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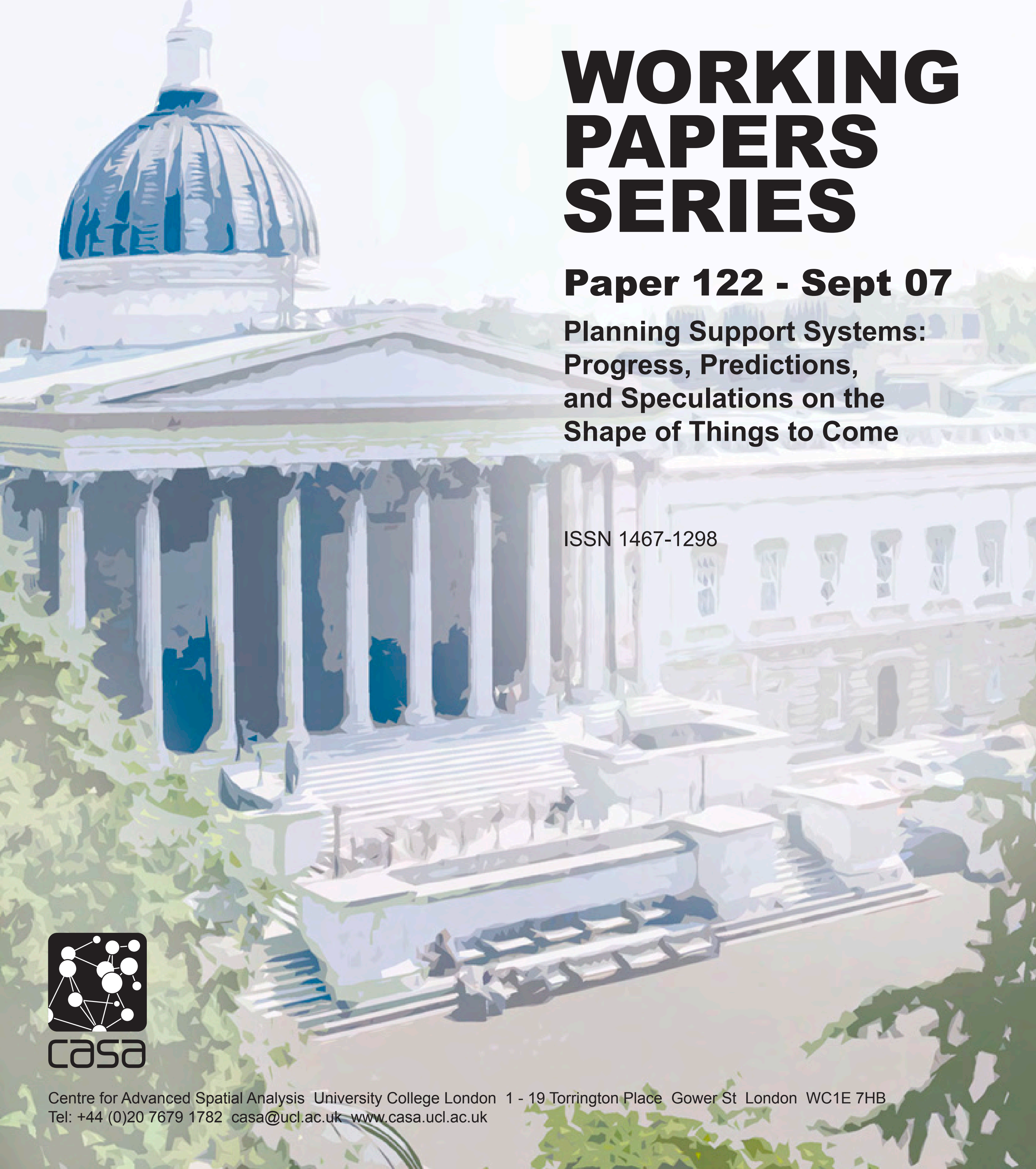

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Planning Support Systems: Progress, Predictions, and Speculations on the Shape of Things to Come

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Planning Support Systems: Progress, Predictions, and Speculations on the Shape of Things to Come

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Abstract

In this paper, we review the brief history of planning support systems, sketching the way both the fields of planning and the software that supports and informs various planning tasks have fragmented and diversified. This is due to many forces which range from changing conceptions of what planning is for and who should be involved, to the rapid dissemination of computers and their software, set against the general quest to build ever more generalized software products applicable to as many activities as possible. We identify two main drivers – the move to visualization which dominates our very interaction with the computer and the move to disseminate and share software data and ideas across the web. We attempt a brief and somewhat unsatisfactory classification of tools for PSS in terms of the planning process and the software that has evolved, but this does serve to point up the state-of-the-art and to focus our attention on the near and medium term future. We illustrate many of these issues with three exemplars: first a land use-transportation model (LUTM) as part of a concern for climate change, second a visualization of cities in their third dimension which is driving an interest in what places look like and in London, a concern for high buildings, and finally various web-based services we are developing to share spatial data which in turn suggests ways in which stakeholders can begin to define urban issues collaboratively. All these are elements in the larger scheme of things – in the development of online collaboratories for planning support. Our review far from comprehensive and our examples are simply indicative, not definitive. We conclude with some brief suggestions for the future.

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I Defining Planning Support

Planning support systems emerged in the late 1980s as the generic term for that loose assemblage of computer-based tools that urban and regional planners had garnered around them. Computers have been applied to human affairs ever since their inception in the mid-20th century, and by 1960, planners were experimenting with large-scale systems for data and simulation. These led immediately to municipal information systems and land use-transportation models which formed the core of the planner's tool-box until the advent of geographic information systems (GIS). By the 1990s, there was a sufficiently varied set of tools informing most of the stages of the technical planning process. It thus made sense to consider these collectively as planning support systems (PSSs) which could be developed in more integrated fashion and adapted to many different contexts in which planning required such support.

Until the idea of PSS emerged, the conventional wisdom was that scientific or rational planning could and should be underpinned by comprehensive computer models which linked how the system in question actually functioned to how it might function under certain design requirements. In this sense, the planning process itself was articulated as a 'system' both within and without the urban and regional 'system' which was the object of design. This bold and perhaps naïve conception emanating from the systems approach (West Churchman, 1968) gradually weakened its grip on planning methodologies. It became ever clearer that such tight structures could not be mapped onto planning problems that were always too diverse, ill-defined and ambiguous to admit of highly structured decision-making supported by well-defined computer technologies. This conception may have met the requirements for 'putting a man on the moon' but it fell far short of solving problems such as 'getting us to the airport', in Mel Webber's hallowed words. Once computers became universally available through the PC, then such tight structures were blown apart as many diverse computer-based tools reflecting a variety of applications became available. Geographic information systems were in the vanguard and by 1990, this proliferation could no longer be imagined as integrative. Planning support systems came to be used as the collective term for this variety.

It was Britton Harris who actually coined the term (Harris, 1989)[1]. Harris in fact had been the doyen of the land use-transportation modeling field since it began in the late 1950s, being the leading commentator and advocate for how such science might be applied and developed. In a landmark paper in 1989 entitled *Beyond Geographic Information Systems: Computers and the Planning Professional* devoted to the impact that GIS was having on the field, he argued that just as management required routine support, planning required strategic support, hence his use of the term planning support systems in contrast to decision support systems. In the early days up until the idea of using networked computer systems really took off, most PSS was focused on non-routine strategic planning although the line between the strategic and the routine was inevitably blurred (Batty, 1995). What has changed this context radically is first

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[1] Harris apparently said that the term was first used by a member of the audience at the 1987 URISA conference in discussion of one of his papers although he once recalled that it was someone from the Delaware Regional Planning Commission who used the term at the 1988 URISA conference. Its origins now lie in the mists of time unless the person who was in Harris's audience can still be identified, or can still come forward!

the proliferation of individual software devoted to countless tasks that are relevant to any kind of problem-solving and second the dissemination of this software and data across the internet from dumb WebPages simply providing 'information' to esoteric software collaboratories. This blurring of the field in fact is one of the key themes in this paper. It traces how the idea of planning support is changing as both the problems to which PSS are applied and the technologies enabling us to generate such support, change in parallel and simultaneously.

This broadening context is based on three related transitions. First urban planning has become highly pluralistic based on increasing uncertainty and ambiguity in society-at-large about well-defined courses of social action. In short, planning problems are no longer regarded as 'soluble' in the classical scientific sense. In Rittel and Webber's (1973) graphic terminology, they are 'wicked'. The notion that there are optimal products in the form of ideal cities to be designed has given way to the possibility that there might only be optimal processes to be used in negotiating futures that are in some general sense 'acceptable'. In fact, this perspective was widely accepted when planning support systems were first articulated but since then it has deepened as our collective view of the future has fragmented. Second, in the last 50 years, the process of planning has moved quickly from rigid professionalism to collective negotiation while its methods have been increasingly used to communicate and disseminate a multitude of ideas to many constituencies with a central interest in the future. In this sense, planning support systems are increasingly used to 'inform'. The focus is thus on adapting more esoteric tools and their products to audience and interest groups that do not have the professional expertise to interpret them. Third, new technologies for disseminating information now largely digital in one form or another, have rapidly developed in the last 20 years through the internet and related systems and this has led to the common media of communication becoming predominantly visual. All these transitions are not necessarily ideal but they form the starting point for the review and speculations that we will develop here.

In the rest of this paper, we will first outline the development of new computer technologies and their import for PSS, largely since the advent of the internet and its visual media in the form of the 'browser'. We will pay particular attention to ways in which computers have merged with communications and the way desktop tools are migrating to the net. This sets the scene for a rudimentary classification of PSS tools, notwithstanding the great diversity of such tools and the fact that planners and professionals stand on the threshold of developing their own tools for specific situations. This is largely due to the massive growth of generic systems such as GIS and the very high level processes that are now available for bypassing expert programming. This classification results in what we call 'The Planner's Toolbox' which in this view contains a series of generic and specialist tools that can be merged with one another and adapted to a wide variety of contexts.

To illustrate these ideas, we choose three exemplars: first a land use-transportation model that is being developed as part of an integrated assessment of climate change scenarios in Greater London over the next 100 years; second an example of how digital geometric modeling of Greater London in the form of a virtual city model that has been created can be used to display and communicate routine measurements of air pollution to interested parties; and third, the way geo-demographic spatial data is being focused on routine applications through linking it to online tools such as *Google*

Maps and online environments or virtual worlds such as *Second Life*. The first example is non-routine, strategic and makes use of traditional mathematical models in the first instance as desktop applications. The second and third are much more routine, based on communicating essential content in a user-friendly form across the web and making use of digital iconic, rather than symbolic modeling, although both styles are beginning to merge in some applications (Batty, 2007). These applications are intrinsically visual and impress the main message of this paper that communication through visualization is rapidly becoming one of the main foci in PSS as the computer revolution moves even more swiftly to graphic and related media in contrast to its origins in numerical data processing. This echoes the implicit sentiments of Brail (2001, page ix) in his earlier emphasis on planning support systems as techniques that " … couple analytic tools and computer simulation models with visual displays".

II New Technologies

There are several fundamental themes that characterize the evolution of digital computation but one of the most deep seated is the development of hardware which is able to process ever increasing amounts of data. In a sense this might seem an almost trivial characteristic for the entire digital world appears to stem from this. But communication systems too have evolved to transmit ever greater amounts of data ever more quickly on all earth-bound scales, and the convergence of computers and communications is now driving the development of computation in all pervasive ways of which planning support systems are of one of many. Miniaturization of computer circuitry through ever more powerful microprocessors is the key to all of this and there seems no end in sight. For 40 years or more 'Moore's Law', which suggests that computer processing power – speed and memory – doubles every 2-3 years[2], has held sway, while 'Metcalfe's Law' suggests that this increase is even faster for bandwidth, capacity doubling every year. Putting together this growth in the number of computers and increasing bandwidth, Gilder (1989) suggests that the growth in digital connectivity between identifiable units of social action – people, firms, governments and so on – might be growing even faster.

By 1990 when PSS were first articulated, part of this technological revolution had taken place in that comparatively massive memories on distributed machines – PCs on the desktop and workstations for more specialist use – were being utilized for computer models of cities and urban information systems. Some of Lee's (1973) critique of the earlier 1960s experience with computer models where the ability to actually complete such simulation and information retrieval at a scale where such tools were 'useful', was thus cast in doubt. Moreover the move to graphics which was occasioned by such increased memories was well under way with the development of GIS although the move to graphical user interfaces following the lead set by Apple and the workstation leaders such as Sun was only just beginning. Visualization was thus significant but the use of computers for sharing information, for enabling the use of common tools through communication across the internet, and for disseminating the graphical and numerical outputs from PSS, were in their infancy. It these later

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[2] The rule of thumb coined by Gordon Moore at Intel in 1965.

technologies that are now forcing the field and this review will be developed from this perspective.

At present, it is the ability to communicate using these new technologies that represents the cutting edge in PSS, rather than any large-scale formal developments in the tools themselves. In urban modeling there has been a move away from aggregate cross-sectional models to more disaggregate, agent-based structures which depend on representing more individual based data and on physical representations of the systems of interest using fine meshes of cells but these developments are largely driven by the existence of fine scale data and by computation itself rather than any theoretical advances in our understanding of the city. In fact, we are living through a time where theories have fragmented and where there is much less consensus about what represent the key ways in which cities evolve and grow than there was fifty years ago. Technique rather than theory has come to dominate and thus developments in computational technologies are tending to drive the field. Developments in large-scale models have not yet availed themselves of the move to communication and visualization other than their embedding within or coupling to GIS for purposes of display. Nor have they moved upstream to avail themselves of super and parallel computer technologies. The ability to distribute such computation across networks has not yet made its mark. Rather the focus is currently on visualization for much more pragmatic purposes such as the move from 2-dimensions to 3 in the construction of virtual city models, and the dissemination of displays for more generic purposes of communication and participation (Batty et al., 2001). The development of PP-GIS (Public Participation Geographic Information Systems), particularly in North America, is one manifestation of this move.

A nice contrast with our current technologies in terms of visualization is contained in Figures 1(a) and 1(b). In Figure 1(a), we show the kind of desktop interface available in the early 1990s on a Macintosh where a variety of well-known tools have been brought together for population forecasting. The modules shown in this desktop which is entitled ‘The Emergent Desktop Environment for a PSS’ can be plugged together in various ways to generate visual outputs and it is suggested there that “ … it is only a matter of time before most software moves to this mode “(Batty, 1995). In fact this has not really happened for the field has become much more fragmented and in so far as such plug and play modules have been designed, they have not been generalized in software systems. There is however less consensus that this is the main way forward for PSS. Figure 1(b) however shows one of the earliest interactive web pages from March 1995 which is traffic flow data being piped from web cameras in San Diego, CA which was then used a diagnostic for traffic control (Batty, 1997). The web was then barely known to planning professionals but this kind of visualization is now writ-large and is so routine that it is barely commented upon[3]. Little of this was anticipated a generation ago when PSS was first defined by Harris.

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[3] The paper referred to by Batty (1997) was presented first in 1995 at CUPUM ’95 in Melbourne, Australia as an example of how planning could be supported by web-based technologies. All the hotlinks in that paper are now dead although the paper is still on the web (e.g. at http://www.acturban.org/biennial/doc_planners/computable_city.htm). An example of what was then possible is archived at *The WayBack Machine* with some links intact. To view this go to: http://web.archive.org/web/19980124005925/www.geog.buffalo.edu/Geo666/batty/melbourne.html

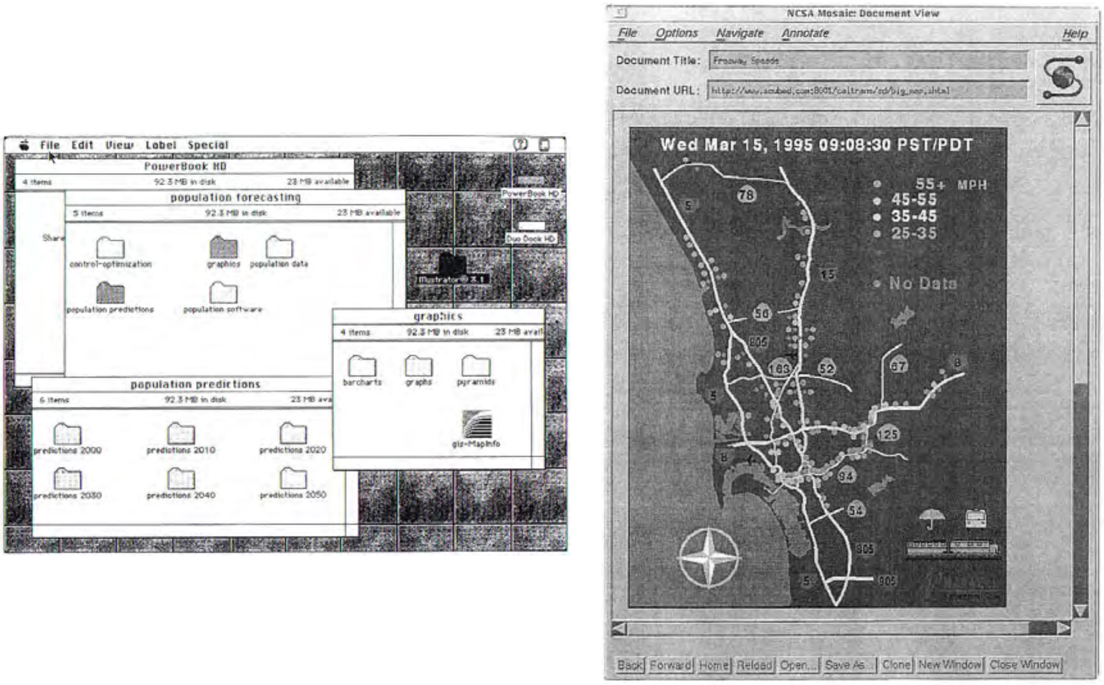

Figure 1: Early Graphics (circa 1995) for PSS:
(a) A PSS loosely coupled on an Apple Mac Desktop (left),
(b) A Real Time Traffic Display through Web Technology, San Diego, CA.

There are various hardware environments for visualization that are of some significance for PSS and these revolve around the creation of theatres into which various participants in PSS can interact. In short, this is part of a wider development in which visualization is used to communicate with participants by creating environments in which the participants can interact through computer tools and between themselves. In their extreme form, these are single user virtual realities in which the software pipes the imagery and interactivity directly into the user's sensory receptors, fully immersive VR through headsets and various interactive hand devices being the original and now somewhat dated examples of such environments. VR theatres are good examples of how these technologies have reached out to embrace computer-computer, user-user and computer-user interactions in a self-contained purpose-built form. Yet these are still fairly specialist and not yet in general use, notwithstanding falling real costs (Batty, 2008). Interactivity and communication is still mainly accomplished by users clustering around a desktop or workstation, or interacting across the web with this latter technology now forming the cutting edge of interactivity, participation and communication between diverse remote users.

The visualization and communication technologies that are now beginning to influence the development of PSS all revolve around interactivity, mainly using the web but with grid computing[4] rapidly gaining ground, at least conceptually. The web

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[4] The 'grid' is a euphemism for a new wave of computation which is available in the same sense as the electricity grid delivers electricity, simply by plugging into the net and generating whatever software and data resources are required. In essence, the grid is conceptually a system for delivering

is now organized into at least four styles of web-based services, the collective term for this variety: vanilla-style web pages which simply present information to users with no interactivity other than simple hyper-linking to other pages, web pages which enable users to download data and software to their desktops, web pages that enable users to run software within their own web page usually through the form of simple Java-based programs, and web pages that enable users to import their own data and run software remotely, often in the style of grid computing. More elaborate systems such as collaboratories – online systems that are remotely linked through web pages that enable users to communicate within one another and to run software jointly – are in their infancy. In a sense, these collaboratories are virtual laboratories, virtual worlds even, that let users communicate in closed environments a little like VR theatres but remotely with much looser limits on the number of users who can interact. Early systems were pioneered as part of PP-GIS (see for example, Kingston, Evans and Carver, 2003) although as yet, there are few workable PPS collaboratories despite some interesting one-off attempts. A comparison of the articles in the two edited collections – Brail and Klosterman's (2001) **Planning Support Systems** composed of reviews of tools largely conceived from the late1980s to the mid-1990s with Geertman and Stillwell's (2003) **Planning Support Systems in Practice** which contain techniques and models developed up to a decade later, impress this change. Online systems dominate the later collection, although none of them quite reach the level of collaboratories in sense implied here. Nevertheless the rudiments of such systems are now in place and substantial developments in this arena are to be expected in the next decade.

As we have implied, many of the traditional tools that dominated computer-aided planning historically such as urban or land use/transportation models no longer form the core of PSS, although as Timmermans (2007) suggests, these are still a substantial part of the field. This lesser emphasis is largely due to the extremely specific nature of the problem contexts to which such models need to be applied and the highly variable data that is required. Models such as *UrbanSim*. *MEPLAN*, *TRANUS*, *CUF*, and the newer generation of cellular automata models of land development (see Maguire, Batty and Goodchild, 2005) are no more widely applied than the Lowry model was in the 1960s and 1970s. This situation is unlikely to change in the short or medium term for GIS software which has developed in modular, generic fashion is still a long way from coupling, incorporating or embedding such models, despite there now being a visual model-building capability within software such as *ArcGIS*. Only when software emerges which enables such models to be constructed on-the-fly so-to-speak will these kinds of tools become more widely used and even then, it might be that the skill base required to build such models will impose intrinsic limits on what is possible. In fact even the addition of visualization capabilities to such models has been weak with attempts limited to a loose coupling with GIS, and/or web-page outputs as in the generalization of the *MEPLAN*, *TRANUS* and *IRPUD* models in the *PROPOLIS* project (Lautso, 2003).

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computational resources – data, software, expertise etc. – from diverse and remote locations to a user who simply has a device – usually a PC – which controls the way the net delivers these resources to the desktop. Usually the grid takes data and software from two or more remote location and delivers the results of the computation which takes place possibly somewhere else in the ether in a different remote location, usually the desktop, but possibly on a hand-held device connected wirelessly to the net.

GIS software as we have noted is more generic, highly descriptive, and much less controversial in terms of its implied tools of spatial analysis than large-scale urban modeling. The focus in its development has been to generalize such software to be capable of any kind of spatial analysis and representation and this has tended to keep the tools descriptive rather then predictive. In-so-far as they can be used prescriptively, this depends entirely on the way they are used to support the design process. In a sense, GIS is 'theory-less' although it depends on the way the user fashions software to the data and whether or not the tools of analysis (such as buffering, simple accessibility measures, overlay analysis and so on) are relevant. In fact more specific applications invariably require some additional tuning of the software. An example is Klosterman's (2007) 'What-If' system which utilizes elements of GIS but is essentially a standalone application of overlay analysis tailored to US style zoning and land use planning.

GIS applications within planning support tend to be both routine and strategic, applicable a variety of scales. Visualization can be much larger scale although more routine than urban modeling. For example, CAD and 3D iconic models are being generated using GIS as well as other software such as *AUTOCAD* and although substantial in terms of size, their application is becoming more routine. As we imply, this is the fastest growth area of PSS on the web where visualization of 2D and 3D map forms are being dramatically accelerated in terms of usage with the availability of 'non-proprietary' software systems such as *Google Earth*, *Google Maps*, *Microsoft Virtual Earth*, and so on. We will show some examples below but now it is worth noting that in contrast to early developments of PSS, the dominant applications are much more routine. They are fashioned from the availability of simple desktop tools and vanilla-style web pages based on quite creative uses of spreadsheets and related databases and graphics systems ranging from paint packages to simple 2D and 3D CAD and GIS, amongst a plethora of newer applications which involve merging simple tools. Many of these tools are facilitated by the ability to 'publish' such applications on the web, thus making them available to a wider group of users. However, these developments are so fragmented and diverse that it is difficult to classify them into coherent themes.

There could be substantial developments in PSS in the next decade. Embedding one style of model into another is already a major force in the field and it is likely that we might see symbolic modeling being embedded in iconic – mathematical urban models being coupled or embedded to 2D and 3D GIS within VR style environments (Batty, 2007). Although there are already examples of this, they remain a long way off. It is more likely that new layers of software will be built up to the point where non-expert but professional users can fashion many new tools from component parts. This is the way in which computing has evolved over the last 50 years since its inception and there is no end in sight. However, this model of building ever successive layers of software comes at a cost and that is that each layer constrains what is possible. The fact that good urban models cannot be easily built using the tools of GIS, for example, is a limit that is not likely to be resolved due to the theory-laden content of such urban models and its conflict with modular, generic software.

Before we attempt to classify PSS, it is worth noting this last feature of computer technology, the relentless march to develop layer upon layer of functionality in the effort to bring computation to the widest possible constituency. The model of technological development suggests that as computers increase in memory and speed and drop in cost – due to the laws proposed by Moore, Metcalfe and Gilder, the way users interact with them becomes ever more friendly. The easiest way to achieve this is to add new layers of more generalised software on top of the less generalized – a classic example being Windows built on top of DOS, but in the long term scheme of things, this transition occurs almost continuously and is seen currently in programming in the object-oriented paradigm and in the introduction of even more general scripting languages. The same is true of networking with more user-friendly applications of web services and related communications applications. It is not hard to now see a time when users will literally pull windows and their applications around a screen with their fingers which not so long ago were the stuff of science fiction.

What all this means for the development of our field is that we should not expect it to stand still. In 1989 when Harris developed his vision of PSS, the field was still dominated by large scale applications such as land use-transportation models and GIS with only spreadsheet applications providing any form of generic media for different kinds of application. Since then, almost all aspects of planning in its various types from urban design to regional policy have been subject to IT support and with the fragmentation of the field, various layers of software have been exploited and built to reflect this diversity. This makes the problem of classification somewhat confusing, or rather much less focused than the rather clear structures we assumed a generation ago for PSS. The tools that we will present below illustrate all these issues as well as the way in which such problems are being resolved in the wider context of visualization and communication.

III A Classification of Planning Support Systems: The Planner’s Toolbox

The traditional classification of PSS is based on the various tasks which define the technical planning process (Batty, 1995). Insofar as planning can be seen as a technical process, it begins with problem identification, moves to analysis, and thence to the generation of alternative plans, with their subsequent evaluation and then the choice of the best plan to implement. This can be a cyclical or iterative process which was the model that emerged from the concern for rational decision in the 1960s (Boyce, Day and McDonald, 1970) but in essence it is based on the long-standing tradition of ‘survey before plan’ associated with the pioneering work of Patrick Geddes at the turn of the last century. This process is driven by survey, motivated by goal setting, tested against objectives, with the ‘best plan’ managed through implementation. Once a plan is produced, then the process begins again through implementation but at lower or different level with various processes of this kind nested within and without one another. One statement of this rational decision or problem-solving process on which PSS is based is given in Batty (1995).

This technical process has always been an idealization which when applied in practice is massively modified. Moreover there is much less consensus about its role currently than ever before as the perceived consensus about planning in general from the top down has fragmented. Nevertheless the series of tasks defining the sequence of stages in the process is as good a vehicle as any on which to base planning support using IT. We assume the process can be arranged in the following sequence:

Define Set
Problem → Goals → Analyze → Generate → Evaluate → Choose → Implement
Data Plan Plan Plan Plan

where distinct theories, models, and techniques can be applied at each of these stages. In a sense, this implies that specialist tools have been developed for each of these stages and indeed they have. Problem-structuring techniques and goal formulation based on brainstorming technologies are quite well developed and are now widely supported by IT although not much applied in urban planning. Analysis techniques largely revolve around GIS in the spatial analysis domain and there are many packages of increasing sophistication that are being used. In fact this set of tools is increasingly generic in that they are not only used for analysis and of course for database application (survey) but also for management at all stages of the process. Plan generation is still largely governed by land use-transportation models whose predictive capacity and what-if capabilities have been widely developed during the last 30-40 years. Evaluation methods tend to rely on these models as well as more qualitative assessments of risk and benefit-cost, and are informed by the whole range of multi-criteria and optimisation models. Implementation involves a series of management techniques developed under the more routine rubric of decision support.

In the 1960s, there was the assumption, at least very early on in the development of land use-transportation models, that the entire planning process might be encapsulated into a general systems model with command and control capabilities akin to managing a complex machine. Models that could describe, predict and prescribe (design) were seen as tools to be aspired for although this phase was short-lived and the complexity and ambiguity of city systems and their planning was quickly realized. In fact it was probably the inadequacy of the tools that was quickly realized as reflected in Lee's (1973) trenchant critique, rather than any insight into the nature of cities that had not been part of our consciousness already. Nevertheless just as the process of planning has broadened and fragmented, so has our vision of what might constitute 'The Planner's Toolbox'. To land use and transportation, GIS was added in the 1980s, while since then the development of much more generic tools at a lower level and of wider applicability has begun to inform all stages of the process. We will chart these below but to complete our discussion of the planning process as the vehicle for classification, it is worth noting that the rather narrow technocratic process above can be extended into a much wider domain of public engagement. Running alongside or perhaps woven into this stream there is public participation of all varieties and these have provided ways in which the process has reached out to its wider context. Such participation has been fashioned particularly around GIS (see PP-GIS: Craig, Harris and Weiner, 2002) but increasingly a whole variety of visualization tools making use of much more bottom-up technologies as well as 3D virtual city models have come onto the agenda. Much of this was anticipated by the mid 1990s as reflected in the edited collection by Brail and Klosterman (2001).

Our next set of ideas on which to classify PSS is considerably more generic in the sense of tasks, and these revolve around issues of how the city system is represented and manipulated. In short we can identify the key activities in problem-solving and use these on which to organize PSS. Survey is based on observation and measurement while analysis is based on the representation and organization of this data. Modeling and simulation are key activities in description and prediction while optimisation is the activity of generating and evaluating some best plan. Management is reflected in implementation while negotiation occurs at all stages and scales of the process. The activities of observing, measuring, analyzing, modeling, simulating, predicting, prescribing or designing, optimizing, evaluating, managing, negotiating – the list is endless – are all tasks that are supported by software, and around which software has and is being developed. However at this point to show the variety of such classification, it is worth noting that distinct packages have been developed which reflect different combinations of these activities to different degrees. These packages can be very roughly classified as GIS, land use-transportation models (LUTM), multi-criteria analysis (MCA), plan generation techniques such as *What-If*, CAD and 3D GIS, and public participation/multimedia community visioning methods (Shiffer, 2001). This is by no means an exhaustive list and such software can be identified at a lower level which can be adapted to all such tasks in the form of spreadsheets, and other more generic software such as animation and visualization packages. At the higher level, several of the standard packages can be added, integrated or coupled together. For example *Community-Viz* is one such application which has reached the point of wider application, building on agent-based models, GIS, and 3D visualization (see http://www.communityviz.com/).

These various packages can all be scored against the activities noted above. For example, GIS is focused on measuring and analyzing but can be adapted to an extent for prediction. There are various routines for simulating and modeling and for optimizing but in general the focus is more on representation, data and some limited 2D visualization. Already we see that such tools have a more generic quality than might be assumed at first sight, and we could compile an exhaustive list of software products against the tasks involved. We will not attempt this here but the point is that most software has an ambiguous role in PSS in that it can be applied at various stages of the planning process and for various planning tasks. The same is true of the scale of the planning problem. This is largely because when software is devised, it is usually in relation to a narrower problem and when refined, if it stands the test of time, it is extended in its applicability. Other software as developed or adapted to some specific stage of the planning process is often extended into other parts of the process and the entire sequence of tasks in some way related to this. For example it is not so unusual to find LUTM and GIS being combined to form the heart of the plan generation and evaluation process with its dissemination often now realized through some web-based interface: *PROPOLIS* is such an example (Lautso, 2003)

Some software is designed for extremely generic tasks but even this varies across scale. For example consider the idea of spreadsheets as PSS tools. The book by Brail, Bossard, and Klosterman (1993) on spreadsheets published in the late 1980s shows a wide variety of analytical and predictive applications – e.g. models implemented in spreadsheets which were initially devices solely used for storing and visualizing and searching data. At the other end of the spectrum, currently there are several packages emerging for new classes of cellular automata model which can be applied to urban development and for agent-based models which specify the system in terms of fine scale disaggregates. These are really toolboxes in their own right that enable users to develop any such model which has the generic properties of the particular application. For example, in the case an agent-based model, the package is often adaptable to represent a very wide range of problems of which spatial ones might only be a subset.

There are several other ways of classifying tools for PSS and before we list the main types of tool, we will note these. The scale of the problem is significant. It is likely that urban design problems for example, especially those that involve say movement in small spaces, require very different types of software from that used to support regional planning. For example, the best developed agent-based models are in the area of crowd dynamics, useful for example for assessing movement and patronage in small spaces like shopping centers. These types of model, even their more aggregate agent equivalents, would not find much use at higher spatial scales. Another feature is context. Often a planning task is ongoing and as it evolves so does software in the outside world and this changes the basis of support. Sometimes the task is not composed of a series of stages as we have envisaged but is based on entry at say the implementation stage where some plan has already been cast and requires modification during its implementation. Sometimes the entire plan might be generated by stakeholder involvement through various forms of participatory design. Again the possibilities are endless and in one sense, this makes the quest to classify PSS an unending one, controversial always.

Before we illustrate what we consider to be the future based on current developments, we will list the main kinds of software package and applications that have been developed and presented at this conference which seeks to chart of the state of the art. It would be useful to provide an unequivocal classification of PSS into which every piece of software and every application would slot but this is not possible because of the fact that software tools can be fashioned quite differently by different professionals in different contexts. In a sense, this is what the tools that we have alluded to so far are designed to do. We can however produce a very rudimentary classification into tools and their software which are focused on spatial problems (or not) and which can be seen as being specialist for a particular spatial focus (or not). This sets up a two way classification which we can array as *Specialist/Generic* against *Spatial/Non-Spatial*. We might consider Non-Spatial as aSpatial for many tools are not specifically designed to deal with spatial problems *per se* but can be so fashioned. This simple classification is shown below in Table 1 with typical examples of the genus contained in each box. We will briefly note each of these sets of tools, attempting to give some comprehensive overview.

Table 1: A Classification of PSS

	Spatial	*aSpatial*
Specialist	e.g. LUTM	e.g. Expert Systems, AI Software, ABM
Generic	e.g. GIS, *Google Maps*, *Earth* etc.	e.g. Spreadsheets, Math Stat Software, Dbases

LUTM is highly specialist software which has hardly reached the stage where it can be purchased and adapted to specific situations by users or professionals who are not involved in developing it themselves. The traditional applications such as *TRANUS*, *DRAM/EMPAL* etc have begun to move in this direction but fall far short of being generic in any way. More recent applications of land use-transportation models such as *TRANSIMS* and *UrbanSim* do offer software as free or shareware but the learning curve is still extremely steep. It is not our purpose to review these models here but to get some sense of the field and how it has persisted, it is worth noting Wegener's (2005) review. But it is important to note that such applications are so intense and large scale that entire planning processes are often built around them. Attempts to link them to GIS through loose coupling are weak and visualization technologies are only just beginning to be exploited (as we demonstrate below in our first exemplar).Transport models as distinct from LUTMs have more or less followed this trend too.

As part of this tradition, new styles of model such as cellular automata tend to be less applicable and more speculative than LUTM. The software is better developed largely because such automata models which simulate urban development, are more visual and simpler in structure but less operational. For example, they hardly contain any transport activity and where they have been widely developed as in the RIKS applications in the Netherlands (see Timmermans, 2007), they are invariably coupled with other models. Agent-based models (ABM) are too new to classify although *TRANSIMS* and *UrbanSim* are highly operational. Most others tend to be slightly more generic and are often demonstrator applications rather than fully-fledged models which support policy making (see Maguire, Batty and Goodchild, 2005). There are various attempts in these kinds of specialist spatial modeling at opening these up to other supporting tools in the other boxes of Table 1 for nothing can truly stand alone but progress is slow.

In contrast if we examine GIS which is clearly a much more generic set of tools than LUTM, then various stages of the planning process can be supported using individual tools from the GIS toolbox. GIS is primarily about spatial information – storing it and then displaying it but many rudimentary and more advanced functions have been added to the toolbox over the years. In particular treating maps as layers and then combining them is a central operation in generating physical plans through overlay analysis, very well developed within GIS. Indeed it is one of the functions that has been present from the beginning. New functions such as spatial statistics of various kinds as well as routing procedures for transport analysis and now the extension of maps in 2D to 3D are all features of the current software. But GIS largely falls short of being applicable at the plan generating and evaluating stages of the process in that models within GIS are at best descriptive rather than predictive. Links to other models – to LUTM, ABM and so on – tend to be the way in which this software is extended.

The GIS toolbox has opened up dramatically in the last 5 years with the appearance of 'free' mapping and visualization software on the web. Web-based GIS has slowly developed with map server technology but it is Google that has led the way through its *Google Maps* and now in the third dimension, *Google Earth* which are being very widely applied for visualization at many stages of the planning process. Our third exemplar below builds on these technologies. In fact *Google Earth* is beginning to supplant the use of CAD and 3D-GIS software for visualizing city development in 3D as virtual cities (as we show in our second exemplar below) for CAD and 3D-GIS are usually tailored to specific applications, despite this software being generic. Each application is quite different and this has meant that each author tends to adapt the generic software to the application. Again, the learning curve is steep as in LUTM in contrast to GIS which is becoming ever user-friendly.

Integrated systems of course which combine the first column of Table 1 – special and generic spatial software are increasingly used to underpin PSS. For example *Community Viz* and *Index*, both reported in edited collection by Brail and Klosterman (2001), fall into this category and now the list of such applications is quite large. In fact these systems are being fast extended to all stages of the planning process, particularly through visualization which enables dissemination of results from modeling, prediction and design. PP-GIS, for example, is built around standard GIS with web-based applications beginning to predominate while the whole area of community visioning through the use of multimedia in desktop and web-based environments is burgeoning. There are now even attempts at developing software based conceptualizations of the entire planning process as, for example, in Hopkins, Kaza, and Pallathucheril's (2005) work.

If we examine the second column of Table 1 where software exists both in specialist and generic forms but focused on problems that are not explicitly spatial, then it is clear that many forms of planning support use these. For example, expert systems informing plan-making activities and participation at different stages of the process have been quite widely developed while the use of spreadsheets, mathematical and statistical as well as database packages are now used routinely to support various parts of the process. In fact this is where our classification begins to fall away as being less useful. What is however very clear is that every bit of software in the domains covered by this table can be adapted and coupled, often embedded within every other bit and that this wide array of possible tools makes every application distinct. This was not the case when PSS was first articulated but it is now a dominant feature of the field. To continue, we will now develop three exemplars which illustrate many but by no means all of the features and characteristics of PSS that we have attempted to identify here.

IV Exemplars

a. Long Term Forecasting at the Strategic Level: Visualizing Land Use and Transportation

We are designing a land use-transportation model for Greater London as part of an integrated assessment of the impact of climate change on the location of population. This process couples together a series of models which move down scale from the predictions taken from global climate models to their impact in small scale environments where pollution and flooding are the main concern. The LUTM we are building is coupled to a global environmental input-output model at the regional scale and to a detailed population allocation mechanism at the site scale which in turn is informed by various flooding and emissions models. The sequence of models is being developed by a consortium charged with looking at long term scenarios to 2050 and

2100 for cities of which Greater London and the Thames gateway is the current application. The models are strung together in the fashion illustrated in Figure 2 and currently there are no feedback loops to enable adaptation to the various model predictions from the local to the global scale. Although this limits the usefulness of these models, the whole process is embedded in a more discursive structure where various stakeholders and experts are using the information from these models to make informed guesses and judgments about the future.

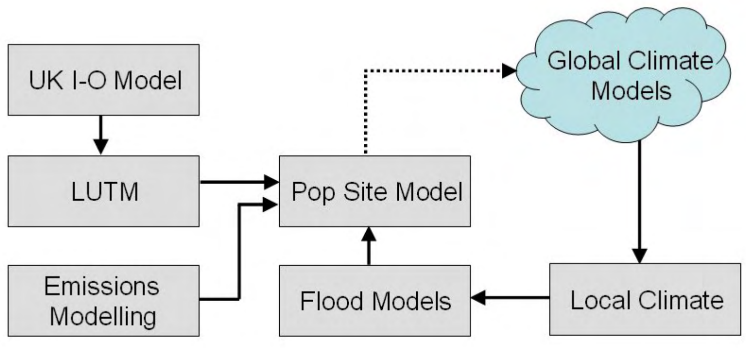
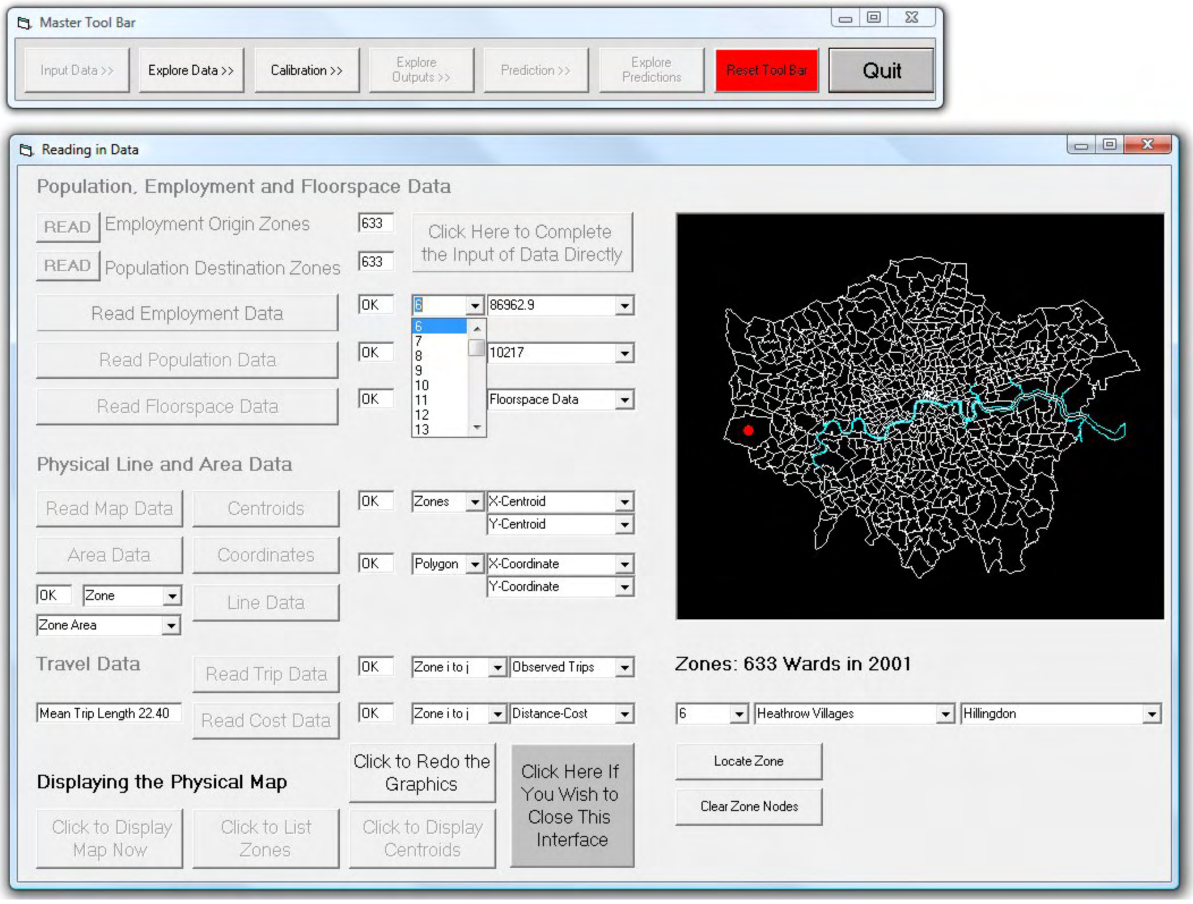


Figure 2: Models in the Integrated Assessment of Local Climate Change

The LUTM sits between the input-output model which has already been developed by Cambridge Econometrics and the population site model which essentially distributes the population outputs at census tract scale from LUTM to a finer 100m x 100m grid which is used to assess the impact of flooding. The details of these other models need not concern us here (but see Dawson et al., 2007). What is of concern is the kind of support that this suite of models and the LUTM in particular provides for other professionals and stakeholders involved in the process of informed guessing about the future. Many of the other model-builders in this process know little or nothing about LUTMs and thus it is essential as first step to communicate this as easily as possible. Moreover the model is quite large – currently 633 zones – and thus to absorb the outputs, we require good visualization so that users can appreciate at a glance what the model is generating. Moreover the setting up of scenarios which are extremely elaborate, needs to be accomplished easily and effectively. Last but not least, the data requirements of the model are large and it is essential to have good and fast ways of checking data.

All this suggests rapid visualization which currently most LUTMs do not have. Moreover many of the models are almost legacy systems in their own right being based on long out-of-date code and built in a time when communication was one of the least important problems. But with modern software, it is now possible to develop clear visualization and also to run these kinds of models interactively. This is what we have been developing and we currently have a prototype residential location which is calibrated – or rather the user can calibrate it on-the-fly – to 633 zones and four modes of transport – bus, subway, heavy rail, and road – for which trip distributions between all origins and destinations are predicted. This is a classic spatial interaction model and in time, we propose to add new submodels of the same structure to deal with other relationships in the urban system. Currently we are dealing only with the journey to work, or rather trips between work (employment) and home (population in residential areas).

We will run the model at the seminar to show how easy it is but here let us show some screenshots. In Figure 3, we show the data entry (from external files) but also the screen through which the user can first interrogate the data on-the-fly. The main tool bar moves from data input, to data exploration, to calibration, then exploration of the calibration, through to the interactive setting of scenarios and thence to predictions and their exploration. All of this can be done extremely rapidly. The program does not use any external graphics routines in GIS and is entirely self-contained in that users can simply load the executable from which various options can be chosen at calibration and prediction. In Figure 4, we show how the model can be interrogated spatially with four screens showing the employment and population distributions as well as single trip pattern from one origin to all residential destinations. These can be kept on screen at all times in different windows. More or less the same structure of spatial data exploration can be done after the model is calibrated and also after predictions have been developed. In Figure 5, we show a typical scenario being constructed where we have doubled the size of the employment at Heathrow airport, a major hub in the London region and also added in a cross rail link from the airport to central London (the CBD). We show some typical predictions in Figure 6 which show the impact of this change in population in residential areas across London which is greater in the west around the airport as we might expect.



Employment Origin Zones 633

Population Destination Zones 633

OK 6 86962.9

OK 10217

OK Floorspace Data

OK Zones X-Centroid Y-Centroid

OK Polygon X-Coordinate Y-Coordinate

OK Zone Zone Area

OK Zone i to j Observed Trips

Mean Trip Length 22.40

OK Zone i to j Distance-Cost

Zones: 633 Wards in 2001

6 Heathrow Villages Hillingdon

Figure 3: Loading the LUTM Toolbar Control, Reading in and Checking the Data

This gives some idea of what is now possible with LUTM and if those involved in such efforts embraced current technologies, then this kind of visualization should become routine with the models being more widely used, appreciated and better adapted to real situations. We have not speculated here on how we might embed this model and its running within the web giving access to much wider range of potential users but it is easy enough to set up the model for distribution to others in this mode.

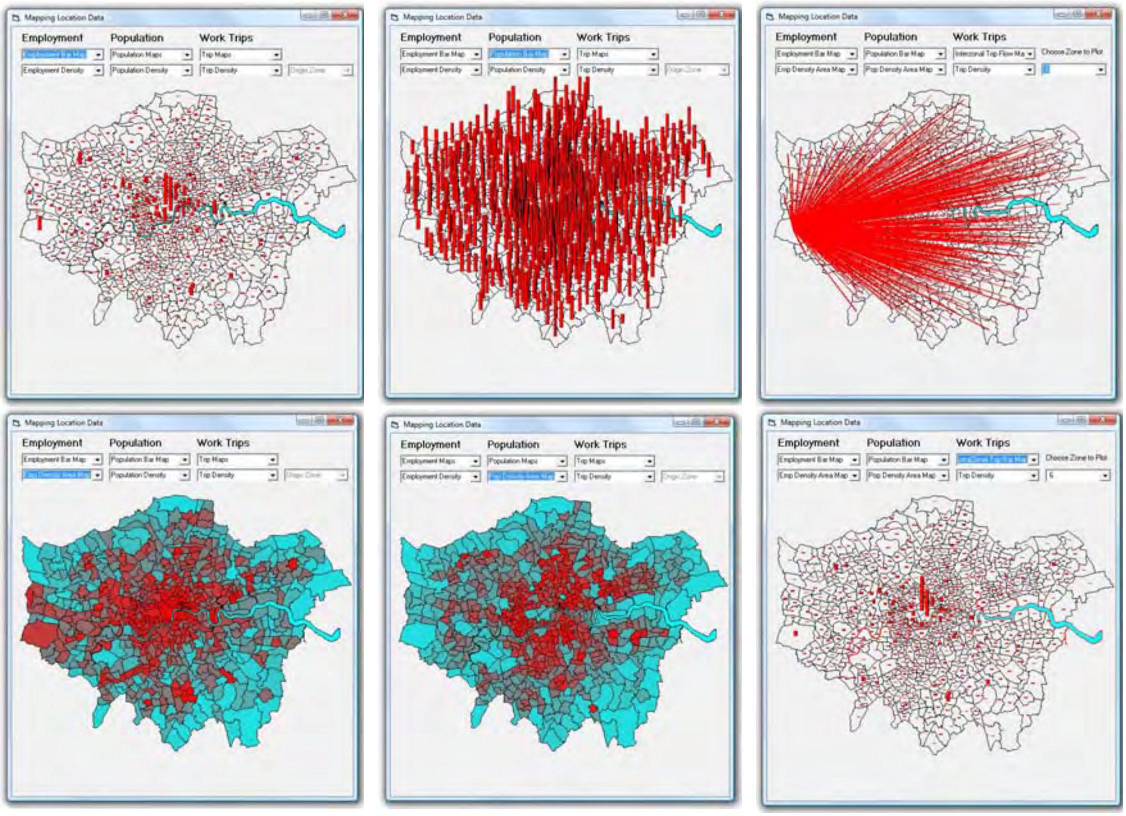
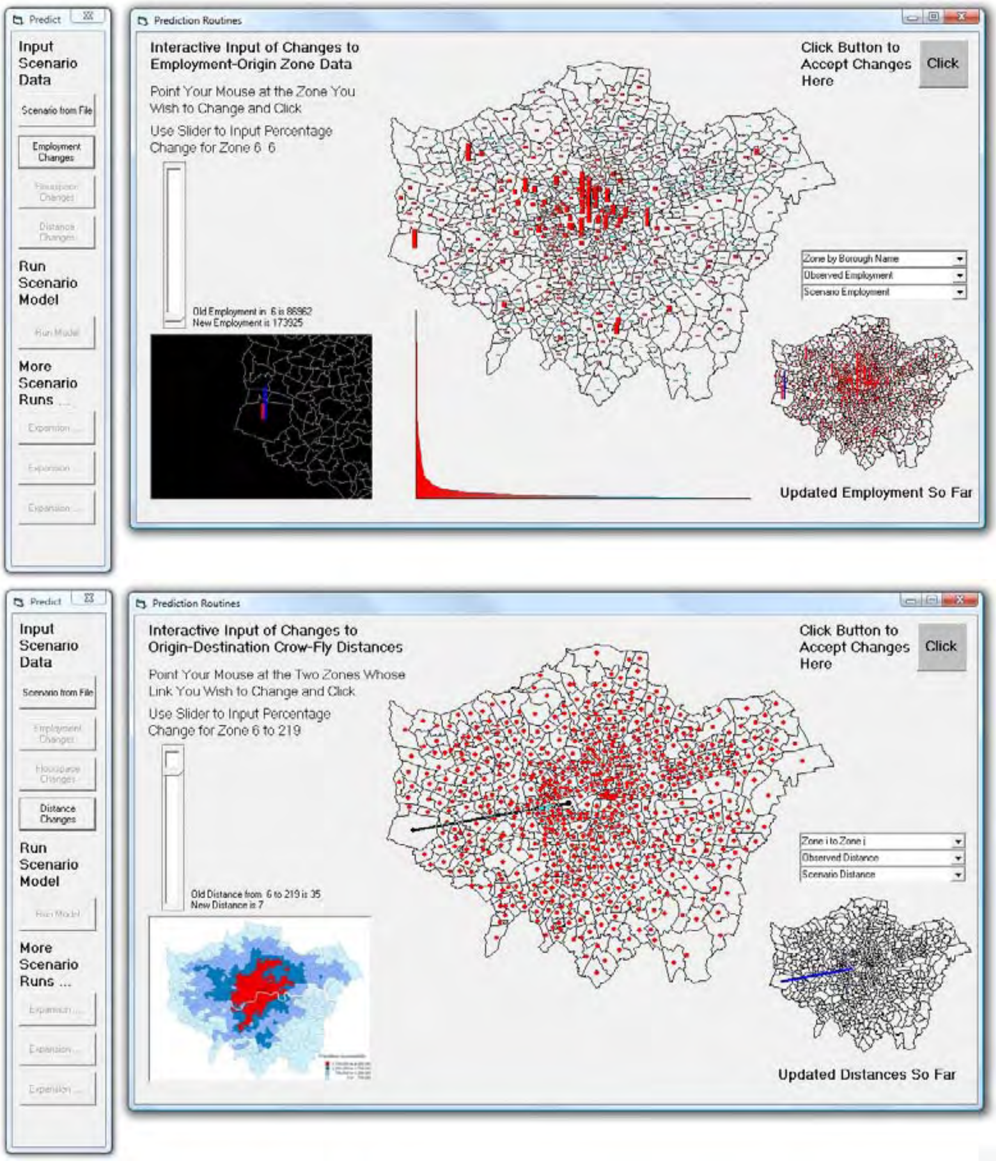


Figure 4: Exploring the Employment, Population and Trip Data Spatially

b. Immediate Forecasting at the Local Level: Visualizing the Impact of Air Pollution Using a Virtual City Model

Our second case study involves an application using the 3D iconic model – Virtual London – we have built for the metropolis. This model is quite different in structure to the LUTM in that it is no mathematical in the symbolic sense, it is iconic but nevertheless digital built from building blocks, land parcels and street data supplemented in the third dimension by LiDAR data. The model was constructed for general visualization and public participation in Greater London and was funded by the metropolitan agency, the Greater London Authority (GLA), primarily for visualizing the impact of high buildings which is the traditional use of such models. As it stands, the model now covers Greater London in which there are 3.6 building blocks. It was originally built for central London with some buildings rendered in detail but then extended to the metro area which is largely configured in terms of building blocks. It was built in *ArcGIS*, improved in *3DStudioMax* and now is available for local municipalities/boroughs in *Google Earth*. For data copyright reasons, it is not generally available and this is proving a source of great frustration in terms of its use for public participation.



Interactive Input of Changes to Employment-Origin Zone Data

Point Your Mouse at the Zone You Wish to Change and Click

Use Slider to Input Percentage Change for Zone 6 6

Old Employment in 6 is 86962
New Employment is 173925

Click Button to Accept Changes Here

Zone by Borough Name
Observed Employment
Scenario Employment

Updated Employment So Far

Interactive Input of Changes to Origin-Destination Crow-Fly Distances

Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click

Use Slider to Input Percentage Change for Zone 6 to 219

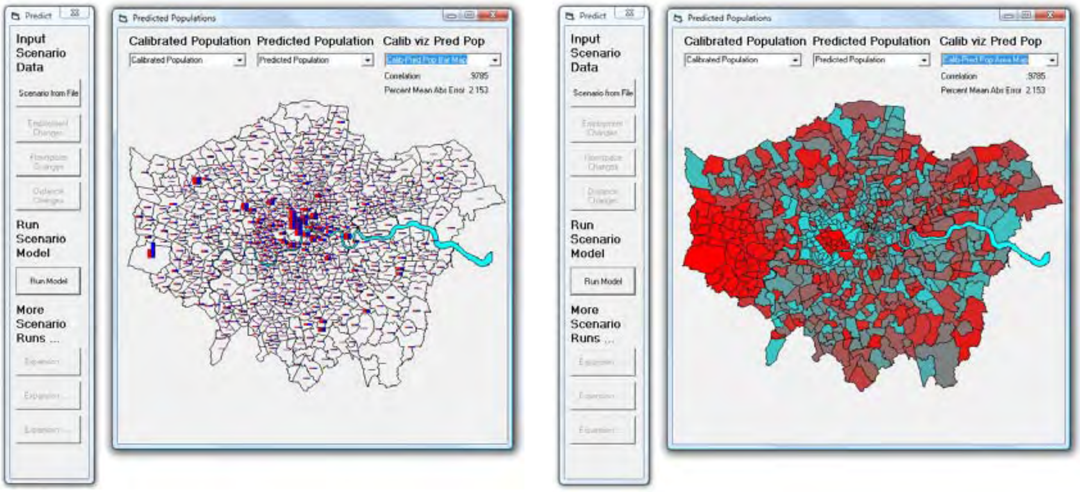
Old Distance from 6 to 219 is 35
New Distance is 7

Click Button to Accept Changes Here

Zone i to Zone j
Observed Distance
Scenario Distance

Updated Distances So Far

Figure 5: *Creating a Scenario Interactively Using Sliders*



Calibrated Population | Predicted Population | Calib viz Pred Pop

Calibrated Population
Predicted Population
Calib Pred Pop Bar Map
Correlation .9785
Percent Mean Abs Error 2.153

Calibrated Population | Predicted Population | Calib viz Pred Pop

Calibrated Population
Predicted Population
Calib Pred Pop Area Map
Correlation .9785
Percent Mean Abs Error 2.153

Figure 6: Predicting the Effects of the Scenario Using the Same Techniques for Exploring the Data

Visualizations of the 3D form are shown in Figure 7 for the original model in *ArcGIS* and also for the new model in *Google Earth*. The model requires some very powerful hardware to run in *ArcGIS* but it runs well in *Google Earth* with detail in the background always suppressed and only loaded as the user flies in. A great deal of multimedia has been ported to the model in terms of linking it to online panoramas and the products from the model tend to be in terms of movies which can be placed online rather than interactive products that users can navigate within themselves. This also minimizes data copyright issues. We have developed several uses in terms of public participation, but a particular innovative one is linking the model to visualize air pollution. The network of air pollution sensors across London provides hourly feeds of data which are then mapped and visualized using the surface routines in *ArcGIS*. We can then overlay these onto the model as we show in Figure 8. This shows the nitrogen dioxide surface for central London where it is clear this pollutant is strongly correlated with the road system and with key traffic intersections. We can do this for a vast array of pollutants but to illustrate its potential, we have tagged the data to the static 3D images from the model, coloring the buildings in this manner. This is presented in a *Flash*-based interface which is available at the London Air Quality Network (see http://www.londonair.org.uk/), a site where air pollution data is visualized in somewhat cruder terms but on a daily basis.

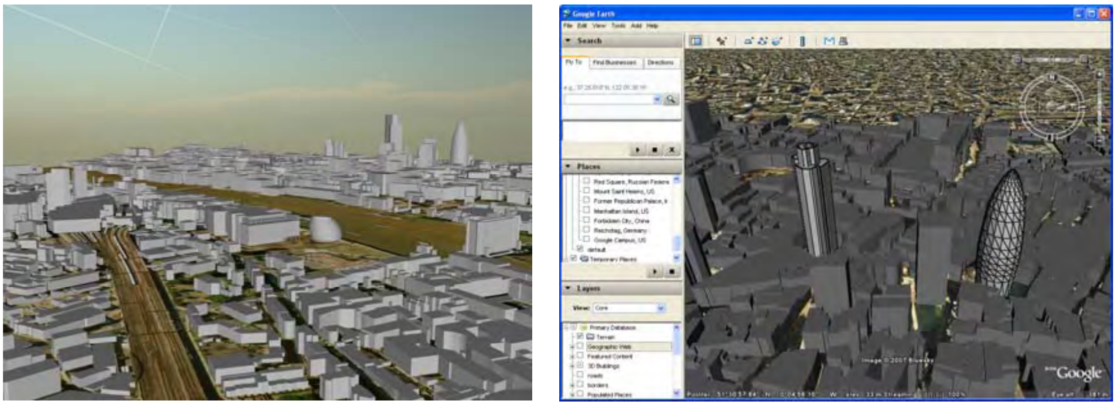


Figure 7: Iconic Modeling: Virtual London
left in ***ArcGIS****, right in* ***Google Earth***

We show the interface in Figure 9 where the coloring shows the intensity of air pollutants in an area of central London that the user can zoom into. The slider also shows how the user can see what predictions of air quality are going to be over the next 10 years for pollution will drop dramatically here due to new controls, congestion charging and so on. At various points in the scene, the user can display the pollutants in 3D where these scenes are taken from the Virtual London model. In fact, the air pollution surfaces are taken from a symbolic model of the hydrodynamics of traffic and pollution, all visualized in a web-based interface for users to get to grips in terms of the significance of these flows and their location. It is not beyond our wit to consider an online updating of this entire media linked to the sensor network just as we presented for San Diego in Figure 1(b) 12 years ago. This makes the point quite forcibly that such systems have enormous importance to serve and support the planning function in real time. This too we expect will be a major development in the next decade.

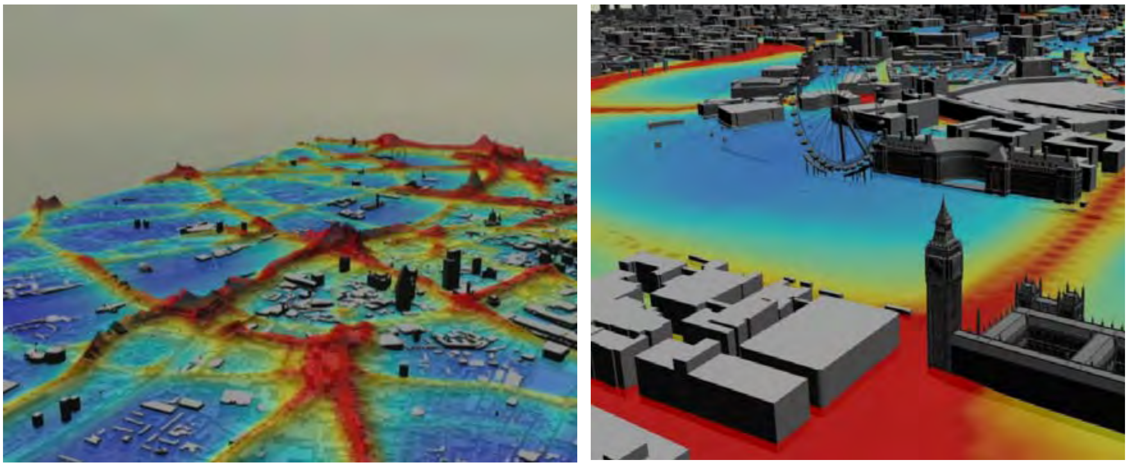
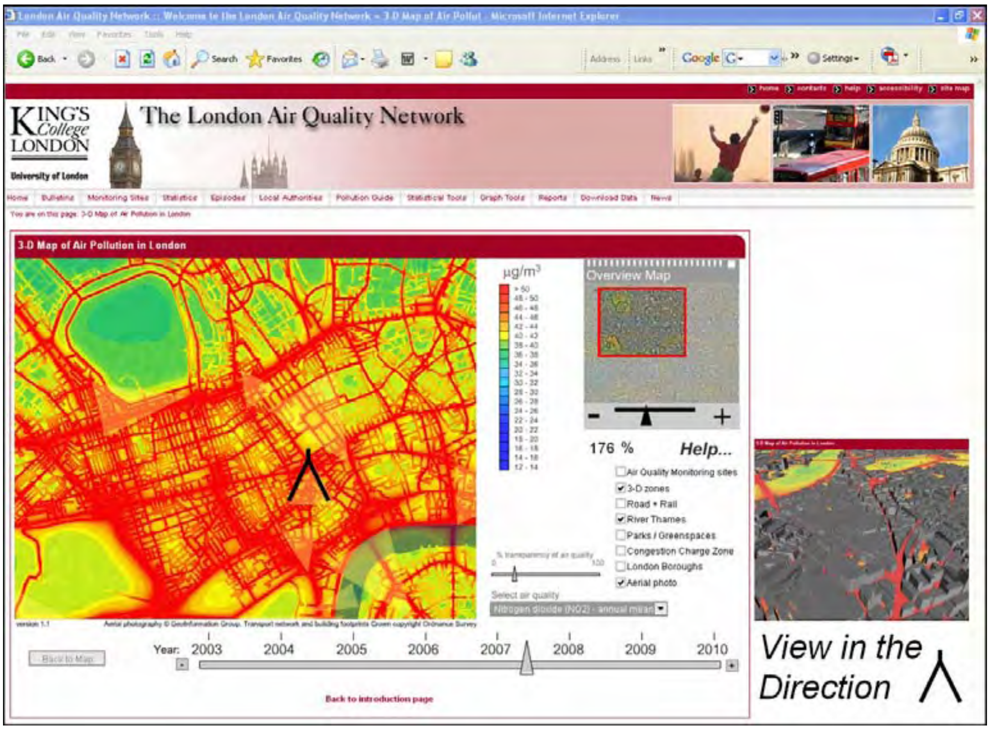


Figure 8: Nitrogen Dioxide Surface Mapped onto Virtual London as a Surface (left) and as Flat Map (right)



☐ Air Quality Monitoring sites
☑ 3-D zones
☐ Road + Rail
☑ River Thames
☐ Parks / Greenspaces
☐ Congestion Charge Zone
☐ London Boroughs
☑ Aerial photo

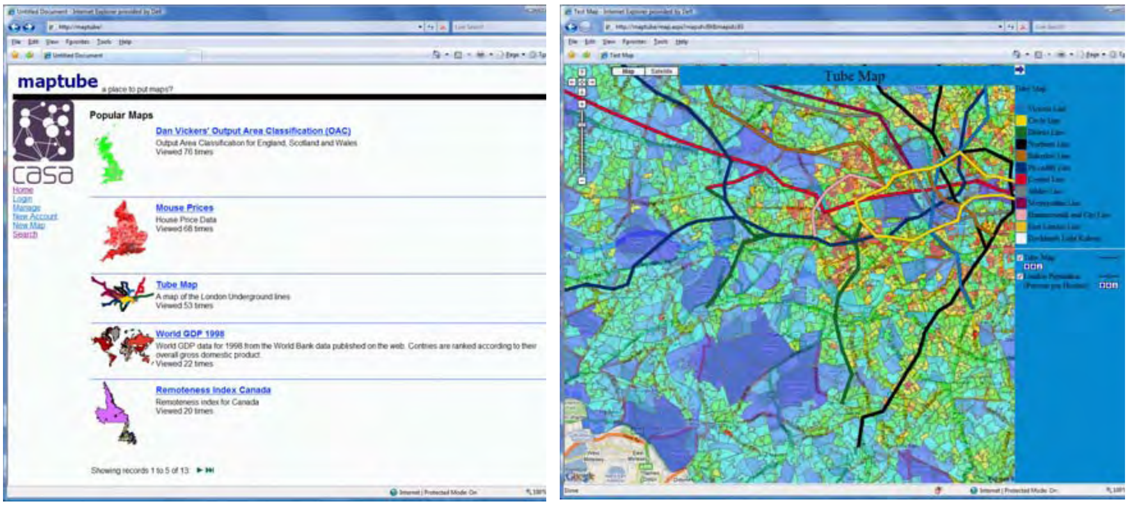
Nitrogen dioxide (NO2) - annual mean

Figure 9: Embedding Predictions from Air Pollution Models Fitted to Current Data into 2D and 3D Virtual City Environments

c. Describing and Exploring Spatial Data: Tools to Enhance the Understanding of Urban Problems

Our third exemplar is quite different. In 1990, this would not have been thought of as a planning support activity at all because the notion of understanding urban structure and urban problems was largely in the personal domain with no online tools available to add value to data by seeking diverse interpretations through participation. In fact, our current and fast expanding ability to share data on the web is leading to new kinds of exploratory analysis that many actors and stakeholders involving in solving planning problems can engage in together. The 'wisdom of crowds' is one of the emerging drivers in terms of developing good science and thus any activity which involves us sharing data and then adding value to it by bringing data together from unusual and hitherto unknown and inaccessible sources supports the process of understanding in ways that have not been available hitherto. In fact many of these possibilities are essential in beginning to use software such as *Google Maps and Google Earth* as these need to be tuned to represent data in ways that inform technical processes.

We are actively engaged in building a web-based service and resources which enables a user with some spatial data in a standard format to use the 'free' software on the web which is available from Google to display their data. A user with a file in some standard GIS format can easily convert this to the ESRI proprietary but widely used shapefile format and then use our software *GMap Creator* to generate a *Google Map* from the data file in a one stop operation. This software is freely downloadable from our web site (see http://www.casa.ucl.ac.uk/software/googlemapcreator.asp) and once the user converts their file to the Google format on their desktop using this, this creates a *Google Map* (which is always of course in a web page) which they can publish on their own site. The facility we have developed enables the user to overlay different layers of data and to manipulate these and it is easy to add more functionality to the interface that is created. However once the map has been created, we ask the user if they will share their URL (where the map is located) with us and if so, we add this to our archive of URLs which are available for any user on the web service we are building. This is called *MapTube*. Essentially *MapTube* is just a bunch of pointers to remote URLs which when accessed, lets the user grab any map at any of these locations, overlay them and manipulate them in other ways involving their presentation but in so doing, adding value to the resultant data (as long as the application is meaningful). We show the interface to *MapTube* in Figure 10.



Popular Maps

Dan Vickers' Output Area Classification (OAC)
Output Area Classification for England, Scotland and Wales
Viewed 76 times

House Prices
House Price Data
Viewed 68 times

Tube Map
A map of the London Underground lines
Viewed 53 times

World GDP 1998
World GDP data for 1998 from the World Bank data published on the web. Contries are ranked according to their overall gross domestic product.
Viewed 22 times

Remoteness Index Canada
Remoteness index for Canada
Viewed 20 times

Showing records 1 to 5 of 13

Figure 10: The MapTube Resource for Retrieving, Displaying and Overlaying Maps

In the context of planning support, experts and stakeholders could share their data this way, could take data from remote sources and all have access to it through the web service. Essentially the idea of storing pointers (URLs) rather the map data itself is that copyright issues, however unwitting, are avoided (by us) and the server will not fall over as maps are added for those maps remain on the site where they are currently published. In fact the data that *GMap Creator* produces is map tiles from vector data and these can be quite large which is purely due to the API that Google uses for its maps. We have various extensions of this which are web-services in their own right. *London Profiler* is a server that assembles geo-demographic data for London and makes this available to users enabling them to perform their own overlays. The focus is on spatial variations in health, ethnicity, deprivation and so on and this tool enables visual correlations of problem data to be rapidly assessed in much the same way that any mapping technology lets the user grasp the map pattern quickly and easily which we show in Figure 11. We are currently extending the *GMap Creator* to creating 3D pictures which can be displayed in *Google Earth* and in time, the 2D *MapTube* server will also be extended to 3D.

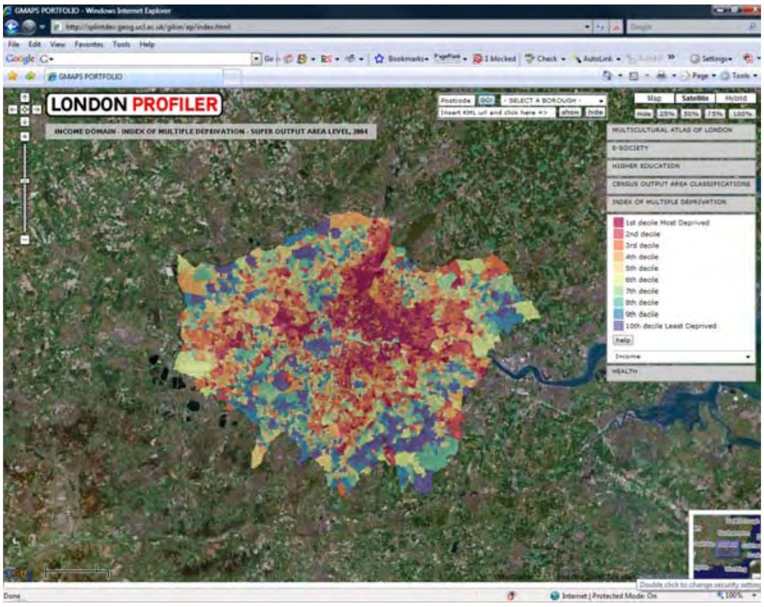


Figure 11: The London Profiler
A web browser enabling users to examine different patterns of spatial inequality

We are also exploring different kinds of environment for the display of spatial data. We noted the Virtual London project above but increasingly we are interested in remote environments – virtual worlds that enable us to display and manipulate content across the web where users interact with such media as avatars. Five or more years ago, we placed our Virtual London model into such a world (using *Adobe Atmosphere*) but currently we are exploring ways in which we can port the kinds of geo-demographic data contained in *MapTube* to such worlds. In fact when the user allows his or her data to be accessed from *MapTube*, we automatically load that data into the *Second Life* virtual world so that we can manipulate the media in lots of different ways – akin to placing the data in a virtual exhibition space through which users can interact. In Figure 12, we show a picture of Virtual London in such a virtual space circa 2001 by the side of the imagery that we now have available in *Second Life*. Our space in *Second Life* is part of **Nature** magazine's *Second Nature* land grab which they are using for the display of scientific outputs. This might appear to be somewhat 'off the wall' but the emergence of such domains which can also be sustained using real time feeds, provides new ways of generating informed support for planning processes. Last but not least, it is entirely possible that these kinds of digital environment might also be able to sustain more conventional software with models running within them while users as avatars sit and watch or manipulate such tools in real time (Batty, 2007).

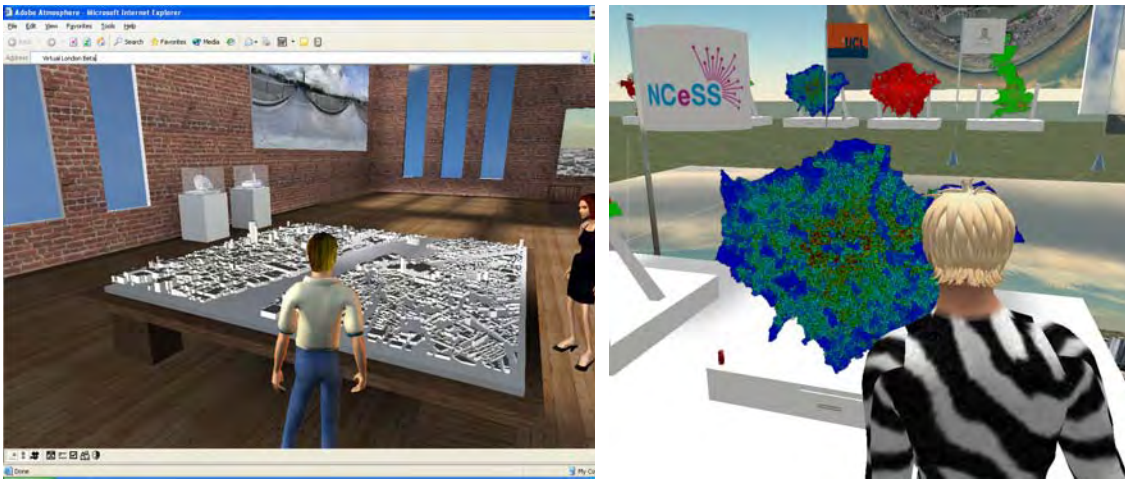


Figure 12: Spatial Data in Virtual World: 2D Merges with 3D

V The Future

We will not speculate in this conclusion and simply note the key findings of this review and what portents they have for the future. The first is that as software proliferates and is generated at higher and higher levels, it is increasingly possible to support the same kinds of task in planning with very different combinations of software. Moreover there now appear to be examples where every kind of software has been linked to another as witnessed in the way LUTM and GIS are coupled, how these are linked to 3D and other forms of visualization, how they are supported by routine database, statistical and mathematical software, and how these support systems are widely disseminated and made accessible on the web.

Second, visualization is now all important. This is particularly the case as the complexity of the models and their data increases and as more and more stakeholders come to be involved in the planning process. Visualization too as well as much of the traditional software is drifting into web-based contexts and the notion of data, software and expertise being available at different places and PSS being systems that enable such remote access is likely to become the dominant paradigm. The notion of a user literally picking software off the web using visual interfaces, as in movies like **Minority Report**, is well on the way to becoming a reality as evidenced for example in the current generation of operating systems.

Third as planning has fragmented, so have the tools and software necessary to support it. The domain is now quite eclectic and it is hard to predict whether the apparent uniqueness in applications and the relative turbulence in possibilities will subside. Only then will a more uniform paradigm for PSS emerge. The difficulty of finding a coherent framework within which to place PSS is dominating the current scene. Much will depend on how physical and land use planning itself matures and evolves and whether or not we move back to a less decentralized more top-down, perhaps more structured style of planning than the current fragmented and diverse pattern.

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