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GIS AND URBAN DESIGN

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ABSTRACT

Although urban planning has used computer models and information systems since the 1950s and architectural practice has recently restructured to the use of computer-aided design (CAD) and computer drafting software, urban design has hardly been touched by the digital world. This is about to change as very fine scale spatial data relevant to such design becomes routinely available, as 2dimensional GIS (geographic information systems) become linked to 3dimensional CAD packages, and as other kinds of photorealistic media are increasingly being fused with these software. In this chapter, we present the role of GIS in urban design, outlining what current desktop software is capable of and showing how various new techniques can be developed which make such software highly suitable as basis for urban design. We first outline the nature of urban design and then present ideas about how various software might form a tool kit to aid its process. We then look in turn at: utilising standard mapping capabilities within GIS relevant to urban design; building functional extensions to GIS which measure local scale accessibility; providing sketch planning capability in GIS and linking 2-d to 3-d visualisations using low cost net-enabled CAD browsers. We finally conclude with some speculations on the future of GIS for urban design across networks whereby a wide range of participants might engage in the design process digitally but remotely.

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Computerising Urban Design

Urban design has been defined as "...... the process of giving physical design direction to urban growth, conservation and change." (Barnett, 1982, page 12). It sits at the interface between architecture and planning, and its emphasis on physical attributes usually restricts its scale of operation to arrangements of streets, buildings, and landscapes. In one sense, urban design represents the heartland of city planning from whence the activity sprung in the late 19th century as civic or town design in a social context, but since the 1950s, planning has dramatically broadened its embrace to include many socio-economic facets of the city. Consequently urban design has become a much smaller activity in the portfolio of urban planning activities, many of which are no longer exclusively concerned with the physical environment. However, traditional definitions of urban design still hold. In terms of residential design, Gibberd (1953) says: "The term 'design'...... means the arrangement of the various parts - the houses, roads, paths and so on - in such a way that they function properly, can be built economically, and give pleasure to look at." (page 20). This implies that urban design includes technical questions of urban functioning, economic issues of cost and benefit, aesthetic issues of appearance, as well as social issues involving allocation and provision. As in mainstream urban planning, urban design represents a synthesis of diverse activities involving social science and architecture. Indeed there is trend to interpreting urban design as being part of a much broader context which is almost, but not quite, synonymous with urban planning itself (Punter and Carmona, 1997).

Since the late 1950s, and particularly in the last decade, both architecture and urban planning have been strongly influenced by the development of digital computing. Since the development of raster graphics following the advent of the microprocessor which heralded in the age of cheap computer memory, architectural drafting has been transformed through computer-aided design (CAD) packages such as *AutoCad*. Of late entire cycles of the design, construction and management of buildings are becoming automated as functional software comes to be linked to building information and its visualisation. In urban planning, the process of computerisation began earlier with municipal information systems and with landuse-transportation modelling but as in architecture, the last decade has seen dramatic developments in tools for visualisation and information representation particularly through geographic information systems (GIS) with desktop packages such as *ArcView* and *MapInfo* becoming standard and near routine.

Urban design however remains largely untouched by these developments for many reasons. It sits astride the world of 2- and the world of 3-dimensions and as yet there are but the most tentative links between desktop GIS and CAD although these are rapidly developing. The fact that software does not exist in appropriate forms for visualising urban designs is perhaps the least important issue for good design depends more on information than on visualisation *per se*. Only recently has good information become available in digital form at the local scale as data providers have begun to release data at the street block and street segment level. Currently, there is an explosion of new data types captured from a variety of sensors and available in off-the-shelf form such as CD-ROM or over the net. In the past, urban designers have had to make use of crude aggregate socio-economic data and to supplement this with their local intuition as to how this kind of data pans out at much finer scales. Consequently urban design, although alluding to the socio-economic and development context, has rarely been able to make any use of such data and has thus been much more oriented to the aesthetic, functional and perceptual issues characterising local environments.

This is all changing as GIS begins to deliver very fine scale data which has profound implications for urban design. The software vacuum at the urban design scale where it has been unclear as to how architectural and urban planning methods might be synthesised is about to be filled as visualisation techniques and information systems begin to merge. To date, the most significant link between GIS and CAD in the context of urban design has been for visualisation. There are countless digital 3-d models of cities now available, most developed using various forms of desktop or net-based CAD, and a few of these are based on linking this kind of visualisation to data stored within a GIS. For example, the UCLA group (Ligget and Jepson, 1995; Ligget, Jepson and Friedman, 1996) have pioneered the delivery of geographic information into a 3-d modelling environment while other researchers such as Day (1994) at Bath and Grant (1993) at Strathclyde have moved back from CAD models towards GIS. Most of these attempts however do not exploit the kind of functionality which GIS has provided in the detailed spatial analyses of local environments. For nearly a decade, the Cincinnati, Melbourne, Toronto, and Zurich (ETH) groups have been exploiting the overlay paradigm from GIS for urban design following its widespread development in landscape design (Dekker, 1992; Bishop and Karadaglis, 1997; Danahy, 1988; Dave and Schmitt, 1994). Some of the most significant developments are taking place at MIT where Shiffer (1992), Singh (1996), and Ferreira and Wiggins (1993) are developing urban design from a GIS perspective by building an array of tools for sketch planning, visualisation, and local urban analysis which incorporate spatial analytic functionality with various types of multimedia and visualisation.

Although many of these developments imply ways in which urban design might be carried out, they are largely concerned with supporting the design process rather than providing a template for carrying out design. In fact throughout architecture and planning, a concern with the design process has rarely been translated into fully computer-aided form. Attempts were made to automate design in the 1960s. An early attempt was the *URBAN 5* design system which was part of MIT's Architecture Machine Group (Negroponte and Groisser, 1970) although it is now widely agreed that design and planning are too wide, too diverse, too participatory, and too political to straightjacket in terms of software. What has emerged are loose amalgams of methods and their software which when organised in some problem-solving, goal-directed frame, provide "support" for design. Planning support systems which build on GIS have grown out of automated planning (Harris, 1989; Klosterman, 1997; Shiffer, 1992) while spatial decision support systems are being developed for more specific location problems such as facility location, retailing and the like (Densham, 1996). There have been few such moves within architecture where after a flurry of interest in design methods more than 30 years ago, ideas for automating the process have been few. In fact, it is around the building rather than around its design that automation has grown.

For urban design, the issue seems clear. To utilise the enormous potential of software for informating the process and for visualising its products, the concern is one of providing effective support, and as such it is the creation of *ad hoc* tool-kits which are able to deliver information in various forms to the designer that should form our concern. These may be loosely organised around the idea of decision support tools for urban design but a strong procedural emphasis is inappropriate at present. In short, enabling the creative aspects of urban design through software is not possible at present (and may never be possible in principle or in practice), and thus the emphasis should be on supporting design through a range of new software tools of which GIS is one of the most important at present.

There is another dimension to urban design which must be noted early for this is likely to affect the development of information technologies in this field more than any other in the next decade. Such design is perhaps the most participatory of any on the urban planning-architecture continuum. Urban design is small-scale enough for many users of urban environments to feel its impact. It is sufficiently broad-based in its influence on those affected that the wider public always have some view of how it might best be carried out. It is less abstract than city planning which exists at larger scales and more populist than architectural design which is remote from those with no formal artistic and engineering training. As such, urban design has the greatest potential of any technologies or practices for involving experts and lay-people. Currently, large volumes of information about the environment and the city are being delivered over the internet and its power to open up such issues to a very wide public who might view, reflect upon, and even manipulate designs digitally and remotely should not be underestimated. In this chapter, we will not be concerned with such technologies *per se* although our foray into visualisation techniques for urban design will involve net-based software which is available and viewable remotely. However it is worth noting that many of the methods indicated here might generate even greater potential for urban design when used in a net-based context using internet GIS and related software tools such as in virtual design studios (Bishop and Mason, 1997), or in computer-supported collaborative work groups which are becoming ever more popular mediums for such activities.

In the rest of this chapter, we will first sketch the process of urban design, showing the key points at which it might be supported using new computer technologies which originate largely from GIS. We will argue that it is tool kit functions which are required to adapt and open up GIS to urban designers. Many of these are already standard to GIS and it simply developing new interfaces to them and making designers aware of their relevance which will secure their use. We will then examine more specific functionality, focussing on the kinds of spatial analysis which are useful to urban design, demonstrating an archetypical example of these by showing how the local syntax of street accessibility in the urban environment can be manipulated by adding new functions to GIS. We will then examine ways of editing the basic building blocks of urban design - streets, buildings and other forms of space as a prelude to visualising such buildings in 3-d, and accessing information within the 2-d GIS from such 3d representations. We will conclude with some brief notes on the extent to which such developments can be web-enabled, indicating that equally fruitful approaches might be developed as virtual design studios or arenas. These will provide us with some pointers to the future of GIS in this specialist domain.

Formalising the Process of Urban Design

There is a very loose consensus amongst urban planners, policy makers, and other interests who generate and implement plans that planning should be conducted in a quasi-scientific manner. The process usually begins with some formal analysis of the problems in question based on good information, followed by systematic analysis of the options that might be designed to solve or alleviate these problems, and ending with the choice of a best option which is then implemented. This rational decision model is implied in various institutional structures which have been devised at various levels of government, certainly in many western countries, although the exigencies of the political process, the uncertainty of definitive analyses, and the pluralism of the constituencies affected by planning somewhat dilute the model in practice.

Since the 1960s, there have been concerted efforts to provide robust representations of urban problems embodied in functional models of the city system. In its most extreme form, this perspective assumes that urban problems can be represented within functional models of the city and that formal planning processes enable such problems to be consistently resolved and their solutions tested using such models. More recently the emphasis has changed within urban planning from functional modelling towards systematic representation of the urban system using various information technologies particularly GIS, and the formality of the rational decision model has reduced as the array of computer technologies for planning come to be used in more of an *ad hoc* fashion, as a tool kit for enabling solutions to be generated and evaluated. Indeed the development of spatial decision support systems (Densham, 1991) has come from much more *ad hoc* approaches to spatial problem solving in any case where the focus has been first on locational models rather than on systematic problem-solving processes. Latterly, planning support systems have been devised which have adopted the ideas of decision support with their emphasis mainly on information, representation, and modelling, fusing these with more formalised processes of urban planning based on the rational decision model (Batty and Densham, 1996; Harris, 1989; Klosterman, 1997).

Urban design has not had such a heritage on which to draw, and this poses important conceptual problems in knowing how new computer technologies might be used in its practice. Historically, urban design insofar as it has been formalised at all, alluded to the process of “Survey-Analysis-Plan” which was the forerunner to the rational decision model articulated by the founding fathers such as Patrick Geddes (1914, 1949) when planning first became institutionalised in the west in the early 20th century. Urban design was largely seen as being part of the wider structure of comprehensive planning, and there was and still remains an assumption that any formal methodologies that might be needed, should take place at larger spatial scales where the functional structure of the urban system is clearer. For most of this century, urban design in terms of both its practice and description has thus been dominated by qualitative substantive issues, by an emphasis on solutions, with a strong focus on visual factors, but definitely not by strong discussion of how good designs might be generated. A recent text (Greed and Roberts, 1998) confirms this view.

However in developing computer technologies for urban design, some formal framework showing how such technologies can inform design must be established, at least so that the potential of such techniques can be seen in context. To this end, we will adopt a simple planning support system approach in which we identify various computer technologies alongside a sequential process through which an urban designer might move in developing a design or set of alternative designs from which one or several might be chosen for further exploration, or one for implementation. The framework is shown in Figure 1 where the righthand side of the chart illustrates the stages through which a designer might pass in generating and adopting some plan. The left-hand side of the chart illustrates the array of representational issues that the designer needs to take account of in generating suitable plans. These issues are information-based and it is here that various computer technologies might be used in tool kit fashion to support the range of decision making that is implied on the right-hand side of the chart. The entire sequence of actions is iterative in that it is assumed that designers may revisit any of the previous stages if this can help progress the design, that designers may use the same structure at different scales, that the process operates continuously through time, and that some form of convergence to a single solution or design is ensured. In practice, stages may be missed, collapsed, and/or elaborated. Our purpose here is simply to suggest that some variant of this process is implicit in urban design and that the use and adoption of new computer technologies must be seen accordingly.

In Figure 1, we identify four ways of representing the urban system at the level of urban design. We have clustered these so that socio-economic information of a macro kind which is the traditional spatial information usually pertaining to areas but also to point and line locations in the city lies at the centre of these representations, usually contained within some kind of GIS. Around this, we can identify functional information such as that pertaining to relationships between elements of the system such as movement for example and which can sometimes be encoded into GIS, behavioural information which usually reflects more micro information such as the way users of the environment respond to its imageability, and finally physical information, geometric in contrast to geographic (which is largely forms the first category - socio-economic). Of course, all this information can be stored within GISs to a greater or lesser degree but other technologies that are relevant include computer mapping, formal models, and of course CAD.

Computer mapping systems represent one side of GIS involved with visual representation in 2d but without any of the information capacities that are useful for relating diverse data and linking this to other software. Such mapping is best seen as part of multimedia, mainly visual, which enable various representations of the system to be captured without formalised analysis procedures. CAD software on the other hand is akin to GIS but in 3-d rather 2-d. The physical form of the environment can be manipulated and in principle everything that can be done in GIS in 2-d can be done with CAD in 3-d. However, much of the analytic capability of CAD has not yet been exploited, largely because the focus has been on flexible manipulation of physical form rather than the analysis of its qualities and attributes. Nevertheless the strongest link between GIS and other software systems recently has been in interfaces to CAD. Finally, various kinds of formal modelling software ranging from spreadsheets to custom-built packages can be employed to simulate functional and behavioural relationships relevant to urban design, particularly the economic evaluation of different design scenarios. It

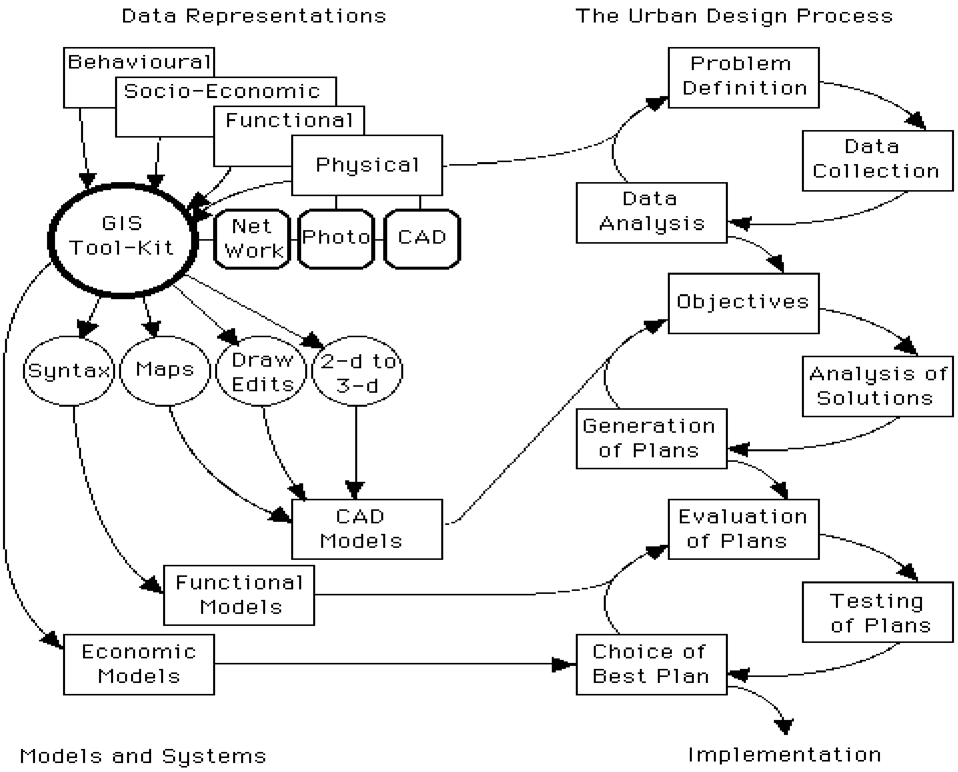

Figure 1: New Computer Technologies in the Process of Urban Design

is important to keep in mind the fact that very diverse links can be made between software of very different kinds, and it is getting easier to use one kind of software to emulate others.

Some idea of how these elements can be captured in software is illustrated on the left-hand side of Figure 1, but from our perspective here, we have set out on the assumption that the best way of informating the urban design process is through GIS. In Figure 1, we show four major connections between GIS and other software. In our illustrations here, we will show how we can build limited modelling capability based on functional relationships into GIS, show how we can extend GIS to embrace many different kinds of multimedia essential to capturing the visual aspects of urban design, and show how we can move from 2-d to 3-d by adding simple CAD capabilities to GIS. It is not possible to develop any kind of comprehensive computersupported urban design process here; in fact it is probably not possible to do this at all at this time, so what we will simply show are examples of how we might develop GIS capabilities in providing tools to support urban design. In time, this may change as computer technologies begin to influence the very process of urban design, as they are used more widely. But at present, we must be content with illustrating the potential of existing GIS in urban design as well as simple ways of extending GIS functionality to deal with urban design type problems.

Finally before we illustrate these technologies, we must be more specific about the kinds of urban design problem for which GIS is relevant. In essence, urban design involves a series of nested small-scale location problems ranging from site selection (essentially local planning in institutional British planning parlance) to the location of buildings and other spaces on the site which demand 3-d as well as 2-d considerations. As we have implied, urban design involves a very wide range of issues from the socio-economic, to the functional and the behavioural, to the aesthetic as well as to the constructional and the environmental. There is no well-defined process of synthesising these requirements although some attempts at representing them in a common spatial metric have been developed in the past, often in the manner of overlay analysis, although these tend to be rather narrow manifestations of the process. Suffice it to say for these purposes, we will assume that the designer has complete control over the process, taking account of these various factors by dipping into the GIS tool kit as and when required.

Using Off-the-Shelf GIS as an Urban Design Tool Kit

Our starting point is to explore the existing functionality of desktop GIS and how it might apply to typical urban design problems, before we show how we can extend GIS capabilities for specific design functions which we will do in later sections. Most desktop GIS do not yet have 3-d capabilities and thus our standard off-the-shelf software is largely devoted to representing 2d spatial information. In fact, although our starting point is mapping, urban designers make widespread use of maps and the new innovations in computer mapping which are springing from GIS are of obvious importance to 2-dimensional design. We must make two key distinctions in exploring GIS and mapping at fine-spatial scales: the first is between geographic and geometric data, the second between vector and raster data. GIS makes no real distinction between geographic and geometric in that it treats all map data as geometric. The difference relates to the fact that much data in GIS is associated with areas which have geographic rather than geometric significance in that when such data is mapped, it produces thematic rather than real representations. For example, data which is usually averaged and associated with administrative geographies such as census tracts/wards, block groups/enumeration districts, or 7-digit zip or unit post codes are data which form such maps and whose basis of representation is geographic. Traditionally this has been rather unimportant in urban design but the existence of this socio-economic data down to the lowest level - 50 metre resolution or less - is providing enormous spatial variability at the finest scales which has a clear influence on site selection.

In contrast, geometric data is associated with the physical configuration of the environment itself. In urban areas, it is parcel and plot data, with digital map bases provided by national mapping agencies such as the Landline data in the UK, and the TIGER files in the US, forming the obvious base. Such data is often classified into points, lines and polygons with lines and polygons being associated with attributes of streets or sites. Many GIS problems are defined in terms of one type or the other - either geographically or geometrically - not both, but what makes the use of GIS in urban design challenging is that this area cuts across both types of representation, requiring ways in which the geographic and the geometric can be handled simultaneously. In short, a rarely discussed limitation of GIS involving the ways different types of representation might be reconciled in conceptual terms, is directly confronted in urban design. This might explain in part why the application of GIS to urban design has been so slow in coming, and why more formal theories of urban design have hardly been developed to date.

Our second distinction is between raster and vector. As scale becomes finer, then differences between raster and vector data become more difficult to resolve. For example, mixing satellite and aerial photographic data which is raster with vector data based on street and parcel line information, becomes tricky: a level of precision which is not usually required at coarser scales, is necessary. Of course, all these kinds of data can be represented in most desktop GIS and can be visualised directly through standard colouring schemes and thematic map functions central to such software. In this chapter, we will illustrate our examples from the town centre of Wolverhampton for which we have some very rich data. In Figure 2 for example, we show a variety of data relevant to geographic mapping; in Figure 2(a), the enumeration district boundaries used in the 1991 Population census with the main road system clearly identifying the ring road which bounds the town centre, in 2(b) a typical landuse (local) plan for the town centre, and in 2(c) environmental data tagged to more detailed geometric data at a finer scale. Numerous other socio-economic data can be displayed in similar ways. In Figure 3, we show a variety of geometric data: street and parcel data in 3(a) and (b), and aerial photographic data in 3(c). These data in Figures 2 and 3 represent the geographic and geometric bases on which many kinds of attributes can be visualised, and as such constitute the raw material for urban design. Moreover, they mix vector and raster representations, which although still important in GIS when it comes to a synthesis of each, are less important in conceptual terms.

There are three major types of function within state-of-the-art desktop GIS. These are thematic mapping of various kinds, overlay analysis of different data layers that can involve synthesising and manipulating spatial layers one to each other, and structured query of the data often leading to new layers of data. We will not say anything at all about structured query other than that this kind of prosaic use is important once a GIS has been set up. Urban design is no different from any other application in that it can make use of such functions extensively during the process of analysis and design. Varieties of thematic mapping have obvious uses in providing different ways of representing the same data, but it is the manipulation of data layers that requires further discussion. For data layers to be comparable, they must be in the same metric and across the same digital base. Most GIS have contouring facilities that enable data to be smoothed into surfaces and then normalised which in turn enable their direct comparison and synthesis. For example, in Wolverhampton, very different types of employment at unit postcode level can be smoothed so that their spatial distributions can be directly compared; examples for retail employment and for commercial employment are shown in Figure 4, and although traditionally these kinds of data and their visualisation have rarely been used in urban design, the fact that such data now exists at such a fine spatial scale, provides enormous potential for learning about what is possible and desirable in socio-economic terms.

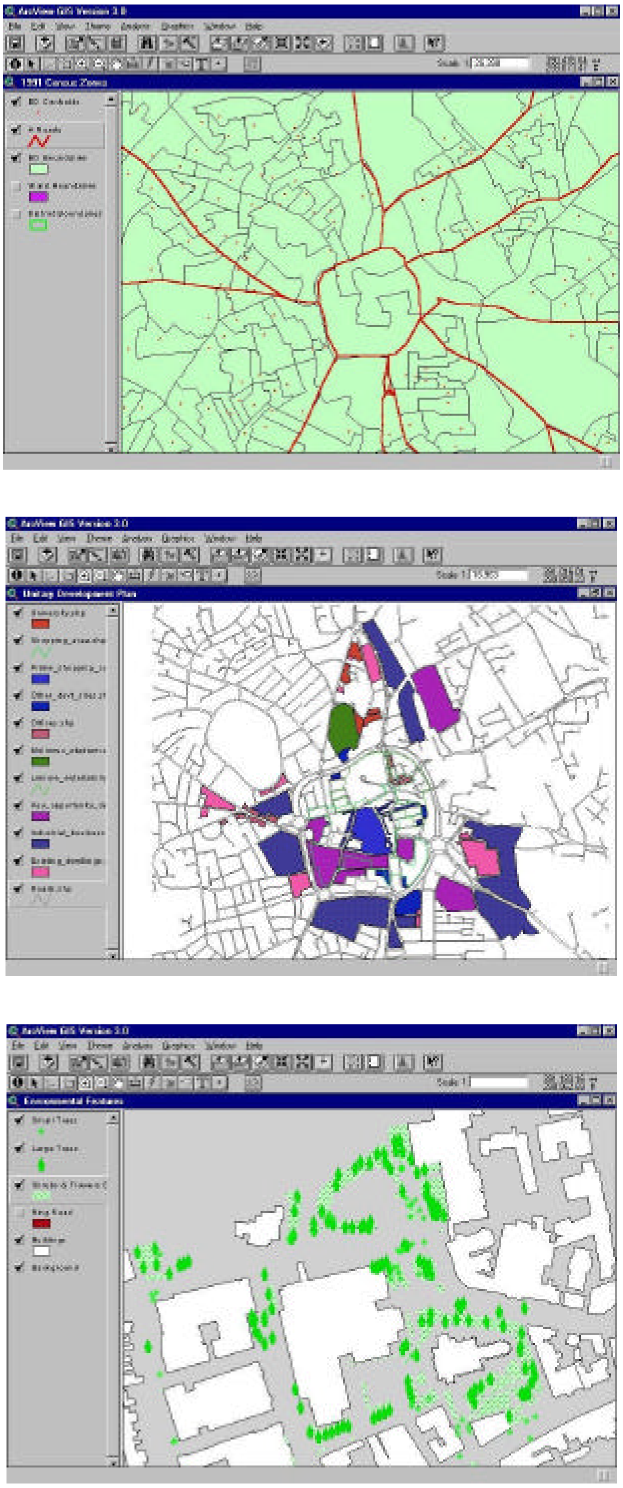

Figure 2: Geographic Data Types

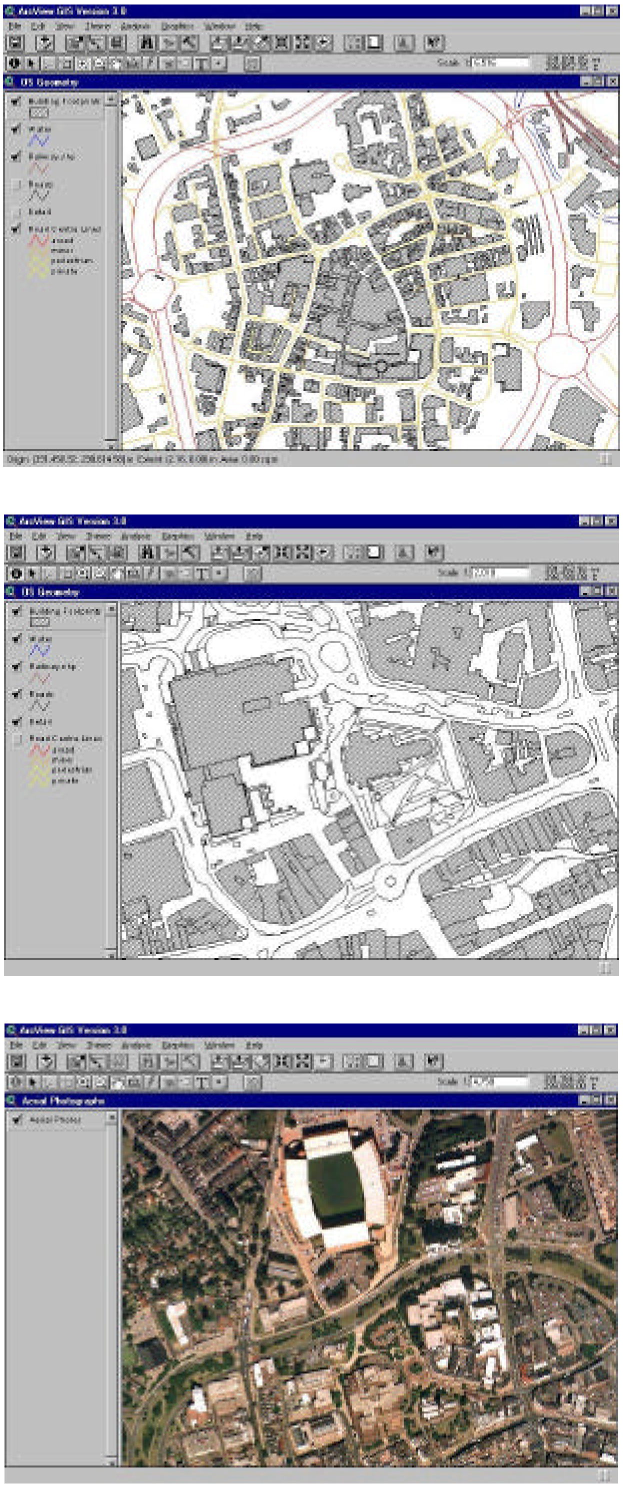

Figure 3: Geometric Data Types

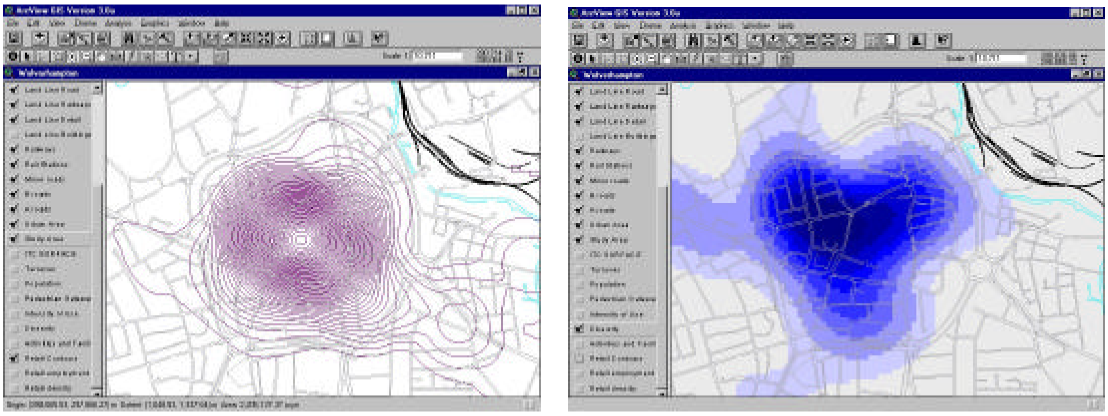

Figure 4: Smoothing Fine-Scale Spatial Data within GIS

The package we use here is *ArcView* which is amongst the most popular and flexible GIS software. In fact, *ArcView* has several plugins or extensions that add functionality to the package, and one of these - *Spatial Analyst* - must be used if contours are to be generated in the manner shown in Figure 4. However it is easy enough to embed various kinds of multimedia, consisting of photographs and video clips which support urban design, into such software. For example, a time-honoured technique of representing qualitative information at the urban design scale consists of keying in photographs to map locations (see Cullen (1961)). In *ArcView*, this can be done using hotlinks which when activated by the users from the map location load the image into the GIS, in the manner shown in Figure 5(a) which illustrates the covered market area in Wolverhampton. Other software and images can be loaded using the hotlink facility as in 5(b) where the Wolverhampton Community Internet page is accessed in this way by activating the link to the internet. Other media can be accessed in the same way, Figure 5(c) shows a video clip (*AVI* format) of the cathedral area which when loaded can be run in animator software, while in 5(d) a 360 degree panoramic vista of the civic centre area can be viewed by hotlinking to the desktop where the *Live Pictures* based on Quick Time VR style software can be loaded.

So far we have not invoked any purpose-built software exploiting GIS in urban design although we have shown how various extensions to the package in question and hotlinks to other proprietary software on the desktop act as simple extensions to GIS. There are other plugins such as *Network Analyst*, *Business Analyst* and *3-D Analyst* for *ArcView* which might be relevant. *Network Analyst* enables network characteristics to be computed so for example, this could be used to calculate very local level street accessibility which is important to design. *Business Analyst* acts at coarser scale in fact but *3-D Analyst* is very important to design. We will postpone any discussion of this until we deal with extensions to 3-d in a later section. Finally, it is worth noting the very diverse range of data types and representation that

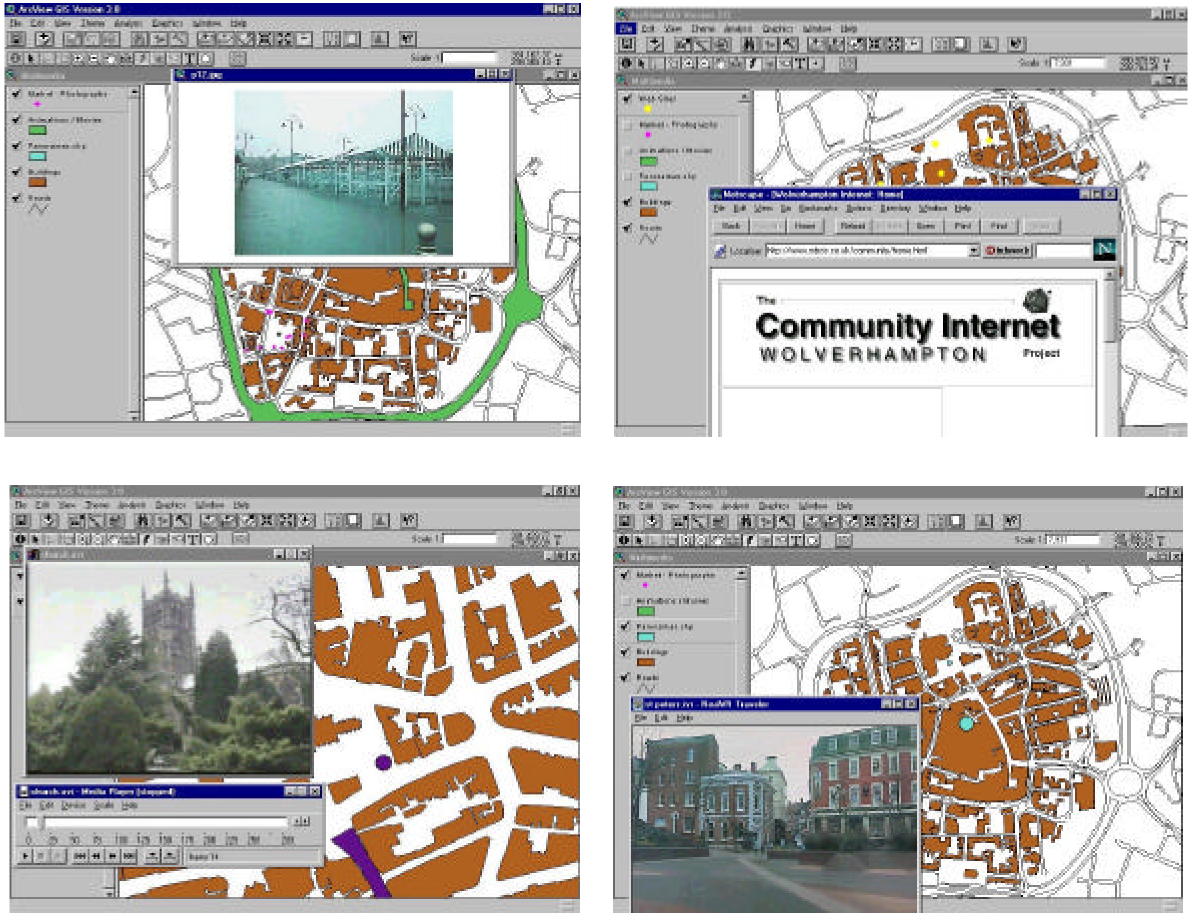

Figure 5: Hotlinking from the GIS to Photo and Video Data

are now possible using GIS and this makes its use in urban design attractive if only for purposes of consistent representation and mapping.

Adding Spatial Analytic Capability

Although GIS has received very wide acclaim as an important tool for urban planning, most software does not include any modelling capability other than through its functions for manipulating spatial data. The software is based around representing spatial systems in fairly descriptive ways with few implications as to how key relationships within the system in question can be best represented. This means that representing a system so that it is best suited to some explicit form of simulation is not part of the GIS agenda. In fact, during the last decade, considerable efforts have been expended in giving GIS some modelling capabilities or rather developing ways in which modelling software can be linked to GIS (Batty, 1994). A second limitation of GIS in representing urban systems is that it is difficult to represent functional relationships based on flow systems such as traffic movements. In an urban design context, the way people move between spaces for example and the way they view buildings is hard to represent in GIS although this kind of data is critical to the design problem. Although only relevant to a limited set of urban design problems, data which is temporally dynamic in the sense of embodying relationships through time is near impossible to represent in GIS.

To illustrate how we might add this kind of functionality into GIS and to demonstrate the general principle of adding new analytic capabilities which are tailor-made for the system, we will show how we have added specific functions to analyse local street level accessibility which we use to measure the relative connection between different spaces and their levels of usage. A technique of accessibility adapted to the local street level has been developed by Hillier and Hanson (1984) based on the theory of graphs; they refer to this technique as 'space syntax'. We will first outline the method and then illustrate how we have built an extension to *ArcView* which enables designers to compute such accessibility within the GIS, thereby giving users the opportunity to compare this with many other point, line and polygon data layers.

Space syntax is based on representing any set of interconnected spaces by a series of axial lines which connect different spaces to one another. These lines are essentially 'lines of sight' which provide, in their raw form, some measure of how far one can see from different points in the system. The technique was first developed for spaces within buildings but recently, it has been extended to problems at the urban scale. Axial lines have their own integrity and it is these that constitute the basic elements of the system. What the method does is to treat these axial lines as nodes in the urban system and to then count the number of links between these nodes by examining if any two axial lines intersect. If two lines intersect, this represents a link between the two respective nodes which are the axial lines. The analysis then continues by working out standard measures of accessibility or connectivity on this graph, and the resulting set of measures is called the 'syntax'. There are many measures of connectivity that can be computed (Teklenberg, Timmermans and Wagenberg, 1993) but the measure which is favoured is called 'integration' which is the average number of links which each axial line has to all others in the system. Local measures of integration can also be formed if these average connectivity measures are taken to different depths of linkage from the node or axial line in question.

It is worth noting that unlike the majority of measures of accessibility which are computed for spaces within buildings or cities which use the <u>planar</u> graph of the spaces (March and Steadman, 1971; Steadman, 1983), space syntax is computed using a first-order generalisation of the planar graph in which axial lines replace street segments or room connectors, the lines themselves becoming the nodes, the junctions between streets where axial lines intersect one another becoming the links. This technique of rewriting the Euclidean geometry enables lines of sight to be handled consistently. In fact, what the technique produces is measures of connectivity which are ascribed to entire lines and this makes the data produced difficult to compare with other data in a GIS which is usually based on Euclidean space. Nevertheless, in most of the examples developed so far, the measure of accessibility (integration/connectivity) of axial lines appears to correlate quite well with street accessibility as computed by more standard measures.

As the method is based on the qualitative definition of a line of sight, it has found quite wide favour amongst architects and some urban designers who use it as their main technique of functional analysis. It is of course impossible to encode into a GIS in any obvious form but GIS is a suitable software system for its development because the technique depends upon good streetline data of the kind which is the workhorse of such software as already seen in Figures 3 (a) and (b). We have developed space syntax measures by defining a new extension to *ArcView* which is written in the scripting language *Avenue*. In essence, the user first calls up a raster or vector map base on which he/she defines a series of axial lines using a new drawing facility. These axial lines constitute the data on which measures of accessibility are computed. When these lines have been completed, the user then activates the computational routine which calculates several different measures of connectivity for each axial line. These measures can be displayed in three ways: first by colouring the axial map using a scale based on the measures, second in terms of the raw data table of measures themselves, and third as graphs of relations between pairs of computed measures. This enables the user to explore the existing syntax in some detail but also to add new axial lines and to use the technique iteratively to explore the impact of new designs on the system of interest.

When *ArcView* is first started, the user either loads the extension which has been placed in the extensions folder or accesses the online 'Help' system which has been written to provide the user with a short tutorial. 'Help' can be accessed at any point during operation of the extension. The user can then either call up an axial map that has already been drawn in the system, one that has been imported, or a raster map on which the axial lines can be drawn and then saved. Three new buttons have been added to the menu bar , one for line drawing, one for computation of the syntax measures, and one for selecting areas of the axial map for further analysis. Once the map is on screen, the user can select part or the whole of the map for syntax analysis using the 'Select' (polygon) tool. The computation of syntax measures is then achieved by activating the "Do It" button which uses a 'breadth first search' traversal of the axial line graph to find the shortest paths which are then used to compute the connectivity measures. The display of the coloured axial map shows the relative spatial accessibilities but relationships between different measures of connectivity at different depth levels of in the syntax graph are important. These can be displayed using the charting function which enables a variety of different types of scatter graph to be displayed with associated measures of correlation. A typical screen within *ArcView* is shown in Figure 6. Here the table of connectivity measures, scatter graph of levels of integration against connectivity, and axial map coloured according to integration values for Wolverhampton are illustrated as separate windows.

There are some limitations to this extension, notably the size of problem that it can handle. The *Avenue* scripting language is quite limited for numerical calculations and as in most modelling efforts linked to GIS, big problems can only be handled by writing the application in some high level language outside the system in the manner developed for example by Batty and Xie (1994) in linking spatial interaction models to *ARC/INFO*. A space syntax extension to *MapInfo* using *MapBasic* has been written which can handle larger problems than this one but the message in GIS continues to be that large scale modelling capability can only be linked to GIS by linking such models to the system using some macro language, thus disguising the fact that the application is really external to the GIS itself. The *Avenue* application here is embedded directly in the GIS but this approach is limited.

Sketching in 2-d and Visualising in 3-d

The obvious extension of GIS into urban design must involve the move from 2- to 3dimensions. There is in fact an *ArcView* extension called *3-D Analyst*, released in early 1998 which effects this translation, although the system we will describe here makes use of *Avenue* to add editing capabilities to *ArcView* and to display 3-d designs using a public domain CAD extension to a browser such as *Netscape Navigator*. Related to this capability is the notion that the user must be able to use the drawing capabilities that are intrinsic to GIS in devising new designs in 2-d which can then be visualised in 3-d. What GIS provides of course as in the previous space syntax extension is access to the entire array of other data layers which can be recalled immediately and then associated with newly sketched 2-d designs and their visualisation in 3-d. What we have not provided (although as far as we know this has only been attempted to date by Intergraph in their *Microstation CAD* products) is a fully-fledged extension of GIS into 3-d in which objects are endowed with attributes in 3-d such as floor areas, materials on walls etc. This is something that is unlikely to be possible in current GIS software and is more likely to emerge by working back from CAD to GIS rather than forward in the manner we espouse here.

ArcView provides a powerful and intuitively attractive set of drawing tools which enable 2-d sketching of geographical features as well as a rich set of map classification and symbolisation options for visualising sketch plans. We have written a series of custom scripts, again in *Avenue*, that convert these 2-d plan sketches into 3-d format which is consistent with the language *VRML 1.0* and *2.0* (*Virtual Reality Modelling Language*). The user can draw on a fresh screen or can add to an existing scene using various polygon and line tools, adding various attributes pertaining to the 3-d attributes of the scene which are then communicated to *Avenue* which produces the *VRML* file. We chose *VRML* as a means of visualising in 3-d because it offers a platform and software independent file format. The user can easily interact with a 3-d model in this form, walking or flying around it or through it, using preprogrammed sequences or moving on-the-fly. *VRML* was also chosen because is can be viewed on the web. There are many *VRML* browsers although there is still considerable variation in how they render the resulting model. We are currently using *Cosmo* which is a *VRML Netscape* plugin available free, and this must be on the desktop when this extension to *ArcView* is to be used.

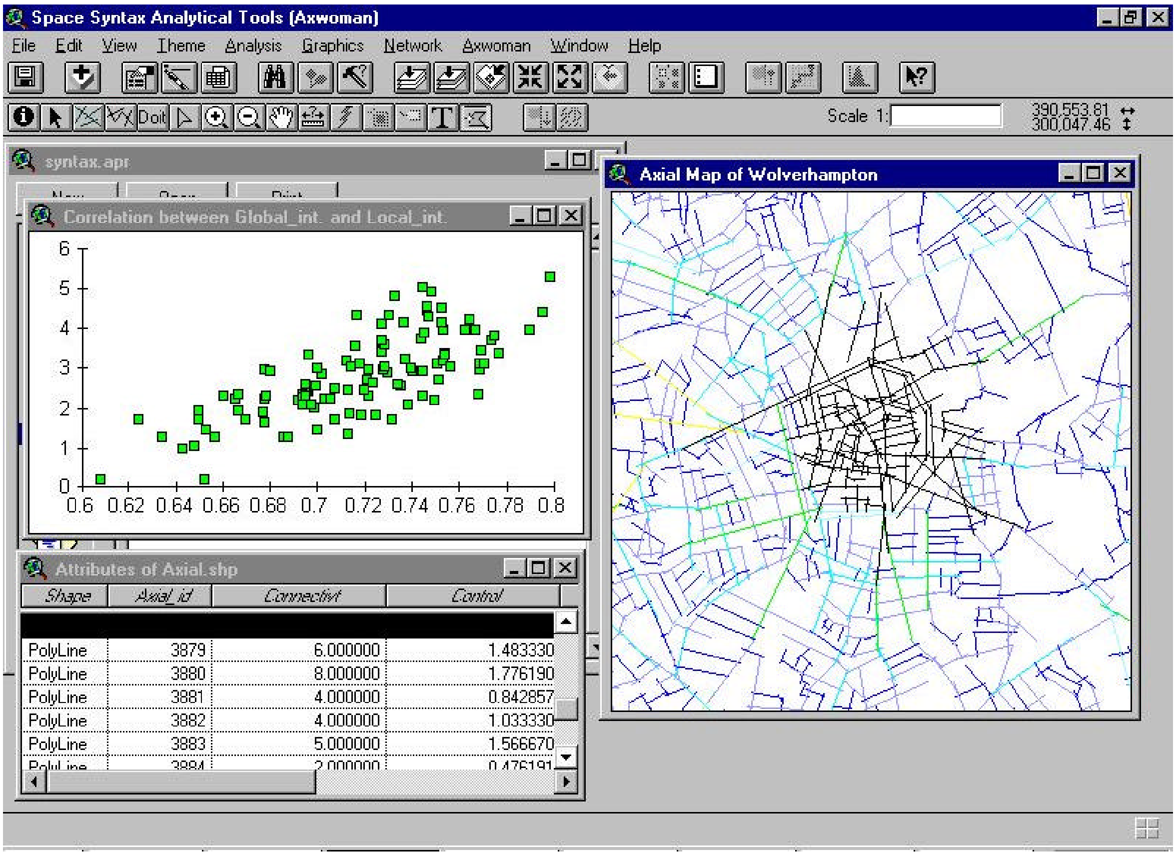

Figure 6: Space Syntax within GIS

Our first example shown in Figure 7 illustrates how we might set up some simple building blocks sketched in 2-d, positioned within some predetermined objects composed of slightly more realistic trees and highly realistic phone boxes. These illustrate that it is a simple matter to develop realistic scenes by importing images and rendering the resulting scene accordingly. The building blocks are stored and represented as 2-d polygons within the GIS, and each polygon has attributes defined by the user pertaining to height and colour which are essential for the *VRML* output. In Figure 7(a), trees are identified as green stars and telephone boxes as red squares and these are retrieved from a standard library of point features. In fact, in one application, we have produced a standard library of house types which can be selected for designing residential housing layouts. Once the user has finished sketching 2-d features and has entered the required attributes such as building heights, the layers are converted into 3-d form by clicking the relevant button on the *ArcView* tool bar. This prompts the user for a filename, writes out the appropriate *VRML* description of the scene as a text file which can the be viewed in the *VRML* browser. Two different positions by navigating inside the model are shown in Figures 7(b) and (c) with the model as a wire frame in Figure 7(d).

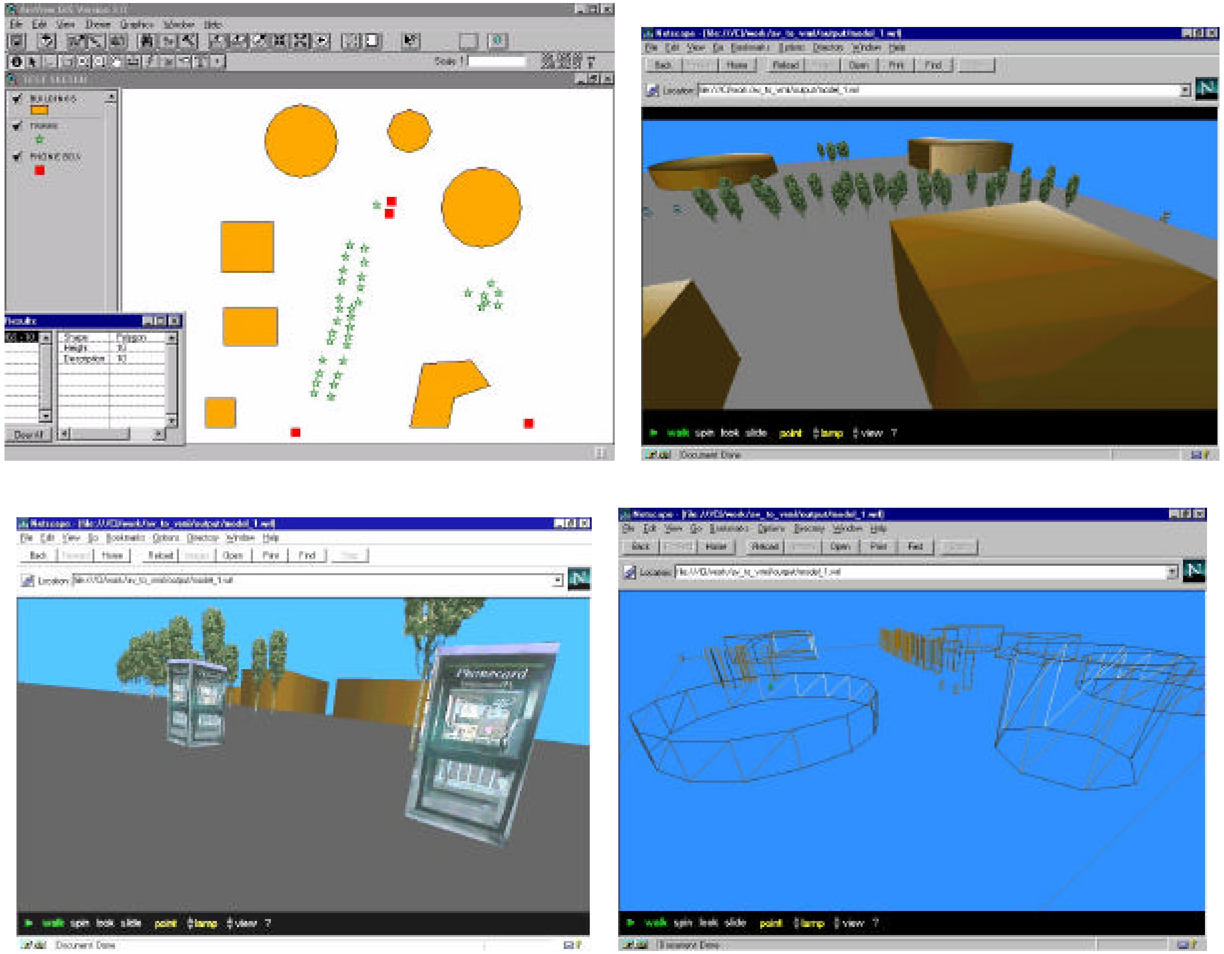

Figure 7: Sketching Building Blocks in 2-d and Viewing in 3-d

Figure 8: The Geometry of Wolverhampton Town Centre in 3-d

We can visualise much more realistic scenes using these procedures. From the Ordnance Survey Landline data in Figure 3(a), we have extracted the building block polygons which are displayed in Figure 8(a). These provide the massing of blocks within Wolverhampton's town centre but we had to generalise the vectors considerably to produce a model small enough to be viewable on average sized PCs (133Mhz, 32KB) running *ArcView* and *Netscape 3*. We have added standard height values, all the same with the exception of a couple of key blocks such as the Mander Centre tower above the central covered shopping centre. Three views of the centre are shown for illustrative purposes only. With a little more effort we could make the rendering much more realistic for *VRML* browsers are becoming ever more sophisticated but we have been limited by the problems of lighting in VRML models and by the fact that we have only assumed simple height data. Strictly speaking we require much better information about daylighting within GIS and this is turn suggests we need better links to 3-d in which height data is ordered with the same rigour that applies to 2-d data. An example of a 2-d contour surface in the town centre encoded in the same manner but with the same limitations is shown in Figure 9.

There are many other developments that we and others are exploring at the present time. Much depends upon the purpose of 3-d visualisation. If detailed rendering is required as may be the case in some urban design contexts, then these kinds of extension are less likely to be acceptable than either a move to fully-fledged CAD or to photorealism. For example, if the design problem is likely to involve the positioning of small but visually intrusive objects in an urban scene, then the kinds of 3-d panoramic views through which the user can move in a limited way using *QTVR* type software but which are completely realistic (see Figure 4(d)) and into which the objects in question - the telephone boxes in Figure 7 for example - can be introduced, are most appropriate. If complex scenes which are to be radically changed are to be visualised in detail, then there is no substitute for full CAD. In the urban design context, then the interest is more likely to be on massing and viewsheds, than on a detailed simulation of the quality of the environment, but in any event, an array of software tools including but wider than GIS will be required.

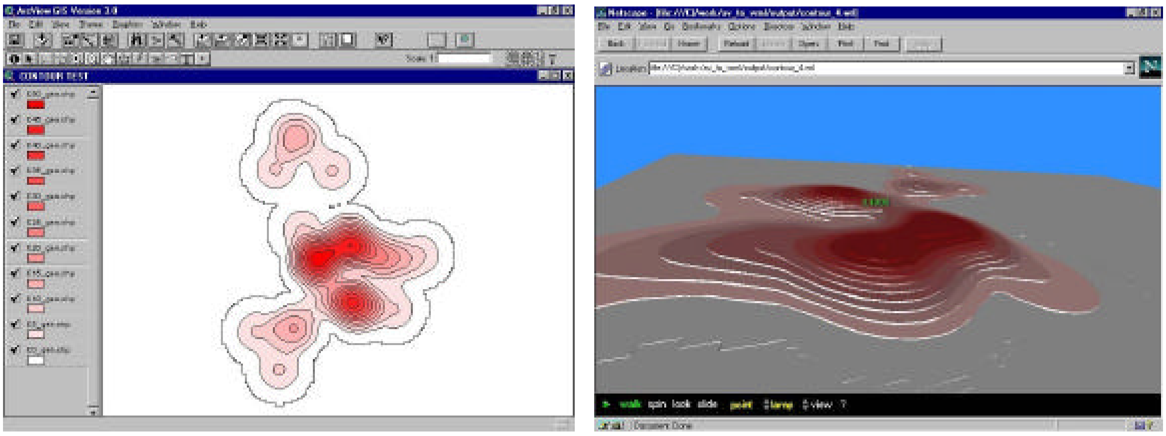

Figure 9: The Geography of Wolverhampton Town Centre in 3-d

Building Online Participatory Systems: Future Developments

So far, the various tools we have illustrated are all accessible by a single user from the desktop with the assumption that all software and data is associated with a standalone machine. In fact, urban design, as we briefly noted in our introduction, more than most other problem solving activities in policy-making, impacts on a very wide sector of the population who have clear views as to what constitutes acceptable design. Public participation in planning is more concerned with such design than any other planning activity and thus any design process must always be open to a wider set of views than those of the designer. In fact, the idea of broadening participation in design is facilitated dramatically by informating the design process in the way we have described. There are two issues that are important and we will deal with these in turn: first the notion that from any software, it is possible to link to any other on the desktop by hotlinking from within the application is important to the way users can move out of and between applications; and second, if users have the facility to leave (and return to) the software, they may leave it not for the desktop itself but for links between the desktop and other computers, hence indirectly to other users across the network.

We have already seen ways in which network-based software can be accessible to GIS on the desktop. The CAD browser that we used - *VRML* - is net-enabled and it is a simple matter to transmit such visualisations across the net using the world wide web. But to develop these ideas so that many users can participate in the same problem using the same software involves developing not desktop but internet-based GIS which currently represents the cutting edge of GIS (Plewe, 1997). Everything that we have presented here could be developed remotely so that users could log onto a server across the network, load the internet GIS and carry out the same kinds of functions - map display, querying spatial data, developing accessibility indicators using space syntax, and developing sketch plans whose display can be achieved in 2d and 3-d - that take place traditionally on the desktop. The prospect then exists for designs to be worked upon by several users, not simultaneously (although steps towards such virtuality are, in principle, possible even within internet GIS), but sequentially, supported by dialog between users across the net. For example, *ArcView* is available as *ArcView Internet Map Server* (*IMS*) which when loaded on a central server, delivers customised answer to queries from the remote client in the form of a platform independent *Java Applet* (*MapCafe*) which is a visually simplified *ArcView* interface. We are already using this software as the basis for an online environmental information systems for London which incorporates some of the multimedia we have linked to GIS here, and it would be a simple matter to extend this system to urban design which in a participatory context is not very different from that we are developing for environmental policy analysis.

A less elaborate but nevertheless effective way if broadening participation in urban design and communicating urban design data and solutions through the digital media is simply through web pages. For example, there are several web resources available for urban design such as our own (http://www.casa.ucl.ac.uk/venue/venue.html) from which there is access to several others, in particular the Resource for Urban Design Information (RUDI) which has been developed at Oxford Brookes University (http://rudi.herts.ac.uk/), and Shiffer's site at MIT (http://gis.mit.edu/projects/). These kinds of resource are rather passive but it would be straightforward matter to begin to make them interactive, to enable them so that software and data might be downloaded, and to provide means through which users might communicate concerning specific problems and ideas using web forum software. There is a plethora of free display and animation software now available on the web and the development of platform independent programming languages such as *Java* now make possible many innovative applications which in fields such as urban design which require much more exploration of the potential of digital media before working prototypes emerge, are likely to provide enormous momentum for development.

Although this chapter has been about desktop GIS and urban design, it is worth concluding by describing the way in which CAD, GIS and VR (virtual reality) systems might come together to provide environments for urban design. The idea of the virtual design studio in which participants come together over the internet to work collaboratively on design problems provides an early example of what has been developed. But more recently, entire urban environments can be set up in CAD fashion and users can remotely access these environments in such a way that they can appear as part of the environment, engage with other users who appear simultaneously but who are linked in from remote sites, and begin to manipulate the environment itself. In short, these kinds of virtual worlds can be so structured as to provide not the studio but the actual urban environment to be (re)designed. Designers or anyone who has an interest in the environment can log on, appear as avatars in such a world, converse with other users/designers who also appear as avatars, and engage in structured design and problem-solving with others. These worlds have emerged from the games industry but are rapidly becoming very realistic forums in which users can take part in serious professional activities such as urban problem solving and design. The world which is under construction at CASA in University College London is called *CVDS (Collaborative Virtual Design Studio)* and currently it is being constructed by importing realistic data contained in GIS, while rules for what participants can and cannot do, and protocols for how they behave in design and other terms are being devised so that structured design can take place. An example of the kind of interface is illustrated in Figure 10. Readers can see this world and gain access to it from the CASA web site or from http://www.plannet.co.uk/olp/design.htm) These ideas will be reported in later papers where the focus will be on the synthesis of GIS, CAD and VR through virtual urban environments such as *CVDS*.

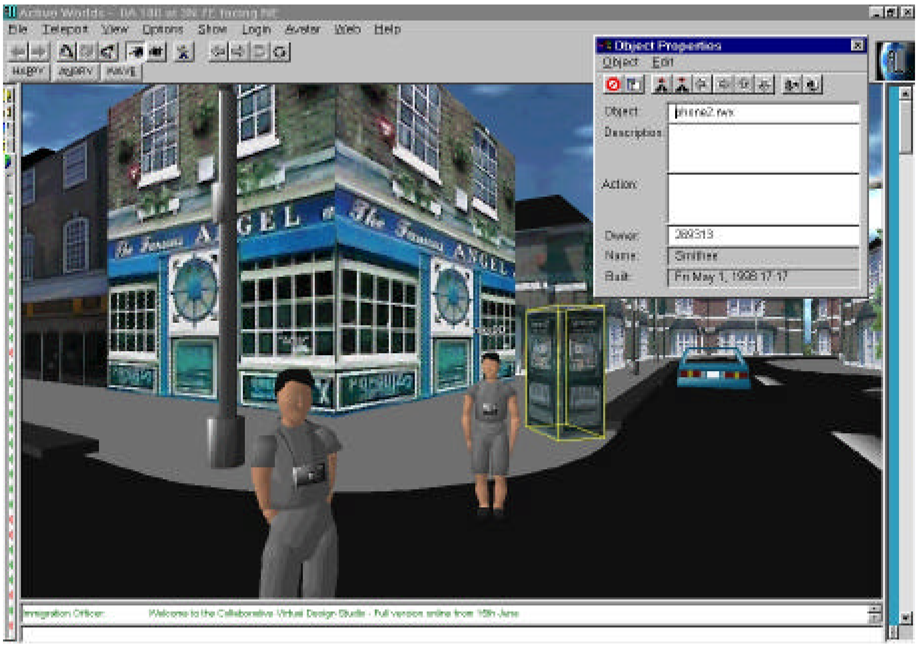

Figure 10: The Collaborative Virtual Design Studio (CVDS)

In this chapter, we have reviewed a number of different tools which provide an eclectic range of software to support urban design. In one sense, readers will not learn how to do urban design from what we have presented; in fact, these techniques taken in isolation appear as a ragbag of methods whose unification can only come from the discipline of urban design itself. Moreover, the range of issues in urban design is so great, that the intention here has been to provide exemplars such as the use of socio-economic information at a very fine spatial scale, the incorporation of multimedia with such data, the development of sketching capabilities, and the visualisation of 2-d maps as 3-d scenes. What is now required are examples of the use of these techniques by urban designers. To this end, we are developing these methods with graduate students of urban design at Oxford Brookes University where this experience is being used to make the techniques ever more usable for practical problems.

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