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by Mahbub Rashid

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Shape-Sensitive Configurational Descriptions Of Building Plans

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Abstract

While the traditional graph-theoretic techniques of space syntax are able to provide a rich description of the spatial configuration of buildings, they are not sufficiently shape sensitive. Therefore, techniques are proposed to describe building plans as configurations of spaces taking into consideration the elements of shape explicitly. First, the traditional space syntax techniques are applied to a more shape-sensitive partition of a plan in order to find out if these techniques would reveal any interesting shape property of the plan. Following this, a technique to characterize the spatial units of a plan is suggested taking into consideration how surfaces become visible from these units. Finally, a plan is described as the configuration of triangles defined by the vertices of the shape of the plan, and triangulation is used as a technique for a shape-sensitive description of spatial configuration.

I. INTRODUCTION AND BACKGROUND

Since as an observer located inside a building one rarely gets to see the building all at once, one is required to construct any global understanding of the building based on its local features. Some hints to this process of construction can be found in the work done by Jean Piaget on the construction of cognitive space (i.e., representational space) [1-3]. In Piaget's opinion, the perceptual space may be assumed the same for all human beings, but the representational space is different for children at different stages of development. Piaget's work suggests that representational space of the child starts with elementary topological intuitions before becoming at the same time projective and Euclidean.

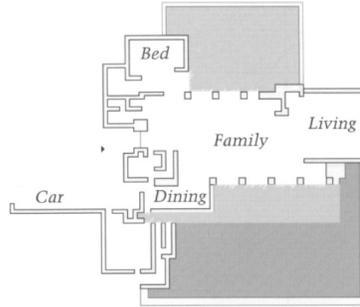
Based on Piaget's ideas, it is possible to develop a framework of configurational studies of buildings involving topology, projective geometry and Euclidean geometry at various stages of representation. To begin with, topology will provide information about neighborliness, connections, and the presence/absence of holes; following this, projective geometry will provide information about convexity/concavity; and finally, metrics or Euclidean geometry will provide information about such properties as compactness, and symmetry. Further, we may use our everyday spatial reasoning to parse these different kinds of information in configurational studies. Like a child's construction of representational space, our everyday spatial reasoning also depends more on topology and projective geometry and less on Euclidean geometry. That is because as observers we are not very good at using exact metric and global properties whereas we can very easily perform context-dependent comparisons or understand relational properties of the environment.

In architecture, space syntax provides such a framework of configurational studies based on theories and techniques that use projective elements/relations in conjunction with topology to explain how situated observers may perceive and understand buildings. The basic units of description of space syntax - the convex unit and the axial line - are elementary projective units [4-7]. Space syntax also uses the 360-degree visual polygon available from a point, called an isovist [8], as a unit of description [e.g. 9-12].

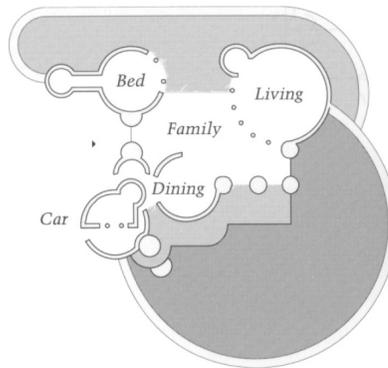
The two most important techniques that space syntax uses to describe buildings are the convex and axial maps. Traditionally, the convex map is defined as the fewest number of fattest convex spaces and the axial map as the fewest number of longest axial lines that cover a spatial system [4]. Once building plans are represented as convex or axial maps, space syntax uses graph-theoretic techniques to describe the topological relationships among the spatial units of these maps. More recently, a well-defined set of visual polygons and their topological relationships, known as the visibility graph analysis, have also been used by space syntax to describe an observer's visual experience of buildings [12].

Taken together, the techniques of space syntax are able to provide a rich description of how observers perceive and experience the spatial configuration of buildings, but they are not sufficiently shape-sensitive. For example, if the axial or convex maps of spatial systems with different shapes have the same graph, the description of these spatial systems does not differ in space syntax. March and Steadman [13] illustrates the problem vividly by showing how F L Wright embedded the same access graph in three house plans with remarkably different shapes (Figure 1).

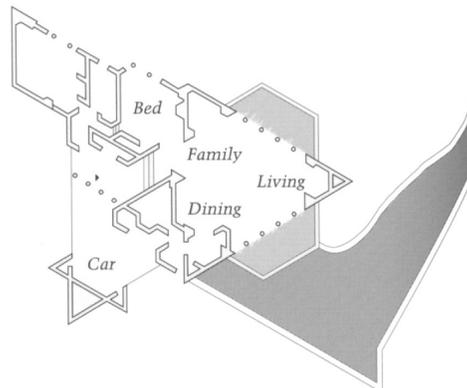
▼ Figure 1: Three F L Wright house plans that have the same access graph embedded in different shapes. (Source: March and Steadman, 1971).



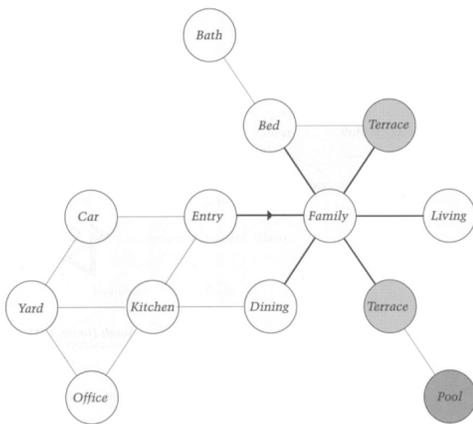
Life House, 1938



Jester House, 1938

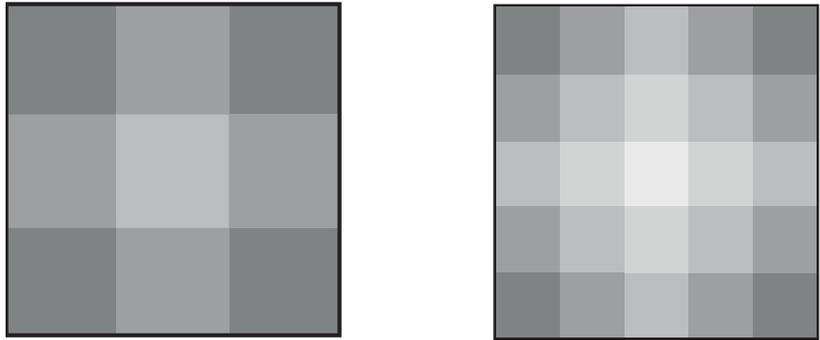


Sundt House, 1941



An adjacency diagram: circles represent spaces and lines represent important adjacencies

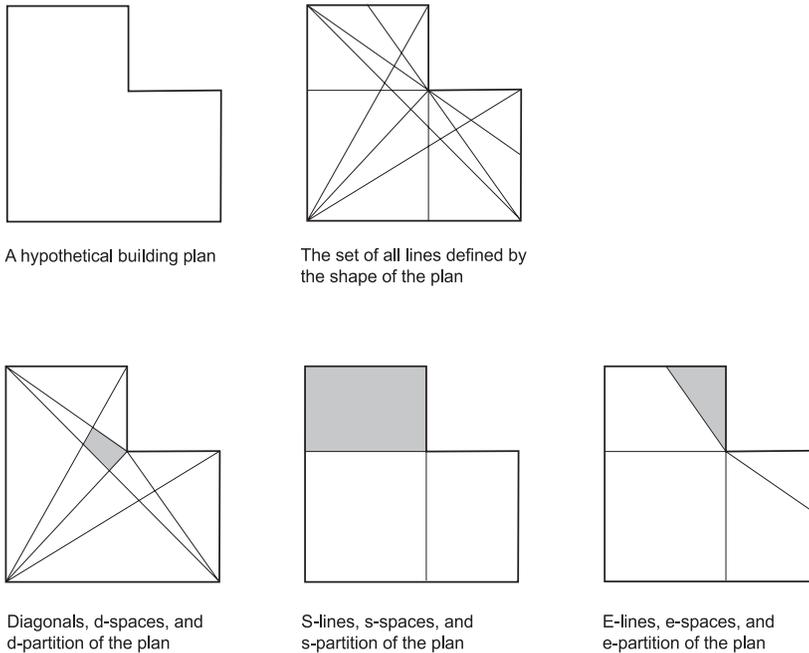
► Figure 2: A shape may have different degrees of spatial differentiation depending on the size of the tessellation used by Hillier (1996).



Hillier [10] applied graph theoretic measures to rectangular tessellations embedded in different shapes in an attempt to overcome this problem. However, Hillier's rectangular tessellations are not intrinsically related to the shapes they helped describe (Figure 2). In the late 1990s, Peponis, Rashid, and colleagues recognized this limitation of early space syntax more explicitly, and proposed shape-sensitive ways to describe visual experience of a situated observer [5, 14]. Inspired by Hillier's overlapping convex partition, Peponis and colleagues [5] use walls of a plan and their surfaces to generate a number of shape-sensitive partitions (Figure 3). They use walls and s-lines (i.e., the extensions of extendible walls or surfaces) to define the s-partition with discrete s-spaces; and walls and e-lines (i.e., the extensions of extendible walls and diagonals) to define the e-partition with discrete e-spaces. 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. 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. 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. This partition represents all possible triangulations of visibility between the endpoints of the plan [14]. Triangulation is important because it represents the most elementary structure of visual relations defined by the endpoints of a plan.

Peponis and his colleagues also help 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 visible [5]. 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 [15] provides techniques to characterize building plans based on mutual visibility of the points defined by the walls and their surfaces within a plan. With the help of these techniques, Rashid is able to describe several elusive properties of different types of building plans.

◀ Figure 3: The d-partition, s-partition and e-partition of a hypothetical building plan.



In summary, Peponis, Rashid, and others have been able to clarify different aspects of the interaction between shape and space from a situated observer's viewpoint within a consistent mathematical framework. Based on their mathematical framework, this paper presents at least three different approaches to describing the spatial configuration of building plans in shape-sensitive ways, which are:

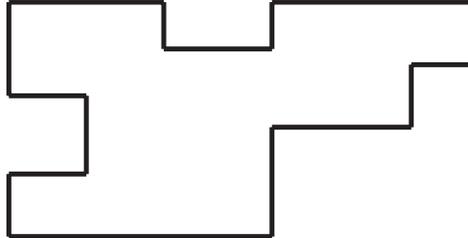
- 1) Use the available graph-theoretic measures of space syntax on a shape-sensitive partition of building plans as defined by Peponis et al. [5] and Rashid [14].
- 2) Augment the available graph-theoretic techniques of space syntax to take into account the aspects of shape explicitly.
- 3) Use d-spaces, which is an elementary spatial unit defined by the shape of a plan, to characterize the plan.

In the following sections, examples of each of these approaches to a shape-sensitive description of spatial configuration are given. Since no software program is available at this time to run the routines of the last two proposed techniques, the paper applies these techniques manually to simple artificial building plans representing cellular, deformed, and open plan types (Figure 4). Architectural theorists often use these types to indicate such contrasting properties as open vs. enclosed space, continuity vs. discontinuity, oneness vs. multiplicity, and interiority vs. exteriority [15-19].

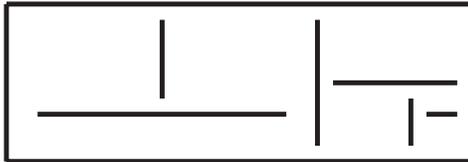
► Figure 4: Three simple artificial building plans representing three different types.



Cellular Plan



Deformed Plan



Open Plan

2. DESCRIBING PLANS AS THE CONFIGURATION OF E-PARTITION

As the first step toward a shape-sensitive description of spatial configuration, the graph-theoretic techniques of space syntax are applied to a shape-sensitive partition, such as the e-partition of a plan. In the technique, every e-space of a plan is treated as a graph node. An e-space is considered directly connected to another e-space only if they share, partly or fully, a common edge that is permeable. The connectivity value of an e-space is the number of e-spaces to which it is permeable. E-spaces that are permeable to a given e-space are treated to be one-step away from the given space in the graph. E-spaces permeable to the one-step-away e-spaces and not permeable to a given e-space are treated to be two steps away from the given space, and so on. In this manner, a connectivity matrix containing the list of e-spaces connected to every e-space of the plan is generated to compute different syntactic values of space syntax [4].

The integration value of an e-space may tell us how central or how peripheral the location of the e-space is in the e-partition of the plan. From a highly integrated e-space, fewer steps are required to get to all other e-spaces of the plan. Put another way, since the e-partition defines the objective structure of all possible discrete changes in visibility of the

vertices of a plan, it may be said that from a highly integrated e-space fewer steps are required to experience all possible discrete changes in visibility of the vertices of the plan. By implication, in a plan with high mean integration the average number of steps is fewer than that required in a plan with low mean integration to experience all discrete changes in visibility of the vertices. To the extent changes in visibility of the vertices are a measure of the visual complexity of a plan, we may say that an integrated e-space provides a less complex visual experience of the shape of the plan.

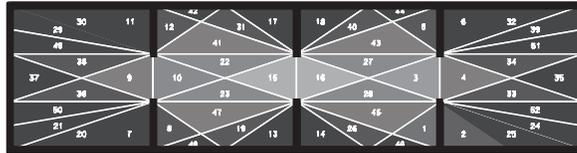
The shape of the integration hub defined by the most integrated set of e-spaces and the mean integration values of the e-spaces of the e-partition were analyzed for the three plans in Figure 4. The analysis was done by the 'Spatialist' software program [5], and the results are shown in Figures 5. It can be observed that the deformed plan has the highest mean integration value because of its openness. This is followed by the cellular plan. Though the axiality of the openings in this plan enhances visibility, it lacks the openness of the deformed plan. Finally, the open plan has the lowest mean integration value, because it lacks the openness of a deformed plan and the axiality of the cellular plan. These observations indicate that the mean integration values of the e-spaces have successfully picked up the differences in the visibility conditions of vertices in these plans. It can also be observed that in the cellular plan the integration hub of e-spaces is anchored around the openings. In the deformed plan, the free-floating integration hub covers the central areas while leaving the corners along the boundary of these plans less affected. In the free plan, the integration hub is localized on one side of the plan, suggesting that the composition of the plan has a strong effect on the hub of this plan. In summary, the graph-theoretic techniques of space syntax when applied to e-partition appear sufficiently sensitive to the shape of plans.

3. DESCRIBING SPATIAL CONFIGURATION BASED ON VISIBILITY OF SURFACES FROM SPATIAL UNITS

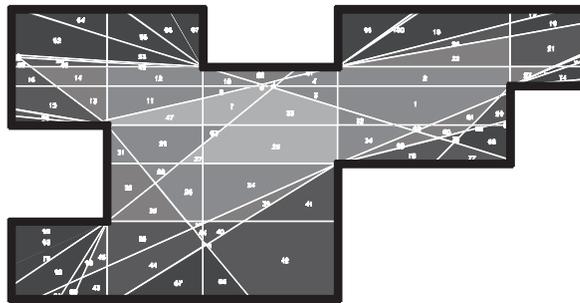
The aim of this section is to describe the spatial configuration of a plan based on visibility of the surfaces of the plan. One obvious way to do this is to study the configuration of the s-partition of these plans, because this partition describes all possible thresholds of appearance or disappearance of entire surfaces in the field of vision of a situated observer [5]. However, since for a large number of building plans, the s-spaces may overlap with the "rooms" of these plans, the available graph-theoretic techniques of space-syntax may not be able to distinguish these plans from each other when applied to s-partition. Therefore, we propose robust techniques to differentiate plans with the same s-spaces and "rooms" based on how the surfaces of a plan may become visible as we move from one space to the other. Put another way, in order to characterize the spaces of a plan based

on surface visibility, we weight every step taken from a given space according to the number of surfaces visible at that step. This technique is interesting because it is related to the problem of finding the space where a guard should be seated in order to make all surfaces of the plan visually most accessible.

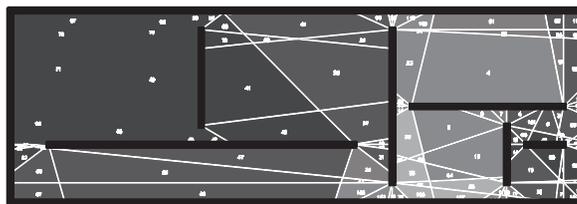
► Figure 5: The distribution of the integration values of e-spaces in the three plans.



Mean Integration: 0.573



Mean Integration: 0.654



Mean Integration: 0.44

Given a convex partition of a plan, any surface is considered visually connected to a convex unit if the surface is fully visible from any part of the unit. The surfaces that can be seen in their entirety from the convex units that are one-step away from a given convex unit but cannot be seen directly from the given unit are considered one visual-step away from the unit. Likewise, the surfaces which can be seen from the units that are two steps away from the given unit (i.e., the convex units which are permeable to the one-step-away convex units from the given unit), but cannot be seen from it and from those convex unit/s that are one step away, are considered to be

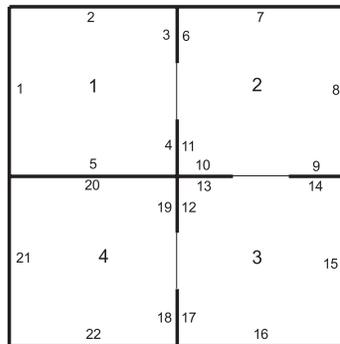
two visual steps away. In this manner, it is possible to determine how many steps one has to take from a given convex unit in order to see all the surfaces of a plan. We may call this the visual-depth of surfaces from the given convex unit. Note, however, that it may not be necessary to go to every convex unit in a plan in order to see all the surfaces of the plan.

In order to calculate the “total visual depth of surfaces” from any given unit within a plan, every surface, not every convex unit, is given a visual depth value according to how many steps one needs to take from the given unit in order to see the surface in its entirety. The sum of the values is called the total visual depth of surfaces from the given unit. The following table illustrates the procedure to compute the value taking Space #2 of the plan in Figure 6 as an example.

#Step	#Spaces Reached	#Surfaces visible	Visual depth value
0	{2}	{1,6,7,8,9,10,11,16,17}	0*9=0
1	{1,3}	{2,3,4,5,12,13,14,15,21}	1*9=9
2	{4}	{18,19,20,22}	2*4=8

Total visual depth of surfaces or TVDS from Space #2 17

▼ Figure 6: Procedure to compute the surface visibility index taking space#2 as an example.

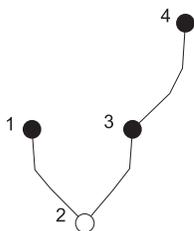


Spaces reached

Step #2

Step #1

Step #0



Surfaces visible



18 ● 19 ● 20 ● 22 ●

2 ● 3 ● 4 ● 5 ● 12 ● 13 ● 14 ● 15 ● 21 ●

1 ● 6 ● 7 ● 8 ● 9 ● 10 ● 11 ● 16 ● 17 ●

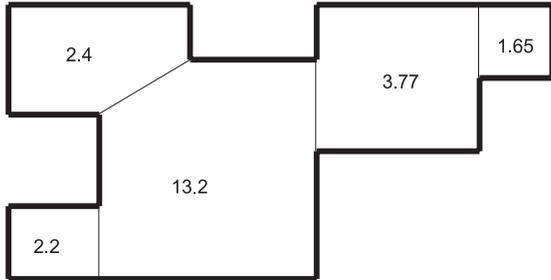
However, since the number of surfaces and convex units may vary from one plan to the other, the mean of TVDS from the convex units may not allow one to compare plans with different number of surfaces and convex units. For this purpose, we propose to compare the value of a convex spatial unit to the range defined by the possible maximum and minimum values for a theoretical plan with the same number of surfaces and convex units. For this, let us take a plan shape with n number of surfaces and m number of convex units (both n and m are integers, and $m \geq 3$) where the number of surfaces visible from every convex unit is equal, which is n/m . In such a plan one may get the minimum total visual depth of surfaces from any unit when all its surfaces are visible from the units one step away from it, which is $1 * (n - (n/m))$. And one may get the maximum total visual depth of surfaces when at every step no more than one convex unit is available, i.e., at each step no more than n/m surfaces are visible. The total visual depth in such a case is $[(0 * n/m) + (1 * n/m) + (2 * n/m) + \dots + ((m-1) * n/m)]$, or $[(m-1)m/2] * (n/m)$, or simply, $n(m-1)/2$. Now it is possible to express the visual depth of surfaces of any unit of a plan with n surfaces and m spaces in relation to the theoretical range defined by these maximum and the minimum values, which is $n(m-1)(m-2)/2m$. The ratio of the theoretical range to the total visual depth of surfaces from a given convex unit may be called the “surface visibility index” or simply the visibility index of the space. In the example in Figure 6, the plan has 22 surfaces and 4 spaces. Hence the visibility index of Space #2 is $[22(4-1)(4-2)/2*4]/17$, or simply 0.97. The higher the visibility index of a space in a plan, the fewer is the number of steps needed to see all the surfaces of the plan. This value should allow one to characterize convex spaces in a plan, as well as to compare plans of the same and different types.

Though the above technique can be applied to any convex partition, for matters of convenience we apply it to characterize the minimum partition of a plan determined following the procedure suggested by Peponis and colleagues [5]. Figure 7 shows the visibility indexes of the plans representing three basic types on their minimum partition. Here, we observe that the deformed plan has the highest mean visibility index, followed by the free plan, and then by the cellular plan. We also observe that the spaces within the plans are also sufficiently differentiated by the surface visibility index. These observations can be explained by the fact that the technique to compute the visibility index of a spatial unit considers surfaces explicitly, hence is able to make greater differentiations among a set of plans.

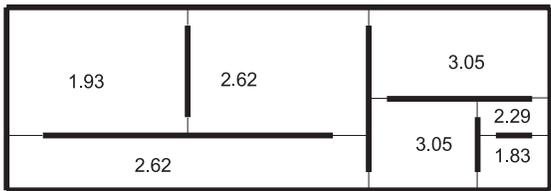
◀ Figure 7: The surface visibility indexes of spaces in the three plans.



Mean S.V.I. = 0.779



Mean S.I.V. = 4.644



Mean S.I.V. = 2.48

4. DESCRIBING PLANS AS THE CONFIGURATION OF TRIANGLES

In this section, the spatial pattern of triangulations as formed by the vertices of a plan is studied. In a plan, a condition of triangulation exists when a triangle defined by any three vertices of the plan does not contain any surface or part of a surface within it. There are at least two advantages in looking at plans using the concept of triangulation. First, the number of triangulations in a plan is a consequence of how the basic elements of the plans are organized, and thus can be a useful way to characterize the shape and space of the plan. Second, since a triangle has a spatial extension, it may allow us to characterize what is contained in it, as well as what comes in to or goes out of our visual fields while located inside it. In other words, on the one hand, the pattern of triangulation in itself may be an interesting object of configurational study; and, on the other hand, it may be used to describe the configuration of the elements of a plan according the visibility of these elements from these triangles.

In discrete and, more recently, in computational geometry triangulation is used as an important partition of a geometric domain. According to Toussaint, a set P , of n points in the plane, is triangulated by a subset, T , of the straight-line segments whose endpoints are in P , if T is a maximal subset such that the line segments in T intersect only at their endpoints [20]. In simple English, a point set is triangulated when its members are connected by the maximum number of non-crossing diagonals or diagonals that intersect at their endpoints only. Likewise, if we add as many non-crossing diagonals as possible in a polygon or in a polyhedron we get the triangulation of the polygon or of the polyhedra. More generally, then, a triangulation is a partition of a geometric domain, such as a point set, polygon, or polyhedron, into triangles that meet only at shared faces [21].

However, in contrast to the above definition where triangulation is used as a partition, the paper treats triangulation as a cover, i.e., a collection of triangles whose union is exactly the plan. Since triangulation is treated as a cover, as opposed to a partition where triangles are not allowed to intersect except at their faces, there can be any number of triangles which may intersect or overlap each other, or which may contain one another. One of the primary reasons to use triangulation as a cover, rather than as a partition, is that the aim of the paper is to characterize plans based on the relational pattern of the triangles themselves. For its purpose, the paper characterizes any given region within a plan based on the number of convex triangles each of which contains the given region.

4.1. Characterizing plans using triangulation

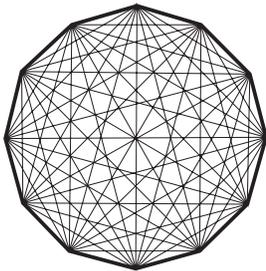
In a plan, wall surfaces restrict the visibility of its vertices. For plans with a given number of surfaces and vertices, the number of visibility relations may depend on the way surfaces are composed in these plans. As a result, the number of triangles may also vary in these plans. Naturally, for plans with a high visual density (i.e., with a higher number of diagonals between its vertices) there may exist a high number of triangulations. Likewise, for plans with a poor visual density, there may exist a low number of diagonals between its vertices, hence a low number of triangulations. Since the number of triangulations in a plan depends also on the number of its vertices, the number of all possible convex triangles of a plan is divided by the range defined by the maximum and minimum number of convex triangles possible for any plan with the same number of vertices in order to characterize and compare plans with different numbers of vertices. This ratio is called the triangulation index of the plan. If one considers visual density as a measure of the visibility condition in a plan, then a high triangulation index may suggest a better visibility condition in the plan.

In order to determine the triangulation index of a plan, first one needs to determine the number of convex triangles in the plan. For this, the

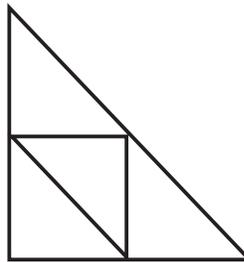
vertices of the plan are labeled from 1 to n. Any triangle that includes vertex 1 is identified and listed:

- {1,2,3}, {1,2,4}, {1,2,5} ... {1,2,n}
- {1,3,4}, {1,3,5}, {1,3,6} ... {1,3,n}
- {1,4,5}, {1,4,6}, {1,4,7} ... {1,4,n}
- ...
- {1,(n-2),(n-1)}, {1,(n-2),n}
- {1,(n-1),n}

Once all possible triangles that include vertex 1 are listed, the vertex is dropped from the list of the vertices to be considered for further triangulation, and any triangle that includes vertex 2 is identified and listed. In a similar manner, when vertex 3 is considered, vertex 1 and vertex 2 are dropped from the list of vertices to be considered for further triangulation. The process is continued until vertex (n-2) is reached, which has one triangle, {(n-2),(n-1),n}, in its list. At this stage, all the non-convex triangles are eliminated from the set of all listed triangles in order to determine the number of convex triangles in a plan.



A



B

◀ Figure 8: For 12 vertices, shape-A has the maximum, while shape-B has the minimum number of triangulations.

In the next stage, it is necessary to determine the maximum number of convex triangles possible for a plan with a given number vertices. For any given number of vertices a plan will have maximum number of triangulation if it is a convex polygon where every vertex of the polygon is visible from every other vertex (Figure 8). In order to determine the number of possible triangles in a given convex polygon, it may be useful to underscore the difference between permutation and combination. In permutation, the order of things matters, while in combination it does not. Therefore, for any three vertices, taken three at a time, there can be one combination only, which is a triangle. It does not matter how one orders the three vertices of a triangle, they will always refer to the same triangle. Hence, the number of triangles for a convex polygon is the number of ways in which a given number of vertices can be combined taken three at a time. The solution to which is given by the expression $n!/[(n-3)!*3!]$, where n is the number of

vertices. For example, for a convex 10-gon the number of triangulations possible between its vertices are $10!/[(10-3)!*3!]$, which is equal to 120.

In the following stage, it is necessary to determine the minimum number of convex triangles possible for a plan with a given number of vertices. For a given number of vertices a shape will have the least number of triangles, if it is possible to partition the plan in such a way that no more than three vertices of the plan are contained by a convex region (Figure 8). The minimum number of possible triangles for an n-vertex plan is equal to $n/3$ only when n is divisible by three. Note, however, that there are numbers that are not divisible by three, hence cannot be partitioned in clusters of three. For such numbers it is also possible to define the minimum number of triangulations. When n is not divisible by three, the remainder is either 1 or 2. When the remainder is 1, the number of minimum triangles is equal to $(n-4)/3$ plus the minimum number of triangles for a 4-gon. And when the remainder is 2, the number of minimum triangles is $(n-5)/3$ plus the minimum number of triangles for a 5-gon. The minimum number of triangles for a 4-vertex plan is two, and for a 5-vertex plan is three. Thus, for a 10-vertex plan the minimum number of triangles is $[(10-4)/3]+2$, which is 4. And for a 11-vertex plan it is $[(11-5)/3]+3$, which is 5. Once the number of convex triangles of a plan with a given number of vertices, and the possible maximum and minimum number of convex triangles for the plans with the same number of vertices are determined, it is possible to compute the triangulation index of the plan using the techniques suggested earlier.

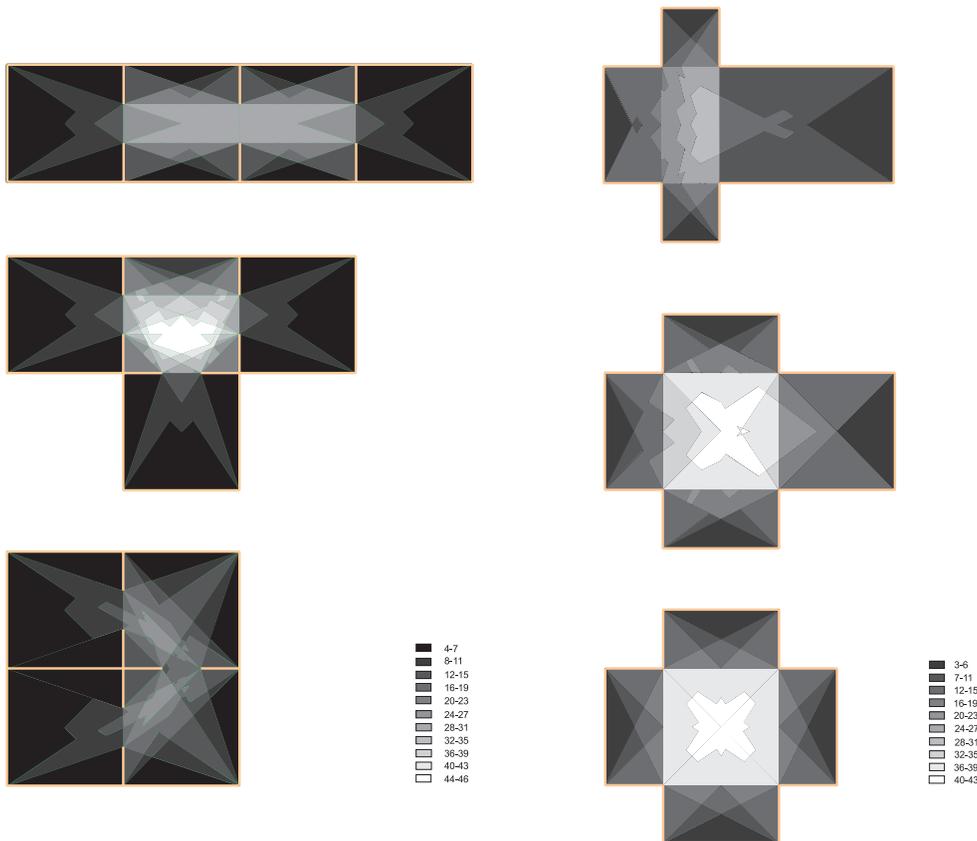
The triangulation indexes of the three plans in Figure 4 were computed. It can be observed that the deformed plan is visually least restricted with a triangulation index of 0.141 suggesting a greater sense of global integrity by approximating a condition where everything sees everything else as in the case of a convex polygon. The free plan is visually most restricted with a triangulation index of 0.087. It allows neither the global nor the local visual integrity because of such compositional rules as asymmetry and non-axiality. Finally, the cellular plan provides an in-between condition with a triangulation index of 0.127, because the composition of the plan limits triangulations within local regions reducing the total number of triangulations in the plan. However, it should be noted here that if the number of vertices is very high around a local convex region of a cellular plan, the number of triangulations in the region may increase significantly suggesting local integrity. In a cellular plan, it is also possible to enhance the global integrity while maintaining local integrity by allowing triangulations across the convex regions or the “rooms” by compositional properties such as axiality and centrality.

4.2. Characterizing regions within a plan using triangulation

In this section, a position or a region in a plan is characterized by the number of convex triangles, each of which contains the position or the region. This number is called the triangulation value of the region or position. Intuitively, a region or a position with a high triangulation value should occupy a more central location in the structure of triangulation of the plan. And if triangulation as an elementary process of construction is important for our understanding of the shape of the plan, then the distribution of the triangulation value in a plan may provide a key to any such understanding. Though it is possible to characterize any convex partition of a plan using the concept of triangulation, for the purpose of the paper the technique is applied to the d-partition (i.e., the partition generated by all the diagonals) of the plan. This partition describes all possible regions with different triangulation values in the plan.

Figure 9 shows the distribution of triangulation values in a set of cellular and deformed plans. As can be seen in the figure, in every cellular plan the locations of the openings seem to have a distinct effect on the distribution pattern of the triangulation value. There is a simple reason for it: In a cellular

▼ Figure 9: The distribution of the triangulation values of d-spaces in plans.

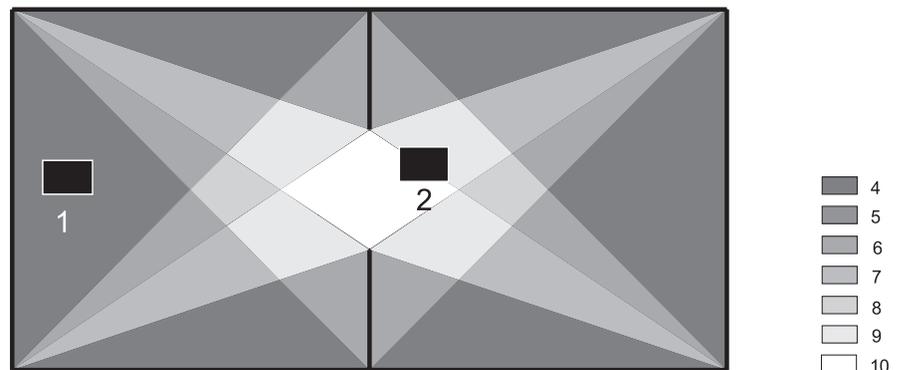


plan, which is composed of rectangular units such as the ones in the figures, each unit would have only four triangulations amongst its own four vertices had there been no opening. Openings introduce additional vertices to these units, and consequently the number of possible triangulations increases within a local region. In fact, the more the number of vertices around a convex unit, the more the number of triangulations within the unit. In addition, openings may also affect the distribution of the triangulation value by providing further possibilities of triangulation across the convex units. Plans become globally oriented when openings allow triangulations across these units, thus affecting our understanding of the plans as wholes.

The above suggestion is supported by the pattern of the distribution of the triangulation value in the deformed plans as well (Figure 9). The pattern in each deformed plan suggests unambiguous centrality. This of course refers to the unity of the shape of these plans. However, the lack of any local center in these plans also suggests that in each of these cases the whole is achieved only at the cost of the parts. Nevertheless, the distribution pattern also picks up certain interesting differences between these plans. For example, in these deformed plans the changes made to the shape not only have affected the triangulation values of d-spaces, but have also resulted in different forms of centrality.

Once the triangulation values of d-spaces in a plan are determined, we can use the values as a filter to characterize the position of an object. For example, if an object is totally contained in a d-space, the object gets the triangulation value of the space. However, if the object intersects more than one d-spaces, it gets the mean of the triangulation values of the intersected d-spaces. Figure 10 shows two objects with their triangulation values.

▼ Figure 10: The distribution of the triangulation values of d-spaces may be used as a filter to characterize objects.



Triangulation value

Object 1: 4

Object 2: 9.5

5. CONCLUSION

In this paper, techniques were developed to provide shape-sensitive descriptions of the spatial configuration of buildings. To begin with, graph-theoretic techniques of space syntax were applied to the e-partition (i.e., the most shape-sensitive partition of building plans) to characterize building plans. The mean integration values of the e-spaces and the shapes of the integration hub of the e-spaces in these plans made it clear that the technique was sufficiently shape-sensitive.

Techniques were also developed to describe spatial configuration of plans based on how surfaces become visible from spatial units. Here the key descriptor was the surface visibility index. A space with a high visibility index requires fewer steps to see all the surfaces of the plan. Based on the study, it was possible to suggest that graph-theoretic techniques that consider surfaces explicitly were also able to provide shape-sensitive descriptions of building plans.

Finally, the concept of triangulation was used to describe the configuration of plans. Here the key descriptors were the triangulation index and the triangulation value. It was suggested that higher triangulation index of a plan should provide better visibility relations among the vertices of the plan, and that higher triangulation value of a spatial unit should indicate stronger centrality of a spatial unit in the structure of triangulation of the plan. Using these descriptors, interesting observations were made on a set of simple building plans. Since triangulation is a property intrinsic to the shape of plans, any description of plans made using triangulation may help bring the aspects of shape and space closer to each other in configurational studies than any other techniques suggested in this paper.

To conclude, we must note the relevance of the techniques proposed here to visual perception in architecture. The literature indicates that our visual perception depends largely on the optic array, which is the pattern of light provided to the eye by the environment and the objects contained within it, and that visual perception in architecture is often difficult to describe for it must include both the static and dynamic optic arrays. Dynamic optic arrays—or the vista as J. J. Gibson calls it [22]—are needed to capture what and how the observer sees as she moves. They provide the interface between the viewer and the world.

Earlier, Michael Benedikt [8] has proposed measures that quantify certain features of isovists and isovist fields in a way that relates to the possible transformations of a view in an architectural space. Over the last two decades, space syntax has made isovists and isovist fields even more relevant to architecture by providing techniques to study the relational patterns among an objectively defined set of isovists [e.g., 7, 12, 15]. In the field of ecological optics, J. J. Gibson and his colleagues [23] made concerted efforts to analyze the information that is specific to the way surface are laid out in the three-dimensional space in which the viewer moves. Gibson's

direct theory of perception holds that we respond directly to the mathematic invariants in the transforming light to the eye. What is invariant despite changes in viewpoint is of course the set of unchanging relationships among the stationary surfaces in the environment. It is in this fact we may find the potential value of the techniques presented in this paper. These techniques allow one to describe the unchanging relationships among a limited set of optic array that define the shape of the environment as represented in two-dimensional plans. With increasingly powerful computers, there is no reason why these techniques cannot be extended to describe the three-dimensional space or to describe more complicated building plans than the ones used in this study, thus enhancing our understanding of the visual structure of the environment.

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