Models in planning: technological imperatives and changing roles

Michael Batty

Centre for Advanced Spatial Analysis, University College London, 1-19 Torrington Place, London WC1E 6BT, UK (e-mail: m.batty@ucl.ac.uk)

KEYWORDS: definitions, computer models, urban land use, transportation, urban form, GIS, 3-dimensional models, public participation

ABSTRACT

The term 'model' entered the lexicon in the 1960s when the idea of symbolically representing complex systems suddenly came of age. This was as much due to computers reaching the point where large data sets could be routinely manipulated as it was to any fundamental shift in our understanding of complex systems in science or society. As computers have pervaded every corner of our world, the idea of a 'model' no longer has the drawing power it once did. Models are everywhere. However for city systems, the role of models has been dramatically changed. Before 1950, models of cities meant architectural representations of its physical form. Mathematical models dominated the 1960s and 1970s, data models then came to dominate the 1980s and 1990s. But now the focus is once more on traditional representations of cities as digital models of three-dimensional form, thus heralding a move back to the iconic models that had dominated physical planning hitherto. In this paper, we review the development of modelling in urban research during the last half century, and suggest that new kinds of synthesis are now possible.

WHAT ARE MODELS? WHAT IS MODELLING?

Wittgenstein's [1921] early definition "A model is a picture of reality" [Paragraph 2.12, page 8, *Tractatus Logico-Philosophicus*] suggests that the basic idea of a model is rooted in the philosophy of science and in scientific method. Yet it was not until the 1950s that the idea of a model began to be used widely in science, and then the classic definition of 'model' was as 'a simplification' rather than 'a picture of reality' [Lowry, 1965]. This was the meaning ascribed to its use in the 1960s as the idea of a model gathered pace as a vehicle on which to develop good theory and applications in countless areas of the physical and social sciences. The term came into fashion first in North America where faith in science was officially translated into various large projects in defence, space exploration, and business. Advances in computing too accelerated the notion that models could be actually built and operated to make better predictions and even better designs for a variety of complex systems.

Before the mid-century, the term model was used for its traditional purpose which reflected 'scaled down' versions of the real thing which were of course simplifications but in a literal, physical sense. The term did, however, begin to enter the 'academic lexicon' as scientists and social scientists began to think more formally about complex systems. In the post-war years, the word seemed to conjure up the power of science and technology in providing tools for understanding less glamorous but equally complex domains, especially in the human and policy sciences. The idea that complex systems might be modelled, hence controlled and thence designed or restructured came to symbolise the cutting edge of quantitative social science and complex systems theory in business, defence, and government. Indeed as good a symbol of the imagery of these times as any is contained in the titles of the various works of the eminent economist-psychologist Herbert Simon whose books were successively called: *Models of Man* [1957], *Models of Discovery* [1977], *Models of Thought* [1979 and 1989], *Models of Bounded Rationality* [1982], and finally his autobiography published in 1991 entitled *Models of My Life*.

Since the 1970s, the term has become widespread, being used to describe many different types of human process or operation, from the most abstract to the most routine. Indeed as its use has broadened, its power to hold all before it has lessened while the term itself has come to describe the widest possible range of 'simplifications' or 'pictures' of reality, as well as prototypical applications and inventions. This trend can be seen quite clearly in urban and regional planning for example through the fact that fewer and fewer books are being written using the title 'model' while the term itself is being used increasingly in everyday professional language. In fact even when it first came to be used generally in a technical sense within planning, its usage was broadly based. Echenique [1972] for example, in an article characteristic of our concern for definition some 30 years ago, says: "A model is a representation of a reality, in which the representation is made by the expression of certain relevant characteristics of the observed reality and where the reality consists of objects or systems that exist, have existed, or may exist" [page 164]. His focus on what constitutes the reality as well as the model broadens this to include past as well as future systems, and as the future is unknowable, this use of models extends from the factual to the fictional, from science to design.

In this paper, our concern is not merely to recount the history of urban modelling for this has been done many times before [Harris, 1968; Batty, 1979; Batty, 1994; Wegener, 1994; Wilson, 1998] but to review this history in terms of the changing perceptions of what 'models in planning' are for, what we might expect of them, and how attitudes and practices continue to change with respect to their use. In this sense, we will exploit four themes that characterise the field. One of these – the changing significance of the term model – we have already noted but a second theme involves the way those involved in using models in planning have become more comfortable with 'abstractions', perhaps even 'theory' in thinking about the planning task. A third theme involves the changing role of data which 50 years ago was rarely thought about as being any form of abstraction, while a fourth theme involves the extent to which not only planners but their publics and clients might be involved in using abstract tools to inform their concerns and interests. These four themes – model use, the role of abstract thinking, data as models, and participation using models – involve ideas that we will weave into our historical analysis so that we might provide a balanced perspective on the wider role of models in planning.

We will organise this paper in a straightforward way, beginning with a brief summary of the way models were first introduced into planning in the post-war years. The high point was reached in the 1960s and we will argue that by then, most of the key ideas that have dominated their practical application ever since had been introduced. We will then recount how the field withdrew into itself, picking up on the way the computer revolution spurred new developments in representation, but rarely in analysis and simulation, culminating in a concern for manipulating data for more pragmatic and less ambitious ends than had been earlier assumed. As the computer revolution has continued, the quest for better and better digital representation has grown rapidly and currently is moving fast toward representing systems more realistically, thus forcing the field once again to reconsider its roots in the physical representation of cities. New kinds of abstraction have emerged which now link the digital to the real world through various interfaces which are not only opening up these kinds of representation to professionals but also to a wider public through networked communications. At the same time, new kinds of mathematical model of cities are being developed, very different from those that marked the field in the 1960s for the emphasis now is more on pedagogic use. A new pluralism dominates the field. The planner's tool box is much expanded as models emphasising representation as well as process and design characterise the field. In conclusion, we will briefly draw all these themes together, attempting a synthesis and some speculation.

IN THE BEGINNING: LAND USE AND TRANSPORTATION MODELLING UP TO THE 1960s

As we have implied already, the term 'model' within planning conjures up the popular image of a scale model of the urban environment, extensively used in architecture and urban design, and traditionally produced from tangible materials where the emphasis is upon visual appearance. In a way, this usage still remains at the heart of the mainstream, at least in the public's imagination. Indeed, one of our themes is that we have now come full circle with the same features of the city being represented no longer with tangible materials but with ethereal ones. Our icons are no longer scaled-down versions of what we see manufactured from traditional materials but digital versions of the same – digital toys – the 'toys of tomorrow' as they have been called by researchers (http://www.media.mit.edu/toys/totweb/index.html) at MIT's Media Lab. Traditional iconic models go back to prehistory but the change in usage in urban planning can be traced to the immediate post-war years. As noted, the idea of abstract 'mathematical models' of cities and their functioning was rooted to developments in systems theory, mathematics within economics, social physics and much else in the inter-war years, but the shift in thinking about cities which presages such applications did not begin until the 1950s.

The first mathematical models which emerged in North America in these years were associated with the beginnings of transportation studies, and these were quickly extended to land use and its prediction. In the 1950s, one of the watchwords of the urban planner was that 'traffic is a function of land use', and this message was to dominate the wave of land use-transport studies which followed in the wake of the massive federal highway building programme that began during those years. Two completely separate but nevertheless essential elements made such modelling possible. First for more than 50 years, a succession of researchers had fashioned a series of rudimentary theories about how urban activities located in cities. These ideas emerged from economics as location theory but were complemented by the application of classical physics to geographical problems – social physics – all of which came to be tied up in the burgeoning field of regional science which provided the early intellectual foundations. The second element related to computation. Almost as soon as digital computers were invented, their prime focus was to provide vehicles for intensive computation in science and then commerce. Cities and their transport systems provided prime candidates for these new technologies.

The final ingredient that set the world of planning humming in the 1960s was the policy context. Cities were growing and restructuring as populations became richer and more mobile, while problems of deprivation and renewal took on a new urgency. Models looked like part of the answer to getting to grips with such complexity. The story of these years is well known. A flurry of different modelling styles emerged in the late 1950s and several applications were made in the subsequent decade. The effort was over ambitious in many ways. Data constituted a problem and many efforts became morassed in data collection. Several models remained incomplete because computation was expensive and problematic. All were adversely affected by budget constraints, the organisational management of such efforts was poorly conceived but the singly biggest problems were that the models were not attuned to what policy-makers wanted [Brewer, 1973]. And in parallel, the theory on which such models were built was inevitably crude, mirroring our poor understanding of how cities worked. Many models were unintelligible to anyone but their developers and produced outputs which were often fanciful in their implications. Lee [1973] summed it all up in his famous paper '*Requiem for Large-Scale Models*'.

Problems of data remain to this day although they are changing while the computation issue has all but been solved. However the real issue related then as now to what was being modelled. In essence, cities were conceived of as being in equilibrium and thus these models attempted to simulate how activities – land uses – located with respect to one another at a cross section in time. Distance or its generalisation as accessibility held the key to such spatial interdependence. If one could develop formal relationships between activities in space based on distance – the key organising concept in social physics and transportation modelling – then models could be calibrated to reproduce the existing situation, and thence used in comparative static fashion, to make one shot predictions of what the equilibrium of a future state of the city might look like. All the models that were produced during that time made this assumption. Few if any attempted to model the dynamics of urban change for it was assumed that cities were most often in or at least near equilibrium and thus even if their dynamics were modelled, these would simply return the city to a static, spatial equilibrium. After all, cities had looked pretty much the same for 100 years or more; at one level, they just seemed to get bigger with no real differences in kind.

Linear econometric models such as the *EMPIRIC* in which spatial interaction was implicit formed one class of models [Hill, 1965] in contrast to those non-linear structures which attempted to model spatial interaction explicitly such as Lowry's [1964] Pittsburgh model. Models based not on simulating the existing city system but on optimising it according to various predetermined 'planning' goals were also attempted as were more behaviourally based models which linked economic optimising to location decisions [Batty, 1972]. All these models operated at a fairly aggregate level in that census tracts and traffic zones formed the level at which cities were represented. This immediately introduced a level of abstraction into the process that took these models away from physical design. In short, these models were aggregative, static, physical and spatial in focus, simplistic in the way they treated urban behaviour, but rather abstract. Thus they were hard to relate to structures on the ground which made them remote from those interested in and entrusted with making decisions about the future form of cities.

From our current vantage point, this early effort always seemed doomed given the conditions under which such models were built. Their failure to address policy issues directly was their downfall but the real critique resided in our ignorance of how cities actually worked. We will return to this later but for the moment it is important to note how this early experience conditioned later developments. Three distinct approaches emerged from these models, each of which complements and has influenced the others to different degrees. The most obvious was involved in the extension of these models to embrace other sectors. These models came to be nested in wider spatial and aspatial economic and demographic structures which enabled populations and employments to be handled in a more integrated way. As part of this, some of these models were generalised to operating over discrete time intervals but their structure is little different from those of the 1960s. They are still static and aggregative in form, notwithstanding the fact that they can now deal with many sectors and many other kinds of spatial flow [Wilson, 1974; Batty, 1976].

The second type of model involved true disaggregation of the spatial units defining cities into individuals. Developments in transport modelling around the idea of discrete choice which is strongly linked to economic preference theory are central to this. Such models, although still largely static, are able to treat space and time as attributes of the choice process, and thus have considerable potential for supporting contemporary views of the city as a system in perpetual disequilibrium. Such models allow much finer tuning of spatial behaviour and have been embedded within wider model structures based on microsimulation, but their performance in mirroring real behaviour has been worse than their aggregate cousins [Ben Akiva & Lerman, 1985]. The third type of model represents a synthesis between both the aggregative and disaggregative but through the notion of economic optimisation. Optimisation had always been a theme in urban modelling given the policy context of urban planning and the idea of providing some unification to the field by linking the way activities actually located to how they might best locate, was an important quest. In many senses, this unification has actually been accomplished in particular through the linking of spatial interaction modelling with discrete choice theory in terms of entropy-utility maximising although few operational models have emerged from these insights [Wilson *et al*, 1981].

What is particularly important is that many of these approaches first developed in 1950s and 1960s are still highly significant 40 years later, and are a part of a new impetus in land use-transport modelling, at least within the United States. In fact, world-wide there are really only two serious practical efforts which continued from these years, notwithstanding the many individuals (like the author) who have continued to work in the field. These are the *DRAM-EMPAL* efforts of Putnam at the University of Pennsylvania which can be traced to a modification of Lowry's early Pittsburgh model and which has now been quite widely applied over the last 30 years to many cities in North America [Putman, 1983, 1991]. Then there is the Lowry-based *MEPLAN* model developed by Echenique at the University of Cambridge which has been widely applied in Europe and South America [Echenique, 1994]. Both these efforts have continued through spin-off consulting companies rather than in the university environments that nurtured them. Although both have embraced disaggregation and some individual behavioural simulation, they are still aggregate and static and suffer from all these shortcomings, which is not to say that they are not useful for particular problem contexts. There are various efforts such as the *TRANUS* model which have spun off from the Echenique work [De La Barra, 1989] but the model systems developed by Wilson at Leeds, Kain at Harvard, Brotchie at CSIRO, amongst others, although existing for 20 years or more, had gone by the early 1990s. Individual efforts such as Wegener's model at Dortmund and Anas's at Buffalo have continued but these are one-off efforts without applications to other cities. New efforts such as Waddell's [2000] *UrbanSim* model are significant and we will return to these later. Wegener [1994] provides a very good summary of applications world-wide which although nearly 10 years old, still provides a useful measure of where the action is. His recent paper updates this experience in the light of the newer, less operational models that we will now describe [Wegener, 2001].

DIVERGENT DIRECTIONS BUT A REAWAKENING OF INTEREST

There have been many commentaries on the first and subsequent waves of urban modelling up until the 1990s [see for example, the papers by Batty, Harris, Wegener, Klosterman & Lee in the special issue of the *Journal of the American Planning Association*, 1994]. All of these argue, to a greater or lesser extent, that although logistical issues were largely responsible for the failure of these efforts to become institutionalised within urban policy-making, the real difficulties lay in deeper concerns, in questions of theory and of policy relevance. The way cities were conceptualised as being in equilibrium, being focused around simple processes of movement, interaction and location, and as being organised into homogeneous areas, have been thrown into grave doubt in the last 30 years as we have moved from industrial to post-industrial society and as the economy has become global. The way policies could be tested and explored in these models was also in doubt. Most of the models which became operational were focused on a narrow range of issues from a policy standpoint – urban growth, transport infrastructure – but not on questions of spatial equity, redevelopment and renaissance, ghetto-isation, housing market analysis and the like which are intrinsically more difficult to associate with unambiguous spatial effects. In short, if anything, the first and later generations of operational models were 'too spatial', ignoring effects on other sectors and groups as well as being unable to deal with competition in time.

The disillusion with aggregate static models based on land use and transport was already evident by the time Lee [1973] presented his critique. In particular, the inability to provide sectoral detail and to orient such models to deal with explicit economic behaviour was being challenged by the development of discrete choice theory. The failure of these models to deal with time and process however required a somewhat more fundamental shift. Apart from Jay Forrester's [1969] somewhat iconoclastic attempt to change the ground rules of urban modelling from space to time through his systems dynamics ideas (which in fact considerably energised the field), ideas about how to treat time in ways other than simple linear progressions of cause and effect were being radically reviewed in science and mathematics itself. The idea of discontinuities in smooth change through notions of catastrophe and chaos came onto the agenda during those years and various groups began to speculate as to how such ideas might account for spontaneous and radical change in cities such as the growth of 'edge cities' for example. Models based on structures that allowed bifurcations in growth paths, enabling surprising or novel change to take place, were developed at different scales by Wilson [1981] in the spatial interaction paradigm, by Allen [1997] through ideas from non-equilibrium physics, and by Dendrinos [1992] through ecological models and chaos theory. But in all these cases, the models were not conceived to be operational in the same way that their predecessor models of the 1960s were designed to be.
This was as much because noise and variation constitutes a major element within the processes which such models

simulate and hence deterministic outcomes are not the main focus. In the last decade, a further twist has occurred as the focus has moved back to ideas in social physics, in scaling and in the far-from-equilibrium processes that such signatures imply. This is bound up with yet further disaggregation of urban processes and states to the point where individual agents and actors are being simulated. Such models focus on the way local actions generate global outcomes, on the way system properties emerge from the bottom up, and on the way systems maintain critical levels. Such is the essence of complexity theory and although many different kinds of urban model are currently being explored, few if any of these have operational content or focus as a brief review of the literature associated with these kinds of efforts reveals [see for example, Batty & Longley, 1994; Portugali, 2000].

In the 1970s the demand for operational urban models did decline although by the late 1980s, the need for systematic frameworks for dealing with land use-transport interactions was evident once again. Federal mandates in the US required municipalities to assess the impact of pollution on local communities generated by new road building while the problem of sprawl set against new ecological concerns raised the need for some large-scale systematic assessment and predictions of the impacts of urban growth. Traditional urban models are once again being seriously considered for application with the *DRAM-EMPAL* and *MEPLAN* frameworks still at the core of such applications. In Europe, the *MEPLAN*, *TRANUS* and Dortmund models are being made consistent with one another through various Europe-wide projects in terms of data and output media and their link to evaluation processes. In North America, other modelling efforts such as Landis's [1994] California Urban Futures Model (*CUF*), Waddell's [2000] *UrbanSim*, and a series of variants that build on these are being applied [Schock, 2000]. Most of these types of model fall within the traditions established through regional science and transportation modelling back in the 1950s and 1960s but interestingly, there are other traditions emerging which seek to provide a rather different focus on urban growth, geared more to representation than to urban process, to physical growth rather than economic structure. To provide some completeness to our discussion, we need to identify these.

In the 1960s, the idea that land use generated traffic and that any model must track such interactions was central to most of the models then built. But there were significant exceptions, in particular Chapin's effort in North Carolina where the emphasis was on the land development process as a driver of urban growth. The models that Chapin and his colleagues proposed [Chapin & Weiss, 1968] were concerned with the growth process and in this sense focused upon the way growth took place through time, growth being a function of the physical infrastructure and accessibility within different parts of the city. This concern for modelling growth through time resonates strongly with current concerns involving urban sprawl. In some senses, Landis's [1994] *CUF* model is close in spirit to Chapin's original efforts although a much closer parallel is in the spate of urban growth models based on cellular automata ideas which have suddenly mushroomed in North America through the efforts of the US Geological Survey to get to grips with urban dynamics and sprawl [Schock, 2000]. These models are also much closer to ideas that are being developed for new ways of treating dynamics in cities, and to notions about cities in terms of their physical morphology. They generally do not contain any processes which incorporate spatial interaction in that urban growth is simulated as a process of diffusion with various types of infrastructure both driving and being driven by the growth that takes place. Insofar as there are explicitly dynamical processes at work in such models, these are ones of local diffusion in the presence of various constraints and noise.

In many ways, these urban growth models are much more pragmatically structured than their traditional counterparts based on spatial interaction. In fact, their appeal to cellular automata ideas is largely incidental. They rarely invoke the strict limits of CA, and hence they are better termed 'cell-space' or 'grid-space' models. One of their main advantages is that they are closely consistent with the functionality and data associated with contemporary GIS, particularly raster based data such as satellite imagery which provides a superb backcloth for a study of the dynamics of urban sprawl. But such models have not been developed in the depth associated with more traditional models and there are clear dangers in developing such untested and untried models for operational policy purposes. Nevertheless, it is worth illustrating the state of the art at this time with one such model in this newer tradition. Batty *et al* [1999a] are developing such a model for the town of Ann Arbor in Michigan where there has been substantial urban sprawl over the last 20 years. One of the features of this model is that it makes use of various mechanisms involving diffusion and capacity constraints as well as differential interaction fields around cells of development, although spatial interactions are not computed explicitly. It takes data from desktop GIS packages such as ArcView and it simulates growth (and decline) starting from a set of seed sites consistent with urban development between two points in time. In Figure 1, we show how the model is able to generate growth consistent with capacity constraints, thus illustrating how the model's dynamics work. In Figure 2, we show various scenarios for growth between 1990 and 1995 from the set of seed sites which form the development from 1985 to 1990.

In a paper such as this, it is not possible to present how any of the models actually work although Figures 1 and 2 illustrate how far we have come in the last 40 years in developing software and data which can be used for widespread exploration of new model forms. Moreover, the software that we have developed is characteristic of the shift from simulation to representation which has occurred in this field in the last 20 years, as there has been a sea change towards digital representation through graphics and GIS. In the next section, we will change tack and examine this revolution in spatial representation but suffice it to say that in the millennium, the mathematical models of cities that we currently have at our disposal are not very good, they are inconsistent with respect to what we know about cities and what we require of urban policy while those that have been explored most represent a way of thinking which is no longer popular. A particularly timely review of the field with respect to operational modelling has recently been provided by Schock [2000] for the Environmental Protection Agency but it is hard not to draw the conclusion that more modest, data-driven approaches based on GIS might in many ways be preferable for urban policy analysis.

REPRESENTATION: MODELS AS DATA AND THE GIS REVOLUTION

The problems that led to the demise of the first generation of urban models produced a very different digital cutting edge to urban planning in the 1980s and 1990s. Our inability to deal with large data systems and the unwieldy nature of computer technology in the 1960s was already changing as the first generation of urban models became operational, but in 1971, the 'microprocessor on a chip' was developed and by the late 1970s, it was clear that computer power would never again be a problem in the development of large-scale models. Moore's Law, now enshrined in the history of miniaturisation, suggests that computer power (and memory) roughly doubles every 18 months, and by the 1980s, graphics and text processing were becoming the predominant applications. In fact, during the 1980s when many main-frame and workstation software applications were being translated into proprietary form and ported to microcomputers, urban models were conspicuous by their absence. Momentum in the field was at such a low ebb that there was little activity in such development and by the time the field woke up again in the mid 1990s, there were few if any applications that utilised the then current power of microcomputing in making generic applications widely available. It might be argued that the market for urban models was too small for such development but those who were still in the field did not attempt to open their software in this way, and they failed to utilise new graphical user interfaces and the range of map-based software that became available. Only now are such efforts under way.

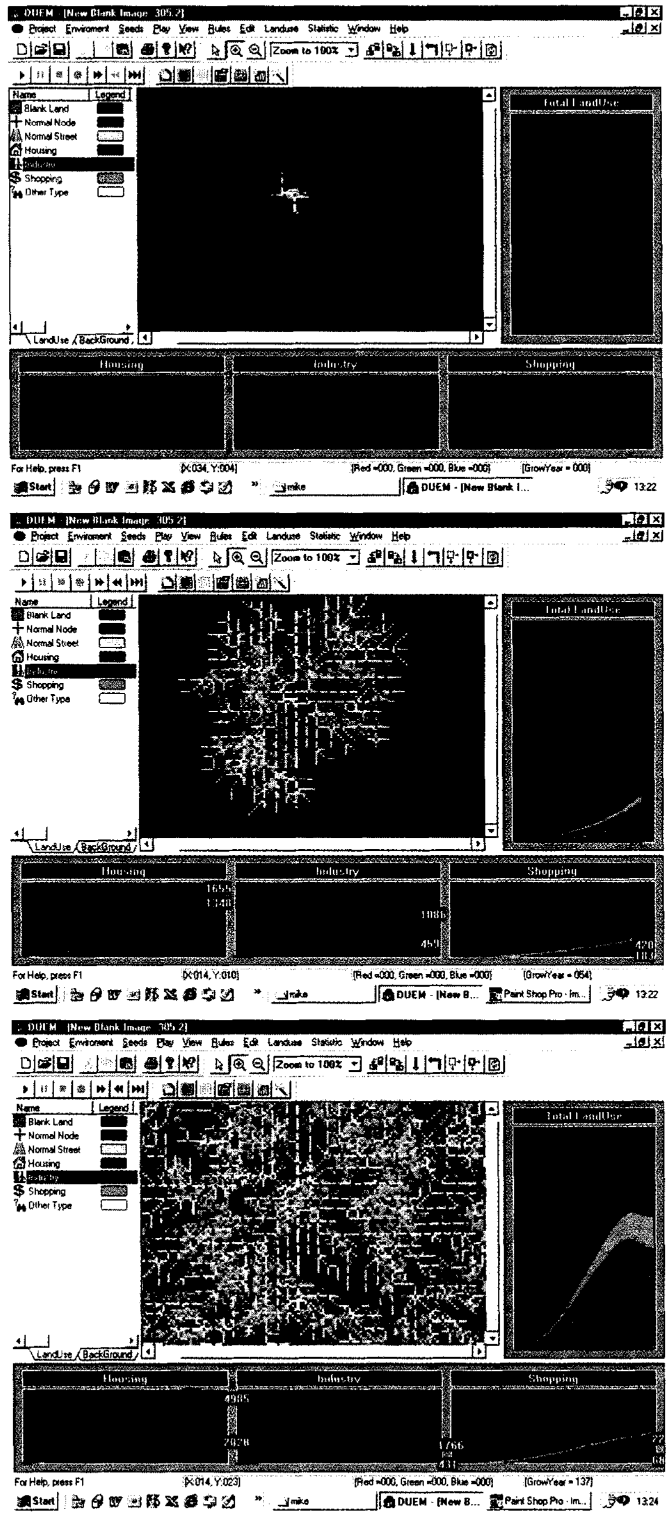

FIGURE 1: New simulation models: urban growth based local diffusion using CA.

In terms of the development of computer methods for planners, what in fact happened was the development of more modest tools based on techniques nearer to the data. In many ways, the development of geographic information systems was an obvious step in moving to a digital world for the processing of maps and storage of their data has very wide applicability, much large than planning *per se*. GIS originated from a synthesis of three

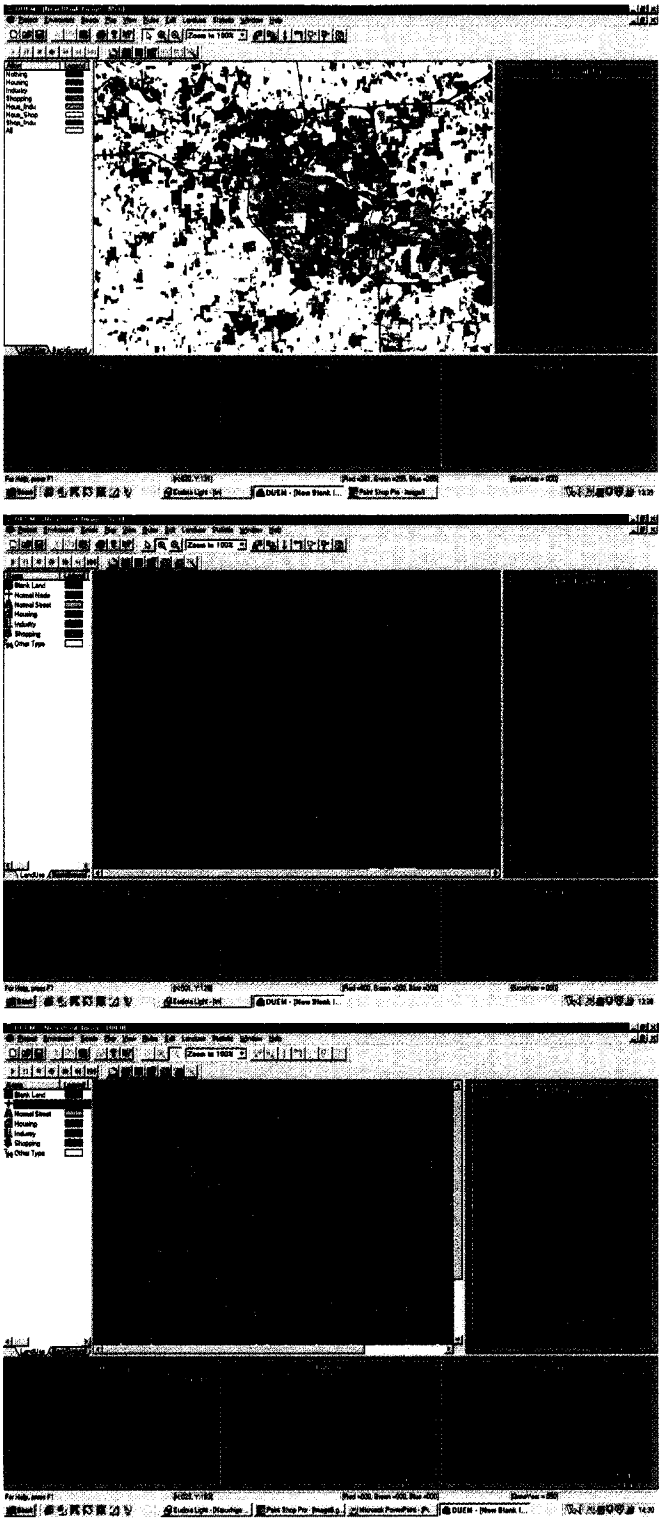

FIGURE 2: Simulating sprawl in the Ann Arbor, MI region.

related areas – from spatial data base technologies that involved developments in how to represent points, lines, polygons, raster structures and so on, from computer cartography where the concern was the automatic production and generalisation of maps across many scales, and from ideas in representing layers in the landscape – from landscape architecture and planning where the notion of associating many data layers together had been a central concern in the development of that field. In fact early line plotting of maps as in SYMAP (SYmbol-MAPping) were based on such associations. By the late 1980s, packages were being marketed which had obvious uses in urban planning, if only for automated land use mapping. But once desktop GIS began in earnest in the early 1990s coinciding with the Windows operating system, then most municipalities began to employ such tools.

The functionality within GIS for modelling and related kinds of urban analysis is still quite limited. Apart from quite elaborate methods for overlaying different maps of data layers and for operating numerically on the process of overlay, most functions need to be added through specialist plug-ins. However the data layer approach is important in that there are many areas of the planning process, particularly those dealing with growth and location, that require such overlay capabilities. Most of the plug-ins to date involve accessibility and network calculations, spatial interpolation and viewing functions, and more recently extensions to 3-dimensions which we will illustrate below. As yet there are few plug-ins for the kinds of tools that were presented a decade or more ago by Brail [1987] in his book *Microcomputers in Urban Planning and Management* where the software used was non-graphical, based on spreadsheets. In fact, the kinds of software that we illustrated in Figures 1 and 2 is still rarely available in that GIS vendors, although intent on adding functionality for planning where there is a market, are less inclined to develop mathematical modelling applications that they still see as somewhat esoteric and controversial in their use.

It is important to note the range of tools that GIS and related software offer planners across their range of tasks. Clearly part of GIS are issues involving the organisation of a planning municipality's data bases in more general terms from routine planning applications and permits to the archiving of map data that might be used for public as well as professional services. In terms of the professional planning process, GIS has many uses at different scales from the regional to the local urban design scale and perhaps even down to the building level. Much of this usage depends upon attitudes, for use of digital technologies requires users to think of their problem in abstracted terms, to think of their system as a model and their professional activity as the use of that model in a problem-solving process where outcomes are then deliberated upon. Moreover, new kinds of data at the fine scale can only be accessed and unlocked using GIS, thus requiring the users to be expert in the digital manipulation of planning data. In Figure 3, we show how data associated with many different types of activity defining the Central Business District of the English town of Bristol can be displayed, smoothed and thence aggregated into layers that are used in defining boundaries. This requires considerable knowledge of statistical operations for smoothing that are embodied in the functionality of many contemporary desktop GISs but it also requires professionals who are able to exploit this kind of usage. In short, GIS provides a toolbox which can be adapted to various kinds of applications which are only limited by the imagination of the user.

One of the reasons why urban designers have been so slow in adopting such technologies is because the subject matter of their design does not embrace the hard data that is available at the most local level. Moreover, they are unaware too of how easy it is to embed multimedia into GIS [Batty *et al*, 1999b]. In Figure 4, we show how various kinds of media can be added into desktop GIS for centre of the English town of Wolverhampton, and the use of these data, displays and technologies implies that we need to think of the problem in more abstract terms. GIS of course can be used in much more routine contexts, such as in the control of development but its real power is not so much in providing a purpose-built set of functions for a typical planning task but in providing a toolbox which can be linked to other software in ingenious ways. In this, the prospect of building mathematical models and linking these to the data models provided by GIS, which in turn can be linked to a range of visual and statistical software, probably marks the most appropriate use of these new digital technologies in planning. Moreover this bottom-up use of software provides a constraint which increases relevance, applicability and also feasibility in that decisions as to how to combine these low level tools and functions are left to the user who is engaged in the planning problem.

This shift to low level models which have largely taken the place of those operational mathematical models fashioned a generation or more ago, is not all based around GIS. In fact although GIS now represents the most effective focus of this kind of basic tool, other software has and continues to be used extensively within urban planning. Spreadsheets represent the most widely employed generic tool for mathematical modelling as reflected in the variety of applications collected together by Klosterman *et al* [1993]. Recently various plug-ins such as those based on the GIS MapInfo have been

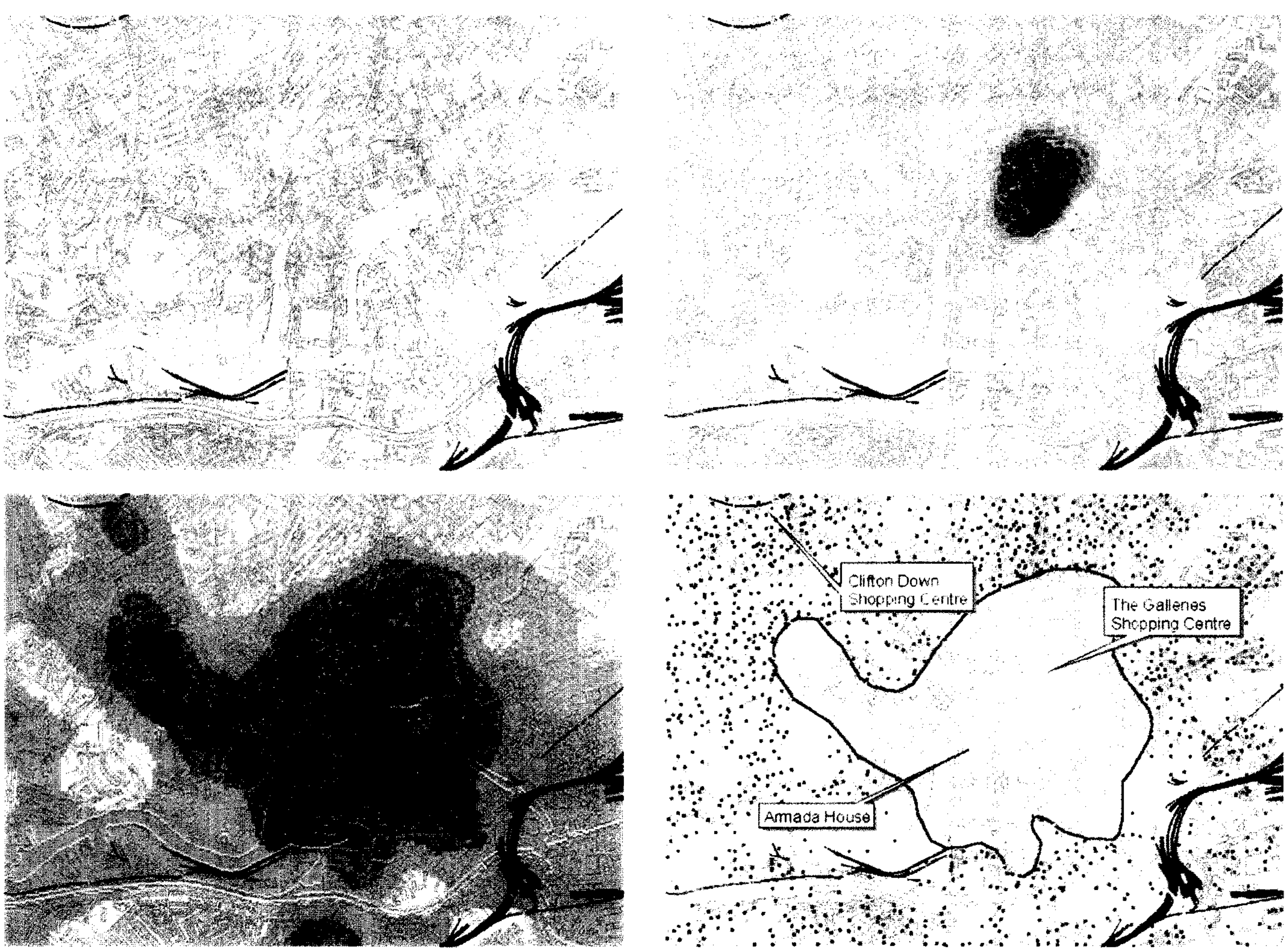

FIGURE 3: New models of urban data at the fine scale: defining a central business district through smoothing and aggregating diverse data layers which define relevant urban activities in Bristol, UK.

linked to the spreadsheet Excel and these kinds of software continue to expand to embrace yet more statistical and related tools. It is now possible to develop extremely elaborate models within a spreadsheet such as Excel and to link this to a variety of other graphics media. Many possibilities abound and the fact that there are so few applications probably reflects the fact that the range of possible applications is so great in comparison to the numbers of researchers and users there are in the field. Few have the time and ability to fashion such extensions, and there are enormous opportunities for the development of new software and applications in the domain of urban planning. Other software too is worthy of note such as the various development of graphical model-building software from Systems Dynamics-like programming such as STELLA to fully-fledged programming environments such as that contained within Mathematica.

Before we turn full circle and show how this new representational point of view is beginning to collapse back into the use of icons, it is worth noting that many of these programming and data environments which imply low-level modelling are in turn changing. Increasingly every piece of software is becoming open to every other and it is becoming possible to develop generic models in many different media. Moreover the way models and data are now being communicated and accessed is increasingly important – not only on the desktop but over the net and in various immersive contexts – and this is beginning to change not only what is simulated and what is communicated but also who is involved in model design and use. We will return to these issues in the penultimate section where we examine how computers are opening up the planning system to wider participation but before this, we must review where we stand on new forms of representation.

MOVING MODELS BACK TO ICONS: REPRESENTATIONS, IMAGES, DIGITAL TOYS

The idea that computers could be used for graphics goes back to the very beginning of the computer era when the pioneers used oscilloscopes for monitoring the workings of the first machines and realised that the scopes could be 'programmed' to produce pictures of various kinds. Indeed the very first arcade game 'Pong' commercialised

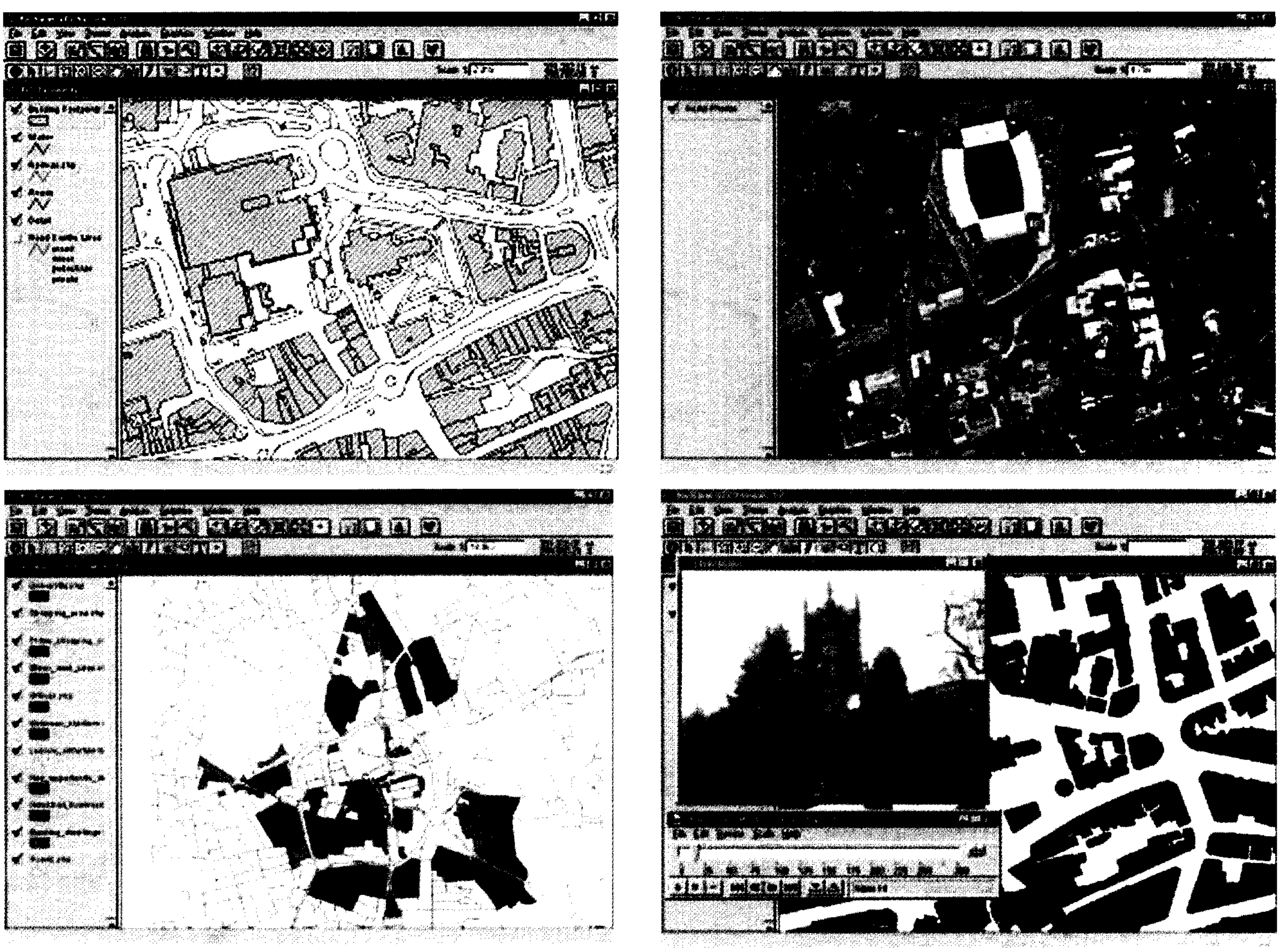

FIGURE 4: New data models for urban design: articulating the local design factors digitally in the town centre of Wolverhampton, UK

in the early 1970s by Atari, was one of the first graphics ever illustrated from a digital computer first shown on US television in the early 1950s. Although it took the micro-revolution to raise graphics to the level where it has become the dominant digital technology, the first attempts at putting the traditional iconic model of the city into a computer go back to earliest days of CAD. The wire frame fly through of buildings in downtown Chicago by Skidmore, Owings and Merrill in the early 1980s showed what was possible but widespread use of these kinds of 3D technologies did not occur until quite recently.

CAD began almost as soon as the personal computer began to invade the market. For example, many 3D architectural and city models have been developed in AutoCAD and with the growth of the web, various internet equivalents such as VRML are being used for display and navigation. However such models are relatively superficial and their usage has been confined to presentational purposes. Although such CAD invokes the idea of design, such design is always offline. In fact, contemporary CAD models of cities are rather limited in that all that one can do with them is use them for visualising changes to the urban geometry. The geometric structures that they form rarely have any content – data – other than that associated with building rendering, and hence their use in anything other than design review is limited.

The dominant thrust which is returning planning and urban design to these digital icons is not from CAD but from GIS. 3D visualisations represent another way of viewing spatial data and in many senses these complement the 2D map view. Many GIS packages now have extensions which enable 2D map data to be extruded into 3D where the 3D content is some spatial attribute. Spatial patterns and errors in data can be more easily visualised in 3D while the ability to pan and zoom enables detail to be examined in a way that is not possible in a map view. In fact, 3D views are very effective ways of looking at multiple patterns in the data. For example, the density of any activity is often taken to mark the third dimension and if this is used, then a further variable can be coded into the scene. If several such scenes are displayed together, then some packages offer ingenious hotlinking that enables users to explore the data by brushing and examining correlations and other associations between different scenes. In Figure 5, we show population density in the London Borough of Westminster which is illustrated as a 2D map and 3D block model using the plug-in 3D Analyst which is part of the desktop GIS ArcView.

Recently we undertook a worldwide review of 3D digital models for the Corporation of London [Batty *et al*, 2001] and concluded that CAD models no longer represented the cutting edge of such technologies. Users now require iconic models in digital form as a means to accessing data, rather than for solely generating aesthetic impacts or providing visual form to their designs. Upwards of 80 serious applications now exist worldwide with GIS and various spatial database technologies representing the predominant means for such model construction. Realism in terms of rendering although important is also being automated through various photorealistic imagery while height data is being sourced through remote sensing of various sorts. For example, in Figure 6, we show once again using desktop GIS, a 3D visualisation of the area around St. Paul's Cathedral in the City (of London) where the building blocks have been taken from crude LIDAR data, the Cathedral itself being constructed from the several thousand points generated by the laser-based technology. This is the state of the art and very shortly

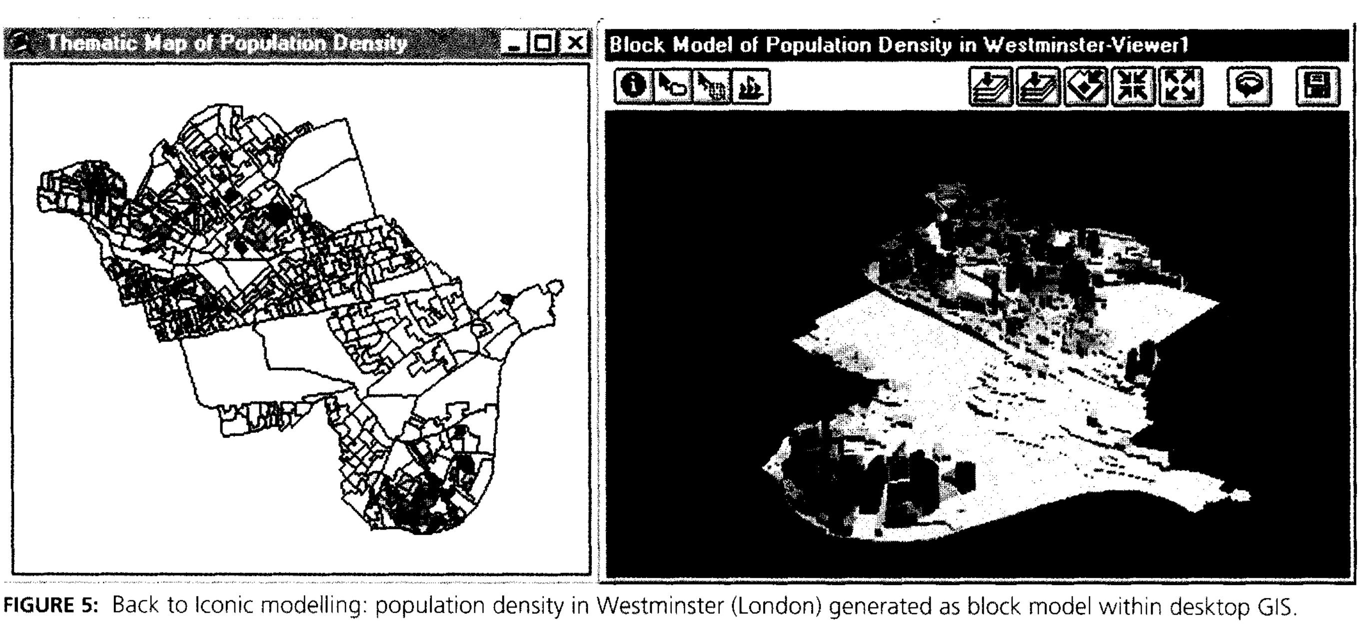

FIGURE 5: Back to Iconic modelling: population density in Westminster (London) generated as block model within desktop GIS.

such models will be generated on the fly as satellite data at the requisite level of resolution becomes available on a daily basis.

One of the main themes in this paper involves the way the idea of the computer model of the city has changed during the last 50 years, and our implicit argument that we have come full circle is clearly being borne out by the flurry of 3D digital block models of cities that are currently being constructed. Yet this circularity is never what it seems. This is no mere return to a world of the architect's models where the focus is purely on visual evaluation. As we shall see in our concluding section, access to these new digital icons is very different from the pre-computer age. The visual simplicity of their form belies their true purpose which is much more likely to be as an interface to a complex and interrelated data base where 3D visualisation is but one way of accessing the data and managing this complexity.

However there is another set of applications which is likely to convolute these examples even further. We have already implied that new functionality is being introduced into GIS which is extending their use from representation to simulation. The same is occurring in 3D. Already there are traffic models where the representation enables actual car movements to be simulated mathematically and visualised in 3D while there are experiments to show how various kinds of model process can be embedded within 3D virtual environments of the kind visualised above. This is the point at which the models themselves must match the level of representation and it implies that the kinds of models that are suitable are those which are less abstract, more micro in scale and form, as well as dealing with routine dynamics processes that might be captured in dynamic realisations of the 2D map or 3D geometry in question. For example, work at the Environmental Simulation Center (http://www.simcenter.org/ Projects/ CommunityViz/communityviz.html) in New York City for the town of Scutney in New England has developed a visualisation of an agent-based model of community development, tying its mathematics back to data as well as to 3D icons. We have ourselves designed various models of the movement of agents in shopping centres and in galleries and have visualised such movements in 3D. In our models of movement in the Tate Gallery, we have visualised agents moving in both 2D and 3D, examining different digital visualisations and simulations of the same system [Batty *et al*, 1998]. We show some of these in Figure 7 but our point is that the argument of this paper is by no means complete. In the next decade we are likely to see many new fusions and extensions of the mathematical, representational and data models which we have through different kinds of digital media

MOVING MODELS BACK TO USERS: PARTICIPATING IN DIGITAL DESIGN

In public policy particularly, there has always been concern as to the relevance and remoteness of the science with respect to the kinds of advice that such science provides for issues that affect a wider public. However

FIGURE 6: A GIS 3D block model of St Paul's district in the city of London with height data from LIDAR data

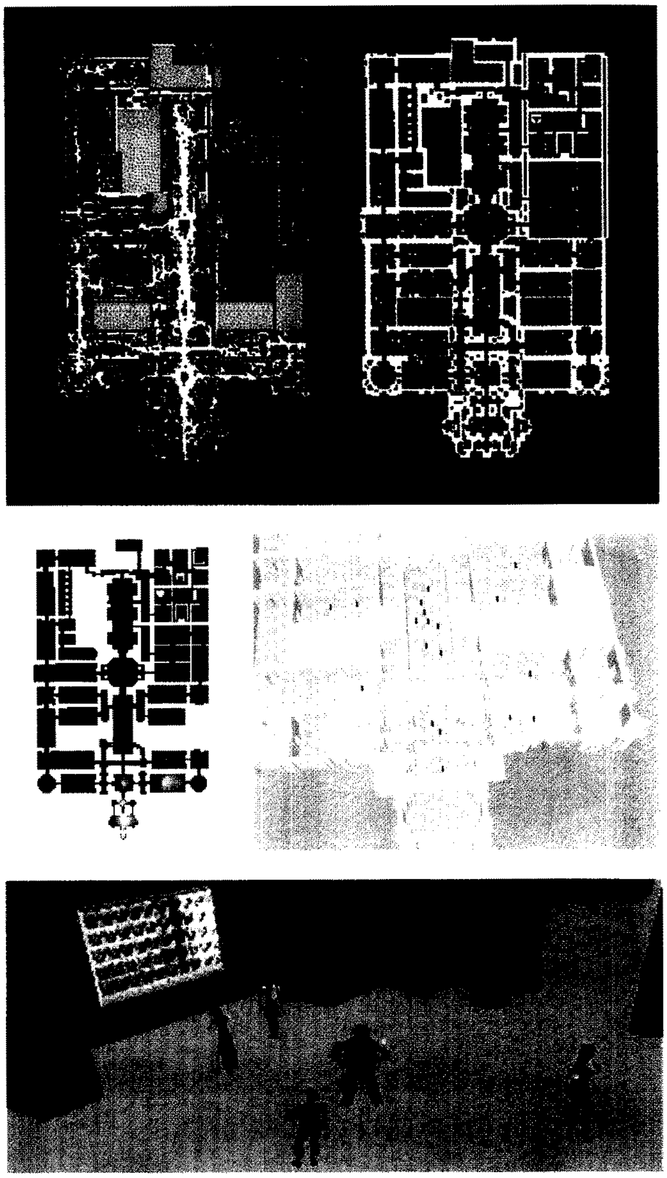

FIGURE 7: Spatial modelling at the finest scale: simulating human movement in 2D with visualisation in 3D.

attempts at developing mathematical models of urban systems in the wider context have been limited. Some attempts at providing environments in which systems dynamics models might be developed jointly with decision-makers have been tried but in general, such efforts have been laboured. However, the new focus on visualisation which GIS and VR are providing and the new concern to open up data and symbolic modelling using visual interfaces is at last providing a context in which interests other than those close to the science are able to make an impact. The notion too of providing more than one approach to the same problem is also intimately associated with this process of participation. The high degree of uncertainty in human systems is such that more than one model is usually required to provide a balanced perspective on policy-making. The process of 'counter modelling' first proposed by Greenberger *et al* [1976] more than 20 years ago is now much more of a reality in a digital world where different perspectives on any problem can be quickly fashioned from the use of different computer based tools.

There are as yet few forums in which a range of users can build models but the world wide web provides enormous potential for different users to generate their own interpretations of data and in principle, build their own models, either individually or in the presence of others. As we have noted, desktop software of various kinds is being ported to the web. Internet GIS and CAD is being gradually established and this is delivering visualisations and map data that can be viewed and acted upon by a wide range of interests. As an example of what is possible, many of the visual techniques that we have presented in this paper, are being used in an inner city context for the development of awareness about problems of regeneration and deprivation in the London Borough of Hackney. The Hackney Building Exploratory is a project which is built around conventional approaches to raising environmental awareness through non digital maps and designs and related products in the local community and this is now being supported by a complementary digital initiative aimed at public participation using digital data and icons to support the process. In Figure 8, we show some images from this project which reveals how VR, CAD and GIS can be used to unlock data and to deliver this to users across the web. This data varies in scale but the intent is to educate and communicate issues of concern in the local community. We have not sought as yet to provide users with model building capability but in the way they are encouraged to put data together, there is an implication that models are being built which reflect the interests and beliefs of those who are being affected by local planning issues.

In Figure 7, we illustrated how models of movement could be linked to virtual worlds and an obvious extension of such worlds involves ways in which users might themselves enter such environments alongside their simulated selves. This sounds like science fiction – the juxtapositions of remote but real individuals with simulated agents and their interactions – but these kinds of environment are now possible and open up a variety of ways in which simulations might be tested and modified in ways that have hitherto not been possible. There is a cornucopia of possibilities which emerges from the digital world which is being constructed and all promise to change the way we involve ourselves in public affairs and urban policy. The only limits to such possibilities are in terms of what we might imagine and this is a far cry from the earliest use of computers in planning and public policy which saw their use in purely passive, top-down contexts. In the next 20 years, there promises to be a fusion of ideas which will broaden the concept of 'models in planning' even further.

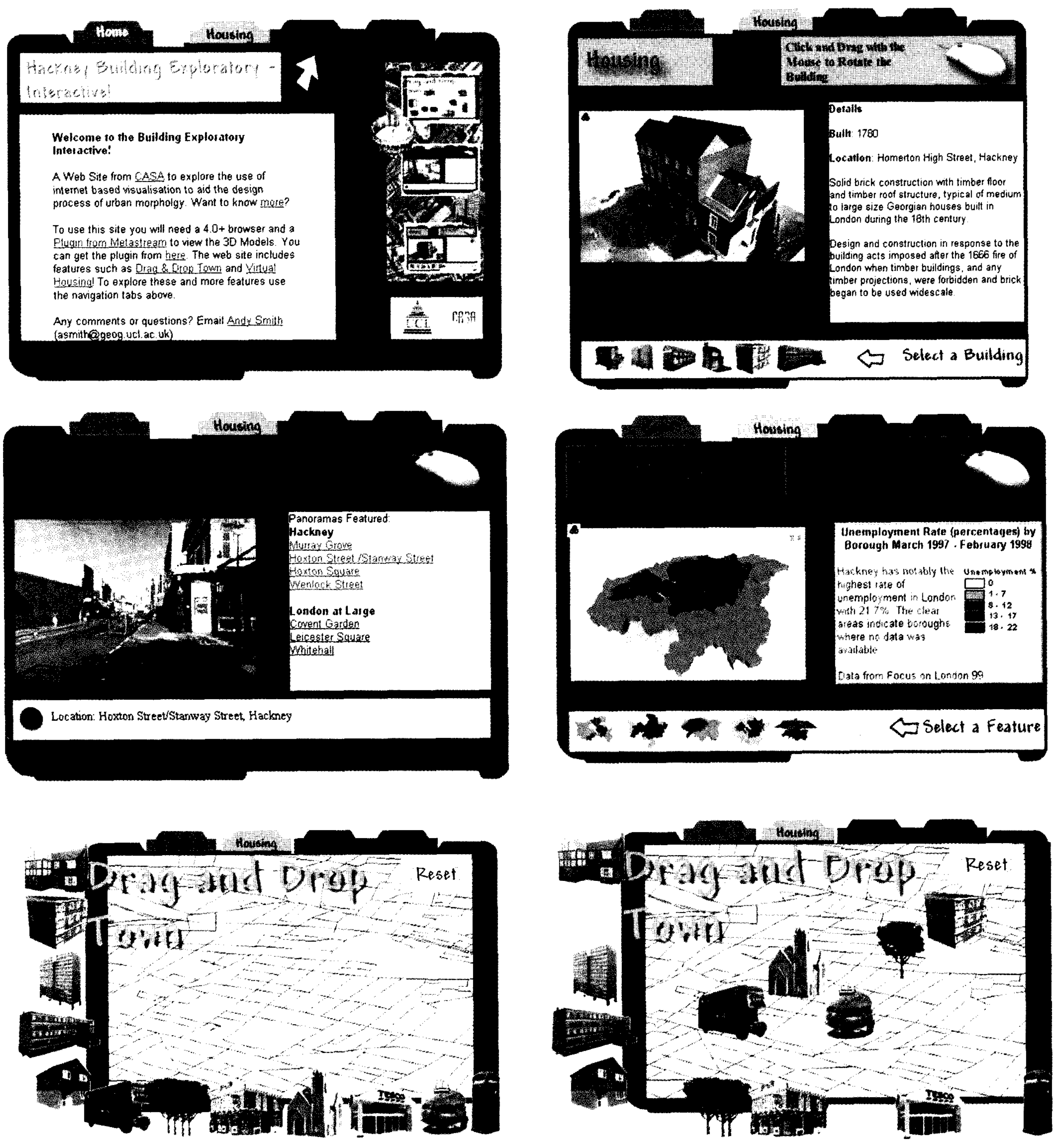

FIGURE 8: Bringing digital data and models to users: participation in environmental issues through the Hackney building exploratory-interactive

CONCLUSIONS: MODELS AND MODELLING FOR PLANNING CITIES IN THE 21ST CENTURY

The critique of models that we have developed in this paper is no more trenchant that those that have been levelled at every area of the human sciences. The effort to get to grips with social complexity in terms of its manifestation as urban phenomena, and the ideology that supposes that the human condition can be bettered by interfering in the process of urban development, is fraught with difficulty as the experience of the last 50 years have shown. We still do not have good theory about how cities function and although there are signs that researchers are becoming more aware of their intrinsic complexity, the models that have been developed are as arbitrary as those which form the conventional wisdom of contemporary economics. Moreover, human systems are ever changing as their populations innovate and develop new sets of preferences and tastes, thus laying waste to theory that once seemed applicable. The current concern for theories that make sense of complexity and change on all scales is indicative of the fact that it is virtually impossible to make meaningful predictions for such systems or at least predictions that would form the basis of medium or long term policy-making.

One of the themes that we have addressed here is that in using models in planning, we have almost come full circle and it worth pausing to briefly reflect on what we might have learned along the way. Models based on material icons, close in terms of their visual superficiality to the real thing, have been supplanted by models based on ethereal, digital forms with the same kinds of visual iconography. To progress this far, the first applications to cities involved much more abstract simulations where the focus was upon the map and the processes that held this kind of space together, but now the prospect exists of synthesising across the realm of relative realism from obvious visual imagery to social and economic processes which lie at the basis of how cities function. It is almost impossible to provide a cliché which sums up this change; absolute comparisons between a world which in the past was best explained in terms of energy to one that is now more explicable in terms of information, are not very fruitful but it is very clear that our understanding of how we need to approach the planning of cities has been much enriched during this era. Complexity is what dominates our thinking today and with this has come a cautiousness that makes us pause in using our knowledge both predictively and prescriptively. There is little doubt that the tools we now have are all the better for this but they now appear even more inadequate than they once were and it is this that marks the challenge.

Thus, new theories of cities are urgently required but these will need to be developed in much more intensive data environments than anything that we have been used to hitherto. In fact, urban studies must move to a new plane in terms of the way it treats data and develops theory, more akin to the way large-scale data systems in the physical sciences are being handled. To this end, many of the representational techniques presented in the latter part of this paper are essential in unlocking complex data sets and developing methods for searching for new patterns in the data that might provide the basis for new notions of causality and association. As ever, the world cannot wait for new theories which in any case are dependent on the very world that they seek to explain. Thus what is required is a strategy of theory building, modelling and prediction in planning which seeks to arrange techniques and models in parallel and in hierarchy, with different ideas tailored to different scales, problems, sectors and processes. Counter-modelling and modelling in parallel are now essential and the data rich environment which we have sketched here has all the potential to provide the basis for this new understanding. This we suggest will mark the next generation of urban research and policy-making.

ACKNOWLEDGEMENTS

This research has been partly financed by the ESRC NEXSUS Project: Network for Complexity and Sustainability (L326253048).

REFERENCES

Allen, P.M., 1997. Cities and Regions as Self-Organising Systems: Models of Complexity. Gordon & Breach, Amsterdam.

Batty, M., 1972. Recent developments in land use modelling: a review of british research. Urban Studies 9: 151-177.

Batty, M., 1976. Urban Modelling: Algorithms, Calibrations, Predictions. Cambridge University Press, Cambridge.

Batty, M., 1979. Progress, success and failure in urban modelling. Environment and Planning A 11: 863-878.

Batty, M., 1994. A chronicle of scientific planning: the Anglo-American modelling experience. Journal of the American Planning Association 60: 7-16.

Batty, M. & P. Longley, 1994. Fractal Cities: A Geometry of Form and Function. Academic Press, San Diego, CA.

Batty, M., R. Conroy, B. Hillier, B. Jiang, J. Desyllas, C. Mottram, A. Penn, A. Smith & A. Turner, 1998. The virtual Tate. Working Paper 5. Centre for Advanced Spatial Analysis, University College London, London. (http://www.casa.ucl.ac.uk/tate.pdf)

Batty, M., Y. Xie, & Z. Sun, 1999a. Modelling urban dynamics through GIS-based cellular automata. Computers, Environments and Urban Systems 23: 205-233.

Batty, M., M. Dodge, B. Jiang & A. Smith, 1999b. Geographical information systems and urban design. In: J. Stillwell, S. Geertman & S. Openshaw (Eds), Geographical Information and Planning. Springer Verlag, Heidelberg, pp. 43-65.

Batty, M., D. Chapman, S. Evans, M. Haklay, S. Kueppers, N. Shiode, A. Smith & P. Torrens, 2001. Visualising the city: communicating urban design to planners and decision-makers. In: R. Brail & R. Klosterman (Eds), Planning Support Systems: Integrating Geographic Information Systems, Models and Visualisation Tools. Rutgers University Press, New Brunswick, NJ/ ESRI Press, Redlands, CA, pp. 405-443.

Ben Akiva, M. & S. Lerman, 1985. Discrete Choice Analysis: Theory and Application to Travel Demand. MIT Press, Cambridge, MA.

Brail, R.K., 1987. Microcomputers in Urban Planning and Management. Rutgers University Press, New Brunswick, NJ.

Brewer, G.D., 1973. Politicians, Bureaucrats and the Consultant: A Critique of Urban Problem-Solving. Basic Books, New York.

Chapin, F.S. & S.F. Weiss, 1968. A probabilistic model for residential growth. Transportation Research 2: 375-390.

De La Barra, T., 1989. Integrated Land Use and Transport Modelling. Cambridge University Press, Cambridge.

Dendrinos, D., 1992. The Dynamics of Cities. Routledge, London.

Echenique, M.H., 1972. Models: a discussion. In: L. Martin & L. March (Eds), Urban Space and Structures. Cambridge University Press, Cambridge, pp. 164-174.

Echenique, M.H., 1994. Urban and regional studies at the Martin Centre: its origins, its present, its future. Environment and Planning B 21: 517-534.

Forrester, J.W., 1969. Urban Dynamics. MIT Press, Cambridge, MA.

Greenberger, M., M.A. Crenson & B.L. Crissey, 1976. Models in the policy process: Public decision-making in the computer era. Russell Sage Foundation, New York, NY.

Harris, B., 1968. Quantitative models of urban development: their role in metropolitan policy-making. In: H.S. Perloff & L. Wingo (Eds), Issues in Urban Economics. The Johns Hopkins University Press, Baltimore, MD, pp. 222-222

Harris, B., 1994. The real issues concerning Lee's 'Requiem'. Journal of the American Planning Association 60: 31-34.

Hill, D.M., 1965. A growth allocation model for the Boston region. Journal of the American Institute of Planners 31: 111-120.

Klosterman, R.E., 1994. Large-scale urban models: retrospect and prospect. Journal of the American Planning Association 60: 3-6.

Klosterman, R.E., R.K. Brail & E.G. Bossard (Eds), 1993. Spreadsheet Models for Urban and Regional Analysis. Rutgers University Press, New Brunswick, NJ.

Landis, J.D., 1994. The California urban futures model: a new generation of metropolitan simulation models. Environment and Planning B 21: 399-420.

Lee, D.B., 1973. Requiem for large-scale models. Journal of the American Institute of Planners 39: 163-178.

Lee, D.B., 1994. Retrospective on large-scale urban models. Journal of the American Planning Association 60: 35-40.

Lowry, I.S., 1964. A Model of Metropolis. RM-4035-RC. The Rand Corporation, Santa Monica, CA.

Lowry, I.S., 1965. A short course in model design. Journal of the American Institute of Planners 31: 158-166.

Portugali, J., 2000. Self-Organisation and the City. Springer-Verlag, Heidelberg.

Putman, S.H., 1983. Integrated Urban Models: Policy Analysis of Transportation and Land Use. Pion, London

Putman, S.H., 1991. Integrated Urban Models 2: New Research and Applications of Optimisation and Dynamics. Pion, London.

Schock, S., (Ed.), 2000. Projecting land use change: a summary of models for assessing the effects of growth and change on land use patterns. EPA/600/R-00/098. National Exposure Research Laboratory, Office of Research and Development, US Environmental Protection Agency, Washington, DC.

Simon, H.A., 1957. Models of Man. John Wiley & Sons, New York, NY.

Simon, H.A., 1977. Models of Discovery and Other Topics in the Methods of Science. D. Reidel, Dordrecht.

Simon, H.A., 1982. Models of Bounded Rationality (2 volumes) MIT Press, Cambridge, MA.

Simon, H.A., 1989. Models of Thought, Volumes 1 and 2. Yale University Press, New Haven, CT. [AUTHOR: I have just given one date although the first volume was published in 1979, the second in 1989, but I think it is overkill to put them in twice as separate entries]

Simon, H.A., 1991. Models of My Life. Basic Books, New York, NY.

Waddell, P., 2000. A behavioural simulation model for metropolitan policy analysis and planning: residential and housing components of UrbanSim. Environment and Planning B 27: 247-263.

Wegener, M., 1994. Operational urban models: state of the art. Journal of the American Planning Association 60: 17-30.

Wegener, M., 2001. New spatial planning models. Unpublished paper, available from Institut fur Raumplanung, Universitat Dortmund, Dortmund, Germany

Wilson, A.G., 1974. Urban and Regional Models in Geography and Planning. John Wiley & Sons, Chichester.

Wilson, A.G., 1981. Catastrophe Theory and Bifurcation: Application to Urban and Regional Systems. University of California Press, Berkeley, CA.

Wilson, A.G., 1998. Land use-transport models: past and future. Journal of Transport Economics and Policy 32: 3-26.

Wilson, A.G., J.D. Coelho, S.M. Macgill & H.C.W.L. Williams, 1981. Optimisation in Locational and Transport Analysis. John Wiley & Sons, Chichester.

Wittgenstein, L., 1921 (revised edition 1961). Tractatus Logico-Philosophicus. Routledge & Kegan Paul, London.

RESUME

Le terme "modèle" est entré dans le dictionnaire au cours des années 60 quand soudainement l'idée de représentation symbolique de systèmes complexes a vu le jour. Ceci était en grande partie due aux ordinateurs qui étaient capables de traiter automatiquement de grandes séries de données ainsi qu'à un changement fondamental de notre compréhension des systèmes dans le domaine de la science ou de la société. Comme les ordinateurs ont envahi tous les domaines de notre monde, l'idée du "modèle" n'avait plus le même pouvoir attractif. Les modèles sont partout. Cependant pour des systèmes urbains, le rôle des modèles a énormément changé. Avant 1950, des modèles urbains désignaient des représentations architecturales de leurs formes physiques. Des modèles mathématiques ont dominé les années 60 et 70, puis il y a eu les modèles de données qui ont dominé au cours des années 80 et 90. Mais maintenant l'accent est de nouveau sur une représentation traditionnelle des villes par des modèles de forme tridimensionnelle, annonçant ainsi un retour des modèles d'icônes qui ont dominé la planification physique jusqu'ici. Dans cet article, nous passons en revue le développement de la modélisation dans la recherche urbaine au cours de la moitié du dernier siècle et nous suggérons que des nouveaux types de synthèse sont maintenant possibles.

RESUMEN

El término "modelo" entró en el léxico en los años 1960, cuando se desarrolló repentinamente la idea de representar simbólicamente sistemas complejos. Esto se debe tanto al hecho que las computadoras habían alcanzado el punto de manipular amplias series de datos en forma rutinaria como a cambios fundamentales en nuestro entendimiento de los sistemas complejos en la ciencia y en la sociedad. Como las computadoras han penetrado cada esquina de nuestro mundo, la idea de modelo ya no tiene más el poder de atracción que tuvo en otro tiempo. Modelos se encuentran en todas partes. Sin embargo, en el caso de los sistemas urbanos, el papel de los modelos ha cambiado substancialmente. Antes de 1950, los modelos de ciudades se referían a representaciones arquitectónicas de su forma física. En los años 1960 y 1970 dominaban los modelos matemáticos, y en los años 1980 y 1990 comenzaron a dominar los modelos de datos. Pero ahora, el enfoque volvió a las representaciones tradicionales de las cuidades como modelos digitales tri-dimensionales, anunciando de esta manera un retorno a los modelos figurativos que habían dominado la planificación física hasta ahora. En este artículo, se analiza el desarrollo de la modelización en investigación urbana durante el último medio siglo y se sugiere que nuevas formas de síntesis son ahora posibles.