ANALYSIS OF CONFIGURATION: KNOWLEDGE OF CONTEXT AND PRECEDENT IN ARCHITECTURAL DESIGN

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Design, and in particular the design of the built environment in which we live and work, is an enterprise about which it is surprisingly difficult to talk. Part of the problem is that the right words don't exist to discuss an activity which seems at once to be highly personal, but whose product is public and, preeminently among the arts, social in its intent. However, if we look at the way that architects and design teams commonly work we discover regular patterns that suggest that there may be an objective logic in what otherwise appears to be a primarily subjective activity. Gaining a principled understanding of the way design is carried out is important if we are to devise ways of helping a process which is now better known for its failures than its successes. In this paper we suggest that there are two main forms of knowledge which are brought to bear on design: knowledge of context - the particularities of site and brief, and the regular behaviours of built forms, the space patterns they create and their functional outcomes; and knowledge of precedent - the body of buildings and projects with which the designer is familiar, which is used as a source, and perhaps more importantly, which forms the index against which the designer checks in aiming to innovate. By developing appropriate representations of built forms and spatial pattern or 'configuration' we shall argue that both forms of knowledge can be moved from their current status as fields of knowledge which are gained through personal experience and applied mainly through intuition, and are in this sense 'autonomic', towards the 'heteronomic' knowledge characteristic of science which it is possible both to share and contest.

One of the common features of the design process is the project team meeting. It takes place in a more or less regular form. Around a table sit the main parties in the process: the architects, engineers of various stripes, the client's representative, their financial advisors, the letting agent, and so on. In the centre of the table are drawings or often a polystyrene 'working model' of the scheme in its current state. Each party brings knowledge of their own particular domain to bear on the single object of discussion - the current design represented by drawings and the model. There is a fundamental asymmetry in the team - the designers (often but not always, architects) propose the 'form' of the scheme - they make a first stab at a 'solution', the other members of the team analyse it from the point of view of their domain of knowledge and comment within their remit. The whole exercise has been compared to solving Rubik's cube, getting one face right messes up the others; solving a structural problem may well create problems for other domains. In this sense design is both complex and interactive, and the project team is the organisational form that has evolved to address these sorts of problems.

There is another sense in which design is both complex and interactive. That is, that changes to one 'geographic' part of a scheme often have implications in other areas. Changing a road alignment on one side of a scheme can create traffic problems somewhere else entirely. Design within each domain of knowledge usually rests on an understanding of how parts and wholes are related and thus is possibly best characterised as 'top-down'. When we describe the problems in these terms it sometimes seems difficult to see how a design ever gets done. The complexity of the interactions is staggering, and is only outstripped by the number of possible solutions that could be considered. The combinatorial explosion has dogged many attempts to apply a logical process to the support of design decision taking. Two factors save the day. The first is that however many domains of knowledge impinge on design, they are all brought together by the model of the current scheme. It is that single physical and spatial 'form' that they all have to comment on. Effectively, the real building resolves the interactions between all the domains at the end of the day. Second, there is a vast array of 'tried and tested' design solutions which are open to evaluation and personal experience. This is the 'precedent record' where one of almost any 'kind' of building you care to mention has probably been built before. Truly original building types are a great rarity, and for this reason are highly sought after by designers.

One approach to uncovering the knowledge applied in design is therefore to begin by developing representations of the single thing the brings together all the interrelated domains - the physical and spatial form of the building itself. By studying the precedent record it seems possible that we can build up a picture of the dynamics of the interactions between the different domains of design knowledge, and of the way that part whole relationships impinge within each domain. The need to consider part whole

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relationships sets a clear form for the types of representation that are likely to be of interest: they must represent parts and the relations between parts. A particularly effective form of this kind of analysis called 'configurational analysis' or 'space syntax' has been developed by Professor Hillier and our team at UCL over the last 15 years. The analysis concentrates on the part of the building that users actually use and that design configures into patterns - the space delimited by the built fabric. The basis of the method is, first, the subdivision of continuous open space into discrete elements, either lines of sight, or convex spaces, and next the representation of the relationship between those elements in the form of a graph. Once a space pattern has been represented as a graph a whole range of measures of the graph can be devised to quantify different aspects of its pattern. It is easy to think of aspects of space that describe its local properties, the size, shape and proportion of a room for example. Some of these properties can be thought of as 'relational'; the number of doorways to other rooms, for example, gives a measure of the degree of connectivity of a space. However, this property is purely local and only gives local information about the pattern of space. The metrics that have been found to be more interesting, and to have greater empirical utility are 'global' in that the describe properties of the way a space is bedded in the whole pattern - they effectively quantify aspects of the relationship between a part and the whole. One such (Figure 1) measures the degree to which a space is deep or shallow on average from all other spaces in a pattern. We call this measure of shallowness in the graph (relativised to take account of the number of spaces in the system) 'spatial integration' since it quantifies the degree to which a space or linear street integrates or is segregated from its urban context.

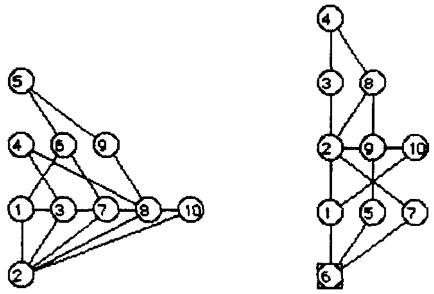


Figure 1 a. b.

The same graph 'justified' from the point of view of node 2 (a) and node 6 (b). The mean depth of all other nodes from each is different. This forms the basis of the global measure of spatial integration.

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 street grid 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 1 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 2, 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 3 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 (on a scale between 0 and 1, where 1 would mean a perfect prediction of movement from the spatial measure).

The key discovery here is that the correlation is between pedestrian flows and a purely spatial measure of the pattern of the street grid. 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 street grid organises simplest routes (involving fewest changes of direction) to and from all locations in an area (2). Of course this runs counter to the premises of most current transport models 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. These findings suggest why it is that designs such as some of those found in London's Docklands, which are based on the old modelling assumptions fail in practice, while others such as the Broadgate development survive under the same economic climate.

The results leave 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, (1). 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 3 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.

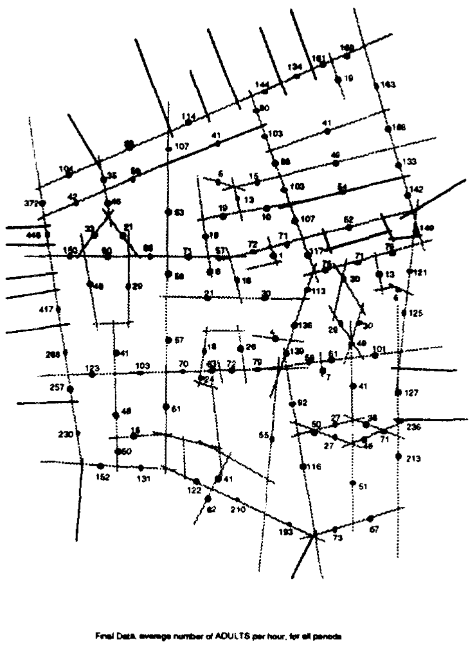


Figure 2

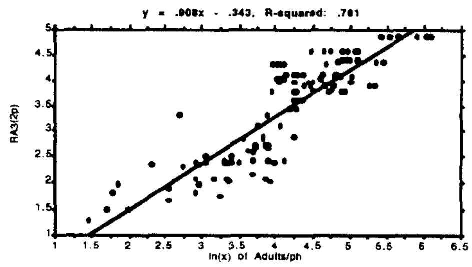


Figure 3: r=.872, p<.0001

There is a marked shift in emphasis from existing urban theory suggested by these findings. Where current urban modelling 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 (3). However, we believe that the potential to elicit useful knowledge from analysis of spatial configuration and observations of human behaviour and social action can go much further. Pressed by the very real public concerns about architectural and planning failures our group has been investigating how the new configurational representations can throw light on social pathology.

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 (4). 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, 5) 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 (6). New computer application fields such as Geographical Information Systems (GIS) face a dilemma as they try to incorporate more extensive modelling capabilities. They risk either concentrating on mechanism to the exclusion of all else, or disregarding mechanism to the point at which its results mislead. We believe one resolution of this problem lies in results of recent studies of space use and abuse in housing areas.

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 within housing estates 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 estates from 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 4. 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.

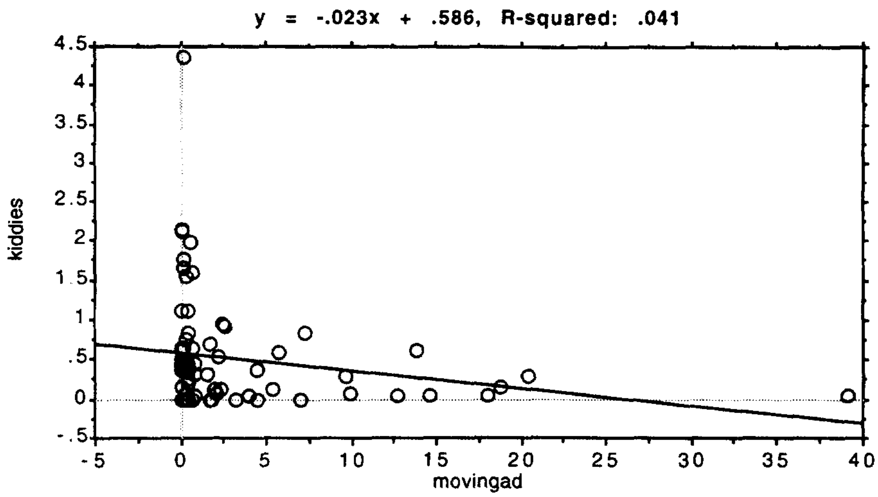


Figure 4

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 pathologies they intended to control. If this is so it is little wonder that 'planning theory' has gained such a poor reputation amongst practitioners and the public alike.

Building for innovation

The problems of urban space are at least well recognised. The problems of poor building design, especially of working environments, are much more subtle and easier to overlook, however, we believe them to be if anything more pervasive. One of the longstanding questions facing architectural researchers is whether buildings have any impact on the way that workers communicate and innovate in organisations. Central to this argument is the case of the scientific research laboratory where scientists often hold that there are 'good' and 'bad' buildings for generating new ideas. Recent research by our group has addressed this problem using the new methods of configurational analysis (7, 8, 9). A sample of 24 building floors in seven sites in different parts of the UK was selected as a part of a study for the Department for Education. The sample spanned public, private and university sectors, and covered a range of scientific disciplines. All the laboratories selected were considered 'good' within their field. The study itself addressed a wide range of spatial and environmental issues, and included detailed surveys of spatial and equipment provision (Figure 5 shows the ground floor of a large world class physics laboratory including a 'dotmap' describing the location and activity of everyone observed on 30 rounds of observations). In addition a questionnaire survey was carried out of all building users to determine the strength of communication networks. The questionnaire listed by name all, or a large sample, of the people who worked in the survey area. Respondents were asked to score on a five point scale the frequency with which they had contact with each individual name in the list. They were also asked whether or not they found that person 'useful' in their work. Although the questionnaires were confidential they were not anonymous, since we needed to know for each respondent which contacts were within their research group and which were between groups.

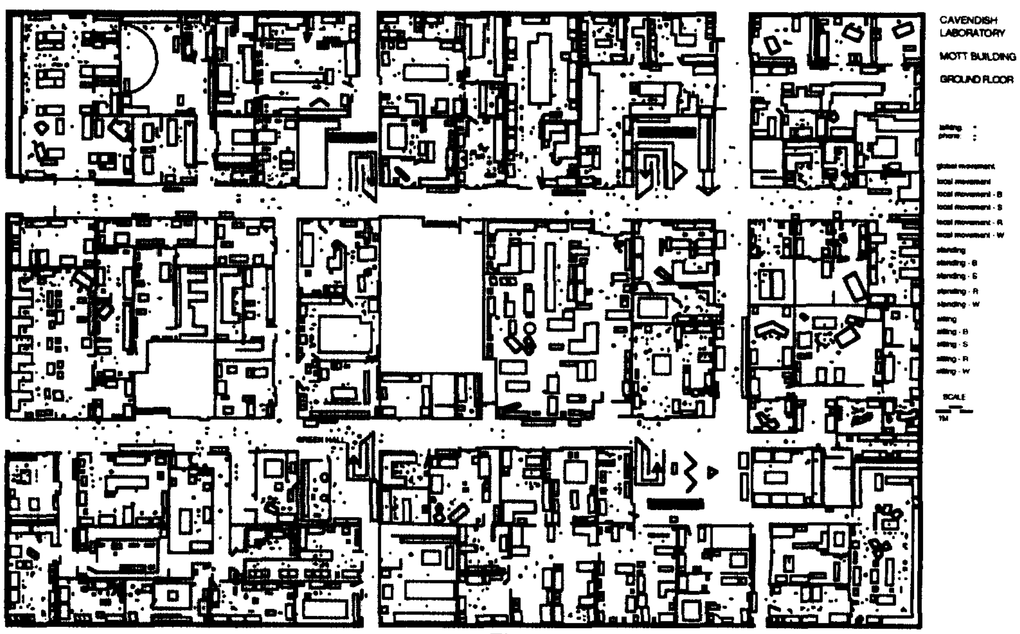
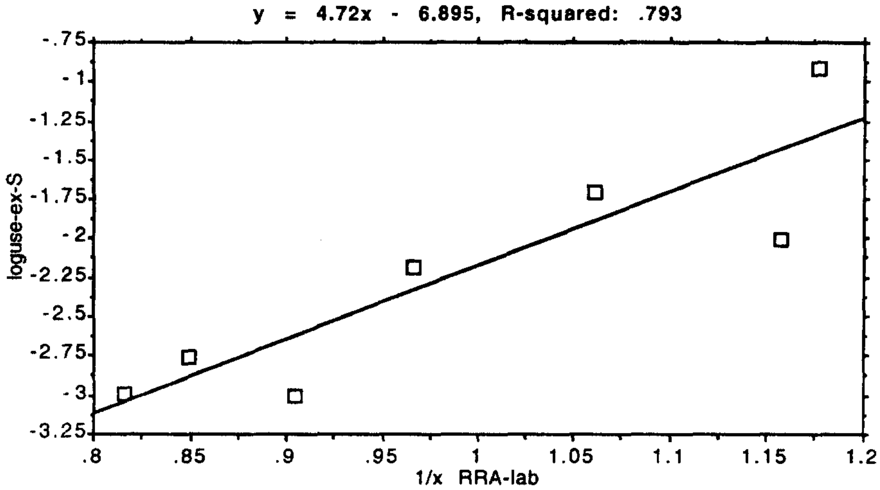


Figure 5

The first findings were predictable: everyone knows everyone in their own research group, sees them daily and finds them useful in their work. Next we had to look at how often each name on the list was cited by every respondent in order to eliminate the possible effects of different interpretations of the question by different respondents - in this way each name on the list had an equal chance of being cited by each respondent. The findings here were strong. People who are found useful by many people outside their own research group are neither the most frequently nor least frequently seen. There was also a strong relationship between the number of inter-group contacts expressed as a percentage of possible contacts and the number of these that were felt to be useful in people's work.

The most striking findings were made, however, when we took the whole sample of building floors, and looked at the mean number of inter-group contacts in each. Here the mean degree of spatial integration of the floor predicted the strength of the networks strongly and significantly. More importantly, the rates of contacts 'useful' in people's work (y axis) was strongly related to building integration (x axis) for the seven whole buildings (Figure 6). More spatially integrated buildings, it seemed, increased the level of useful work related inter-group communication that Tom Allen (10) found to be so important for innovation.



r=.891, p<.0001
Figure 6

The strength of these findings is such that it leaves little doubt that the spatial configuration of laboratory buildings can affect patterns of communication amongst researchers, however it does raise a question regarding the precise mechanism that could give rise to these effects. Light has recently been cast on this through the work of Paul Drew and Alan Backhouse at the University of York (11). In a study of a large open plan professional design office they used careful observations and video recordings to look at the behaviour of workers engaged in work related interaction. They found that when an individual is at his desk he is usually regarded by others as engaged in work and 'not to be disturbed'. However, should that individual leave his desk to move to some other area, whether or not that movement is dictated by the needs of work, he is regarded as 'free' and so available for 'recruitment' into interaction.

This micro-scale mechanism suggests that movement in buildings may be more intimately involved in the work process than has hitherto been recognised or allowed for. If, as Backhouse and Drew suggest, a significant proportion (possibly 80%) of work related interaction arises in this 'contingent' and unplanned manner, then providing the opportunity for movement and the recruitment which results may be the key to maximising work related communication. The model has other attractive properties. To the degree that movement takes people from one part of the organisation past workstations of people from other parts of the organisation, the opportunity for recruitment will serve to create - or allow the reinforcement of - contacts between organisational segments. If as Allen has suggested, these are the important contacts from the point of view of innovative problem solving, we can begin to imagine the way that building design might inhibit or facilitate this.

We can also imagine what will happen if we set out to design our buildings and organisations with efficiency in mind. Let us assume that the state of knowledge in the task area covered by an organisation is broadly understood by management and that pains have been taken to structure the organisation in a relatively rational way. It follows that groups within the organisation will reflect the current understanding and existing state of knowledge of the task area. People who this understanding gives us to believe need to interact often will be located within a group, those between whom there seems to be no rational need for communication may be separated. Steps may even be taken in the interests of organisational 'efficiency' to minimise the intrusion of unrelated groups on each other and to minimise the need for movement on the part of staff by making sure that all facilities required for work are conveniently located near to each group. These would seem to be reasonable steps to take in order to produce a rational and efficient building plan.

What would be the effect of such a plan on the progress of the state of knowledge in the organisation? We believe that the effects would be chronic rather than acute. By and large the existing state of knowledge in a field is a pretty good starting point for problem solving, but slowly it would become apparent that other organisations were making the innovative breakthroughs. These breakthroughs are so rare in any case that their lack may never be noticed. The solutions to problems in the 'efficient' organisation would largely be produced as a result of the people put together for that purpose by the organisation on the basis of current knowledge, and because the opportunity to interact with people outside that definition of knowledge would be reduced in the interests of efficiency the boundaries of knowledge would seldom be challenged or broken.

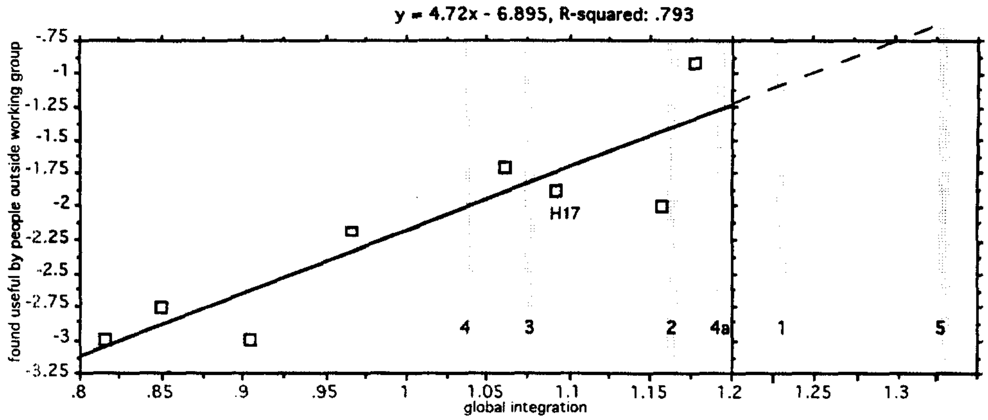
In this sense we believe that organisational efficiency and true innovation run counter to each other. Innovation requires probabilistic interaction and the opportunity to recruit provided by bringing the large scale movement structure close to the workstation. Moreover, it requires that the large scale movement structure takes people with knowledge in one field past people with problems to solve in another. In this way it seems possible that spatial configuration of buildings and the disposition of the organisations that inhabit them are actively involved in the evolution of the boundaries of both knowledge and of the organisational structures that allow firms to respond effectively to new circumstances in their operating environment. We would suggest that part of the role that spatial design of buildings plays in innovative work organisations is to act as a shuffling mechanism whilst the proper role of organisation and management is to act as a sorting mechanism. This is not to say that managers cannot help shuffle (think of matrix management) and buildings should not help sort. It is just that for a class of buildings that seem to work well somehow naturally - often old and messy labs or the proverbial 'portacabins in the car park' - the other process is taking place.

The design cycle - using knowledge in design

Expert building users show a remarkable degree of awareness of the sort of issues described here in the way they use the built environment. Perhaps this is not surprising: the knowledge we are accumulating comes in part from careful observation of how the 'lay public' uses its buildings. But we think that there is more that can be said. Architecture, like language, has structure of which one does not have to be consciously aware in order to demonstrate competence. We don't usually think of the rules of grammar when we speak, and we hardly ever need to think of the rules of spatial configuration in order to use the built environment. In this sense the knowledge that we apply as we use the built environment is largely autonomic. It is learned through experience, applied through intuition, and almost impossible to share or discuss. The application of knowledge in architectural design is also mainly autonomic. This suggests why it has proved so difficult to use conventional knowledge elicitation techniques to capture the designer's expertise: most of these techniques pass through the filter of language, and it is a property of the domain that we do not have a common language to describe the properties of interest. Our approach has been to try to convert knowledge in the domain into a heteronomic form that is open to being shared and contested. By looking for regular associations between spatial configuration and outcomes such as patterns of movement, social pathologies or communications networks the hope is that knowledge of principles can be derived that will allow knowledge in the form of predictive theories to be developed.

A single example will help to illustrate the intention. In a recent consultancy project the techniques of configurational analysis have been applied in predictive mode as a decision support tool for refurbishment of a pharmaceutical research laboratory. First, the laboratory was studied using the same techniques described earlier. The particular area to be refurbished was analysed in the context of the neighbouring parts of the building, and both patterns of space use and movement were observed. A key element of the exercise was to apply the questionnaire method of assessment of the strength of useful work related contacts in amongst the individuals who worked in the part of the building to be refurbished. This allowed us to 'benchmark' the existing organisation against the precedent database of other laboratories that have been studied previously. The purpose was twofold. First to confirm that the organisation and its buildings fell within the existing model, and second, to provide a starting point for the evaluation of design options. Figure 7 shows the outcome of this process. It is a copy of the scattergram shown in Figure 6 above, but with the new laboratory floor inserted (as a dot marked H17). The model clearly holds for the new organisation, and it can now be added to the precedent database. The grey vertical bands show the calculated spatial integration for various design options developed by the architects and analysed using the configurational analysis computer program.

These allow us to infer, and communicate to the client and their architects in an immediate and visual way, the likely outcome of different design strategies on one of the key variables in which they were interested. By iteratively analysing and giving feedback to the design team the design can be fine tuned to resolve the wide range of constraints that need to be reconciled into any complex building. The design as it evolved could effectively be tracked around the model space that encapsulates the knowledge that had been derived from studies of precedent. The fact that this could be represented in an easily understood graphical form turned out to be of great value in discussions with the building users and the design team. It became possible to discuss issues that both the users and their designers had up until then found difficult to even talk about for the lack of a common language. Perhaps more importantly, it allowed the clients and their project managers to maintain a quality audit trail through the detailed physical design on matters that up till now, it has only been possible to rely on the experience and authority of the architect.



The correlation of the mean integration value for each whole building with the mean useful contact rates for all the buildings in the sample. With first 5 options plotted.

Figure 7

We have written elsewhere (12) about the possible impact of these new techniques for generating real feedback from end users into the design process, by making it possible to turn a project based industry into the 'virtuous circle' of incremental product development that other areas of manufacturing have begun to enjoy. The central point in this paper is that that enterprise will depend not only on a radical restructuring of the construction industry - which is already well under way through the drive given by the major client bodies - but also on the development of heteronomic knowledge of the functional effects of design decisions. This knowledge is only now beginning to appear.

References

1. Hillier B., Penn A., Hanson J., Grajewski T., Xu J., 1993, Natural Movement: or configuration and attraction in urban pedestrian movement, Planning and Design: Environment and Planning B, Pion, London.

2. Penn A. & Dalton N, 1992, The Architecture of Society: stochastic simulations of urban pedestrian movement, Surrey Conferences on Sociological Methods: Simulating Societies, University of Surrey, Guilford.

3. Hillier B. & Penn A., 1989, Dense Civilisations: or the shape of cities in the 21st century, Applied Energy, Elsevier, London.

4. Batty M.,1989, Urban Modelling and Planning: Reflections, retrodictions and prescriptions, from Macmillan B. (ed) Remodelling Geography, Basil Blackwell, Oxford. 147-169.

5. Colman A., 1985, Utopia on trial: vision and reality in planned housing, Hilary Shipman, London.

6. Hillier B., 1986, City of Alice's Dreams, Architects Journal, London, 9th July 1986, 39-41.

7. Hillier, B., O'Sullivan, P., Penn, A., Kolokotroni, M., Rasmussen, M., Xu, J., Young, A., 1990, The design of research laboratories: Report to the steering committee, 23 November 1990, The Bartlett, London.

8. Hillier, B. & Penn, A., 1991, Visible colleges: structure and randomness in the place of discovery, Science in Context, 4.1 pp 23-49.

9. Penn, A. & Hillier, B., 1992, The Social Potential of Buildings: Spatial structure and the innovative milieu in scientific research laboratories. Proceedings of the Corporate Space and Architecture Conference, Paris, 1992. p39-43. Also tr. French: Structure spatiale et innovation dans les laboratoires de recherche scientifique: le potentiel social des bâtiments, in Evette, T., & Lautier, F., (eds) De l'atelier au territoire: le travail en quête d'espaces, L'Harmattan, Paris, 1994, 215-224.

10. Allen, T., 1977, Managing the flow of technology, MIT Press.

11. Backhouse A. & Drew P., 1992, The design implications of social interaction in a workplace setting, Environment and Planning B: Planning and Design, 19: 573-584, Pion, London, 1992.

12. Hillier, B., & Penn, A., 1993, Virtuous circles, building sciences and the science of buildings: using computers to integrate product and process in the built environment, The International Journal of Construction Information Technology, 1,4 69-92, The University of Salford, Manchester.