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Rejoinder to Carlo Ratti

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Abstract. In this rejoinder, we answer questions about space syntax raised in Carlo Ratti's paper "Urban texture and space syntax: some inconsistencies", and discuss theoretical assumptions underlying some of his criticisms.

Introduction

In this rejoinder we will deal with the specific issues that Ratti (2004) raises in the form of questions: Can the same urban configuration give rise to different axial maps? Can space syntax deal with regular grids? Does it take into account such factors as building height and land use? Can it be used for innovative design and planning? Does it fail to deal with boundary conditions and edge effects? Does it, in general, discard "precious metric information" (Ratti's abstract)? We also examine certain theoretical assumptions made by Ratti.

Can the same configuration give rise to two mappings?

Ratti argues that either one single (in his abstract) or similar (in his text, page ...) urban configuration can give rise to two different axial maps [his figures 5(a) and 5(b)]. In space syntax terms, the two configurations he shows are actually 'syntactically' different, because in one, the lines are broken, in the other not, and axial analysis is, exactly and only, *about* such differences. But Ratti's point is subtler: he argues that axial maps are *over* sensitive to differences in built form. He shows that by gradually changing one built-form pattern into the other there is a *sudden* discontinuity in the axial map with only a small continuous change in the metric situation. Although hypothetical, in that it depends on all the buildings being moved at once, there is an interesting question here. A line discontinuity can indeed come from a marginal shift in a single built form. The question then is: are such marginally produced discontinuities—or continuities—important in urban space? Two kinds of evidence, morphological and behavioural, suggest they are.

Morphologically, chapter 4 of *Space is the Machine* (Hillier, 1996a) points out that in certain kinds of urban layout, such as the City of London, the phenomenon of 'just about' axiality is regularly found; that is, cases where a line of sight is 'just about' allowed by the placing of buildings to pass through a series of spaces. In other kinds, for example, in many Islamic cities, we find the opposite occurs with comparable frequency: that alignments are regularly 'just about' broken, even though the general linearity of space is retained. Both phenomena are marked regularities in their own type of system, and are too common to have occurred in other than a rule-governed way. This is one reason for the consistent statistical differences we find between cities in different parts of the world. For example, the mean line connectivity in European cities is 4.61, in UK cities 3.71, and in Islamic cities 2.97 (Hillier, 2002). Marginally breaking or conserving lines seems then to be a key difference between urban space cultures.

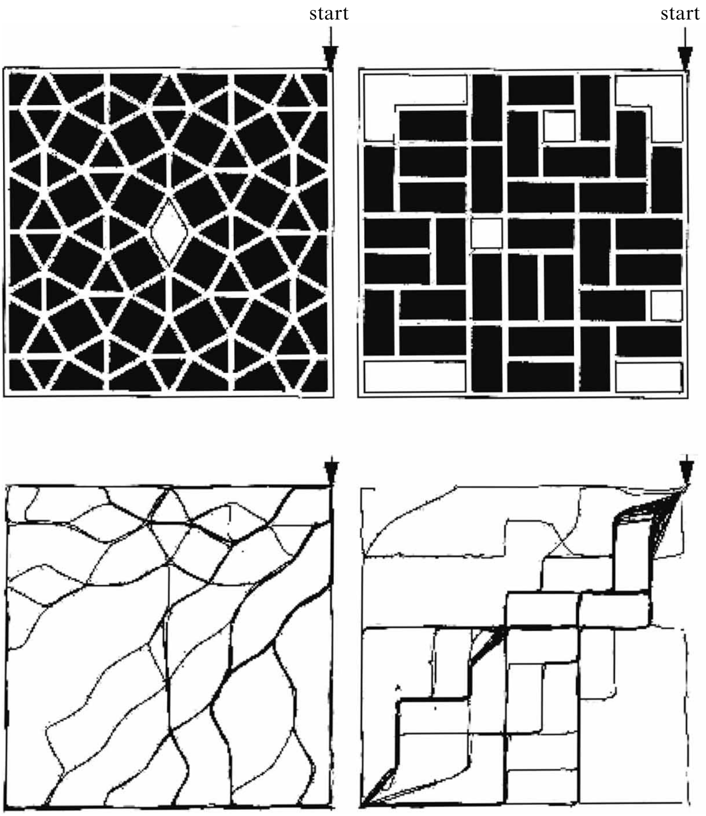


Figure 1. Subjects' wayfinding trails in two immersive three-dimensional worlds (source: Conroy Dalton, 2001).

Behavioural evidence is also compelling. In her PhD thesis, Conroy Dalton (2001), constructed an experiment with navigation in immersive worlds, including one with an angular structure very similar to Ratti's world. She asked thirty subjects to navigate from top right to bottom left, and compared the results with those from a more orthogonal grid. Both grids and the traces of the paths taken by subjects are reproduced in figure 1. In the angularly distorted grid, very few subjects stayed close to the optimal diagonal line, whereas in the more orthogonal grid a majority did. Experientially, as well as in urban reality, it seems that Ratti's two grids are simply not the same, and the kind of discontinuities arising from minor geometric changes which are captured by axial mapping to have significant effects.(1)

In fact, the theory of the impact of marginal metric and geometric differences on axial maps is quite explicitly dealt with at some length in several main texts, notably Hillier (1996a, page 124 et seq), where a system of identical blocks are shifted slightly

(1) In fact, in the 'fractional' version of axial analysis (Dalton, 2001) implemented first in the Meanda software and now in the WebMap software package, sudden changes of the kind Ratti describes are smoothed by varying the value given to the connection between two lines according to their angle of incidence, between 1 for a right-angle connection and 0 for a straight connection. The detailed argument in Hillier (1999a, pages 187 – 188) about why broken lines connected continuously by highly obtuse angles create 'integrated routes' in cities is relevant to this issue. We must also point out that it is fundamental to space syntax procedures that no forecasts of movement rates can be made in the kind of system that Ratti shows without knowing its syntactic relation to context (see "Boundary conditions and edge effects" below).

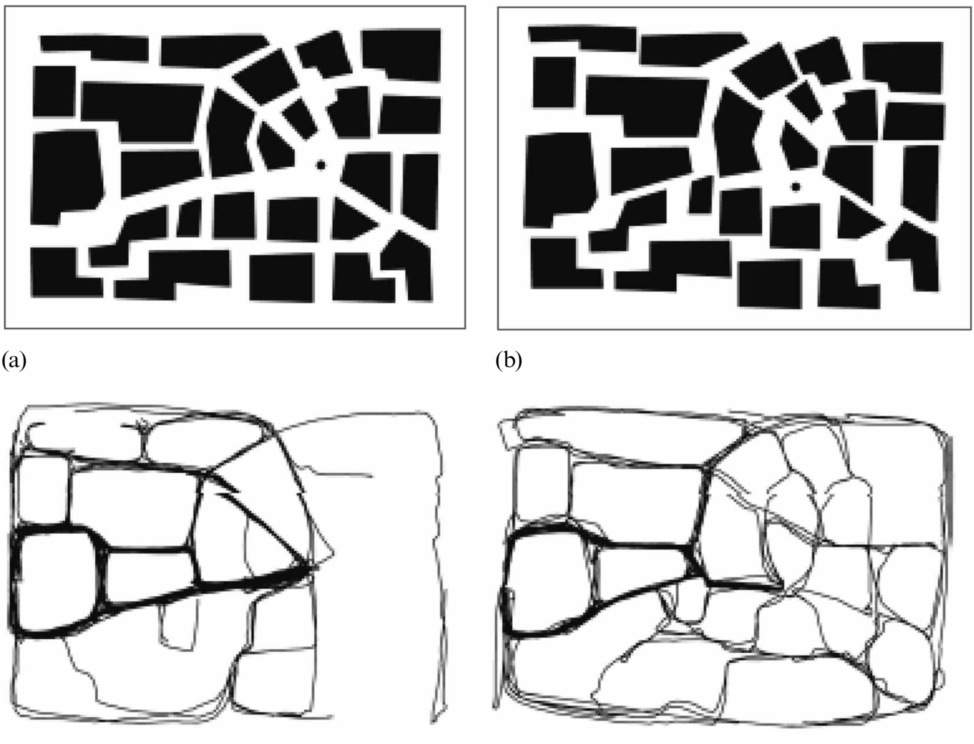


Figure 2. Subjects' trails in an 'intelligible' and marginally different 'unintelligible' immersive three-dimensional world: (a) is an 'intelligible' (as defined in the text) 'urban'-type layout; in (b), the blocks have been slightly moved with the effect that syntactic 'intelligibility' is substantially reduced. Below each are traces of Conroy Dalton's subjects in immersive three-dimensional worlds of each layout, navigating from the centre-left edge to the 'monument' and back. The results show that navigation is much less successful in the 'unintelligible' world (source: Conroy Dalton, 2001).

with respect to each other, with the effect of transforming the layout from a syntactically 'intelligible' (defined as the correlation between the connectivity and integration values of lines, and so the degree to which the global pattern is inferable from the local) to an 'unintelligible' system [figures 2(a) and 2(b)]. Once again, these formal characterisations of the differences between layouts received strong empirical support in Conroy Dalton's thesis. She investigated this experimentally by asking subjects to navigate in immersive three-dimensional models of the layouts from the mid-left edge to the 'monument' in the square and back, while she recorded their movement traces as in figures 2(c) and 2(d). She found that subjects did indeed find it much harder to navigate in the 'unintelligible' world. Clear behavioural as well as morphological evidence then suggests that reflecting small shifts in built-form geometries in the line topology is meaningful.

Can space syntax deal with regular grids?

Ratti also questions how far space syntax can deal with regular grids. In fact, it does so normally and without difficulty, because in spite of the fact that, theoretically, a pure orthogonal grid yields standardised values for axial lines, in practice such grids do not occur, for two reasons. First, at least some lines will connect to the outside, and thus gain significantly in integration value over others which do not. In the case of an 'ideal' city plan like Palmanova, for example, this simple fact has been enough to shape the pattern of land use in a way that syntax would expect, with movement-sensitive uses aligned in the main along the streets which connect to the outside (Hillier and Penn, 1992). Second, we find that urban grids which retain an overall geometric discipline will still differentiate lines configurationally by interrupting some lines and not others with buildings and other blockages, in the way that Grand Central Station interrupts the line of Park Avenue. We call such grids 'interrupted', in contrast to those which are geometrically 'deformed' as many European grids are. In general American grids—notably Manhattan (Stonor, 1991)—as well as typical Greek and Roman grids, are of this 'interrupted' kind.

Ratii's observations about the Manhattan grid also betray a misapprehension of what it is that space syntax seeks to predict. Space syntax in itself says nothing about 'pedestrian choice making', but deals only with observed flows and thus only with aggregate statistical effects in different alignments in the grid. We would not therefore *in principle* seek to persuade a Manhattan resident that long routes are the same as short routes. It is true that there is interest in why we regularly find correlations between observed movement rates and configurational variables, and there are different views on why this happens. One is psychological, and is undergoing investigation by several groups [for a recent overview of this field, see Zimring and Conroy Dalton (2003)]. But there is also a view that the effect includes a strong emergent mathematical dimension. We know, for example, that, in any graph with random one-step movement, visits to each node will go to a limit proportionate to the degree (or connectivity) of that node as the number of iterations increases [see Hillier (2003a) and, for example, Norris (1997, theorem 1.10.2)], so it seems likely that spatial configuration will have at least some effect on emergent movement flows independent of the intentions and choices of movers, even though human movement is neither random nor one step.

Does space syntax ignore building height?

Does space syntax then have difficulty taking into account such variables as building height? The answer is: no difficulty at all, but we deal with such factors in the regression model rather than in the spatial model. As Ratti says, the aim of space syntax is to understand "the influence of spatial configuration on social life" (page ...), so, for research purposes, we prefer not to obscure the effects of spatial configuration by compounding it with other variables within the spatial model. In Penn et al (1998a; 1998b), for example, building height along with many other metric variables, such as road width and length, is dealt with extensively in a study of pedestrian and vehicular movement in five separate areas of London. Each road segment (between intersections) was observed throughout the day in each area, giving a total of over 400 observation 'gates'. This study showed that building height was a significant variable in pedestrian movement at the level of the area, though not at the level of the individual road segment, and that pavement width was significant at the level of the road segment, but that both effects were minor compared with configurational variables. For vehicular movement, net road width (total road width minus pavement and parking) was more powerful than configurational variables, although these still correlated with $r^2 = 0.68$. However, net road width is a 'managed' variable (for example, parking is often restricted according to flow)—and total road width (and length) were less significant than configurational variables in the multivariate analysis. The land-use aspects of this question are dealt with below.

Does space syntax deal with boundary conditions and edge effects?

What then of 'boundary conditions' and 'edge effects'? In fact, the text to which Ratti refers (Hillier et al, 1993) discusses the two issues carefully. It explains that the spatial analysis of the Kings Cross area was carried out at two levels (the 'large' and 'smaller' areas) with the explicit purpose of checking "for any (spatial) analytic effect that might result from the choice of boundary" (page 36), at the same time making sure that any edge effect was remote from the area of study. This research was carried out before we had developed the concept of variable radius integration, and thus before we knew that, by setting the radius of integration at the mean depth of the system from its most integrated line, we could arrive at a 'global' analysis which shows very little sign of any edge effect or variation with the selection of boundary (Hillier, 1996a, chapter 4, page 163). Bearing in mind the pervasiveness of the problems of dealing with boundary conditions and edge effect in spatial analysis in general, through variable radius analysis, space syntax actually appears to have arrived at some interesting approaches to these generic problems.

In making his point, Ratti uses La Defense as an example of where space syntax cannot be applied. This is surprising. La Defense was conceived and built as an extension of the major axis of Paris, which links centre to edge via the Champs Elysées, the Arc de Triomphe, and the Avenue de la Grande Armée. As such it is of course a highly syntactic piece of design, and functions accordingly. Most of the movement is in or around the main axis, and this is also where most of the movement-sensitive land uses are concentrated. As a syntax analysis would lead us to expect, there is very little activity in the parts of the area which are close to the spatial discontinuities with physically adjacent areas. One of us was there during the summer of 2003 on a Saturday, when virtually all the movement is along the powerful pedestrian axis linking the centre of La Defense to the Pont de Neuilly by a long ramp. However, Ratti—but not we—might be surprised at the extent to which this is also the case on weekdays when, as he rightly says, most people do not arrive on foot. In fact, many of our studies are of such controlled entry point systems—department stores, shopping centres, galleries, and museums. They do not present problems for syntactic study because, given knowledge of points of entry, internal configuration still has a powerful effect on the distribution of movement (see, for example, Fong, 2003).

However, Ratti is right in one sense. Axial analysis does not in itself aim to model the absolute *rates* of movement in an area, but their *distribution* in its constituent spaces. To ascertain average levels in an area as a whole would require, of course, knowledge of other variables, such as those built into our regression models alongside the configurational measures. Having said this, there are two studies (Penn et al, 1998b; Read, 1999) that show strong correlations between the mean levels of movement in urban areas and their mean degree of axial integration. We are not yet clear why this should be the case, but prima facie it does seem to offer evidence in support of the kinds of configuration-led multiplier effects from land uses that we discuss below under "Does space syntax ignore land use?"

Does space syntax "discard precious metric information"?

Do we then *in general* "discard precious metric information"? The key issue here is the relation between topology and metrics in axial maps. On reflection, we believe there should have been more explicit discussion about this in earlier texts. There is a fundamental problem when trying to link metric and topological information within a configurational model of space. As soon as toplogical measures of an axial map are weighted by, say, length of segment, the integration pattern resulting from configurational analysis will always focus on the geometric centre of the system (because that is in general metrically closer to all other parts of the system), and decrease smoothly from centre to edge. This has two effects. First, it means that a short backstreet close to a main centre of the system will appear configurationally more 'integrated' than a major line remote from the geometric centre. Second, it will make the model so sensitive to the choice of boundary that it will be this that defines where the centre of integration is. An instance of this effect from a pure 'metric integration analysis' (in which an arbitrarily fine grid of points are analysed in terms of the metric distance from each point to all other points in the system) is shown and discussed in Hillier (2003b). The analysis shown there of the City of London identifies a comparatively minor intersection as the most integrated point, and this would move as soon as the boundary of the system were changed. Together, these two factors would effectively mask all the relations we find between spatial configuration and function variables.(2) This is why we deal with metric factors in the regression model rather than the spatial model.

Does space syntax ignore land use?

Ratti also suggests that an axial map "does not take into account land use" (page ....). Technically he is of course right. We do not try to add land-use factors to spatial values. But there are good scientific reasons for this. Having discovered the powerful and independent effect that spatial configuration had on movement (Hillier et al, 1987; 1993; Peponis et al, 1989) nothing would have been simpler than to 'calibrate' lines with land uses to improve the r^2 values. However, from the point of view of developing a theoretical understanding of cities, it was far more productive to keep these separate in order to investigate the impact of both configuration and movement on land uses (Hillier, 1996b), and then on to the formation of centres and subcentres (Hillier, 1999b). Understanding these processes has also been of great practical importance, because "where should we put the shops?" is one of the commonest questions asked by designers and planners.

There are then powerful theoretical reasons for not conflating spatial analysis with land uses. In space syntax theories of the city, land use is expected (at least in historically evolved cities) to be a *dependent* variable, because if spatial configuration influences movement it can be expected to influence land-use patterns according to their demands for being close to or avoiding movement. This is not, as Ratti remarks, "assumed", but is a hypothesis that has been extensively empirically investigated (see, for example, Hillier 1999a; Hillier et al, 2000). It is primarily this process from spatial configuration through movement to land-use patterns, with multiplier effects leading to local intensification of land use and densities, and feedback on the evolution of the local grid structure itself, that seems to shape the traditional city as a seamless network of centres and subcentres against a background of residential space (Hillier, 1999a; 2002). This may be difficult for some to accept, because it seems to propose a primary role for the relatively static—though in fact slowly changing—variable of spatial configuration in urban dynamics. However, such a possibility was clearly foreseen by Batty and Tinkler in 1979, when they characterised structural statics "as a special case of dynamics". Indeed, recent studies suggest that changes in land-use patterns, and especially the shifting of 'live' centres towards the edges of urban areas, can often be shown to follow the evolution of the pattern of integration in the axial map as settlements grow and change (see, for example, several papers in Hanson, 2003).

Of course, there are real situations where the combined effects of all variables on movement rates is exactly what needs to be understood, and to this end Space Syntax

(2) For a more detailed analysis of the role of metric factors in movement in highly unintelligible systems see Chang and Penn (1999).

Limited in collaboration with Transport for London are developing a 'Walkability Index' which seeks to build in all factors which could affect movement, including land uses, metric variables, local generators and attractors, and so on, into a single model (Stonor et al, 2002; 2003). However, we find this kind of modelling is most appropriate not when dealing with the well-formed patterns that have been produced by decades or centuries of the evolution of a city, and where land uses have for the most part evolved to be in the 'right' places from the point of view of grid configuration and movement, but where these relations have broken down. Most commonly, this has occurred where an ill-conceived intervention has failed to build spatial structure into the larger scale grid, or to locate land uses according to the patterns of natural movement implied by the spatial structure. Space syntax in that sense offers a *diagnostic* of urban areas, and this is indeed one of its primary functions on live projects.

This is why, contrary to Ratti's proposition, space syntax is ideal for use in innovative design. Because space syntax attempts to uncover theoretical principles of how cities work spatially, it is not tied to simple copying of existing urban phenotypes. In fact, one current debate on live urban projects is that historical preservationists (currently influential in urban development in the United Kingdom) seek to conserve 'traditional' street patterns, whereas space syntax argues that they should be changed because functional patterns have changed. A theory after all is the means by which science seeks to move from the actual to the possible. This is why designs which have been influenced by space syntax tend to the innovative rather than the conservative. And this is why architects such as Zaha Hadid, who may use unconventional forms, but whose spatial planning is highly intentional, have made use of these techniques (Major and Penn, 2001).

Are axial maps arbitrary?

Are axial maps then arbitrary as Ratti suggests, referring to Batty (2001) and others. It seems unlikely in view of the large number of empirical and theoretical results that they have delivered over the years. Also, in a statistical analysis of axial line lengths for thirty-six cities, Carvalho and Penn (2004) showed that the probability distributions of twenty eight of these cities collapse onto two master curves. This suggests both that axial lines are significant elements of cities and that errors associated with tracing them are not statistically significant.

In practice, axial maps are far from arbitrary, and the axial *graphs* through which all computations are made, seem clearly to be unique. We can show the first by distinguishing between the procedure for creating a draft map and the procedure for checking it. Axial maps, however initially drawn, arrive at the 'correct' map by applying a set of simple questions that reflect the definition of what an axial map is (the fewest lines that cover the system and make all direct line to line connections) to all parts of the draft map: Can a line be extended to make further connections? Can two lines be simplified into one? Are all pairs of lines which have a direct connection (that can 'see' one another) connected by a line? Are all parts of space covered? Are all 'rings' around built forms represented? And so on. We have not yet come across an urban system where more than one topologically distinct mapping—that is, one with a different line graph—can be shown to be possible within the given definitions. But, even if one could be found, it would scarcely undermine the usefulness of axial maps as urban representations, because such cases are, at worst, extremely rare.

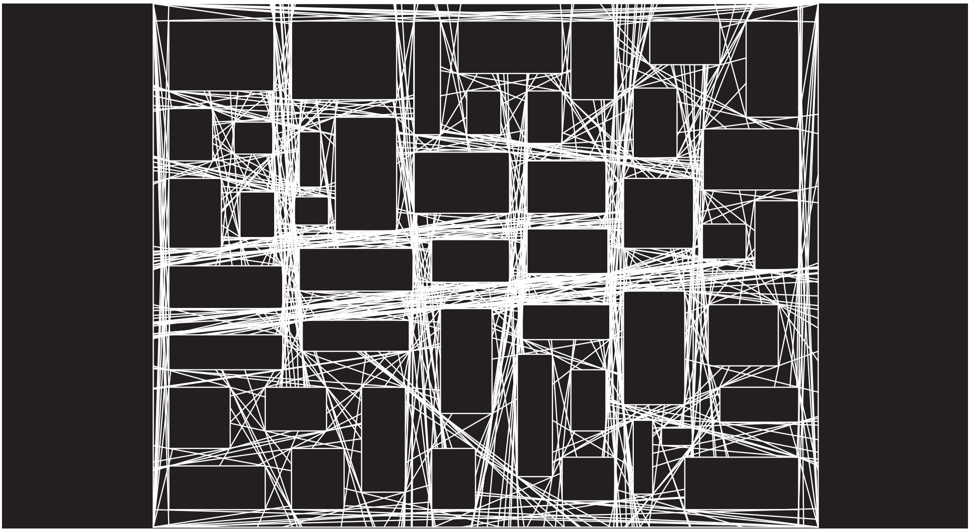
There is a caveat to this claim for definitional rigour: it must first be agreed what is being mapped: for example, what level of articulation of surfaces is to be taken into account, how is landscaping to be treated, how are traffic barriers to be handled, and so on. But this would apply to at least the same degree to any analysis of space. In fact, automated methods such as visibility graph analysis (Turner and Penn, 1999; Turner et al, 2001) often require *more* subjective judgments to be made about the initial map because, in addition to all the factors already noted which must be dealt with explicitly, prior decisions are also required on such critical factors as the scaling, location, and orientation of the grid to be imposed on the layout before analysis can begin.

But Ratti also refers to Batty's (2001) more powerful, formal argument against the uniqueness of axial maps: that axial maps must be arbitrary, because drawing them depends on the prior breakdown of urban space into a unique set of discrete convex elements, and that because there is known to be no uniquely definable minimal set of convex polygons which partition space there can be no unique set of axial lines. This argument holds only if axial maps do in fact depend on the prior construction of a unique convex map, and they do not, either practically or theoretically. In the procedure for drawing an axial map, lines are required to pass through any locally definable convex space, but this does not depend on the prior construction of a *unique* convex map overall. All that is needed is that, wherever a convex element can be identified locally, a line must pass through it.(3)

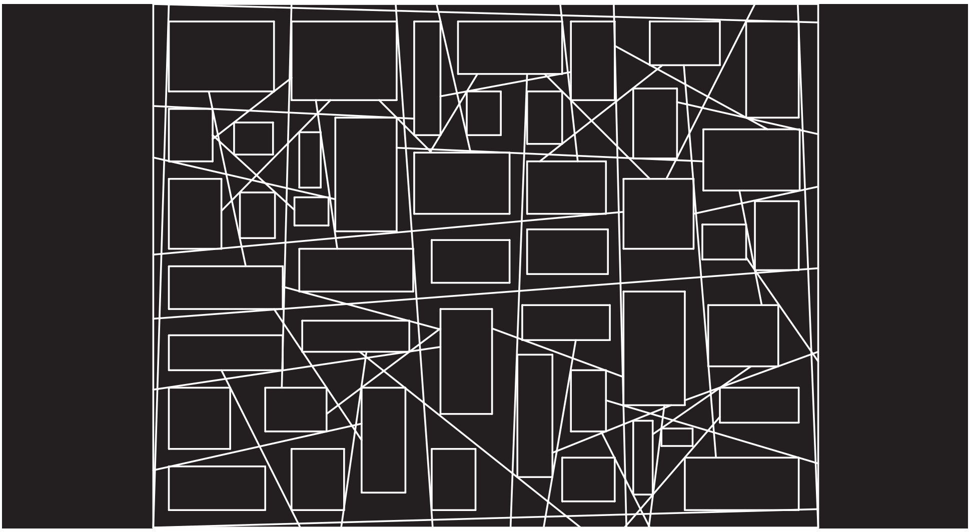
The question as to whether axial maps or their graphs are unique is then not closed by Batty's argument. In fact, for normal urban-type systems, careful thought can demonstrate that, even if minor variations are possible in axial maps, there is only one correct line graph. Let there be an arbitrary draft map which satisfies three empirically verifiable conditions: that all lines that can be directly connected to other lines by a line are so connected; that all built-form blocks are continuously surrounded by lines; and that all locally definable convex spaces have a line incident on them (so the whole space can be seen from the line—we can call this 'weak coverage' as opposed to 'strong coverage' which would require a line to pass through each space on its longest diameter). Then create a graph with lines as nodes and intersections as links, in the manner of an axial map. Necessarily, in this graph, graph distances between any pair of lines, and, therefore in the whole line system, are minimised. There must then be a graph with fewest nodes which conserve these minima. We can find this by simply eliminating all nodes whose connections are a subset of those of another node while preserving conditions 2 and 3 above; then where two lines have the same set of connections, eliminate all but one, again preserving the conditions. In other words, selections between candidate lines can be made only where there is no effect on the graph, and no effect on the conditions. The resulting graph will then be both the unique graph for that system and the most 'integrated' possible, because we have by definition conserved all minimum graph distances between pairs of lines, and therefore graph distance in the system as a whole. Because all syntactic consequences follow from the graph rather than the map, it follows that the values calculated from this are also unique.

In 1986 an algorithm for this was developed by Czapski and Penn, using 'all-line' maps as the initial draft maps (that is, maps composed of all lines linking built form vertices that can see each other) and extending them until they strike another built-form surface or leave the system, and defining 'overlapping' convex spaces as all those definable by extending built-form surfaces (Penn et al, 1997). Turner has recently written a new implementation of this, and an example of a spatial system with an

(3) This is based on an observation in *The Social Logic of Space* (Hillier and Hanson, 1984, page 91) about the continuous space of urban systems: "any point in space ... can be seen to be part of a linearly extended space ... [and] also part of a fully convex fat space ... [which] represents the maximum extension of the point in the second dimension, given the first."



(a)



(b)

Figure 3. All-line analysis and least-line reduction of a hypothetical layout. (a) Shows an 'all-line' analysis of a hypothetical space pattern created by built-form blocks. A line is drawn between all pairs of built-form vertices that can see each other, and then each line is extended until it reaches another built form or the boundary of the system. (b) Shows a reduction to the unique least-line axial map using the algorithm outlined in the text.

all-line map and an algorithmic reduction of this to its correct least-line map is given in figure 3. This will be published in the near future (Turner et al, in preparation).

Conclusion

In spite of their simplicity, axial maps have delivered striking results on many different functional aspects of cities, and have also allowed the development of a theory of urban space, linking grid configuration, movement, land-use patterns, and centre formation, which has proved robust enough to use in design. Our current view is that, although we fully agree with Ratti that current computational power will soon allow these things to be done much better, axial maps may work because they capture key properties of urban complexity in a simple way. These properties include not only that both urban space and movement are essentially linear phenomena, but also perhaps that linearity is a key aspect of the way in which we cognise urban space (Hillier, 2003b). For these reasons, we suspect that improvements to the syntactic modelling of city space may need to retain the focus on linearity and 'configurational' equations of the kind that space syntax has made central to its methods, while being much more sensitive to detailed variation along lines.

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