INTELLIGENT ANALYSIS OF URBAN SPACE PATTERNS: GRAPHICAL INTERFACES TO PRECEDENT DATABASES FOR URBAN DESIGN

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ABSTRACT

Where urban models of the 1960's and 70's were criticised for lack of data, Geographic Information Systems are now being criticised for a lack of analysis. The problem is that there is a fundamental lack of theory of how complex urban systems work, and of how they relate to the spatial and physical structure of cities. New techniques of Configurational Analysis of Space (CAS) based on Hillier's 'space syntax' theories (Hillier & Hanson, 1984) describe cities as patterns of interconnected spaces. By describing and quantifying pattern properties the techniques allow researchers to investigate the way urban function and spatial design relate. One of the main findings of this research is that the pattern of the street grid is a primary determinant of patterns of both pedestrian and vehicular movement. It appears that, given their head, urban land use patterns evolve to take advantage of movement and the opportunities this creates for transaction. The theoretical understanding of urban systems which is being developed using the new analytic techniques is now being applied in design. By building together interactive analysis of space patterns with databases of existing cities and urban areas in which we understand the principles governing function, knowledge of precedent is brought to bear on design.

USEFUL THEORY AND THE CREATION OF PHENOMENA

It is a characteristic of most fields of study that deal with human and social systems that practice runs well ahead of theory. There is perhaps no better illustration of this than in urban planning and design where theory, following the disasters constructed in its name during the hey-day of modernism, is widely held to be a discredited force. Practice must move on with or without the help of theory, and the 'applicability gap' between research and application in the social sciences is often cited as the reason why more often than not practice makes do without theory. It was not always so. Amongst the strongest remnants of the scientific optimism of modernism are the urban models developed during the late fifties and sixties. Transport modelling at least remains a strong force (some would say too strong) in design practice today. But modelling seems not to have borne out its promise as the generalised tool for urban planning. Why is this? Michael Batty in his review of some thirty years of urban modelling (Batty 1989) suggests that it is because the social and political context that gave rise to modelling in the first place has disappeared. Models were, he suggests, a product of planners working towards a 'collective or public interest'. In a period in which individualism and self interest are in the ascendancy the very intellectual underpinning of modelling as tool for rational redistribution has disappeared. In its absence, he argues, modelling has all but died as a policy tool.

In a sense this is ironic. One of the main problems to dog modelling in its early years was a lack of data. Today data sources are expanding more rapidly than ever before. Private sector data providers have taken over as governments have reduced their efforts, and the storage and retrieval of spatial data using Geographic Information Systems has never been easier. But GIS is itself being criticised for failing to synthesise data into useful knowledge (Openshaw, Cross & Charlton, 1990). I believe the failure of urban models to move with the times and answer current questions and the criticisms of GIS for lack of application follow from the same root cause: that no one has defined what 'useful knowledge' is in the context of spatial systems. In this paper I discuss just what form 'useful knowledge' might take in terms of the questions designers and urban masterplanners ask. I suggest that for design the two most important forms of knowledge are knowledge of precedent and knowledge of context. The utility of knowledge derives from its ability to allow one to act intentionally. I will argue that for knowledge to be useful it must be theoretical in the sense that it must allow one to predict. Scientific theories and scientific knowledge have just this property. I believe that Batty's calls for a stronger theoretical base for urban modelling and Openshaw's for a stronger analytic base for GIS amount to the same thing. They are both asking for urban phenomena to be put on a firm scientific basis in which knowledge will allow reasonable predictions to be made, and so will allow actions to be intentional. The suggestion is that it is only when theory becomes useful in this sense that it will begin to influence practice.

On the face of it these calls for a stronger scientific basis for urban analysis seem contradictory. From the beginning urban models *looked* very scientific. They are dressed in complex equations and based on concepts like gravity and equilibria with a respectable history in physics and chemistry. But those that criticised these models for their lack of data missed their real weakness. It was not that they lacked data, it was that they failed for the most part to generate their theories from the data. Geographic Information Systems appear to suffer from the reverse problem. They too look very scientific in that they gather data in huge quantities - something that we know scientists do a lot of. But they are now being criticised for a lack of analytic capability. I believe the main problem is not that they lack analysis, on the contrary they are highly flexible analytic tools. It is that the analysis they provide is if anything of too general application. Given data in a GIS the user is left pretty much to their own devices to decide how best to add value to that data. In this sense it seems that the form of the analysis they provide does not follow closely enough from they kinds of problem they are being asked to help solve. Perhaps the contradiction, and so our sense of dissatisfaction with both urban modelling and increasingly with GIS, is based on the fact that each is bedded in a particular paradigmatic view of science. Where urban modelling fulfilled an essentially Popperian hypothesis testing programme - the hypothesis or model comes first and the data second as a check or calibration of the model - GIS provides for an inductive approach led by the provision and manipulation of raw data in the hope that theory will emerge.

Ian Hacking in an influential recent contribution to the philosophy of science (Hacking 1983) suggests a resolution of these two opposed views of the scientific process. He proposes that one of the activities of science that is all too often overlooked is 'the creation of phenomena' which then become the subject matter for theory. He is talking mainly of the work of experimentalists. The people who like to tinker and produce phenomena - regular occurrences that seem consistent but often baffle explanation - and which provide the driving force behind new theory. He describes this activity in a way that sets it apart from mere data gathering. Creating phenomena requires the active manipulation of data, finding new ways of representing things so that regularities are revealed (it is important that phenomena are visible), measuring and calculating so that you can quantify what you see.

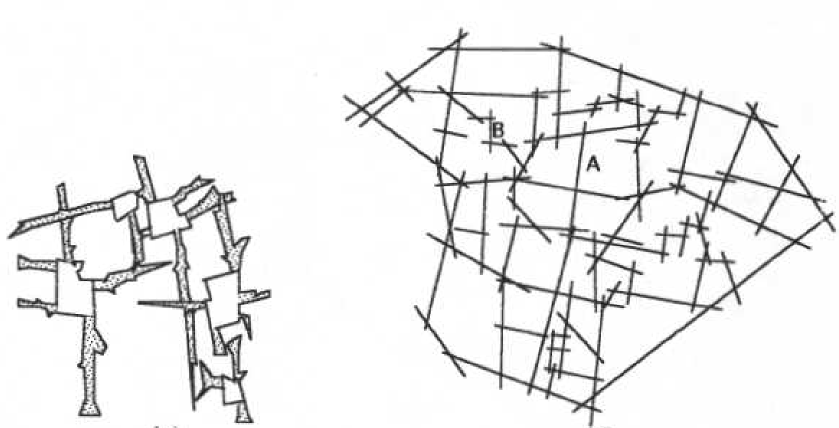
I believe that what urban theory lacks at the moment are the regular phenomena about which to theorise. Some phenomena like the regular motion of the planets, as Hacking notes, are open to observation. Others have to be worked at and actively created. Useful urban theory will only come about if we first create some phenomena about which to theorise. In a subject area which is social and evolutionary, and in which the physical objects we deal with cover areas of hundreds of square kilometres, the computer is likely to be a useful tool in creating phenomena. It is particularly good at calculating and transforming representations, and these are important aspects of the creation of phenomena.

SPATIAL CONFIGURATION AND URBAN PHENOMENA

The concentration of econometric models on the 'process' aspects of urban function has led them to overlook, or at best simplify, their representation of the spatial and physical form of cities to the point at which it ceases to be an input to the process. For designers, though, the spatial and physical city is the major concern - what they need to know is 'what difference does it make if I design this one way or another?' Conversely, where GIS is concerned, representations of social and economic processes are almost entirely lacking. The description of nearly all aspects of urban form is possible, but without a basis in knowing which aspects are important in urban processes it is all just so much data. What seems to be lacking is an urban theory relating the physical city and the social processes that take place within it.

In the late 70's Bill Hillier began to develop just such a theory. Central to his efforts was the notion that an understanding of urban systems requires a description not just of individual elements of the city - this building or that space - but a description of whole systems of spaces and buildings considered as patterns. Hillier and our group at UCL have developed representational and analytic techniques which combine the geographer's concern for located data with the modeller's concerns for processes. They are based on a simplified description of space, neither as the geographer's 2-D homogeneous plane which is accessible 'as the crow flies', nor as the modeller's arbitrary zones and links, but in terms that obey the real physical constraints that built form places on visibility and movement since you can neither see nor move through solid objects, only through open space. Figure 1. shows something of what I mean. 1a. is the map of a French market town; 1b. shows the pattern of open space in the town coloured in black. This pattern of space is the part of the town that people use and move through. It is the object we are interested in studying. We are looking for ways of representing this irregular pattern that carry some social 'potential'; 1c. picks out the main 'convex' elements of space in the town, and plots the fields of view - all space that can be seen from those spaces. As can be seen, the open squares are all visually interlinked by more or less linear pieces of space; 1d. then passes the longest lines of sight and access through the open space pattern - it essentially simplifies the plan into a series of linear spaces of the sort that approximate shortest and simplest routes between different parts of the town.

Figure 1a) 1b)



1c) 1d)

Marked on the line map 1d are two locations 'A' and 'B'. Both are close to each other and relatively central in the town, but in terms of their locations relative to the whole town considered as a configuration they are radically different. What do I mean by a 'configuration'? A simple transformation of the representation illustrates the phenomenon. Figure 2a represents line 'A' as a dot at the bottom of a graph, the five lines that intersect with line 'A' are represented as dots one level above, those that intersect with each of the five appear at level 2, and so on until all the lines in the town have been represented. In other words, the graph represents the minimum number of changes of direction that need to be made to get from line 'A' to anywhere else in the town, since each move from one line to another involves a change of direction. Figure 2b does the same thing from the point of view of line 'B'. The two graphs are very different. From line 'A' the rest of the town is relatively shallow. That is, it is accessible by making fewer changes of direction than from line 'B'. On the basis of this we can say that considered in terms of their relationship to the whole configuration the two lines are different. The property of depth is 'global' in that it relates a line to its whole context.

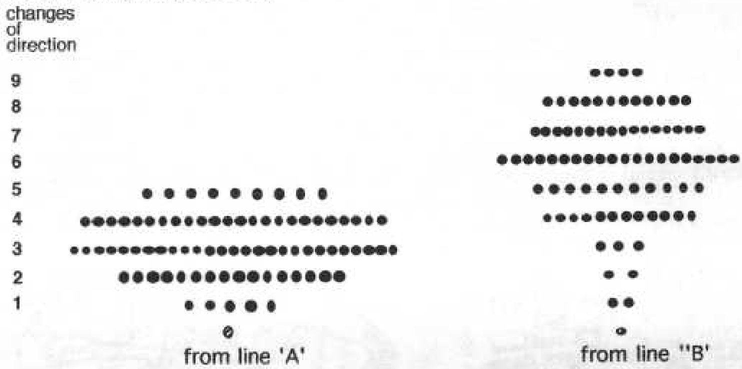


Figure 2a) 2b)

The difference between 'A' and 'B'is clearly measurable: all we have to do is measure the mean 'depth' of the graph from the point of view of each line in turn and we have a global, relational measure of how each piece of linear space in the town relates to all others. This exercise has been carried out and the depths represented back on the line map in Figure 3 as a greyscale from black for shallowest through to light grey for deepest.

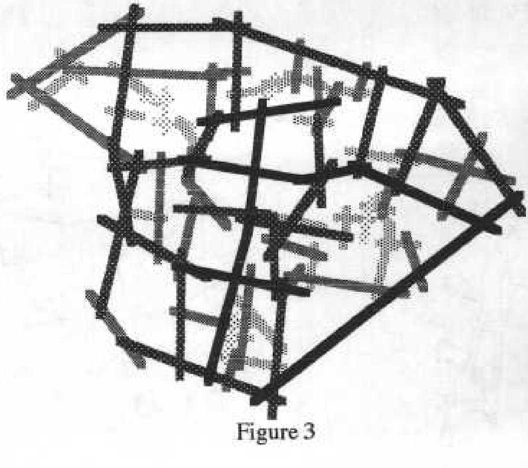


Figure 3

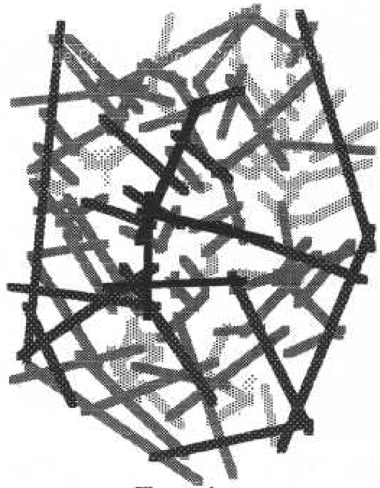


Figure 4

We call the measure of shallowness in the graph (relativised to take account of the number of lines in the system) 'spatial integration' since it quantifies the degree to which a linear space or street integrates or is segregated from its urban context. The shape distribution of the back 'integrated' streets forms a 'deformed wheel' with part of the rim, a number of spokes leading from edge to centre in several directions and a discontinuity at the hub. The more segregated areas lie in the interstices of this integration structure. The pattern is quite characteristic of a large class of settlements from all parts of the world. Figure 4, for example, is the integration core of a hutted settlement from southwestern Africa in which a 'deformed wheel' of shallow space allows easy and controlled access for visitors from outside to the centre town and back out again.

The similarities go deeper than just the distribution of integration. In both settlements there is a strong relationship between local properties of space, such as the number of other lines each line is connected to, and the global property of integration. We call the correlation between local and global spatial properties the 'intelligibility' of a system since it gives an index of the degree to which it is possible to predict where you are in terms of the whole configuration (everything that you cannot see) on the basis of what you can see locally. Figure 5a and b show the intelligibility scattergrams for the two settlements shown in Figures 3 and 4 respectively.

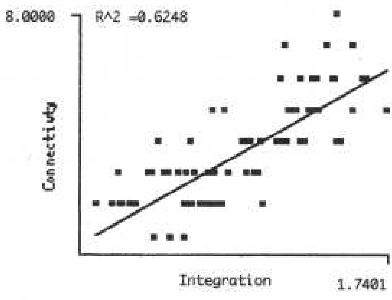
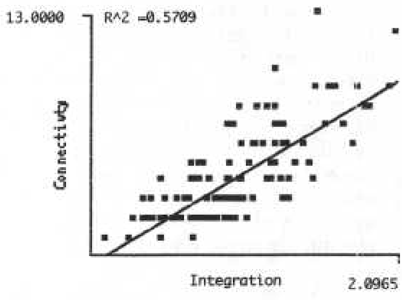


Figure 5a)



5b)

Again we find that intelligibility is a general property of a large class of 'organic' settlements of this size. This is not a trivial finding. It is simple to design settlements in which the relationship between local and global is broken, and significantly we find this has been done in many of the problematic recent public housing schemes in the UK which are often referred to by residents as 'maze like'. Although we have no direct psychological evidence, is tempting to suggest that the human mind may act as a 'correlation detector' in activities such as spatial searches and wayfinding. Where no correlations can be found confusion may result.

NATURAL MOVEMENT AND THE MOVEMENT ECONOMY

One of the other most common accusations made against our modern housing schemes is that they lack 'vitality' and at worst turn into 'urban deserts' devoid of people even in the middle of the day. It is a longstanding question whether the design of the schemes is in any way at fault in this, or whether the blame rests with the way that the schemes are managed, with the socioeconomic status of the residents and so on. The multivariate nature of this sort of socio-spatial question has made it seem almost impossible to resolve one way or the other. However, the new techniques for describing and quantifying the geometric and topological form of urban space allow us to approach some of the simpler questions at the heart of this issue.

Since we can now describe and quantify radically different spatial designs on the same basis we can begin to 'control' the design variable in studies of other aspects of urban function. It is possible to detect effects of spatial design on patterns of pedestrian movement simply by observing pedestrian flow rates at a number of locations in the streetgrid and then using simple bivariate statistics to look for the relationship between configurational measures of those locations and flows. A large number of studies has now established that spatial integration is consistently the strongest predictor of pedestrian flow rates (see Hillier et al, 1993, for a comprehensive review of the evidence). Spatially integrated lines carry greater pedestrian flows than more segregated ones. The effects are strong and consistent. Figure 6, for example shows the line map for an area of north London in which we have made detailed observations of pedestrian movement patterns. Each street segment has been observed for a total of over 50 minutes at different times of day and on different days of the week. The all day mean hourly pedestrian flow is noted on each segment. Figure 7 shows the scattergram of a measure of 'local integration' in a much larger model of the area against the log of pedestrian flow rates. The 'local integration' value is measured in the same way as global integration but restricting the number of lines considered to those within three changes of direction. In this case the model is much larger than that shown, extending approximately two kilometres away from the observation area in all directions. The correlation is remarkably strong at $r=.872$, $p<.0001$.

The key discovery here is that the correlation is between pedestrian flows and a purely spatial measure of the pattern of the streetgrid. No account has been taken of the location of attractors or generators of movement in constructing the measure of spatial integration. It seems that movement patterns result naturally from the way the spatial configuration of the streetgrid organises simplest routes (involving fewest changes of direction) to and from all locations in an area (Penn & Dalton, 1992). Of course this runs counter to the premises of urban modelling which hold that the key facts in urban systems are the distributions of activities and land uses that 'generate' or 'attract' flows between different geographic locations. Our results leave us in little doubt that the primary fact is the pattern of space, and that if there is a relationship between land uses and pedestrian flows (which there certainly is - you find more people on streets with shops than on streets without) this is most likely to be due to retailers choosing their shop sites with care in order to take advantage of the opportunities for passing trade provided by the natural movement pattern resulting from the grid.

We find support for this hypothesis when we look at samples of shopping and non-shopping streets (Hillier et al 1993). Consistently we find that in areas that include shopping streets there is an exponential increase in pedestrian flows with integration (hence the linearisation of the pedestrian rates in Figure 7 using a logarithmic scale). In non-shopping areas, however, the correlation is predominantly linear. A possible explanation for this would invoke a mechanism in which shops locate themselves in numbers that are in proportion to the level of passing trade generated by the pattern of the grid. The shops then attract a number of additional trips in proportion to the attractiveness of the shop. We might then expect areas including shopping to exhibit a multiplier on the basic pattern of natural movement that would be consistent with an exponential growth in pedestrian flows.

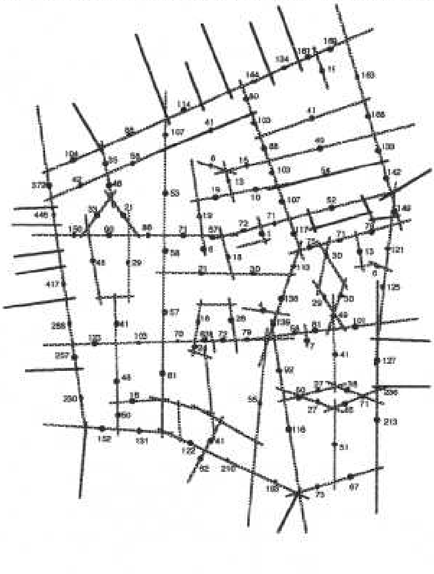


Figure 6

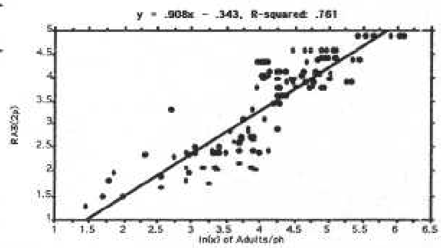


Figure 7

There is a marked shift in emphasis from existing urban theory suggested by these findings. Where current theory takes activities and land uses as the prime movers in urban systems the new results suggest that the spatial configuration of the city exerts systemic effects on both land use and flows. A new economics of the city would move from considering movement as a cost, to movement as a resource that brings potential transactions past land parcels. Trips are as important in terms of what they take you past as they are in terms of where they take you from or to. This moves the scope of urban theory from a subjective individual view in which origins and destinations are the important facts, to an objective social theory in which individual trips are primarily of interest in that they add together to create a probabilistic field of potential encounter and transaction which other members of society can take advantage of in deciding their actions. This suggests an economics of the city based on movement as its principal resource and spatial configuration as its main implement (Hillier & Penn 1989).

THE PROBABILISTIC INTERFACE AND SOCIAL PATHOLOGY

One of the most pertinent criticisms of urban models focuses on their apparent lack of a conception of human or social life in cities. They are criticised for taking a mechanistic view of urban systems in which the missing elements are the people. Conversely, where the geography of urban pathology has been studied by looking at clusters of social malaise (most recently by Colman, 1985) the main criticism has been that of mistaking correlation for causality, and that the mechanisms through which design was supposed to be related to social malaise were either disregarded or unsubstantiated (Hillier 1986). GIS apparently faces a dilemma as it tries to incorporate more extensive modelling capabilities. It risks either concentrating on mechanism to the exclusion of all else, or disregarding mechanism to the point at which its results mislead. I believe one resolution of this problem lies in results of recent studies of space use and abuse in housing areas.

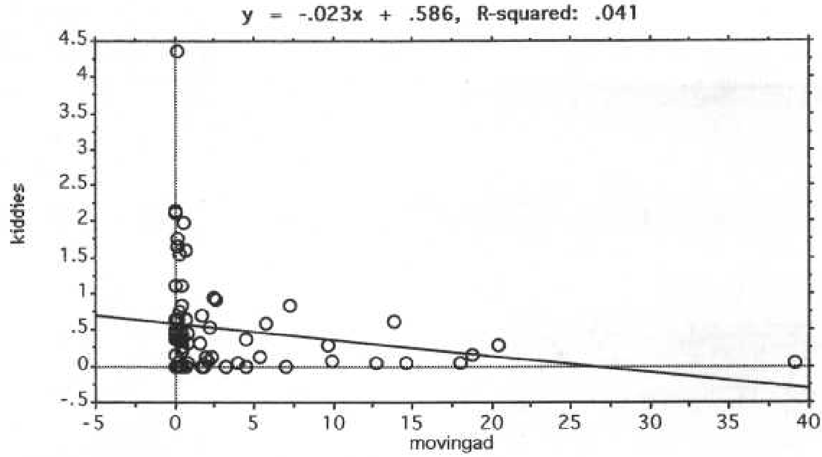


Figure 8. The correlation between adults and children in a public housing scheme

There is remarkable consistency in the way that post war public housing in the UK has sought to segregate its public open space from the surrounding street fabric. This is demonstrated by substantially reduced integration values in for housing estate spaces compared to traditional street areas in configurational analyses. As might be expected, presence of pedestrians also drops substantially in estate interiors, to the point at which they are sometimes referred to as 'deserts' or being in a state of 'perpetual night'. It seems that spatial segregation serves to isolate the estates from all through movement to the point at which you can be alone in space for most of the time. However, where we observe space use patterns by different categories of people simultaneously we find still more suggestive results. Patterns of space use by children and teenagers of school age differ radically from those of adults. Children gather in groups, often not moving much but using space to 'hang out' in locally strategic locations which are cut off from the outside world in the estate interior.

These locations tend to remove them from informal overseeing by adults as they move into and out of the estate, and if we look at the correlation between adult and child presence in estate interiors we find a characteristic 'L-shaped' distribution shown in Figure 8. Where there are greater numbers of adults there are low numbers of children, and where there are larger numbers of children there are lower numbers of adults. In normal urban streets there is a much stronger correlation between adults and children suggesting that an informal interface is maintained. These findings are now being added to by more recent studies of crime locations which suggest that the strategic locations in estate interiors which are emptied of normal adult levels of movement by being segregated from through movement to and from surrounding areas become the favoured locations for specific types of crime and abuse.

It seems quite possible that the configuration of urban space through its effects on patterns of movement may construct informal probabilistic interfaces between different categories of people. The interface between shop owners and buyers makes transaction possible, that between adults and children may turn socialisation and control into natural and unforced processes. Alternatively, where space structures lead to a polarisation of space use by different social categories, we suspect that distrust, stigmatisation and crime result. It seems possible given this view of the relation between social processes and spatial configuration that the theories which gave rise to zoning of 'communities' in their own 'territories' served to create the social pathologi es they intended to control. If this is so it is little wonder that 'theory' has gained such a poor reputation amongst practitioners and the public alike.

APPLYING KNOWLEDGE IN DESIGN

Making theory useful in design depends above all on answering questions posed in the form of physical designs. Designers are good at generating physical and spatial 'form'. They find it more difficult to judge the likely outcomes of that form in terms of all the interacting criteria they are expected to handle in a functioning urban area. In most fields they employ engineers to advise on outcomes in specific domains - structures, air movement and so on. However, when it comes to social outcomes they have no one to refer to. This is where configurational analysis techniques come into their own. Since they analyse spatial patterns directly and in some detail they are able to analyse designs on the drawing board as well as existing urban areas. Essentially, the analysis speaks in the same terms that the designer uses to design. To the extent that research findings are general across all the areas that have been studied previously, advice can be given on the expected outcomes of physical design in human and social terms. The principle of natural movement following spatial integration is a case in point. Following an analysis of a design, predictions can be made of likely patterns of pedestrian movement. These can then be used to ensure adequate levels of space use to make areas safe as well as to make sure that land uses are located to take advantage of the pattern of natural movement. To the extent that findings are specific to particular locations or areas, advice can only be given if studies have been made of the particular context for a scheme. Two types of knowledge are therefore useful in design: knowledge of precedent and knowledge of context.

The whole programme of research at UCL is geared to this. By carrying out consultancy projects for design teams engaged in live projects research questions are kept in line with those that designers need to answer. The spin off is an ever increasing database of studied areas each with its own set of specific design problems. By carrying out funded research the methodologies and software are developed to keep abreast of the questions emerging from practice. A typical consultancy project requires the construction of a large area context model for the development site in question. Figure 9 shows the context model of Shanghai recently constructed for Sir Richard Rogers' competition winning scheme for the new financial capital for China. Next the model is amended to include the new design and the analysis is rerun. On the basis of the analysis advice is given in the light of knowledge of precedent from other cities and of the specific context of Shanghai. The design is then amended and the analysis rerun in a process akin to hypothesis testing.

Figure 9. The integration map for Shanghai

In this particular case the aim of the design was to synthesise a whole range of issues from energy usage to social contact and microclimate in order to create a sustainable low energy city for the next millennium. The programme for the design was therefore to obtain the maximum output for a given input in the pursuit of social, economic and environmental sustainability. The arena within which the new techniques are being developed is thus quite different from the 'rational redistribution' goals that drove the first urban models. Instead, the aims are to use an understanding of the processes which drive urban systems to develop new urban forms that function in a natural way requiring the minimum intervention. I believe that this sets the new CAS techniques apart from traditional urban modelling approaches which found their roots in the interventionist planning ideology of the 60's.

The new graphic computer technologies available today make these aims achievable. The creation of visual phenomena is central to the development of theory as well as to its application in practice. Graphic devices that internalise and make visible knowledge of precedent, such as the depth graph, the integration pattern or the intelligibility scattergram, are vital tools in communicating to designers and the lay public. People like to see the results of design changes and to have somthing to work towards. Engineers have been able to provide this for some time in the domains of air movement and structures, but it is only now that we are beginning to provide the same kinds of graphic and interactive capability in the more social domains of design.

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