would be difficult to show that by selecting these occlusion points humans would actually create an axial structure to help them make higher navigation decisions.

The SS community also uses evidence from cognitive science and psychology to suggest that individuals may indeed have something like an axial map as an internalized cognitive representation of large-scale space. The two most frequently cited articles in the SS literature on this topic are Tversky (2003) and Kuipers et al. (2003). Tversky (2003) suggests that humans use reference frames to build a coherent representation of the space of navigation from the fragments of their experiences. Kuipers and colleagues (2003) suggest that experts often use a few well-connected lines of a topological map of large-scale space to make their origin-to-destination trips. They call this the 'skeleton' in the cognitive map. The SS community argues that while an axial representation may represent one of many versions of Tversky's reference frame, the most integrated set of axial lines of an axial representation may represent Kuipers' and colleagues' skeleton of the cognitive map. No doubt both ideas have some heuristics value for SS, but it is quite clear that an axial representation is much too refined a geometric representation to become a true example of Tversky's reference frame or Kuipers' and colleagues' skeleton of a topological map.

If axial representations are too refined to become embedded in human cognition, an isovist may be a better candidate because it appears to be more readily available than a convex space. In fact, Meilinger and colleagues (2009) use isovists in an experiment aimed at linking environmental structures to mental structures via wayfinding behavior. More specifically, they use partial isovists in accordance with anatomical constraints of the human visual apparatus, and shifted the reference points of isovists toward the approach direction in response to the fact that humans encode spatial information from the point of view that they encounter them, at least for familiar environments (e.g., Garsoffky et al., 2002; Mallot and Gillner, 2000). Based on their findings, the authors argue that the study is better able to close the gap between environmental structure and mental structure because it takes into account perception and mental representations more accurately by including perspective dependency in the isovist analysis.

Notwithstanding the claims made by the authors, the study does little to prove unambiguously that our mental representations of large-scale space depend on isovists as perceptual primitives. Despite a sense that an isovist is more readily available to us, experimental findings on the human visual apparatus suggest otherwise. These studies show that detailed vision is available only in a very small part of the retina, known as the fovea. It is a region about 2 degrees in extent, which would be covered by a hand's width at 10 feet. Outside of that region, acuity falls very rapidly - only large separations can be detected, only large masses discerned (Hochberg, 1983). While there is a fair amount of debate in the literature on what these physiological limitations may mean for human perception and cognition (e.g., O'Regan, 1992; Pylyshyn, 1999), the fact remains that even a simple isovist would require us to engage in complex mental acts of putting together successive views taken over time. To complete this process, we need motivation and awareness. In the absence of motivation and awareness, we may simply not take note of all that is there in an isovist. In addition, the properties of isovists that Meilinger and colleagues found relevant for spatial navigation were highly context dependent. The fact that in most cities on rectangular grid the kind of geometric properties the authors found relevant for spatial navigation are absent may point to the fact that we may need to build the foundation of our visual experience based on elements simpler than the isovist.

Simply put, the convex space, the axial line and the isovist are already quite sophisticated representations. Therefore, it may be difficult to gain any direct access to the underlying cognitive processes of these elements. A more effective way to validate the cognitive importance of these basic elements of SS may be to identify a set of more elementary perceptual primitives, which would then become the foundations of a mathematical system explaining the representations of the basic elements of SS. The author wishes to present such a set of primitives in a future paper.

CONCLUDING REMARKS

In this paper a CTA from a SOV was developed to help explain how a situated observer may build her understanding of buildings. The structure of the theory was defined using three interrelated levels of description-proper, representation, and interpretation. Using evidence from geometry, psychology/cognition, and spatial reasoning it was argued that the level of description-proper of a CTA from a SOV should include unambiguously defined perceptual primitives and their perceivable elementary topological and projective relations. Subsequently, the levels of representation and interpretation should describe and explain the complex relational properties of buildings based on these perceptual primitives.

SS was studied as an example of a CTA from a SOV. From its early days, SS included all three levels of a theory of configuration. SS also emphasized, through its techniques, the need for a bottom-up approach. Additionally, its focus on topological and projective properties also made it suitable for a CTA from a SOV. However, early SS had several limitations concerning a CTA from a SOV. The paper discussed six of these limitations and the efforts made by the SS community to overcome these limitations. At this stage, it would appear that the SS community has solved all but two of the limitations of early SS.

One of the remaining limitations is that while SS has been able to better integrate its apparently disparate techniques into a coherent mathematical system, it has not yet provided a framework for configurational studies using the system. As "space syntax is becoming a flourishing paradigm for spatial studies, increasingly well integrated with other approaches and increasingly expanding its scope and scale of investigation," (Hillier, 2007, p. viii) such a framework will be needed for SS to define clearly what falls within its purview and what does not.

The other remaining limitation is that the theorists, who helped develop the mathematical system integrating the apparently disparate techniques of SS, did not adequately explain the reasons for using the elements of the shape of a building plan as the primitives of the system. This is important because any direct access to the underlying cognitive processes of the basic elements of early SS, such as convex spaces, axial lines, and isovists, does not seem easy. They involve complex processes of abstract nature. Therefore, it was argued in this paper that a more effective way to validate the cognitive importance of the basic elements of early SS would be to find the cognitive importance of the primitives used in the new mathematical system of SS.

The above suggestion is somewhat at odds with the more recent attempts made by the SS community aimed at explaining the cognitive basis of axial lines. Undoubtedly, these attempts are important because an original finding of SS is that the configuration of the urban street network as described by axial lines is in itself a major determinant of pedestrian and vehicular movements. However, it should be noted here that finding the cognitive basis of axial lines may not be enough to explain the fact that, in addition to movement in urban environments (or more generally navigation in large-scale space), SS has also been used to explain many other behavioral and sociological functions of buildings. In simple words, over the last several decades SS has become much more than a theory related to navigation in large-scale space.

If SS is not merely a theory related to spatial navigation in large-scale space, then what is it? This paper wished to answer this question by framing SS as a CTA from a SOV, which is different from the kind of configurational theory SS theorists generally have in mind. As Hillier explained, "in addition to functioning as bodily protection, buildings operate socially in two ways: they constitute the social organization of everyday life as the spatial configurations of space in which we live and move, and represent social organization as physical configurations of forms and elements that we see. Both social dimensions of building are therefore configurational in nature, and it is the habit of the human mind to handle configuration unconsciously and intuitively…" (Hillier, 2007: 3). Therefore, the traditional purpose of a configurational theory, as defined by Hillier, has been to subject the non-discursive social aspects of buildings to rational analysis. In contrast, the purpose of a CTA from a SOV, as proposed in this paper, has been to explain the role of individuals in a bottom-up process that may help explain how buildings as configurations may become socially meaningful.

Finally, it must be noted here that having a mathematically sound CTA from a SOV will not automatically explain the relationship between configuration and composition or order and structure that space syntax theorists have been concerned with and that this paper started with. However, it may provide us the right kind of primitives and formalism that we can then apply to understand how a situated observer may construct more complex relational attributes of the built environment.

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REFERENCES

Batty M, 2001, “Exploring isovist fields: space and shape in architectural and urban morphology” Environment and Planning B: Planning and Design 28(1) 123-150

Batty M, Rana S, 2004, “The automatic definition and generation of axial lines and axial maps” Environment and Planning B: Planning and Design 31 615-640

Benedikt M L, 1975, “To take hold of space: isovists and isovist fields” Environment and Planning B: Planning and Design 6 (1) 47-65

Conroy Dalton R, 2003, “The secret is to follow your nose: route path selection and angularity” Environment and Behavior 35 (1) 107-131

Conroy Dalton R, Hölscher C, Turner A, eds., 2007 Space syntax and spatial cognition, Proceedings of the Workshop held in Bremen, 24th September 2006, SFB/TR 8, Volume 2 (Universität Bremen, Bremen, 2007)

Evans G W, 1980, “Environmental cognition” Psychological Bulletin 88 259-267

Evans G W, Smith C, Pezdek K, 1982, “Cognitive maps and urban form” Journal of the American Planning Association 48 232-244

Figueiredo L, Amorim L, 2005, “Continuity Lines in the axial System,” Proceedings of the Fifth Space Syntax International Symposium (Delft University of Technology, Delft) 162-174

Franz G, Mallot H A, Wiener J M, 2005, “Graph-based models of space in architecture and cognitive scienceöa comparative analysis,” in G E Lasker, ed., Proceedings of INTERSYMP-2005, (International Institute for Advanced Studies in Systems Research and Cybernetics, Windsor, Canada, 2005), 30-38

Franz G, Wiener J M, 2008, “From Space Syntax to Semantics: A behaviorally and perceptually oriented methodology for the efficient description of the geometry and topology of environments” Environment and Planning B: Planning and Design 35 574 - 592

Franz M O, Stürzl W, Hübner W, Mallot HA, 2008, “A robot system for biomimetic navigation - from snapshots to metric embeddings og view graphs,” in M E Jefferies et al., eds., Robot. & Cogn. Approach. to Spat. Map., STAR 38, 297-314

Garsoffky B, Schwan S, Hesse F W, 2002, “Viewpoint dependency in the recognition of dynamic scenes’’ Journal of Experimental Psychology: Learning, Memory, and Cognition 28 1035-1050

Gross C G, Graziano M S A, 1995, “Multiple representations of space in the brain” The Neuroscientist 1 43-50

Hanson J, 1994, “Deconstructing architects’ houses” Environment and Planning B: Planning and Design 21 675-704

Hanson J, 1989, “Order and structure in urban design: The plans for the rebuilding of London after the Great Fire of 1666” Ekistics 334-5 22-44

Haq S, 2003, “Investigating the syntax line: configurational properties and cognitive correlates” Environment and Planning B: Planning and Design 30 841-863

Hillier B, 2007 Space is the Machine, (Space Syntax, London) electronic edition

Hillier B, 2007 “Studying cities to learn about minds: How geometric intuitions shape urban space and make it work,” in Conroy Dalton R, Hölscher C, Turner A, eds., Space syntax and spatial cognition, Proceedings of the Workshop held in Bremen, 24th September 2006, SFB/TR 8, Volume 2 (Universität Bremen, Bremen, 2007) 11-33

Hillier B, 1996 Space is the Machine (Cambridge University Press, Cambridge)

Hillier B, Burdett R, Peponis J, Penn A, 1987 “Creating life: Or does architecture determine anything?” Arch. & Comport./Arch. & Behav. 3 (3) 233-250

Hillier B, Iida S, 2005, “Network effects and psychological effects: A theory of urban movement,” in van Nes, A., ed., Proceedings of the 5th International Symposium on Space Syntax, Volume I. (TU Delft, Delft, Netherlands) 553-564

Hillier B, Hanson J, 1984 The Social Logic of Space (Cambridge University Press, Cambridge)

Hillier B, Penn A, Hanson J, Grajewski T, XU J,1993, "Natural movement; or, configuration and attraction In urban pedestrian movement" Environment and Planning B: Planning and Design 20 29-66
Hochberg J, 1983, "Visual perception in architecture" VIA 6 26-45
Hochmair H, Frank A U, 2002, "Influence of estimation errors on wayfinding-decisions in unknown street networks - analyzing the least-angle strategy" Spatial Cognition and Computation 2 283-313
Kim Y O, Penn A, 2004, "Linking the spatial syntax of cognitive maps to the spatial syntax of the environment" Environment and Behavior 36 (4) 483-504
Klein F, 1893, trans., Verglecheinde Betrachtungenüber neuere geometrischen Forschungen. Bulletin of the New York Mathematical Society 2 215–249
Kritchevshy M, 1988, "The elementary spatial functions of the brain" in J Stiles-Davis, M Kritchevsky, U Bellugi, eds., Spatial cognition: Brain bases and development (Erlbaum, Hillsdale, NJ)
Kuipers B, 2008, "An intellectual history of the spatial semantic hierarchy," in M E Jefferies et al., eds., Robot. & Cogn. Approach. to Spat. Map., STAR 38, 243–264
Kuipers B, 2000, "The Spatial Semantic Hierarchy" Artificial Intelligence 119 191–233
Kuipers B, 1978, "Modeling spatial knowledge" Cognitive Science 2 129–153
Kuipers B, Modayil, J, Beeson P, MacMahon M, Savelli F, 2004, "Local metrical and global topological maps in the hybrid spatial semantic hierarchy, " in ICRA 2004. IEEE Int. Conf. on Robotics & Automation (IEEE Computer Society Press, Los Alamitos, 2004)
Kuipers B, Tecuci D, Stankiewicz B J, 2003, "The skeleton in the cognitive map: A computational and empirical exploration" Environment and Behavior 35 (1) 81-106
Lieblich I, Arbib M A, 1982, "Multiple representations of space underlying behavior" The Behavioral and Brain Sciences 5 627-659
Lynch K, 1960 The Image of the City (MIT Press, Cambridge, MA)
Mallot H A, Gillner S, 2000, "Route navigation without place recognition: What is recognized in recognition-triggered responses? ‘’ Perception 29 43-55
March L, Steadman P, 1971 The Geometry of Environment (MIT Press, Cambridge, MA)
Meilinger T, Franz G, Bülthoff H H, 2009, "From isovists via mental representations to behavior" Environment and Planning B: Planning and Design, advance online publication
Montello D R, 1998, "A new framework for understanding the acquisition of spatial knowledge in large-scale environments," in Egenhofer M J, Golledge R G, eds., Spatial and Temporal Reasoning in Geographic Information Systems (Oxford University Press, New York) 143-154
Montello D R, 1991, "Spatial orientation and the angularity of urban routes: A field study," Environment and Behavior 23 47-69
Moore G T, 1979, "Knowing about environmental knowing: The current state of theory and research on environmental cognition" Environment and Behavior 11 33-70
O'Keefe J, Nadel L, 1974, "Maps in the brain" New Scientist, 749-751.
O'Keefe J, Nadel L, 1978 The hippocampus as a cognitive map (Clarendon, Oxford)
O'Regan J K, 1992, "Solving the "real" mysteries of visual perception: the world as an outside memory" Canadian Journal of Psychology 46 (3) 461-488
Penn A, 2003, "Space syntax and spatial cognition, or why the axial line?" Environment and Behavior 35 (1) 30-65
Penn A, Dalton N, 1994, "The architecture of society: Stochastic simulation of urban movement," in N Gilbert N, Doran J, eds., Simulating Societies: The Computer Simulation of Social Phenomena (UCL Press, London) 85-125
Peponis J, 1993a, "The architectural configuration of lyric form at La Tourette" Ekistics 362-363 237-252
Peponis J, 1993b, "Evaluation and formulation in design: The Implications of Morphological Theories of Function" Nordisk Architekturforsking 6 (2) 53-62

Peponis J, Bafna S, Zhang Z, 2008, “The connectivity of streets: reach and directional distance,” Environment and Planning B: Planning and Design 35 881-901
Peponis J, Wineman J, Rashid M, Kim S H, Bafna S,1997, “On the description of shape and spatial configuration inside buildings: convex partitions and their local properties” Environment and Planning B 24 761-781
Peponis J, Wineman J, Bafna S, Rashid M, Kim S H, 1998a, “On the Generation of Linear Representations of Spatial Configuration” Environment and Planning B 25 559-576
Peponis J, Wineman J, Rashid M, Bafna S, Kim S H, 1998b, “Describing plan configuration according to the co-visibility of surfaces” Environment and Planning B 25 693-708
Peponis J, Wineman J, 2002, “Spatial structure of environment and behavior,” in Bechtel R B and Churchman A, eds., Handbook of Environmental Psychology (John Wiley & Sons, Inc., New York), 271-91
Peponis J, Zimring C, Choi Y K, 1990, “Finding the building in the wayfinding,” Environment and Behavior 22 (5) 555-590
Piaget J, 1970 Psychology and Epistemology (Penguin)
Piaget J, 1969 The mechanisms of perception Trans. by G N Seagrim (Basic Books, New York)
Piaget J, Inhelder B, 1967 (Reprint of the 1956 edition) The child’s conception of space Trans. by F J Langdon, J L Lunzer (Routledge & K. Paul, London)
Pick H L, 1976, “Transactional-constructivist approach to environmental knowing: A commentary, “ in G T Moore, R G Gollege, eds., Environmental knowing: Theories, research, and methods (Dowden, Hutchinson and Ross: Stroudsburg, PA)
Psarra S, 2009 Architecture and Narrative (Routledge, New York)
Pylyshyn Z, 1999, ‘Is vision continuous with cognition? The case for cognitive impenetrability of visual perception,” Behavioral and Brain Sciences 22 341-423
Rashid M, 1998 On the configurational studies of building plans from the viewpoint of a situated observer: a partial theory of configuration for plans not involving curves PhD Dissertation (Georgia Institute of Technology, Atlanta, Georgia)
Rashid M, 2011, “Mutual visibility of point in building plans,” Journal of Architecture 16 (2) 231-266
Ratti C, 2004, “Space syntax: Some inconsistencies” Environment and Planning B: Planning and Design 31(4) 487-499
Remolina E, Kuipers B, 2004, “Towards a general theory of topological maps” Artificial Intelligence 152 47–104
Sadalla E K, Montello D R, 1989, “Remembering changes in direction” Environment and Behavior 21 346-363
Turner A, 2007, “From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis” Environment and Planning B: Planning and Design 34(3) 539 – 555
Turner A, 2007, “The ingredients of an exosomatic cognitive map: Isovists, agents and axial lines?” in Conroy Dalton R, Hölscher C, Turner A, eds., Space syntax and spatial cognition, Proceedings of the Workshop held in Bremen, 24th September 2006, SFB/TR 8, Volume 2 (Universität Bremen, Bremen, 2007) 163-180
Turner A, Doxa M, O’Sullivan D, Penn A, 2001, “From isovists to visibility graphs: a methodology for the analysis of architectural space” Environment and Planning B: Planning and Design 28 103-121
Turner A, Penn A, Hillier B, 2005, “An algorithmic definition of the axial map” Environment and Planning B 32 425-444
Tversky B, 2003, “Structures of mental spaces: How people think about space” Environment and Behavior 35 (1) 66-80
Tversky B, 2000, “Levels and structure of cognitive mapping,” in Kitchin R and Freundschuh S M, eds., Cognitive mapping: Past, present and future (London: Routledge) 24-43
Zimring C, Conroy Dalton R, 2003, “Linking objective measures of space to cognition and action” Environment and Behavior 35 (1) 3-16