10 Methods of spatial analysis for natural ventilation potential

10.1 Introduction

The basic theory of space syntax was described in section 2 of chapter 9. Some methods have been developed from the theory of spatial analysis to explore the spatial structure of buildings and cities. The DepthmapX-one graph-based representations and measures program (Turner, 2001) is one of the most important platforms for space syntax analysis. Convex and axial analysis, isovist and VGA analysis, as well as segment analysis are the methods involved in this programme (Al_Sayed, Turner, Hillier, Iida, & Penn, 2014). The axial and segment analysis are more suitable for the analysis at the urban scale. The convex analysis is suitable for the building scale and isovist and VGA analysis are suitable for both urban and building scale. Many cases have been studied to reveal the topological relationship between the spaces which is related to the social behaviour of human in building or urban scale via DepthmapX.

In this chapter, the traditional space syntax methods for building spatial analysis used in the Depthmap were discussed firstly. Then, the author shows how to extended the traditional methods for natural ventilation potential analysis.

10.2 Traditional space syntax methods for spatial analysis

10.2.1 Convex analysis

The convex analysis uses a topological graph representation of a buildings. Figure 10.1 shows an example for decoding a building layout designed by Frank Gehry using the convex space representation (Al_Sayed et al., 2014). Figure 10.1(a) is the original layout of the house. The spaces of the building are represented by a set of convex spaces. In this case, the convex spaces are convex polygons which are shown in grey in figure 10.1(b). In each convex space, all pairs of points are inter-visible. These spaces are linked where there is direct access from one space to another. The relationship between the convex spaces is then represented by a graph where the convex spaces are represented by nodes (figure 10.1(c)). The different Connectivity value for each node can be calculated and highlighted (figure 10.1(d)). The values of Connectivity are then illuminated on the convex map to reveal the spatial structure of the building layout (figure 10.1(e)).

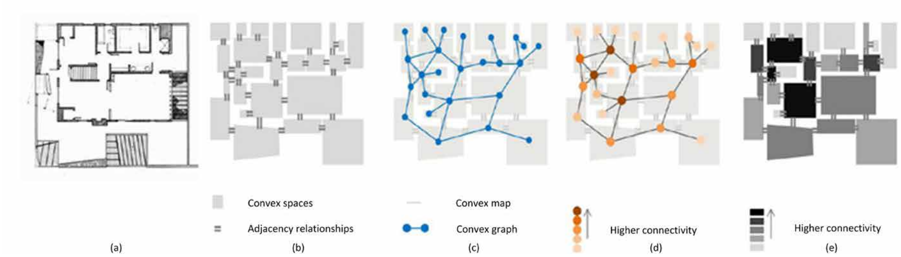

FIG. 10.1 The convex representation of Space Syntax method: (a) original layout of the house; (b) spaces of the building were represented by a set of convex spaces; (c) convex spaces are represented by a graph;(d) the value of connectivity is highlighted;(e) the value of connectivity is illuminated on the convex map (Al_ Sayed et al., 2014)

The topological relationship of the convex spaces of the layout can also be represented by a “justified graph” (figure 10.2) which was first proposed by Hillier and Hanson (1984). A justified graph shows the spatial network of spaces from one root space to all others. Each convex space is represented as a circle and the connection between two spaces are represented with a line. From a root space, all spaces that are one syntactic step away are put on the first level above the root space, all spaces that are two steps away are placed on the second row, etc. The convex spaces can be classified into four types (Al_Sayed et al., 2014), see also figure 10.2.

1 Types that are characterised as dead-end spaces and connect to no more than one space in a graph (a)
2 Types that connect to two or more spaces in a graph without being part of any ring of movement (b)
3 Types that are usually positioned on one ring of movement (c)
4 Types of spaces that must be in a joint location connecting two or more rings (d)

A justified graph might be deep or shallow, depending on the relationship of the root space to other spaces (Al_Sayed et al., 2014). From the justified graph, some global (integration and choice) and local (connectivity and control) syntactic measures can be calculated which are described in section 9.2 of chapter 9.

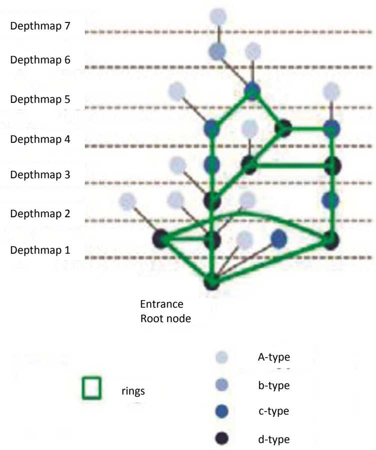

FIG. 10.2 The “justified graph” of Frank Gehry’s house from the entrance root node (Al_Sayed et al., 2014)

10.2.2 Isovist and VGA analysis

An isovist (viewshed) is the area in a spatial environment directly visible from a point. The isovist was first introduced by Benedikt (1979). An isovist is a physical body bound by a closed polygon; hence it has geometric properties such as area and length of perimeter (figure 10.3). Table 10.1 lists the commonly used isovist variables, measures and related spatial perceptive indicators. The isovist method can quantitatively measure the visibility features of a spatial environment: the inter-visibility between each pair of points in a layout and how that builds into the visual configurations of the built environment (Al_Sayed et al., 2014). The isovist theory reveals that the visual configuration is strongly related to people's spatial perception from a certain position. The visual perception is correlated with people's behaviour, such as movement.

Turner, Doxa, O'Sullivan, and Penn (2001) developed the visibility graph analysis, which extends both isovist and current graph-based analysis of architectural space to form a new methodology for the investigation of configuration relationship. "The measurement of local and global characteristics of the graph, for each vertex, or for the system as a whole, is of interest from an architectural perspective, allowing us to describe a configuration with reference to accessibility and visibility, to compare from location to location within a system, and to compare systems with different geometries" (Turner et al., 2001).In the visibility graph, each point is notated as a node and inter-visibility is the condition for linking one node to the other. The visual relationships between different nodes in the system can be calculated using different local and global measures (Al_Sayed et al., 2014).

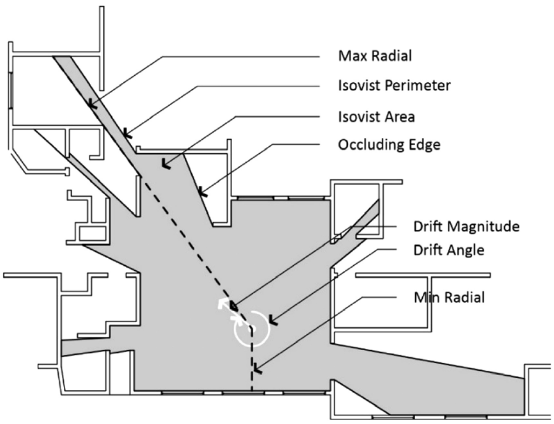

FIG. 10.3 The concept of isovist and the measures (Lee, Ostwald, & Lee, 2017)

TABLE 10.1 Isovist variables, measures and perceptual indicators

Isovist variables	Measures	Spatial experience
Isovist area (A)	Area of isovist polygon	Spaciousness, enclosure and openness
Isovist perimeter (P)	Perimeter of isovist polygon	Spaciousness, enclosure and openness
Maximum radial line (RLl)	Length of the longest single radial line used to generate the isovist	Openness
Minimum radial line (RLs)	Length of the shortest single radial line used to generate the isovist	Enclosure
Occlusivity (O)	Total length of all occluded edges	Mystery
Jaggedness (J)	The radio of perimeter2 to area. A high J value indicates a more visually complex isovist	Complexity, openness
Drift magnitude	Distance from observation point to centre of mass of isovist polygon	Visual pull strength
Drift angle	Angle between occupant facing direction and centre of mass of isovist polygon	Visual pull direction

10.3 Extension of the traditional space syntax methods for natural ventilation potential analysis

In chapter 9, the relationship between the spatial indicators in the space syntax method and the air flow behaviour in a building was found to be related for a case study. There is potential using the space syntax method to predict the air flow performance of buildings. The basic assumption is that there are common characteristics of people flows and air flows related to the spatial configuration. Therefore, the spatial measures in the space syntax method can also predict the air flow behaviour in buildings and cities. However, people movement behaviour is not exactly the same as the air flow behaviour, even though some characteristics are both correlated to the spatial configuration. Thus, an extension of the traditional space syntax method is necessary when this method is used for the air flow analysis.

In the traditional space syntax method, the relationships between spaces in the building or the city are the main concerns. This is because the logical relationship of connection of the inter-spaces can influence the route choice of people (Bhatia, Chalup, & Ostwald, 2013; Holscher & Brosamle, 2012; Li, Xiao, Ye, Xu, & Law, 2016).

The outside environment is not considered. In the building scale analysis, the outdoor environment is generally considered as one node at the entrance. Nevertheless, if the natural ventilation behaviour is concerned, the outside environment is the most important factor. Therefore, in this study the important extension of the traditional space syntax method is the focus on the connection between the indoor spaces and the outdoor spaces. Figure10.4 shows an example of the graphic expression of the traditional space syntax method and the new proposed method by the author. Figure 10.4(a) shows a building layout and the inter-connections with nine spaces. The logical connections of the spaces can be expressed by the justified graph (figure 10.4 (c)). Figure 10.4(b) shows a building layout where the outside environment is involved. The connections of the indoor spaces and the outside environment is expressed. The justified graph is showed in figure 10.4(d). As we can see, the outside space is represented as a circle and the indoor spaces are represented as circles with numbers. The outside nodes are involved in the space syntax measures. In a particular spatial structure, in the case of one node with low depth or high connectivity and integration value, the space represented by the node has high accessibility in the whole spatial system and high potential to obtain airflows from the other spaces, especially the outside spaces. However, this assumption derives from the analogy between airflow movement and human movement.

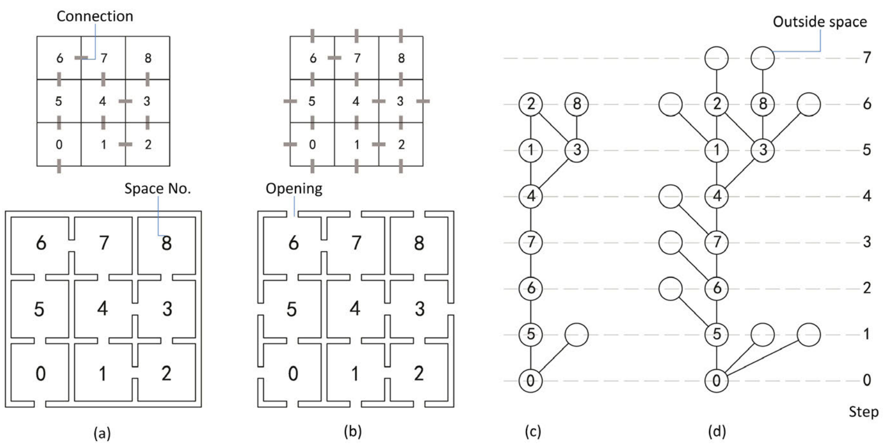

FIG. 10.4 An example of the traditional space syntax method and the new proposed method (a) the building layout and the inter-connections with nine spaces (b) the building layout and the connections of the nine inter-spaces and outside environment (c) the justified graph of the nine inter-spaces from space “0” (d) the justified graph of the nine inter-spaces and the outside spaces from space “0”

The opening size and location, which are significant for airflow and are not significant for human movement, are not represented in the justified graph. Figure 10.5 shows five layouts with nine spaces. The logical connections of the nine spaces are the same for the five layouts. Figure 10.5(f) shows the justified graphs of spaces "0", "1", "2" and "4" of the five layouts. It is obvious that the air flow performance in the five layouts is different. But the justified graphs are not. This means that a justified graph cannot evaluate the airflow behaviour completely through representing the convex space as a node and measuring the logical connections of the nodes.

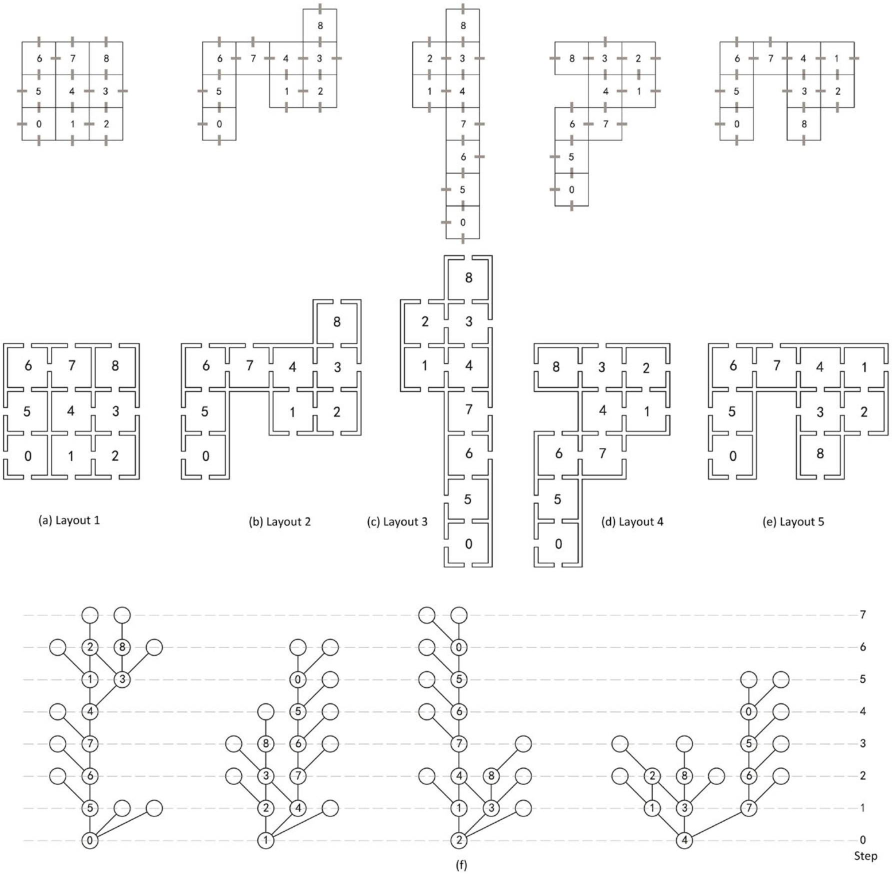

FIG. 10.5 Five layouts with nine spaces and the justified graph of space "0", "1", "2" and "4"

Fortunately, the VGA analysis considers not only the logical connection of spaces but also the visual relationship between the spaces through the measures of connectivity value and visual integration. This relationship is related to the opening size and the location of the spaces. Figure 10.6 shows the connectivity and integration maps, and figure 10.7 shows the variation of the connectivity value and visual integration value of the five layouts in the VGA analysis. In this VGA analysis, to involve the outside environment, the outside border was extended to a certain scale. As we can see, respecting different layouts, the connectivity and visual integration value of room 0, room 1, room 2 and room 4 are different. Therefore, the VGA analysis method seems the best choice of the space syntax analysis method for the airflow analysis.

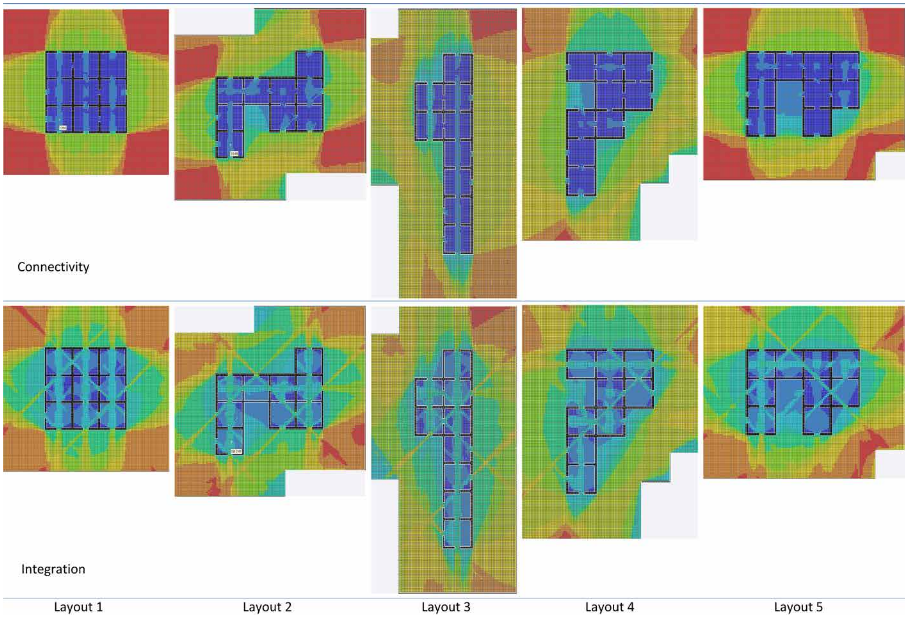

FIG. 10.6 The connectivity and integration maps of the five layouts

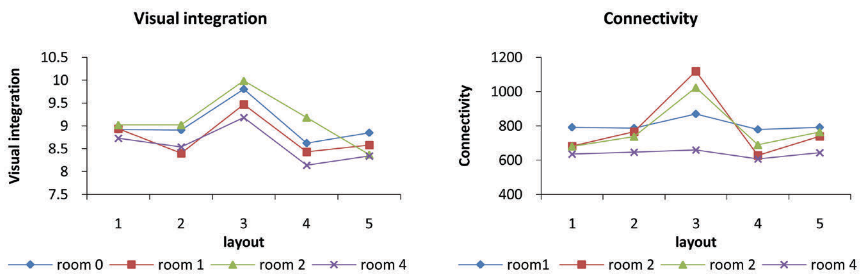

FIG. 10.7 The variation of the connectivity value and visual integration value of the five layouts in the VGA analysis

As mentioned in section 10.2.2, many measures in the isovist are related to the boundary conditions between the spaces such as the opening size and the location on the walls between the spaces (figure 10.3). The parameters can reflect the spaciousness, enclosure and openness of spaces in a particular environment (table 10.1). Therefore, the isovist analysis is considered to be applicable for airflow analysis as well. Figure 8 shows the example of the measure of isovist area in a room with different openings to the outside environment. There are two openings in the room. The width of every opening is assumed as W in case 1, 2 and 3 (figure 10.8 (a)(b)(c). In case 4 (figure 10.8(d)), every opening is assumed as 2.5 times W. The outside environment is extended to a certain area. The green colour represents the isovist and the value is shown in the room. As we can see, in case 1, 2 and 3, the isovist area is different, which is caused by the difference of the location of the openings, even though the total opening area is the same. Case 2 shows the highest isovist area, which means it has the best openness to the outside environment and the highest potential for natural ventilation. Comparing case 4 to case 1, 2 and 3, the isovist area in case 4is much larger than others. This is because the room has the largest opening area in case 4. Therefore, case 4 has the highest potential to achieve natural ventilation.

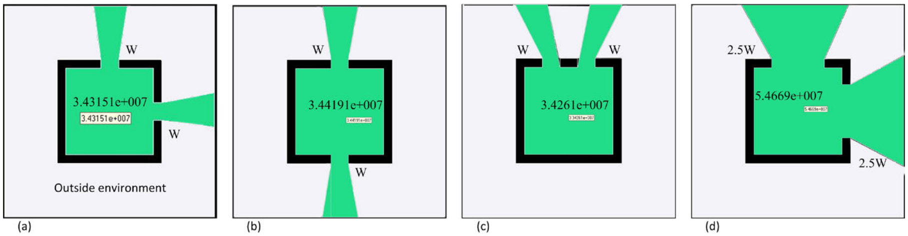

FIG. 10.8 The measure of isovist area in a room with different openings to the outside environment

10.4 Conclusion

In this chapter, the spatial analysis method, which was extended from the traditional space syntax method, was introduced for the analysis of natural ventilation potential. Both the logical relationship between the spaces and the boundary conditions can influence the accessibility of a particular spatial configuration, and then influence the natural ventilation potential. The convex method can show the logical relationship of spaces, but cannot reflect the natural ventilation potential completely. It can be developed for the preliminary analysis because it is easy and clear to show the relationship of the spaces which is important for architects to deliberate the solution through a graphical method. The extended VGA method is the best choice for the natural ventilation potential analysis for a spatial configuration. The isovist measure can be used for the natural ventilation potential for a single space.

In the next two chapters, the extended methods in the Depthmap program will be applied for the evaluation of natural ventilation potential of Chinese rural house design layout.

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