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Research

Differentiating between Line and Point Maps Using Spatial Experience: Considering Richard Neutra's Lovell House

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Abstract. Space Syntax researchers have demonstrated methods for mapping and analysing zones (rooms) and lines (paths) in plans. One Space Syntax technique that is rarely used is focussed on the mapping of points (intersections) in architectural plans, and is an inversion of a more common approach to the mapping of lines (paths) in plans. From a graph theory perspective, the former point map is a dual of the latter, primal line map; meaning the two are numerically comparable. In this paper such a comparison is used to investigate if there is any difference between the capacity of line and point maps to suggest the spatial experience of the individual. The case study chosen to develop such a comparative analysis is Richard Neutra's Lovell House. This design is mapped, using both line and point techniques, and mathematically analysed to determine the socially significant paths and intersections. A selected investigation of the intelligibility implications of these lines and points along with their three-dimensional properties is then developed. The paper concludes that there is some evidence that, for point and line maps with similar mathematical properties, point maps are more successful at suggesting the experiential qualities of space.

Introduction

Since the 1980s, mathematical and computational methods have been successfully used to study the social patterns embedded in architectural and urban spatial configurations [Hillier and Hanson 1984]. Such methods have been used to analyse security, optimise pedestrian routes, model rental income and predict where crime may occur [Hillier 1996; Desyllas 2000; Hillier and Shu 2000]. Despite the apparent sophistication of these approaches, they remain largely focussed on generalised spatial models (zones and lines) that are not easily conceptualised as representing the experience of an individual. This is not a criticism of Space Syntax techniques, the majority of which are deliberately attuned to considering social patterns in major public spaces and institutional buildings. However, this focus does limit the potential of these methods to be applied to more specific questions about the spatial experience of the individual, as part of a larger social pattern.

That researchers modelling the social patterns of space have rarely considered individual spatial experience is not unexpected. This type of analysis is typically undertaken as part of the phenomenological tradition of reading space and form [Thiis-

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Evensen 1987]. In architectural phenomenology, personal observations of texture, temperature, acoustics and lines of sight are used to interpret a building [Pallasmaa 1996]. Such techniques privilege the role of the observer as being uniquely capable of processing the complete range of sensual experience. Dovey [1993: 248] argues that the implication of this proposition is that a clear separation exists between "lived space" (the realm of personal feelings, emotions and particulars) and "geometric space" (the space of plans, forms and universals). However, while the mathematical analysis of geometric space may be incompatible with the intricacy of personal experience, it does offer an important "universal language of spatial representation [which] has predictive value" [Dovey 1993: 250]. Thus, while attempts to use mathematical analysis to consider the social or experiential qualities of architecture are necessarily both limited and abstract, they have the advantage of being transparent, consistent and repeatable. Moreover, some approaches to geometric analysis, including mathematical techniques that model vision and movement, are also potentially significant from the point of view of the experience of lived space [Benedikt and Burnham 1985; Aspinall 1993; Montello 2003].

It has been repeatedly argued that, in plan analysis, configurational patterns both represent and shape the values and behaviours of groups of people [Hillier and Hanson 1984; Hillier 1996]. By implication such patterns confirm the existence of a similarly artificial, but nevertheless representative, individual. In essence, the social is predicated on the existence of the individual and, from an analytical perspective, this means that the social and the experiential represent related patterns of inhabitation [Montello 2007]. Conversely, the social and the experiential could be said to represent two versions of the same pattern [Aspinall 1993]. This is because a social pattern is a statistical reflection of the behaviour of a set of individuals. While this does not imply that mathematical analysis is capable of replicating even a limited part of personal experience, it does confirm that certain approaches to plan analysis may, if suitably inverted, provide insights into both social and experiential patterns. The primary motive for the present paper is to examine this proposition, through a comparison between two related approaches to plan analysis and their application in a common case study. The two mathematical methods which are the focus of the present paper are axial line mapping and intersection mapping.

Axial line mapping is a well-known Space Syntax approach that identifies the optimal set of paths through a building and then mathematically derives various values for each path [Penn 2003]. These values are typically regarded as relative indicators of social patterns, including those pertaining to accessibility, adjacency and permeability. While this first method has been widely applied, the second method has rarely been used and never – in architectural analysis at least – in comparison with the first. Importantly, the second method, intersection mapping, is essentially an inversion of the first. Where the former method emphasises the social values embedded in networks of paths, the latter concerns the properties of those positions where the paths intersect. Batty [2004], echoing Aspinall [1993], implies that intersection or point mapping more closely replicates the human experience of being in space while path or line mapping is more akin to the production of traffic density charts. Thus, while both methods are effectively social in nature and rely on the same mathematics, they are expected to identify slightly different spatial properties. In order to determine if this is true, the present paper constructs axial line and intersection point maps of the same design before undertaking a visual and numerical analysis of the two, culminating in the construction of a comparative intelligibility graph. Finally, isovists generated from the most integrated lines and points are converted into three-dimensional views of space (perspectives) to provide additional qualitative information to assist in interpreting the mathematical data. An isovist is a representation of the space that can be viewed from a single point on a plan [Benedikt 1979; Turner et al. 2001]. The isovist is universal and computable (because a set of repeatable rules governs its generation), but it is also particular in its capacity to suggest the visual experience of a single person [Ellard 2009].

The case study used to compare the two methods is Richard Neutra's 1929 Lovell House in Los Angeles. This design is ideal for the present research for four reasons. First, Neutra's design theory repeatedly described the importance of paths through space, for gaining an understanding of a building, and points in space, for experiencing architecture. Thus, Neutra's design intentions are well attuned to the two methods. Second, this house is large enough to develop a statistically viable sample size for both methods, but small enough that the study can accommodate the complete building. Next, spaces in the house are effectively orthogonal in three dimensions. This means that, because the house does not have complex raked and angled ceilings, the experiential comparison between the plan and perspective results is relatively direct. Finally, many scholars have written about this house, offering personal descriptions of their experiences. While largely beyond the scope of the present paper, this last body of work may be used to evaluate the results at a future time.

The paper commences with an overview of Space Syntax and the application of graph theory to architectural and urban works. Thereafter, the axial line method is briefly presented along with references to some of the many examples of its application and the mathematical processes used to analyse the maps it produces. A more extensive discussion follows about intersection mapping, including an explanation of critical methodological decisions that must be made to achieve a meaningful result. This section describes several variations of the procedure along with some practical decisions about its application. In the second half of the paper the Lovell House is introduced along with an overview of the relevant parts of Neutra's theory. Two maps, one of lines and the other of points are developed and selected mathematical data associated with each are provided. In the penultimate section these results are discussed comparatively and finally they are supplemented with perspective images (and parallel isovist maps) to assist in formulating the paper's conclusions.

Space Syntax and graph mathematics

Space Syntax is both a theory and a set of techniques for the analysis of the spatial configuration of architectural and urban plans. Space Syntax uses a series of protocols to create geometric maps from these plans that are then used to develop numerical data describing the relative properties of various parts of the map. The mathematics at the core of the Space Syntax method is derived from graph theory, a field which has its origins in the eighteenth century but was largely developed in the mid-twentieth century as a means for examining spatial, geographic and social phenomenon. Graph theory relies on the conversion of information into a network diagram that can be mathematically analysed to determine the relative depth or significance of the nodes or edges which make up the network [Seppanen and Moore 1970]. Urban geographers, town planners and transport planners were amongst the first to apply graph mathematics to spatial analysis [Hansen 1959; Kansky 1963; Wilson 1970; Taaffe and Gauthier 1973] although architectural applications were also developed [March and Steadman 1971; Steadman 1983]. Despite this initial interest, it wasn't until the 1980s that Hillier and Hanson

[1984] developed both a way of applying graph mathematics to architecture and a theory explaining the implications of the method. Over time, Space Syntax researchers provided evidence for the concept that the configuration of a plan is a reflection of the social values or behaviours of the inhabitants of the space.

While there are multiple Space Syntax techniques, the most common are the Convex Plan and the Axial Line methods. Both of these processes commence with an architectural plan that is divided into convex spaces (fig. 1). Convex spaces are those that can be completely surveyed from any point in the space, while concave spaces are those wherein vision of some part is occluded from certain positions. Once the set of convex spaces is identified, it is converted into a graph (a set of nodes connected by edges) for mathematical analysis. There are many variations describing how a graph is constructed from a plan, but in principle it must be both efficient and comprehensive [Hillier and Hanson 1984]. Furthermore, regardless of which approach to generating the graph is followed, the mathematical processing remains largely identical.

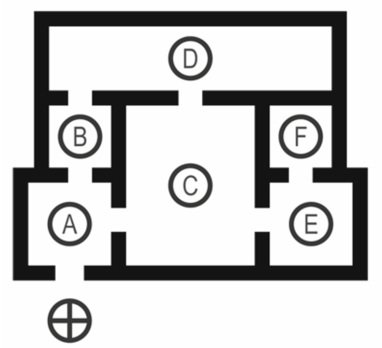

Fig. 1. Architectural plan with six major convex spaces

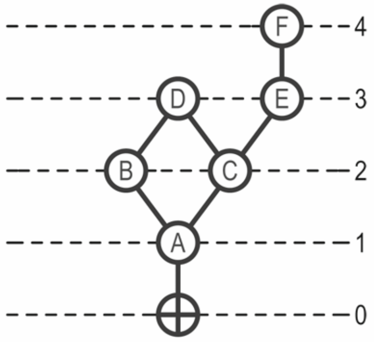

Fig. 2. Justified Plan graph of the convex map, with the exterior as carrier (⊕)

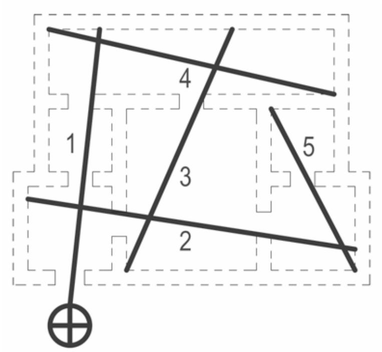

Fig. 3. Axial line map of the five lines or paths required to surveil all spaces

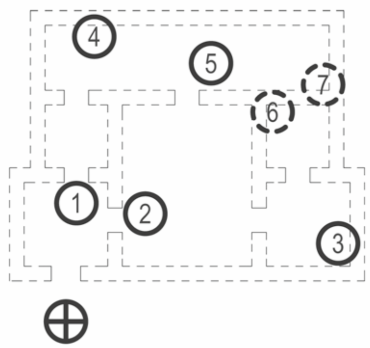

Fig. 4. Intersection map of the points needed to surveil all spaces

The Convex Space variation, which is typically used to produce a Justified Plan Graph, treats zones or rooms as nodes and the connections between them (typically doors) as edges in generating a graph diagram (fig. 2). In this way, the method is effectively quantifying the properties or importance of functional spaces in a plan [Ostwald 2011]. In contrast, the Axial Line approach identifies lines or paths through space as nodes and each intersection between them as edges (fig. 3). This method determines the significance of various routes through and around buildings or cities for both efficiency and intelligibility [Hillier 1996]. Both of these techniques could be regarded as providing a measure of various social values, including relative permeability (freedom or control) and structural depth (centrality or isolation). While these two methods account for the majority of examples of Space Syntax analysis, it is also possible to invert the line map to produce a point map; where the intersections are nodes and the paths between them are edges (fig. 4).

Both line and point maps, once converted into graphs, are processed mathematically to determine a range of properties. The most significant for the present paper are *depth*, *asymmetry*, *integration* and *intelligibility*. The number of lines/points that must be traversed through/over to reach a particular space, from every other space, is a measure of the Total Depth (*TD*) of that line/point in the plan. The Mean Depth (*MD*) of lines/points in a plan can also be determined to classify those that are shallow or deep, relative to the entire building. Relative Asymmetry (*RA*) is a measure of the degree of isolation of a line/point in relation to the rest of the system. Integration (i) is a measure of the distance in steps or stages from a single line/point to every other line/point in the system. A higher i value suggests that a line/point is more accessible to every other line/point in the system than one with a lower i value. In combination, several of these results can be used to determine the "intelligibility" of a plan [Peponis et al. 1990; Haq and Girotto 2003]. Intelligibility is a measure of the global-local relationships, that is, how well the entire configuration is understood by traversing through, or being located at, the components of the configuration. The intelligibility measure is developed from a scatter graph of the connection and integration values of each line/point. The logic behind this process is that integration represents a global measure of the connectivity of a given line/point to all other lines/points in the system. The number of connections the line/point makes represents how much of a configuration can be seen from each line/point; therefore the relationship between these measures indicates how intelligible a plan is. Finally, the higher the correlation of points, the more intelligible the system.

Line Analysis

Axial line analysis is probably the most well known of all Space Syntax approaches. It has been widely applied in the analysis of urban scale systems [Read 1999; Desyllas 2000] and large buildings [Rashid et al. 2009; Ueno et al. 2009]. The method has also been used for the analysis of domestic scale structures by architects including Mario Botta, Richard Meier, John Hejduk and Adolf Loos [Hanson 1998] as well as for the analysis of Richard Neutra's mid-career houses [Dawes and Ostwald 2011].

Axial line analysis relies on reducing the complexity of a building's plan to a map of the fewest and longest lines required to account for all non-trivial spatial features. While this method is well known, there are a range of variations that produce different, but potentially equally valid maps for a single spatial configuration [Penn et al. 1997; Peponis et al. 1998; Peponis and Wineman 2002; Batty and Carvalho 2003, Penn 2003; Turner et al. 2005; Yoon 2009].

One criticism of the axial line method argues that minor changes in spatial geometry may drastically alter the analytical map, while providing a similar spatial experience [Ratti 2004a; Ratti 2004b]. A related criticism from Ratti is that geometric distance is poorly handled by the approach. Hillier and Penn [2004] counter this position, arguing that the minor change in geometry alters the perception and thus the cognition of space. They also propose that geometric distance is internalised into the resultant analytical map. The present paper is not concerned with determining which if any of these arguments are true, but it is significant that these disagreements concern the difference between social and experiential patterns. A final limitation of the method, which is known as the "edge effect", is concerned with its tendency to automatically underestimate the significance of peripheral spaces. Careful selection of boundary conditions to expand or define the limits of a study can reduce the impact of this anomaly [Hiller 1996].

Point Analysis

While maps of zones (rooms) and lines (paths) are clearly concerned with the generalised network of relations between functions and movement, point (intersection) maps are about the properties of a particular location in space. Despite this potentially useful attribute, relatively little has been written about point or intersection analysis in architectural research. In the most comprehensive example, Michael Batty argues that a "key characteristic in space syntax is that precedence is given to linear features such as streets in contrast to fixed points which approximate locations" [2004: 3]. Like this argument from Batty, the majority of architectural research into point graphs has been framed as an alternative to more conventional Space Syntax techniques [Jiang and Claramunt 2004; Turner 2005; Porta et al. 2006a; 2006b]. For this reason, there is not yet a consistent process for applying point map analysis to architecture. However, from a graph theory perspective, whereas in the axial line map, lines are nodes and intersections are edges, the point map does the reverse, defining intersections as nodes and lines as edges.

Understanding conceptually that the intersection graph is an inversion of the axial line graph, is relatively straightforward, but mathematically this operation is more involved. Any graph that is planar (that is, the edges between nodes do not cross other edges) can be represented in two versions; the original, or *primal* graph, and its *dual,* or inverted graph. In graph theory, the primal and the dual have a reciprocal relationship, with a new set of nodes being located within or between the spaces of the primal map, and new edges drawn connecting these nodes. Axial line maps of buildings are rarely planar and so the changed relationship between nodes and edges (changing the focus from lines to points) requires an additional step.

Consider an axial map (fig. 5a) with lines 1-4 and intersections X-Z which can be drawn as a graph (fig. 5b) with lines 1-4 represented by nodes and the intersections as edges linking nodes. Converting this primal graph into its dual presents a problem, highlighted by line 1: a node with three edges cannot be changed into an edge linking three nodes; each edge can only connect two nodes. Therefore, when considering only this line (fig. 5c) when nodes and edges change positions in the graph (to generate the dual) one edge, line 1, is required to link three nodes X-Y, Y-Z and X-Z. Because this is impossible, additional measures must be taken to preserve the character of the axial map when converted to a dual for the consideration of intersection points. To solve this problem the intersection graph requires the addition of "side links" (fig. 5d) to ensure that each node connects with each other node it shares an axial line with. Jiang and Claramunt [2002] define these links as all having a depth of one, for analytical purposes, thus all nodes on a single axial line are one step from all others, regardless of the number of intermediary nodes.

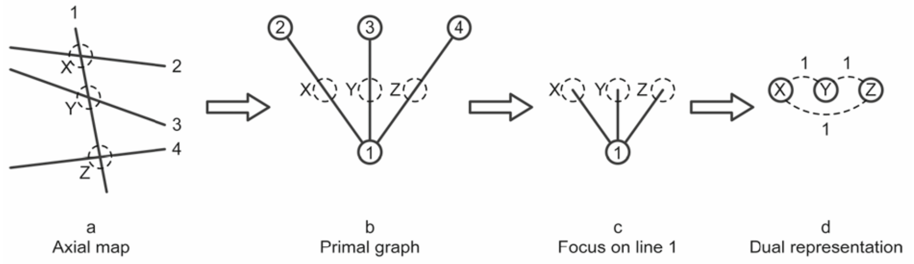

Fig. 5. Translation of axial map to intersection graph

A final methodological challenge with intersection analysis relates to the handling of endpoints or "stubs" of lines. When two lines cross, a clear intersection point is determined, but each line also has an endpoint or potential node where it reaches a wall. Such endpoints are not intersections between paths, but between paths and surfaces. Turner [2005] implies that the need for an end node might be determined by measuring the relative length of the line beyond the last intersection (that is, the length of the stub). A stub that is less than 25% of the length of the complete line is ignored as representing only a minor extension. This is a rule that can be applied uniformly, categorising stubs into long (≥25%) or short (<25%) and then only retaining line/surface "intersections" for the long stubs. However, it is entirely possible that an intersection between a short stub and a surface is the only point in a particular convex space. Conversely, a long stub may simply add an additional point in a space already adequately surveyed or included in a map. Therefore, a combination of two criteria should be considered in parallel when selecting which endpoints to include; endpoints generated by long stubs are automatically included (fig 4. point 7) along with those that are located in a convex space which is not otherwise part of the set (fig 4. point 6). This is the approach adopted in the present paper.

Applying the methods

All of the analysis, described hereafter, of the Lovell House was undertaken using a newly constructed computer model developed by the authors from the final working drawings held in the Neutra Archive in California. The high degree of accuracy in the model allowed for both maps to be developed with a minimum of interpretation. The axial map of plans generated from this model was developed using a manual-intuitive method informed by research into developing automated generation methods [Peponis et al. 1997; Turner et al 2005; Ostwald and Dawes 2011]. The definition of axial lines used in the map is that of unobstructed lines of sight and movement. This requires, for example, axial lines to fully encircle the swimming pool and allows vertical transitions across the staircases of the house. To maintain the focus on patterns of inhabitation, rather than more general land use, the boundaries of the analysis were cropped close to the residence prior to map generation. Inclusion of external circulation occurred only where it formed a critical link between inhabitable spaces. This decision excluded the garages, housed in a separate building, the handball court and the machine room located under the pool. Also excluded were spaces dedicated to non-social functions, such as storage closets. Identification of nodes for the intersection map consisted of two stages: first, designating all axial line intersection points as nodes, followed by analysing each stub for inclusion or deletion based on both length and coverage criteria and assigning nodes to the end of retained lines.

The mathematical analysis of the axial map was undertaken using UCL Depthmap. The software allowed the axial lines to be traced and automatically linked at intersections and manually linked between levels. Intersection analysis followed a similar process making use of the software's convex analysis tool. This tool allows node and edge diagrams to be artificially constructed and processed. Over the two maps, 132 lines/points were analysed leading to the production of 792 results. In the present paper only results for the highest three lines or points (using integration as a measure), the lowest three and the three closest to the median are reported.

For graphical representation purposes, the lines and points were divided into three categories by integration levels, with the top third, middle third and lowest third differentiated. Furthermore, for both line and point maps, the most integrated, least integrated and closest to the median are identified by number. Axial lines that cross between levels (typically passing through stairwells) are connected on the map by a curved line; a graphic convention that has no impact on the calculations. Intersection points which occur between levels have been transposed to the map of the nearest level, and curved lines – once again having no impact on the calculations – drawn between the levels to signify this change. The following section briefly describes the house and provides an overview of the relevant parts of Neutra's theory.

The Lovell House

Designed by Richard Neutra, the Lovell House (or Lovell Health House. as it is sometimes known) was completed in 1929 on a steep site in the Hollywood hills (figs. 6-7). Commissioned by Dr Phillip and Leah Lovell, the house was intended to promote the clients' public profile and business interests. Dr Lovell, a passionate advocate for the natural health movement, owned a private clinic and had "periodically written articles" advising people how to build a home "so that [they] can derive from it the maximum degree of health and beauty" [Lovell 1929: 26]. Neutra's design for the Lovell family followed an intensive period of observation of their social interactions and lifestyle. As a result of this process, the house features open porches for outdoor sleeping and private spaces for sunbathing, both of which the Lovells regarded as being critical to maintaining physical health [Hines 2009].

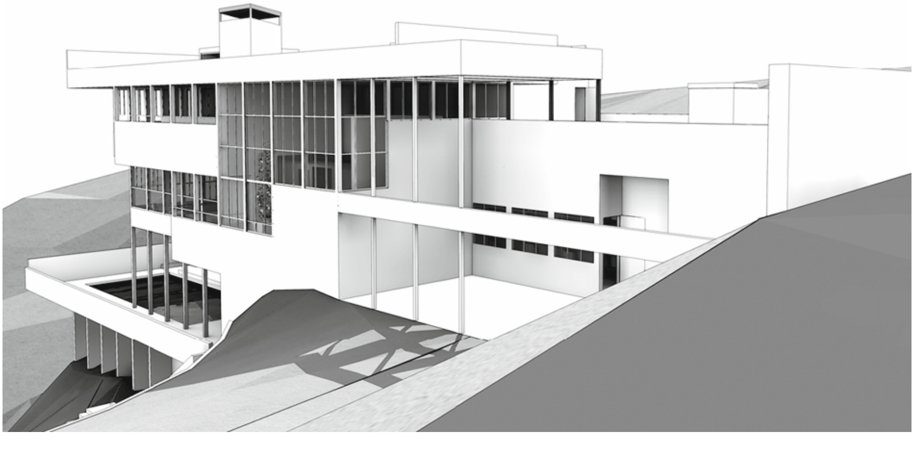

Fig. 6. Lovell House, Los Angeles, California, 1929. Richard Neutra

Programmatically, the design is spread over three main levels, with the formal entrance to the building on the highest floor (level 3) along with the owner's sleeping quarters. Below this, the intermediate level (2) contains the main living and social spaces, additional sleeping quarters for guests and a gymnasium courtyard providing access to the garages. The lowest level (1) houses a swimming "tank" and Leah's home schooling rooms (fig. 8). The Lovell House was the first residence in the United States to make exclusive use of a prefabricated steel frame and shot-concrete sprayed over wire mesh to complete the structure's walls.

Today the Lovell House is widely regarded as one of the great works of Modernism. Willy Boesiger argues that with this design "Neutra burst open the portals of a new era in the history of American architecture" [1964: 18] and Esther McCoy states that it was "through this house that Los Angeles architecture first became widely known in Europe" [1960: 13]. For O'Gorman, the design swiftly became "a paradigmatic emblem of the new by the application of the implacable platonic grid-work of internationalism" [2007: 216] and Kenneth Frampton has praised the design as "the apotheosis of International Style" [quoted in Sack 1992: 23].

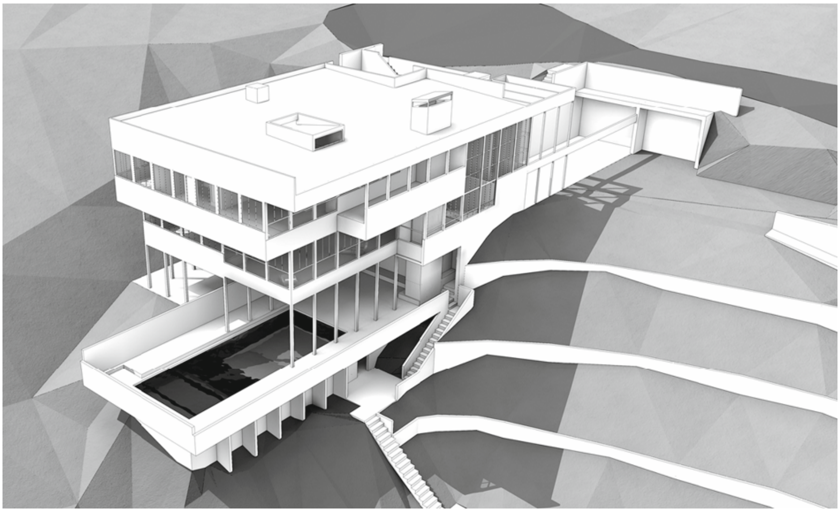

Fig. 7. Lovell House, Los Angeles, California, 1929. Richard Neutra

In the present context, two facets of Neutra's design theory are of particular relevance. At the time when this house was commissioned, Neutra had not yet published his extensive body of architectural theory, but it is clear from his biography that many of the ideas he was later to develop were, even at this early stage, influencing his work. For example, in the following decade Neutra designed a series of houses that create long paths through space, to draw the eye, and define particular locations in space, where the building and the environment could be simultaneously experienced. He summarised these intentions in *Life and Human Habitat* when he argued that a person's "greatest awareness … is linked to our visual impression of the house which we 'see not merely to see' but see in order to act upon vision" [1956: 13]. Neutra went on to propose that vision activates "a person's locomotor urges" [1956: 14], causing them to follow a particular path or look in certain directions. While the purpose of this paper is not to put Neutra's theory to a vigorous test, his ideas about paths and locations in space resonate with the properties identified in line and point maps.

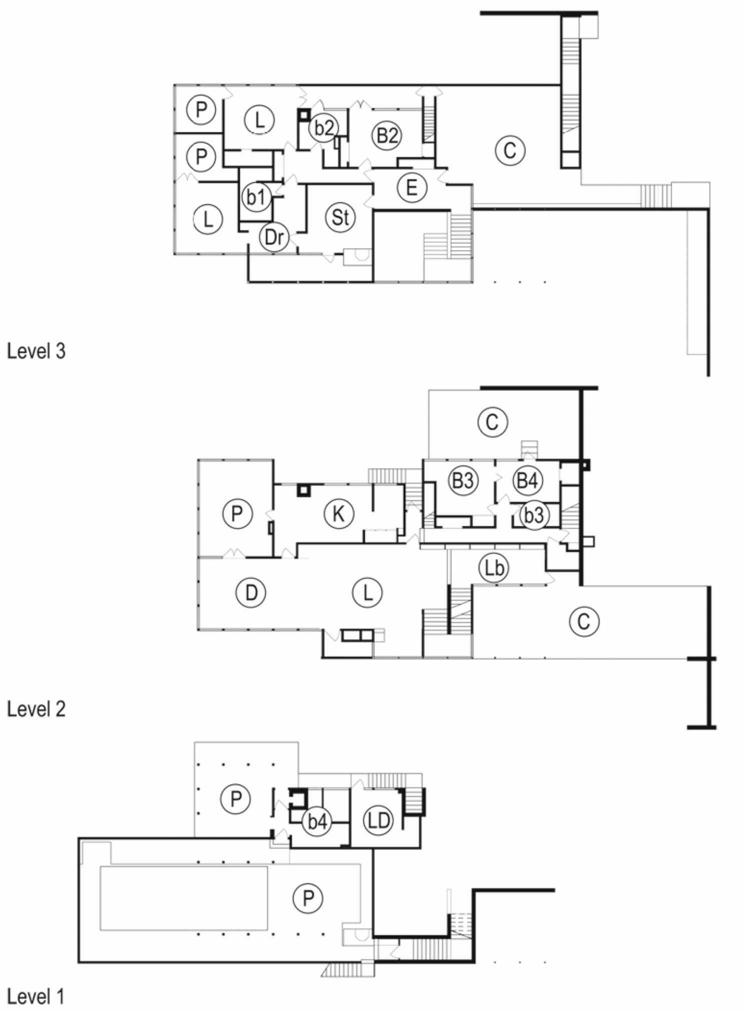

Fig. 8. Lovell House annotated plan showing Levels 1 (lowest), 2 (middle) and 3 (highest and entry level). Key: Courtyard (C), Entry (E), Porch (P), Kitchen (K), Dining (D), Living (L), Library (Lb), Study (St), Bedroom 1, 2, 3 (B#), Bathroom 1, 2, 3 (b#), Dressing Room (Dr), Laundry (LD)

Results

The axial map for the Lovell House contains 41 lines (fig. 9) and the intersection map identifies 92 points (fig 10). In accordance with the previous description in this paper, these two maps were converted into a primal line graph and its point dual graph, and both were mathematically analysed producing two sets of results (tables 1-2). While all of the lines or points are mapped, only the numerical data for selected lines and points are reported. These lines or points represent the locations where a pattern of differentiation is most likely to occur. However, because all points are formed by the intersections of lines, or subject to certain rules between a line and a surface, the two maps possess substantial similarities. Nevertheless, a visual analysis of the two maps reveals several differences that are reinforced by consideration of the numerical data.

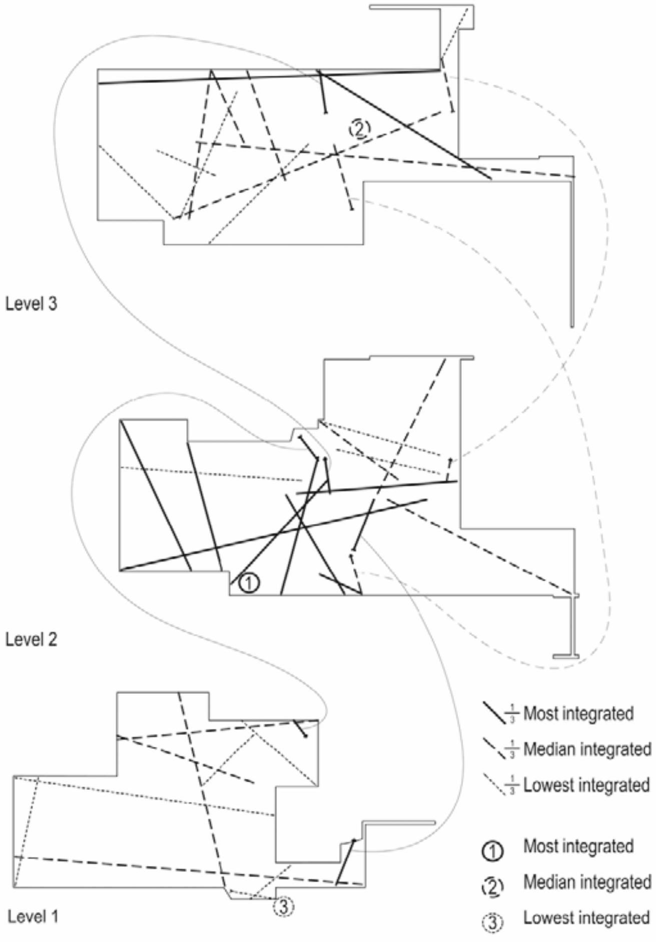

Fig. 9. Axial line maps of the Lovell house

Line Map Data	*TD*	*MD*	*RA*	*i*	*Connectivity*	*Line Length*
Highest three *i* values	114	2.85	0.094872	1.587749	5	10347.05
	119	2.975	0.101282	1.487258	5	10204.12
	122	3.05	0.105128	1.432846	7	22463.58
Middle three *i* values	170	4.25	0.166667	0.903795	2	5920.215
	171	4.275	0.167949	0.896896	8	20696.96
	172	4.3	0.169231	0.890101	7	27240.73
Lowest three *i* values	219	5.475	0.229487	0.656388	2	18916.15
	231	5.775	0.244872	0.615149	1	5011.122
	239	5.975	0.255128	0.590419	1	5008.426

Table 1. Line map data

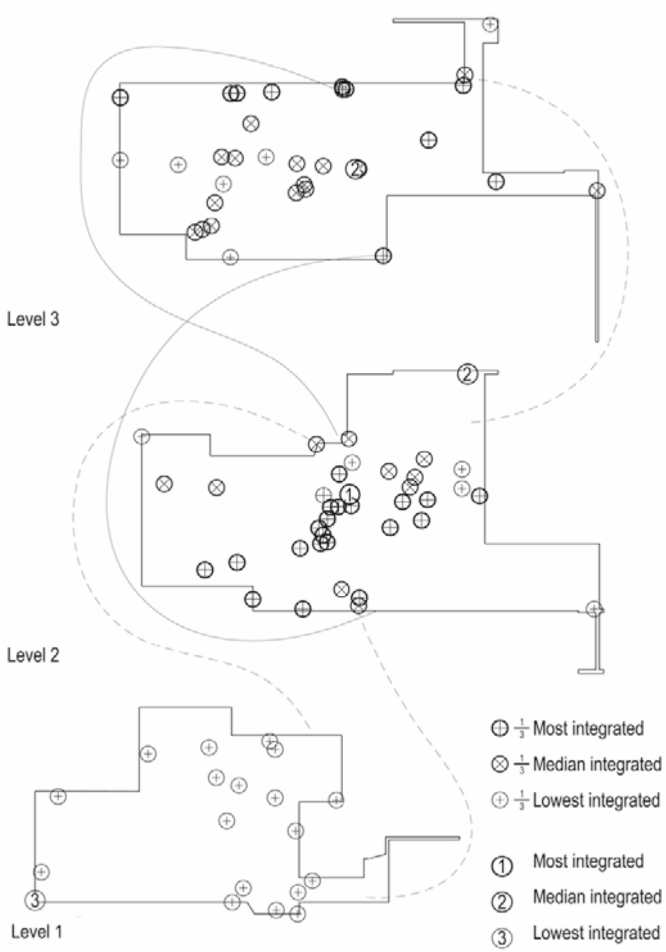

Fig. 10. Intersection (point) maps of the Lovell house

Point Map Data	*TD*	*MD*	*RA*	*i*	*Connectivity*
Highest three *i* values	280	3.076923	0.046154	1.937596	8
	289	3.175824	0.048352	1.849523	11
	290	3.186813	0.048596	1.840229	9
Middle three *i* values	401	4.406593	0.075702	1.181309	4
	401	4.406593	0.075702	1.181309	9
	401	4.406593	0.075702	1.181309	11
Lowest three *i* values	606	6.659341	0.125763	0.711079	1
	614	6.747253	0.127717	0.700202	2
	614	6.747253	0.127717	0.700202	2

Table 2. Point map data

An initial visual analysis of the line map reveals that the majority of highly integrated lines are located in the middle level (2) around the major social spaces of the house, including the dining and living rooms. The lower level (1) contains no lines from the highest third of integration values, meaning it is largely isolated or of reduced importance. The formal entrance possesses lines with below average integration values, an unexpected result given past analysis of large houses [Hanson 1998]. Overall, axial line integration values range between 0.5904 and 1.5877 with a median of 0.8968 and average of 0.9320. The intersection map also identifies the majority of high integration points clustering around the primary social spaces of the second floor living and dining rooms. A small number of high integration intersection points are also located on the upper floor with none present on the lower level. Integration values for the point map range between 0.7002 and 1.9375 with a median of 1.1813 and average of 1.2308. In combination, the points display a similar range of distribution of integration values as the line map, albeit with different absolute values. Overall, the integration values in the line map are higher than in the point map.

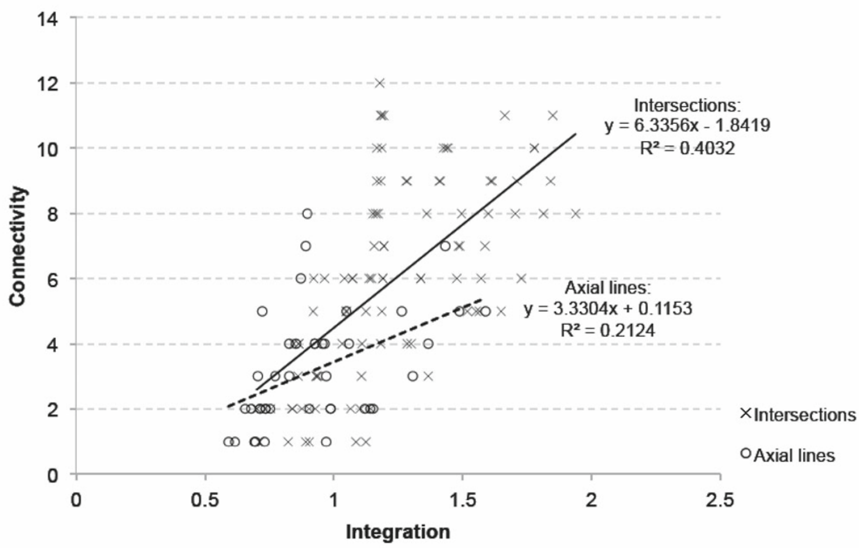

Fig 11. Intelligibility graph of axial line and intersection map data

Neutra's architectural theory [1956] repeatedly dictated that spaces be "non-chaotic" and went on to define this quality as relating to the extent to which a design may be visually understood. In Space Syntax analysis the property of intelligibility closely approximates this condition; intelligibility is a measure where a direct comparison can be constructed between the line and point maps. The combined intelligibly chart for the maps of the Lovell House (fig. 11) contains a point graph with a higher degree of correlation between integration and connectivity than the equivalent line graph possesses. This suggests that the house is more readily understandable using points in space rather than paths through space. The variation between the two, expressed as a pair of R^2 values, can then be used to quantify this difference and compare it against benchmark results. For example, Hillier [et al. 1987] calculates the mean R^2 value for a set of seventy-five urban towns as 0.68 and postulates that this should decrease as the system grows (and thereby becomes more complex and less intelligible). However, the point graph R^2 result of 0.41 is less intelligible than Hillier suggests would be reasonable for a house, and the axial line result of 0.21 is less than a third of the average for urban spaces. This implies that the Lovell House is as labyrinthine as the plans suggest, but reinforces the idea that intersections are more important for understanding the experience of the space than paths.

Despite this result, the difference is potentially not as pronounced as the results imply. The standard deviation for integration results from the line graph is 0.2455, giving a relative standard deviation of 26.3393%, whereas the standard deviation for the point graph integration values is 0.3002, giving a relative standard deviation of 24.3940%. The result, while reinforcing the general importance of the point graph approach, suggests that it may be less substantial than the intelligibility graph indicates.

Discussion

Does this result indicate that a point map is superior to a line map for measuring intelligibility? Points in spaces are often, but not always, areas where a 360° isovist can be constructed. In contrast, the ends of lines are typically constrained in some way and often to a range of only 180°. Perhaps then, by virtue of viewshed potential, points offer a heightened capacity for integrating local and global information in an intelligible way? However, axial lines are sometimes described as approximating the passage of a person through space and over time (rather than simply end points defining a vector). If this description is taken to imply that a person experiences space while traversing a path, it may change the results. Conversely, past research has suggested that a person is more likely to make observations about global and location connections while paused at discrete points in space [Aspinall 1993; Montello 1998]. As Ruth Conroy observes, occupants travel along paths pausing "only in locations offering maximum visual, local/global information, reducing the necessity to pause more frequently. People's navigational tactics can therefore be seen to be both strategic and maximally efficient" [2001: 208].

Finally, while prior to this point the paper has been concerned with computable and repeatable methods, it is also possible to examine the three-dimensional visual experience of the most integrated lines and points in the Lovell House to provide a final commentary on their differences. While it is possible to undertake a complete statistical analysis and classification of the 300+ images identified by the two maps, such an endeavour is beyond the scope of the present paper. Instead, perspectives and isovist maps were produced for the most integrated lines and points in the house. Line perspectives were generated from endpoints and point perspectives at right angles to the line with the highest integration level. In all cases isovist maps and perspective views were considered in combination. The authors used two simple and subjective criteria to inform their interpretation of the results: the quality (a measure of how useful) and quantity (a measure of how much) of information contained in the image. Visual "information" was taken to mean the cues, orienting devices and features which a conventional user of a space might use to navigate [Ellard 2009]. Such "information" is also central to the construction of spatial intelligibility.

Of the set of images with similar integration results, it was clear that some views, generated by both lines and points, contained a high quantity and quality of conventional spatial information (including a clear capacity to use the view to orient the position on a plan). For example, one of the line-perspectives generated the most informative view of the primary floor level (fig. 12). Despite this, from the point of view of the quality and quantity of information, the point-perspectives were relatively consistent (fig. 13).

Fig 12. Isovist map and perspective for axial line (i = 1.43)

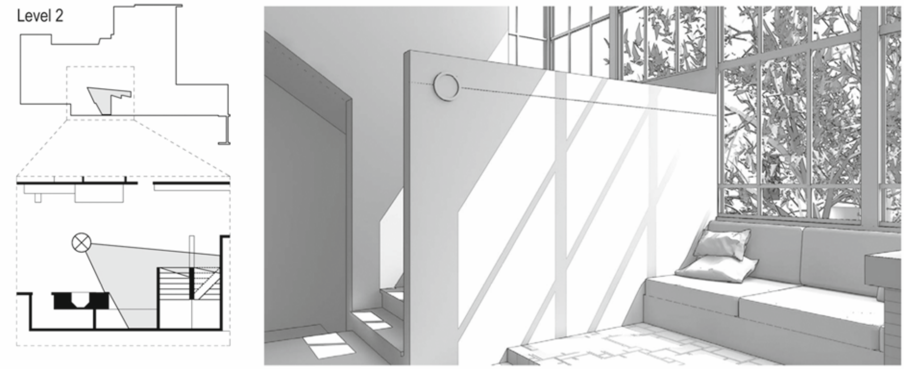

Fig 13. Isovist map and perspective for intersection point (i = 1.94)

Both line and point maps also generated some perspectives and isovists with a far lower quality and quantity of conventional visual information. Surprisingly, several lines with the highest integration values in the entire house were largely devoid of any spatial cues and orientation features. Many others were oriented to narrow gaps between angled walls, more suggestive of "peeping" at space than passing through it or inhabiting it (fig. 14).

Fig 14. Isovist map and perspective for axial line (i = 1.59)

Point maps too, produced views of walls in close proximity along with some narrow spatial vistas, although several of these did provide a critical perspective of the connection between major circulation paths (fig. 15). Such views could be regarded as containing a low level of information, but what information there is, was useful. A few of the point-perspectives also had a similar low-level "peeping" quality, but this was not so obvious as it was for the line maps.

Fig 15. Isovist map and perspective for intersection point (i = 1.84)

In combination, when the set of these highly integrated lines and points were considered, the differences were relatively minor. On average, point maps appeared to contain an intermediate quantum of conventional visual information, whereas some line maps contained more, and many contained less. In terms of the quality of information, the three-dimensional vision represented in the line maps was often peripheral, evoking glimpses of space, while the intersection points typically produced views which, regardless of the quantity of information they contained, were sufficiently centred to suggest a useful view a person make actually peruse if trying to understand a space.

Conclusion

Michael Batty [2004] argues that dual graphs should be as important to the interpretation of architectural and urban plans as their more common primal graphs. The present analysis confirms that, in the specific case of the primal *line* graph and its dual *point* graph, this is certainly the case. Indeed, there is also some limited evidence to suggest that the point graph may be more appropriate for use in smaller scale architectural analysis and for calculating intelligibility. Many authors have separately suggested that point graphs might also represent different spatial experiences to line graphs. While a much more extensive analysis is needed to conclusively test this proposition, the limited evidence collected in the present paper confirms that intersections in space may be slightly more informative than paths for engendering spatial awareness and orientation. Finally, the mapping process has confirmed that while extensive networks of paths connect zones in the Lovell house, they typically lead the visitor to particular locations, from which spaces, and the exterior, may be viewed. This broadly conforms to Neutra's later argument that, throughout his career, he designed internal vistas to lead the body to places where it could experience complex phenomenal reactions.

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