COMPARING THE PROPERTIES OF DIFFERENT SPACE SYNTAX TECHNIQUES FOR ANALYSING INTERIORS

PEIMAN A. BEHBAHANI, NING GU, and MICHAEL J. OSTWALD
University of Newcastle, NSW, Australia
peiman.aminibehbahani@uon.edu.au
{ning.gu, michael.ostwald}@newcastle.edu.au

Abstract. This paper examines the practical differences between several accepted techniques of Space Syntax analysis, including their application or procedure and their usefulness for analysing building interiors. Five techniques are investigated in this paper through a case study of a proposed scheme for Francis W. Little house (1908) in order to determine their similarities and quantify their differences in regard to this case. The study provides a basis for selecting the proper analytical technique for a given purpose and also reveals some spatial characteristics of this famous Prairie Style house.

Keywords. Space Syntax; Prairie style, Francis W. Little house.

1. Introduction

The title Space Syntax refers to a set of techniques for quantifying and analysing the properties of architectural and urban space (Hillier and Hanson, 1984). These techniques typically abstract the spatial properties of a design into a graph and then use the mechanisms of graph theory to perform measurements and analysis. Generally, these techniques follow a similar procedure for abstracting space into a graph and then interpreting the results. However, they differ more significantly in the detailed way in which they apply their methods, which in turn affects their results and interpretation.

This paper discusses and demonstrates the similarities and differences in several Space Syntax techniques as well as identifying factors which influence the results of each. The focus of the testing and review is mainly on techniques that can be used for the analysis of building interiors rather than urban spaces. In order to compare the approaches the paper tests each on the

same case, Francis W. Little house, deriving data from this design to assist the analysis. This paper concludes by identifying which technique may be most suitable for certain analytical purposes, further explaining what might be expected from the results of the application of that method.

2. Space Syntax and its techniques

Space is often described as a continuous and concrete three dimensional entity (Franz and Wiener, 2008). In order to analyse architectural space, Space Syntax methods typically convert or abstract some aspects of the spatial configuration into a syntactic and discrete model (Bafna 2003). To this end, Space Syntax approaches privilege the topological properties of a space over its geography, because people tend to behave (i.e. move) in ways that are based on topology (Ostwald, 2011). As a result, a Space Syntax approach uses graph theory because it provides the perfect basis for analysing topological relationships.

The abstraction of space into a graph is done by first simplifying 3D space into a 2D floor plan or section and, then by devising a graph based on the properties of this simplified space. Following the abstraction process, the measurements are performed. Graph mathematics is based on two concepts of *connectivity* and *depth* (Klarqvist, 1993). However, the definition and measurement of these values differ in regard to the way the graph is created during the abstraction stage. The differences of the Space Syntax techniques in the above steps and considerations are discussed in the following subsections and form the basis for the techniques analysed in this paper.

2.1. ABSTRACTION OF THE 3D SPACE

The Space Syntax approach to the abstraction of space into a 2D representation can be summarised into two questions relating to what features and which parts of the space are retained after the abstraction or simplification.

Space Syntax theory is largely concerned with the permanent boundaries of the space that are typically equivalent to all non-movable vertical partitions (i.e. walls) in addition to doors which separate indoors and outdoors (as for buildings). However, changes in ceiling height or floor level (i.e. stairs) can also be considered boundaries which separate two internal parts of a space (Peponis and Bellal, 2003). Doors, except main entrances, are usually considered non-permanent or movable. However, depending on the authorisation of access, a door may be considered as non-movable and thus, permanent. An example of this distinction for boundaries can be seen in Haq's (2003) case study of hospitals. In addition, depending on the purpose of the analysis, a space separated by a door may be excluded. For example, Ost-

wald and Dawes (2011), argue for the exclusion of spaces that are without a "social" activity (like store rooms) or are too small to be inhabited (like service risers).

2.2. ABSTRACTION AS A GRAPH

Klarqvist (1993) identifies three approaches to devising the graph of a space, including convex *mapping* (dividing space into 2D areas), *axial mapping* (representing space using 1D lines) and *isovist mapping* (articulating space using a grid of dimensionless points). Each approach has several versions which are explained briefly as follows.

2.2.1. Convex mapping

The definition of architectural space has traditionally had a strong connection to ideas of visual enclosure. In Space Syntax, this idea is mainly captured by the definition of a *convex* space, that is an area in the shape of a convex polygon in which all points are mutually visible to each other (Hillier and Hanson, 1984). In this method space is divided into a number of convex spaces, which are the "fattest" or largest, and fewest in number, which are collectively termed a *convex map* (Klarqvist, 1993).

The convex spaces in the map are then translated into the nodes of a graph while their connections are typically converted into the edges of a graph. The connection is usually defined as a property of both adjacency and permeability that is the availability of direct access (by way of a door or opening) between two spaces (Peponis and Wineman, 2003). This method of convex mapping is the most commonly used approach to devising the graph. However, differentiations in floor level or ceiling height may also be treated the same way as the vertical boundaries like walls (Peponis and Wineman, 2003). In addition, some researchers tend to use social boundaries, including the "function" of the room, instead of geometry (convexity) to define a spatial entity.

Convex map graphs are used to investigate the configurational relationships between rooms (Dawes and Ostwald, 2013a). They provide a measure for the arrangement of architectural programmes relative to how spaces are used (Bafna, 2003). Due to the "fat" nature of the shapes of the convex map, this approach is best suitable for defined spaces such as building interiors in contrast to narrow and long streets in urban spaces (Miranda Carranza and Koch, 2013).

The graph of a convex map presents a dimensionless topology devoid of geographic and proportional properties. Because of the dimensionless quality, this approach falls short in several areas. First, it is not efficient for cap-

turing visual relationships between spaces. Second, it has a static approach to space (as points) which neglects the movement and paths within the space. Finally, because of the abstraction of the convex area to a single node in the graph, the precise mapping of this space to the node is not clear (Dawes and Ostwald, 2013a).

2.2.2. Axial mapping

People orientate themselves by what they see and where they can go (Turner *et al*, 2001). This can be represented on a plan by a straight line without any visual or access interruption that indicates how far a person can see or go in a direction. In Space Syntax terminology this vector is called an *axial line* (Klarqvist, 1993). An axial line through a point in space is the longest line within the space boundaries that includes this point (Turner and Hillier, 2005). A common algorithm for producing a map of such lines is called the *all-line* approach. It draws all of the possible lines passing through, or to, all vertices of the boundary (Turner and Hillier, 2005). Other algorithms (Peponis et al, 1998; Turner, 2003; Batty, 2004) further reduce the number of axial lines to the *fewest* and longest lines which together cover or pass through every convex space in the floor plan (Ostwald and Dawes, 2011). In space syntax terminology, the total layout of the lines is called the *axial map* (Klarqvist, 1993).

Primal axial map graph

In a classic axial map the lines comprised the nodes of the graph and their intersections are considered as the Boolean state of connection which is represented by the edges of the graph (Hillier and Hanson, 1984). The intersection as the edge variation represents the turning point in the line of sight while navigating the space. This approach to graph development is described as a *primal* (Batty, 2004) wherein the axial lines represent the likely paths of movement. In regard to their geometrical properties, these maps may be more suitable for representing long and narrow urban spaces (i.e. streets) and are frequently used for analysing such spaces (Bafna, 2003).

   The primal axial graphs also capture some behavioural characteristics of the spatial settings and show the ideal paths of movement within a space where the significance of each portion of them can be measured (Bafna, 2003; Dawes and Ostwald, 2013a). The axial lines can also be used to detect important vistas. However, in this process the space is abstracted so intensively that many geographic properties of space are neglected, especially in geometrically distinct building spaces. Furthermore, the lines do not refer to

a clear location in the space, but a range of locations (Dawes and Ostwald 2013a).

Dual axial map graph

Batty (2004) formalised an inverted version of the primal fewest lines graph, which he termed a *dual*. In this variation, the intersections of the axial lines are represented by the nodes of the graph while the edges of the graph represent the segments of axial lines which attach the intersections. The dual axial mapping has the properties of the primal axial map graphs as the line layout remains the same. However, the nodes (intersections) in this approach actually represent a precise spot in the space.

Dual axial graphs are only rarely used for analysing building interiors although this may be because they are not well understood (Ostwald and Dawes 2013). One issue of using them in building interiors is that the intersections do not necessarily cover all (convex) spaces in the building and so some information may be lost. To resolve this issue, Dawes and Ostwald (2013a), following Peponis *et al* (1997), proposed a method to consider the end of certain axial lines as nodes of the graph.

Overall, there are two major types of axial line analysis, primal and dual maps. The advantage of axial map graphs is their capacity to capture the ideal paths of movement and, in the dual approach, the most important visual nodes in a space.

2.2.3. Isovist mapping or visibility graph analysis

Each point in space has a unique geometrical relationship with its surroundings which gives it unique visual properties. In a floor plan, a unique property of each point is the area visible and accessible from that point, in the shape of a polygon; this is called an *isovist* (Benedict, 1979). Due to the impracticality of considering all points, the space is typically articulated into a fine grid (ideally in the size of a human) and isovists of each cell on the grid are drawn. A graph (called a visibility graph) is then developed with the cells as its nodes and the existence of visibility between cells as its edges (Turner, 2001). This visibility graph has a low level of abstraction because every node represents an actual point in space. Therefore, the nodes can possess detailed geometrical properties such as position and isovist characteristics.

Visibility graph analysis (VGA) reveals the properties of the points in space. These properties include, amongst many others, enclosure, compactness (Franz and Wiener, 2008) and trans-visibility and visual control (Ostwald and Dawes, 2013b). the visibility graph is essentially derived from a 2D collection of points or, in other words, a defined area. It is therefore suit-

ed to spaces with fat areas and clear boundaries like building interiors (Dawes and Ostwald, 2013a).

2.3. MEASURING OF PARAMETERS

Graph topology is fundamentally concerned with the nature of direct connection between nodes which defines the state of their adjacency. From this property, another fundamental concept, depth, can be defined. The depth between two nodes is a numerical value representing the shortest possible path that connects those nodes. While a few measures like control value (CV) are calculated using connectivity, most topological measurements such as mean depth (MD), integration (i) and centrality are based on depth value.

The calculation of depth depends on the definition of the shortest path between the nodes of the graph. For an unweighted graph, the shortest path between two nodes is an integer equal to the minimum possible number of edges that can connect them (Hillier and Hanson, 1984). This definition applies to convex maps, unweighted axial maps and non-angular visibility graph maps. On the other hand, the shortest path in angular analysis (angular VGA) is defined as the minimum angular turn depth required for travelling between any two nodes of the graph. In this case, the depth will be a real number in radians. However, Turner (2007) proposes considering a 90 degree change in direction as one unit of turning. In addition, there are geometrical (non-topological) concepts that can be extracted from isovist maps. Isovist area, perimeter, drift and compactness are examples of isovist-based values.

2.4. ANALYSING AND INTERPRETING RESULTS

The interpretation of the results derived from a graph mainly depends on various factors, ranging from the nature of the measured value to the type of space abstraction used for the map. In general, the convex map graphs reveal the hierarchy and permeability of spaces. The axial map graphs reveal the likely or efficient paths of movements or surveillance in space. The visibility graphs show the visual properties of different parts of a space.

An important measure that is widely used to interpret a graph is integration (i), which reveals the degree of integration of a node within the graph system. A more integrated space is one with more connection (access or visual) to other spaces. That is, it is both more "open" to them and more controlling over them, properties that correlate with distribution of population or frequency of use (Bafna, 2003).

2.5. SUMMARY OF SPACE SYNTAX

The theory of Space Syntax is demonstrated through different techniques with each having different versions of the standard measures. However, only a few of them are applicable for building spaces while others are more suitable for urban contexts.

The techniques of space syntax follow a similar general procedure to abstract, measure and interpret the 3D architectural space. However, they differ in the details of steps of this procedure. In addition, considerations, in regard to the purpose of the analysis may also lead to different abstractions of space.

3. Case study

In order to compare and analyse the different Space Syntax techniques described previously, in this section a study is undertaken into the Prairie style, the proposition for Francis Little house which was designed by Frank Lloyd Wright in 1908. In terms of geometry, this proposed plan of Little house is an example of the typical characteristics of Prairie design (especially in its earlier days) with a central hall with a fireplace and a perfect pseudo-symmetrical cruciform plan layout with clear functional zoning (Chan, 1992). The case study is limited only to the first floor plan, excluding the outdoor spaces (porches and gardens). There is no access limit considered, allowing all spaces to be measured.

Considering the limitations of this paper, the applied techniques are limited to the graphs based on a primal axial map of Peponis *et al* (1997), a dual axial map (Dawes and Ostwald, 2013a), convex and social spaces maps, and angular VGA. The integration (i) values for all graphs are measured and compared. For this paper, the integration value (i) of VGA is normalised to the other measures by dividing it by 1000.

The mapping for primal, dual axial maps and convex maps is done manually in AutoCAD® environment and imported to depthmapX software (SpaceGroupUCL, 2014). Figure 1 shows the mappings of the Little house for these techniques. In this figure, the important functional spaces are identified by their first letter: living (L) and dining (D) rooms, hall (H), entrance (E), pantry (P), kitchen (K), and a circulation area (C) between P and D. In addition, three approximate areas (α, β and γ) are considered which act as important connection zones between large spaces (L, D and H). In this figure, the darkness of lines, polygons and grid cells graphically represents their respective integration values (darker being higher). The results of the analysis, the derived integration values, are displayed in Tables 1, 2, and 3. In addition, Figure 2 illustrates the integration values in all measures for the de-

fined spaces and areas. The figure includes the identification number of lines and intersection (besides their respective symbol in the chart) as shown in Figure 1. Each axial line is displayed by a set of round nodes and dashed arcs. The nodes represent the spaces which they cross, and the dashes indicate the sequence of crossing.
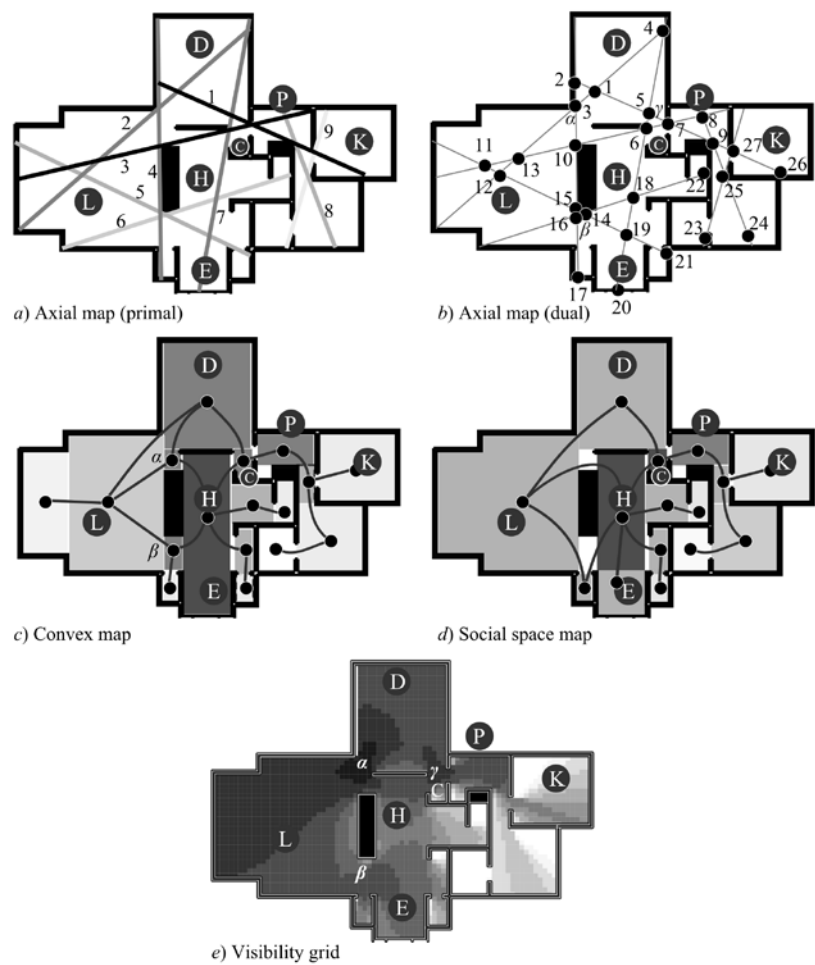

a) Axial map (primal)

b) Axial map (dual)

c) Convex map

d) Social space map

e) Visibility grid

Figure 1. The plans showing the graph mapping for different techniques of Space Syntax.

Table 1. Integration values for primal axial map.

Line	1	2	3	4	5	6	7	8	9
i	4.43	2.95	4.43	2.95	2.21	1.26	2.95	1.47	1.10

Table 2. Integration values for dual axial map.

Point	1	2	3	4	5	6	7	8	9	10
i	3.45	3.67	2.93	2.79	3.67	3.26	3.67	3.26	2.93	3.26

Point	11	12	13	14	15	16	17	18	19	20
i	3.45	2.93	3.09	2.35	3.09	2.79	2.45	2.67	2.93	2.09

Table 3. Integration value for convex and social space mapping and angular VGA.

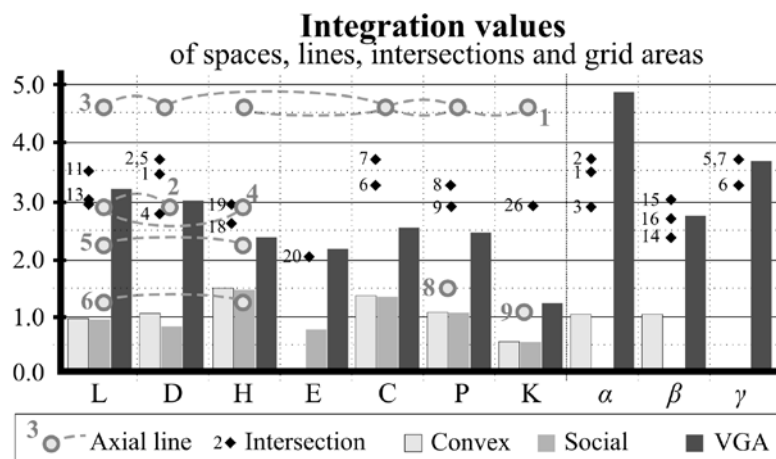| Space	L	D	H	E	C	P	K	α	β	γ
convex	0.94	1.04	1.46	-	1.39	1.04	0.56	1.00	1.04	-
social	0.90	0.87	1.47	0.81	1.38	1.06	0.56	-	-	-
VGA	3.24	3.02	2.33	2.21	2.50	2.46	1.26	4.91	2.76	3.68

Figure 2. Integration values for the selected spaces, areas, intersection and lines.

3.1. ANALYSIS OF RESULTS

Primal axial graph

Lines 1 and 3 are the most integrated (*i* = 4.43), connecting L and D to the service area of the house, respectively. These two lines form two visual axes whose intersection on the joint of P, D and C might have some significance in making movement decisions.

Dual axial graph

Three intersection points (2, 5 and 7) in D and C (and also in *α* and *γ*), respectively, are the most integrated points in the plan ($i = 3.76$). They are located on the axial line 1 that extends from K and P to D. The next most integrated points (1 and 11) with $i = 3.45$ are located on lines 1 and 3. Point 11 is in the centre of L and on the axial line 3. Regarding the spaces and areas, D and C have the most integrated points, followed by L and P. In addition, five highly integrated points are concentrated on the α and γ transition zones, suggesting their visual and surveillance significance. On the other hand, the hall (H) does not have a significant role in visual configuration of the house despite its central location. We can assume that the two visual barriers of fireplace and the thin partition wall (between H and D) are the reason behind the visual insignificance of the hall.

Convex and social mapping

Although the definitions of space-nodes are slightly different in convex mapping and social space mapping, their results have many similarities in part because in this particular plan most spaces are orthogonal and have a single defined function. In both approaches, the hall (H) has the highest integration ($i \approx 1.46$) and C comes next with $i \approx 1.36$. We can infer that H is the main hub of for the whole house while the circulation space is the local hub between open and service areas. The major differences between the two approaches are the absence of an entry space (E) in the convex mapping and the significantly lower integration value for D in social space mapping ($i = 0.87$ cf. $i = 1.04$ in convex mapping).

Visibility graph analysis

The area α (between D and L) has the highest integration ($i = 4.91$), followed by γ ($i = 3.68$). Regarding the social spaces, the living room (L) has the highest i (3.24) followed by D ($i = 3.02$), C ($i = 2.50$) and P ($i = 2.46$). While the high i value for L and D is influenced by their own large areas, the i value of pantry and C can be explained only by their visual surveillance. Despite the relatively large area of the hall (H), this space has relatively low integration. This seems to be because there is neither an axial nor a diagonal wide visual connection between the hall and the other two large spaces (D and L).

Comparing results

The results of the two axial maps and the angular VGA show several similarities. In all of them it is the intersection of interior spaces (notably α and γ) that possess the highest integration or least mean depth. On the other hand, using these techniques the central hall has no significant visual role in the house. A difference between axial map analysis and VGA is the higher relative integration of intersection between H and L in the axial maps. This may be because the importance of area size in VGA, considering this intersection points have less visual connection towards the large D space compared to the intersection point in D and P. In contrast, the convex and social mapping graphs reveal the importance of the hall in organising the functional permeability of the house. Nevertheless, in all techniques, the circulation area (C) has a high integration. We may conclude that this area has both functional and visual significance in connecting the open (visible to visitors) and closed areas of the house.

Overall, the analysis reveals a sharp difference between the visual and functional organisation of the Little house. While the functional organisation follows Wright's description of the house as an organism which grows from the centre and expands in each direction (Wright, 1943), the visual configuration of the house is more consistent with his idea of breaking the box shape of the room by opening its corners to embrace a dynamic flow of space (Chan, 1992). This contrast can also be seen in the geometrical axes (the arms of the cruciform) and visual axes (the most integrated axial lines) of the plan which have considerable angular difference from each other.

4. Conclusion

This paper identifies a number of factors which influence the definition and application of Space Syntax techniques for analysing building interiors. A handful of these factors are demonstrated in the case study.

Regarding this particular case study, it seems that the main influencing factor is the definition of connection (visibility versus adjacency) rather than the abstraction of the space or measurement methods. Of course, there are relatively minor differences between the results of different techniques for each type of connection. However, despite their differences they are able to individually verify some historical observations about this design that will be verified in a larger study of multiple prairie houses.

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