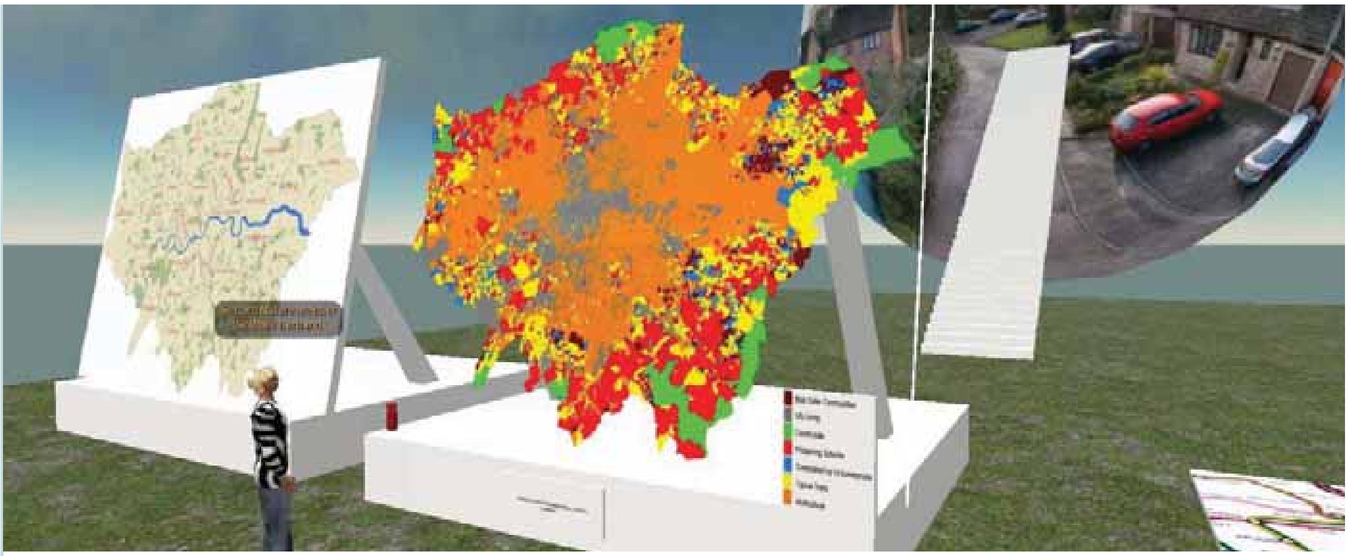

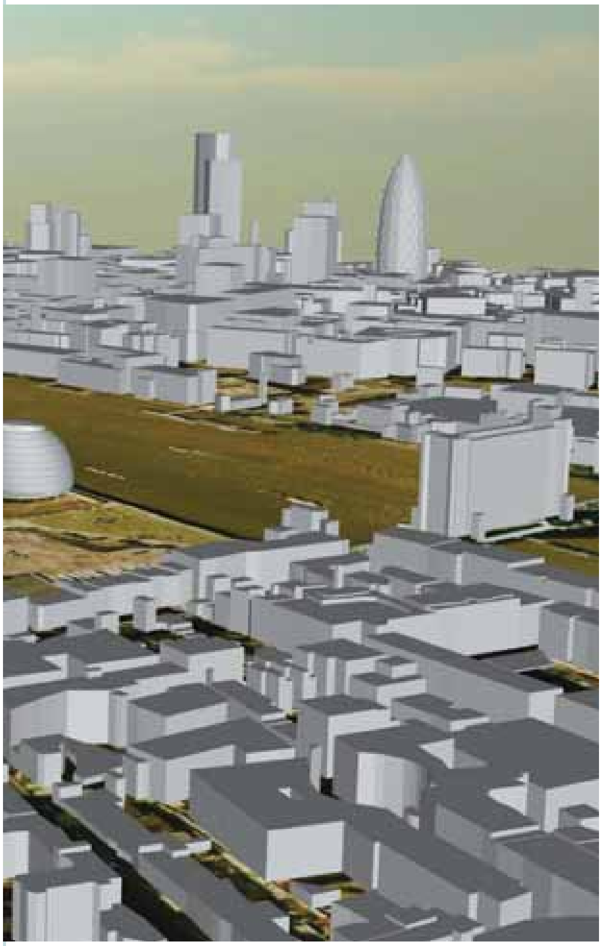

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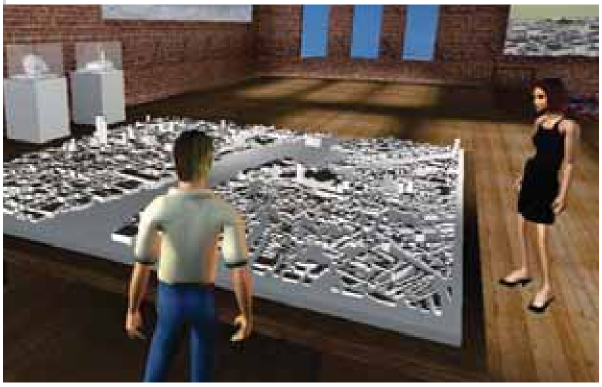

Planning Support Systems for Cities and Regions

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1

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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-twentieth 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 that formed the core of the planner's toolbox until the advent of geographic information systems (GIS). By the 1990s, a sufficiently varied set of tools informed most of the stages of the technical planning process. It thus made sense to consider these collectively as planning support systems (PSS) that 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 held that scientific or rational planning could and should be underpinned by comprehensive computer models that 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 wider 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 (1979). 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.

Britton Harris (1989a) actually coined the term.[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," 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 networked computer systems really took off, most PSS were focused on nonroutine, strategic planning although the line between the strategic and the routine was inevitably blurred (Batty 1995).

What has changed this context radically is, first, 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 Web pages that simply provide information to esoteric software collaboratories. This blurring of the field is one of the key themes of this chapter. 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, both simultaneously and in parallel.

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 used increasingly 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 audiences and interest groups that do not ordinarily 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. Not all these transitions are necessarily ideal, but they form the starting point for this review and the speculations we will develop.

We first outline the development of new computer technologies and their importance for PSS, largely since the advent of the Internet and its visual media in the form of the browser. We pay particular attention to ways in which computers have merged with communications and the way desktop tools are migrating to the Internet. 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 at 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 chose three exemplars: (1) 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; (2) 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 (3) the way geodemographic spatial data are being focused on routine applications through linking them to online tools such as Google Maps and online environments or virtual worlds such as Second Life®.

The first example is nonroutine, 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 chapter that communication through visualization is rapidly becoming one of the main foci in PSS as the computer revolution moves ever more swiftly to graphic and related media in contrast to its origins in numerical data processing. This echoes the implicit sentiments of Brail in his earlier emphasis on planning support systems as techniques that "couple analytic tools and computer simulation models with visual displays" (Brail and Klosterman 2001, ix).

New Technologies

Several fundamental themes characterize the evolution of digital computation, but one of the most deep-seated is the development of hardware that is able to process ever-increasing amounts of data. In a sense this might seem an almost trivial characteristic since 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 earthbound scales, and the convergence of computers and communications is now driving the development of computation in all-pervasive ways, of which PSS is just one of many. Miniaturization of computer circuitry through increasingly powerful microprocessors is the key to all of this and there seems to be no end in sight.

For forty years or more Moore's Law, which holds that computer processing power—speed and memory—doubles every two to three years, has held sway, while Gilder's Law suggests that this increase is even faster for bandwidth, with capacity growing at least three times faster than computer power (Gilder 1989). Putting together this growth in the number of computers and increasing bandwidth, Metcalfe's Law suggests that the growth in digital connectivity between identifiable units of social action—people, firms, governments, and so on—grows at least as the square of the number of users, which is even faster still.[2]

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 specialized 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 memory, 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. These later technologies 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. Urban modeling has moved away from aggregate, cross-sectional models to more disaggregate, agent-based structures that depend on representing more individual-based data (Waddell, Liu, and Wang, chapter 6) and on physical representations of the systems of interest using fine meshes of cells (Clarke, chapter 3), but these developments are largely driven by the existence of fine-scale data and by computation itself rather than by any theoretical advances in our understanding of cities.

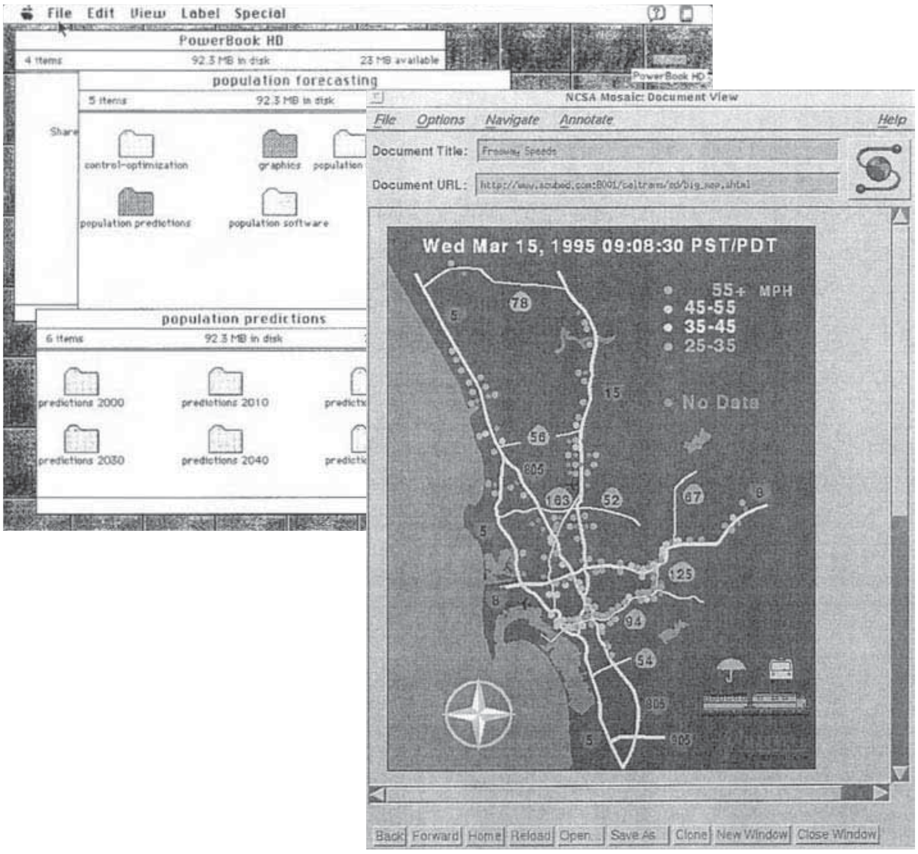
In fact, we are living through a time when theories have fragmented and there is much less consensus than there was 50 years ago about what represents the key ways in which cities evolve and grow. Technique rather than theory has come to dominate, and thus developments in computational technologies are 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 two to three dimensions 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 1.1(a) and 1.1(b). Figure 1.1(a) shows the kind of desktop interface available in the early 1990s on a Macintosh computer, where a variety of well-known tools have been brought together for population forecasting. The modules shown on 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 linked software systems. Now, however, there is less consensus that this is the main way forward for PSS. Figure 1.1(b) shows one of the earliest interactive Web pages from March 1995—traffic-flow data being piped from Web cameras in San Diego, California—used as a diagnostic tool for traffic control (Batty 1997b). 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.

Various hardware environments for visualization are of some significance for PSS, and these revolve around the creation of theaters in 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 among 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 specialized and not yet in general use, notwithstanding reductions in real costs (Batty 2008). Interactivity and communication are 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 among diverse remote users.

FIGURE 1.1

Early Graphics (ca. 1995) for PSS:
A. PSS Loosely Coupled on an Apple Mac Desktop
B. Real Time Traffic Display Through Web Technology, San Diego, CA



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 rapidly gaining ground, at least conceptually.[4] The Web 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 hyperlinking to other pages; Web pages that 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 remotely linked through Web pages that enable users to communicate with 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 theaters, 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 individual attempts. A comparison of the articles in the two edited collections—Brail and Klosterman's (2001) *Planning Support Systems,* which is composed of reviews of tools largely conceived before the early 1990s, and Geertman and Stillwell's (2003b) *Planning Support Systems in Practice,* which contains techniques and models developed up to a decade later—impress this change. Online systems strongly feature in the later collection, although none of them quite reaches the level of collaboratories in the sense implied here. Nevertheless, the rudiments of such systems are now in place and substantial developments in this area are to be expected in the next decade.

As we have suggested, many of the traditional tools that historically dominated computer-aided planning, such as urban or land use transportation models, no longer form the core of PSS, although as Timmermans (chapter 2) 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 are 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 and 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 that enables such models to be constructed on the fly will these kinds of tools become more widely used. 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 loose couplings with GIS, and/or Web-page outputs, such as in the generalization of the MEPLAN, TRANUS, and IRPUD models in the PROPOLIS project (Lautso 2003).

GIS software is more generic, highly descriptive, and much less controversial in terms of its implicit 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 than predictive. Insofar 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 "theoryless," 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 additional tuning of the software. An example is Klosterman's What if?™ system (2007; chapter 5), which utilizes elements of GIS but is essentially a stand-alone application of overlay analysis tailored to U.S.-style zoning and land use planning.

Within planning support, GIS applications tend to be both routine and strategic as well as applicable across 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. 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 nonproprietary software systems such as Google Earth, Google Maps, and Microsoft®'s Virtual Earth™, among others.

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 creative uses of spreadsheets and related databases and graphics systems ranging from paint packages to simple 2D and 3D CAD and GIS, among a plethora of newer applications that 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.

Substantial developments in PSS could arise 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—that is, mathematical urban models being coupled to or embedded in 2D and 3D GIS within virtual reality–style environments (Batty 2007). Although there are already examples of this, their routine application remains a long way off. It is more likely that new layers of software will be built up to the point where nonexpert but professional users can fashion many new tools from component parts. This is the way computing has evolved over the last 50 years since its inception and there is no end in sight. However, this model of building successive layers of software comes at a cost: Each additional layer constrains what is possible within that layer. 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.

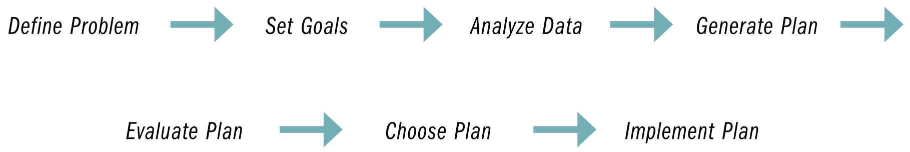
Before we attempt to classify PSS, it is worth noting this last feature of computer technology, the relentless march to develop layer upon layer of functionality in the effort to bring computation to the widest possible constituency. The model of technological development suggests that as computers increase 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 generalized software on top of the less generalized. A classic example is the Windows operating system, which was built on top of DOS. In the long term, however, this transition occurs almost continuously. It is seen currently in programming in the object-oriented paradigm and in the introduction of ever 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 now to foresee a time when users will literally pull windows and their applications around a screen with their fingers, which not so long ago was 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 applications. 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 for PSS a generation ago. The tools presented below illustrate all these issues as well as ways in which such problems are being resolved in the wider context of visualization and communication.

A Classification of Planning Support Systems: The Planner's Toolbox

The traditional classification of PSS is based on the various tasks that 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, then to the generation of alternative plans with their subsequent evaluation, and finally to the choice of the best plan to implement. This can be a cyclical or iterative process, as 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 a 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 ideal type that 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 think about planning support using IT. We assume the process can be arranged in the following sequence:



Here distinct theories, models, and techniques can be applied at each of these stages. Specialist tools have been developed for each of these stages. 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 many packages of increasing sophistication 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, the predictive capacity and what-if capabilities of which have been widely developed during the last 30 to 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 multicriteria and optimization models. Implementation involves a series of management techniques developed under the more routine rubric of decision support.

In the 1960s, very early in the development of land use transportation models, it was assumed 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 to, although this phase was short lived and the complexity and ambiguity of city systems and their planning were quickly realized. In fact, it was probably the inadequacy of the tools that was most clearly sensed, 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. GIS was added to land use and transportation in the 1980s. Since then the development of much more generic tools such as spreadsheets at a lower level and of wider applicability has begun to inform all stages of the process. The rather narrow technocratic process above can be extended into a much wider domain of public engagement, however. Running alongside or perhaps woven into this fabric is public participation of all kinds, which has provided ways in which the process has reached out to its wider context. Such participation has been fashioned particularly around PP-GIS (Craig, Harris, and Weiner 2002), but increasingly a whole variety of visualization tools making use of more bottom-up technologies as well as 3D virtual city models have come into play. Much of this was anticipated by the mid-1990s as reflected in Brail and Klosterman (2001).

The next set of ideas by 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 to organize PSS. Survey is based on observation and measurement while analysis is based on the representation and organization of these data. Modeling and simulation are key activities in description and prediction while optimization 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, and negotiating, among others, can all be supported by software, and software has and is being developed around them. To show the variety of such classification at this point, however, it is worth noting that distinct packages have been developed that reflect different combinations of these activities to different degrees. These packages can be roughly classified as GIS; land use transportation models (LUTM); multicriteria 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 lower-level, generic software can also be identified that can be adapted to all such tasks in the form of spreadsheets, animation, and visualization packages. At the higher level, several of the standard packages can be added, integrated, or coupled together. For example, CommunityViz® is one such application that has reached the point of wider application, building on agent-based models, GIS, and 3D visualization.[5]

These packages can all be scored against the activities noted above. For example, GIS is focused on measuring and analyzing but can be adapted to prediction to an extent. Various routines are available 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 an exhaustive list of software products and the tasks they involve could be compiled. 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 planning problems at different scales. This is largely because when software is devised, it is usually in relation to a narrower problem; when it is 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 is related to this in some way. For example, it is not 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 scales. For example, consider the idea of spreadsheets as PSS tools. Klosterman, Brail, and Bossard's *Spreadsheet Models for Urban and Regional Analysis* (1993) shows a wide variety of analytical and predictive applications (e.g., models implemented in spreadsheets that were initially devices solely used for storing, visualizing, and searching data). Currently, at the other end of the spectrum, several packages are emerging for new classes of the cellular automata model that 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 with the generic properties of the particular application. For example, in the case of 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.

Several other ways exist to classify tools for PSS. The scale of the problem is significant. It is likely that urban design problems, for example, especially those that involve movement in small spaces, require very different types of software from those used to support regional planning. The best-developed agent-based models are in the area of crowd dynamics, making them useful for assessing movement and patronage in small spaces like shopping centers. This type of model, even its 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; this changes the basis of support. Sometimes the task is not composed of a series of stages as 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 may 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 and controversial one.

Before illustrating what we consider to be the future based on current developments, we will list the main kinds of software packages and applications that characterize 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 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 rudimentary classification into tools and their software focuses on spatial problems (or not) and 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/Nonspatial. We can consider Nonspatial to be Aspatial because many tools are not specifically designed to deal with spatial problems per se, but can be fashioned to do so. This simple classification is shown in table 1.1 with typical examples of the genus contained in each box.

LUTM is highly specialist software that has hardly reached the stage where it can be purchased and adapted to specific situations by users or professionals who are not involved in its development. 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

TABLE 1.1 **A Classification of PSS**

	Spatial	*Aspatial*
Specialist	*e.g., LUTM*	*e.g., Expert Systems, AI Software, Agent-based models (ABM)*
Generic	*e.g., GIS, Google Maps, Google Earth, etc.*	*e.g., Spreadsheets, Math-stat software, Databases*

free or shareware but the learning curve is still extremely steep (Waddell, Liu, and Wang, chapter 6). 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. 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. 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 to policy and more speculative than LUTM. The software is better developed largely because such automata models that simulate urban development are more visual and simpler in structure, but also less operational (Clarke, chapter 3). For example, they contain hardly any transport activity, and where they have been widely developed as in the RIKS (Research Institute for Knowledge Systems) applications in the Netherlands (see Timmermans, chapter 2), 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 pedagogic applications rather than fully fledged models that support policy making (see Maguire, Batty, and Goodchild 2005). In these kinds of Specialist/Spatial models, various attempts have been made to open them up to supporting tools in the other boxes of table 1.1. 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, various stages of the planning process can be supported using individual tools from the GIS toolbox. GIS is primarily about spatial information—storing and then displaying it—but many rudimentary and some 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, and it has been very well developed within GIS. 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. Linking to other models (LUTM, ABM, and so on) tends to be the way in which this software is extended.

The GIS toolbox has opened up dramatically in the last five 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. The 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 urban development in 3D as virtual cities. CAD and 3D GIS are usually tailored to specific applications, despite the software being generic. Each application is quite different, which 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 more user friendly.

Integrated systems that combine the first column of table 1.1—specialist and generic spatial software—are increasingly used to underpin PSS. For example, CommunityViz and INDEX (Allen, chapter 7) fall into this category, and now the list of such applications is quite large. 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. Attempts are now being made to develop software-based conceptualizations of the entire planning process (Hopkins, Kaza, and Pallathucheril 2005a).

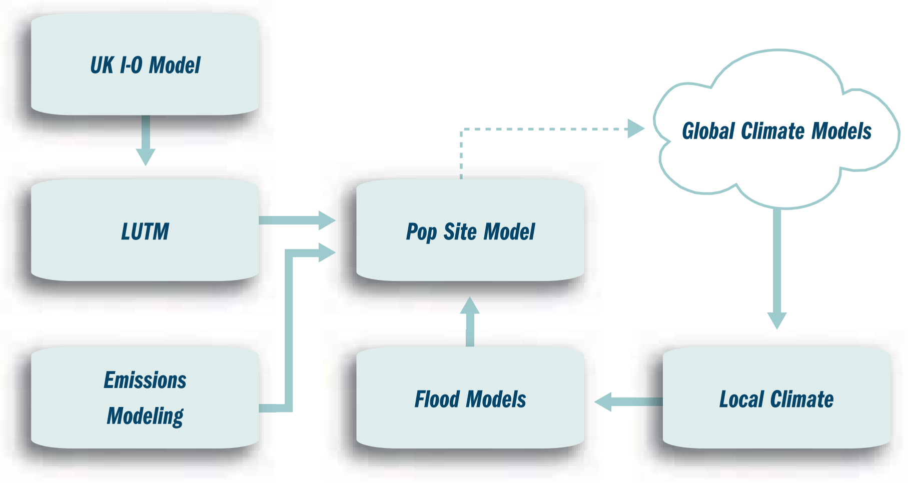
The second column of table 1.1, where software exists both in specialist and generic forms but is focused on problems that are not explicitly spatial, makes it clear that many forms of planning support use these. For example, expert systems informing plan-making activities and participation at different stages of the process have been quite widely developed while spreadsheets, mathematical and statistical, as well as database packages are now used routinely to support various parts of the process. This is where our classification begins to fall away as being less useful. What is very clear, however, 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.

Exemplars

We now develop three exemplars that illustrate many, but by no means all, of the features and characteristics of PSS identified above.

LONG-TERM FORECASTING AT THE STRATEGIC LEVEL: VISUALIZING LAND USE AND TRANSPORTATION We are designing a land use transportation model for

FIGURE 1.2 **Models in the Integrated Assessment of Local Climate Change**

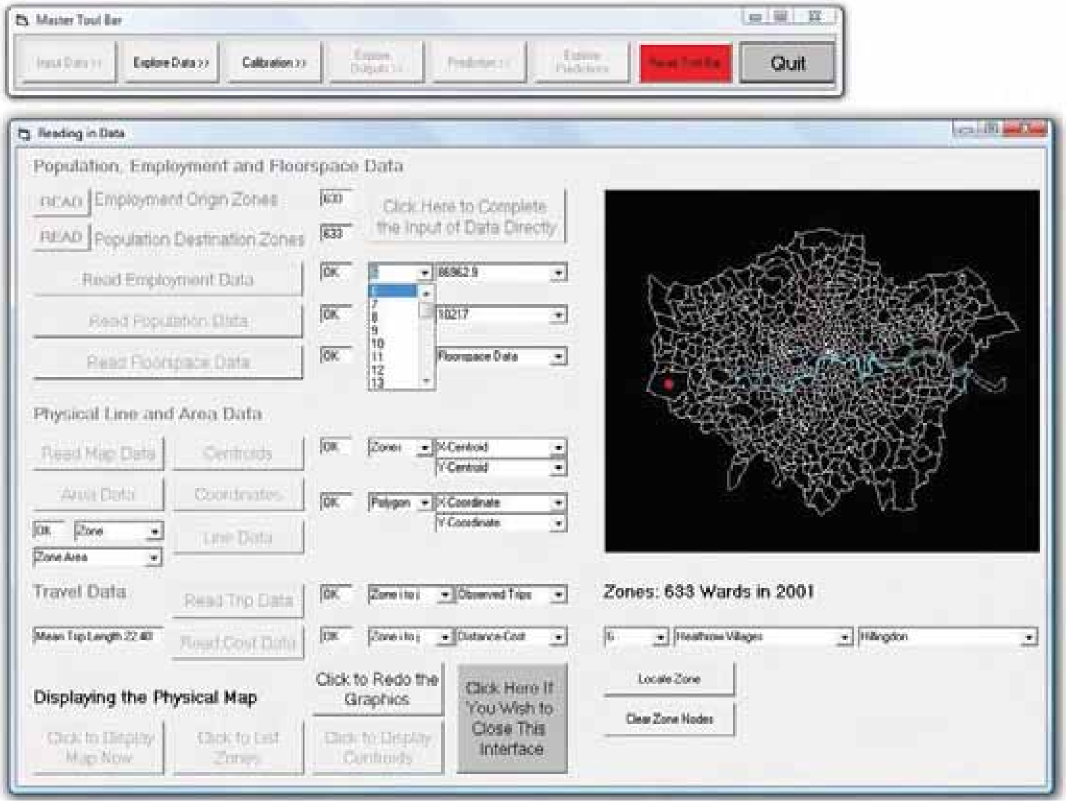


Greater London as part of an integrated assessment of the impact of climate change on the location of population. This process couples a series of models that move down scale from predictions taken from global climate models to their impact on small-scale environments where pollution and flooding are the main concerns. The LUTM we are building is coupled to a global environmental input-output model at the regional scale and, at the site scale, to a detailed population-allocation mechanism that, 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 comprise the current application. The models are strung together in the fashion illustrated in figure 1.2, 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 in which various stakeholders and experts use the information from these models to make informed guesses and judgments about the future.

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 the LUTM to a finer 100 meter by 100 meter grid used to assess the impact of flooding (see Dawson et al. 2007). What is of concern is the kind of support that this suite of models and the LUTM in particular provide 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 LUTM and thus it is essential as a 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, setting up 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 most LUTM currently do not have. Moreover, many of the models are almost legacy systems, 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 that the user can calibrate on the fly, applied 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).

FIGURE 1.3 **Loading the LUTM Toolbar Control, Reading in, and Checking the Data**



In figure 1.3, 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 toolbar moves from data input, to data exploration, to calibration, then exploration of the calibration results, through to the interactive setting of scenarios, and finally 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 file from which various options can be chosen at calibration and prediction. Figure 1.4 shows how the model can be interrogated spatially, with six screens showing the employment and population distributions as well as a 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. Figure 1.5 depicts 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 see some typical predictions in figure 1.6, which shows 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.

FIGURE
1.4

Exploring the Employment, Population, and Trip Data Spatially

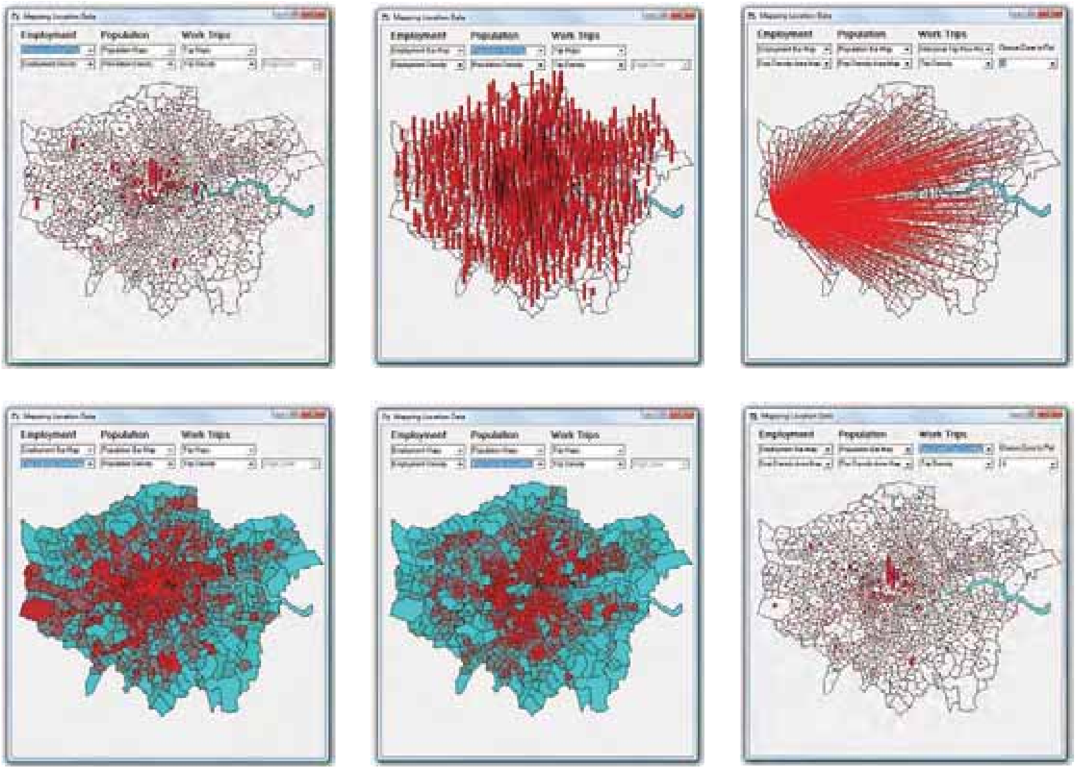
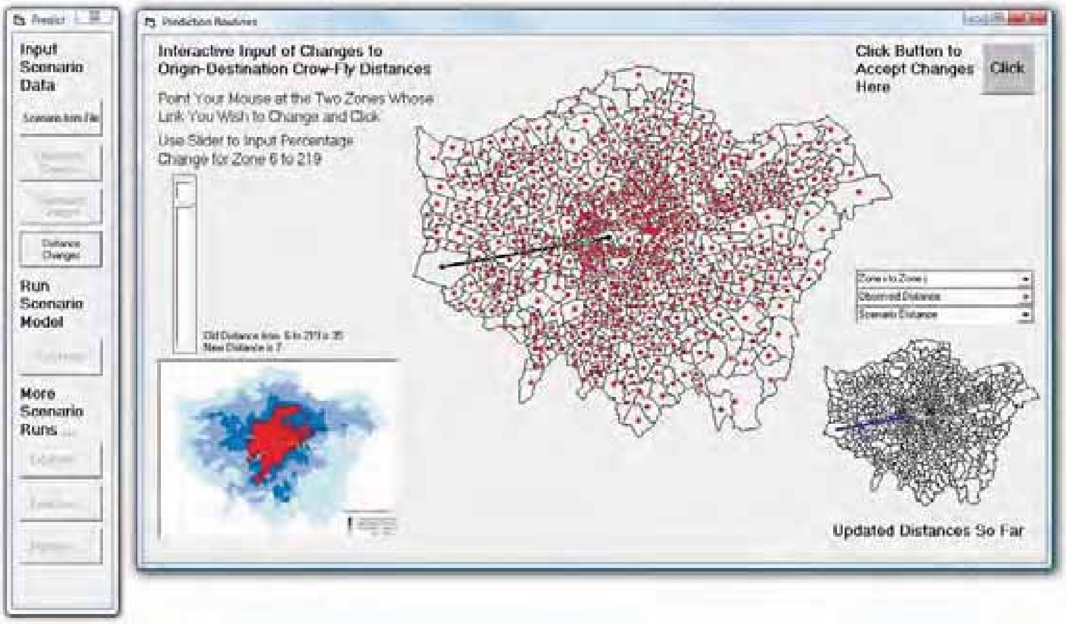


FIGURE 1.5 **Creating a Scenario Interactively Using Sliders**



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

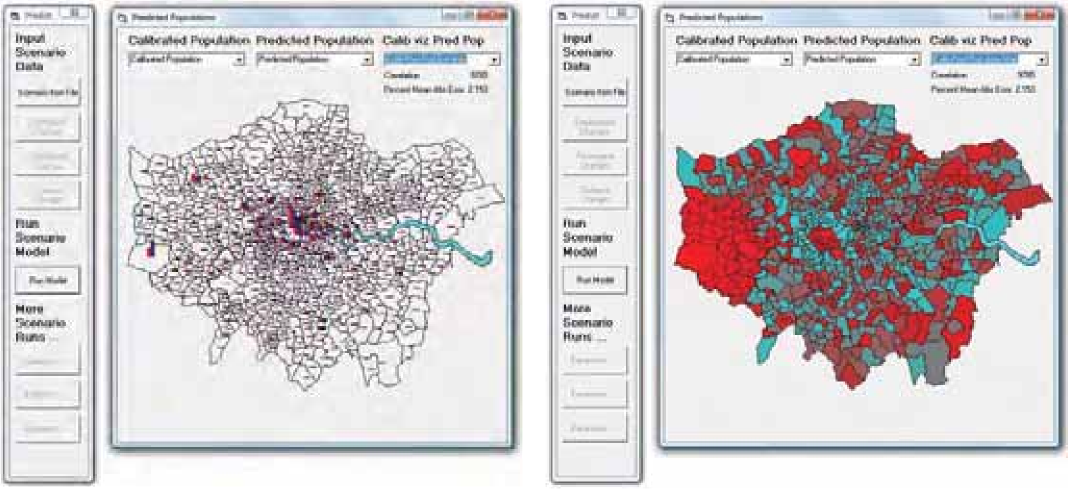
Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click

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

FIGURE 1.6 **Predicting the Effects of the Scenario Using the Same Techniques for Exploring the Data**



This gives an idea of what is now possible with LUTM. If those involved embraced current technologies, 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 a much wider range of users, but it is easy enough to set up the model for distribution to others in this mode.

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—that we have built for the metropolis. This model is quite different in structure from the LUTM. It is not mathematical in the symbolic sense; it is iconic, but nevertheless digital, and constructed from building blocks, land parcels, and street data supplemented in the third dimension by light detection and ranging (LiDAR) data. The model was constructed for general visualization and public participation in Greater London and was funded by a 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 million 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 3ds® Max, and now is available for local municipalities/boroughs in Google Earth. For data copyright reasons, it is not available as a public Web site, which is a source of great frustration in terms of its use for public participation.

Visualizations of the 3D form are shown in figure 1.7 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 order to link it to online panoramas. The products from the model tend to be movies that can be placed online rather than interactive products within which users can navigate. This also minimizes data copyright issues. We have developed several uses in terms of public participation, but a particularly innovative one links with the model to visualize air pollution. The network of air pollution sensors across London provides hourly feeds of data that are mapped and visualized using the surface routines in ArcGIS. We can then overlay these onto the model as shown in figure 1.8. This illustrates the nitrogen dioxide surface for central London where it is clear that 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 that is available at the London Air Quality Network,[6] a Web site where air pollution data are visualized in somewhat cruder terms, but on a daily basis.

In figure 1.9 the coloring shows the intensity of air pollutants in an area of central London into which the user can zoom. The slider allows the user to see predictions of air quality 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

FIGURE 1.7 **Iconic Modeling: Virtual London in ArcGIS** (top) **and in Google Earth** (bottom)

FIGURE 1.8

Nitrogen Dioxide Surface Mapped onto Virtual London as a Surface (top) **and as a Flat Map** (bottom)

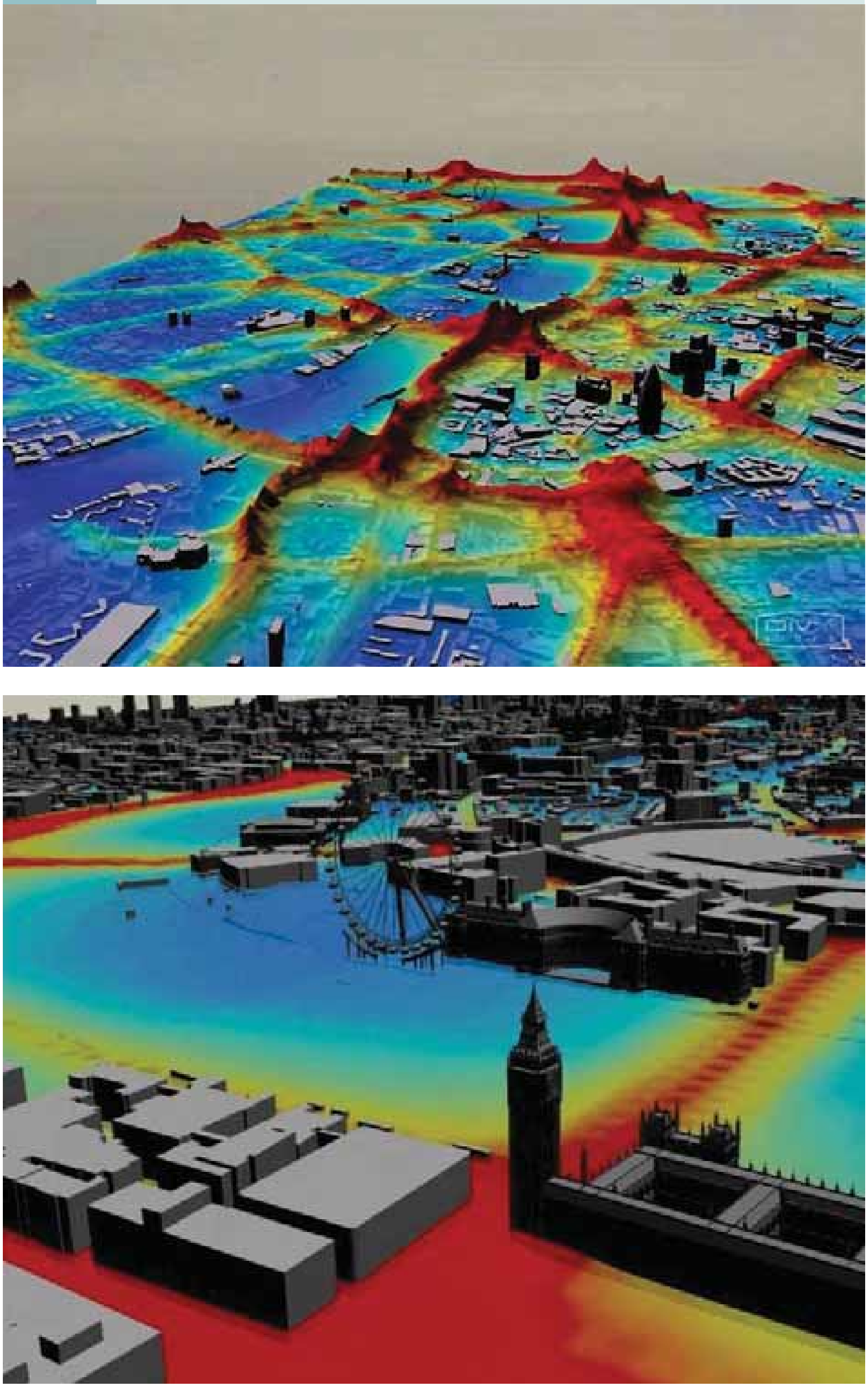
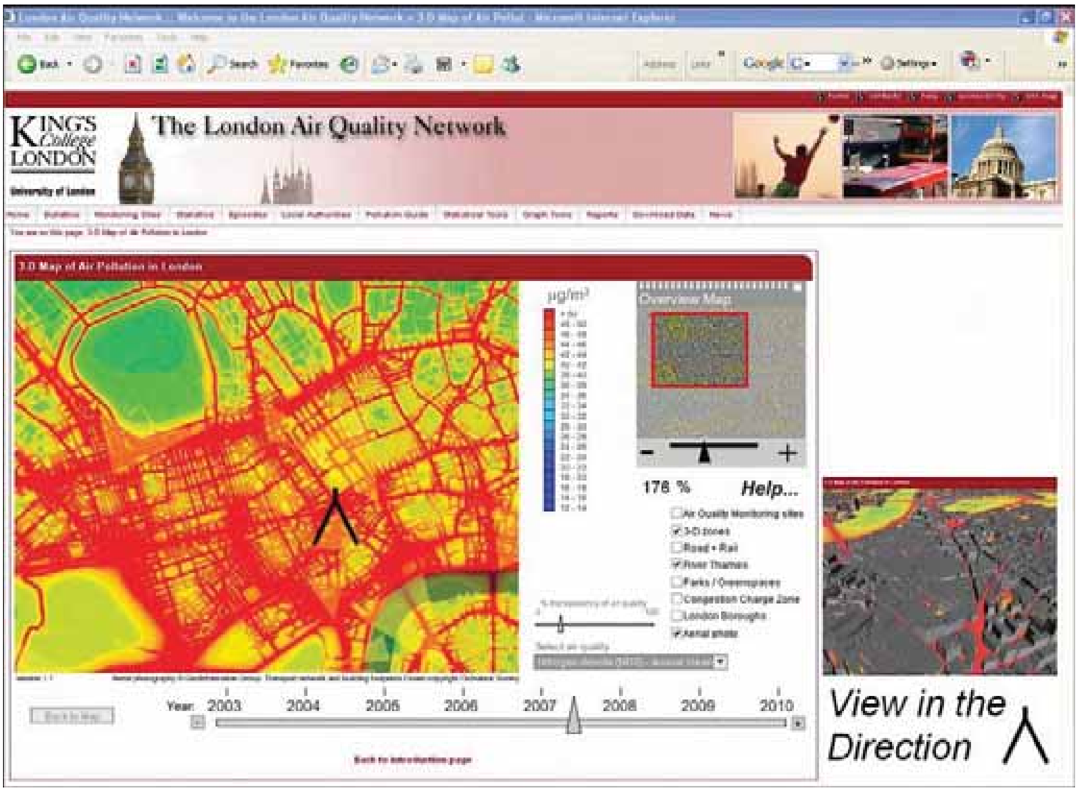


FIGURE 1.9 **Predictions from Air Pollution Models Fitted to Current Data Visualized in 2D and 3D Virtual City Environments as a Web-based Service**



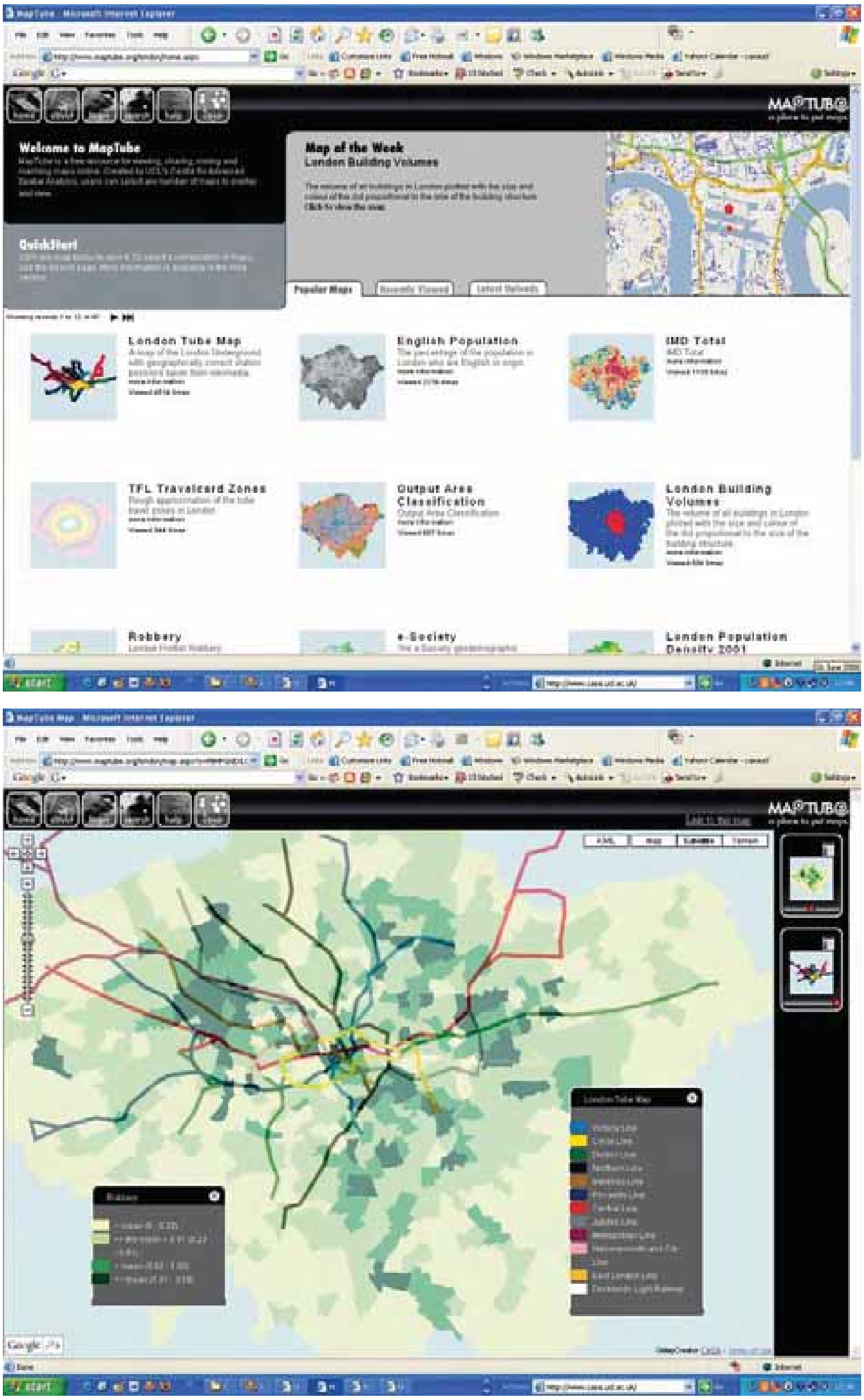
taken from a symbolic model of the hydrodynamics of traffic and pollution, all visualized in a Web-based interface where users can get to grips with the significance of these flows and their location. It is not beyond our wit to consider an online updating of this entire media linked to the sensor network just as we presented for San Diego 12 years ago, as shown in figure 1.1(b). This makes the point quite forcibly that such systems have enormous importance in serving and supporting the planning function in real time. This, too, we expect will be a major development in the next decade.

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, fast-expanding ability to share data on the Web is leading to new kinds of exploratory analysis that many actors and stakeholders involved 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 that involves sharing data and then adding value by bringing data together from unusual and hitherto unknown and inaccessible sources supports the process of understanding in ways that have not been available until recently. 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 that enable a user with some spatial data in a standard format to use the free software that is available from Google to display the data. A user with a file in some standard GIS format can easily convert this to ESRI's 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,[7] and once the user uses it to convert a file to the Google format it creates a Google map (which is always in a Web page) that can be published on the user's own site. The facility we have developed enables the user to overlay different layers of data and to manipulate them, and it is easy to add more functionality to the interface that is created. Once the map has been created, however, we ask the user to share the URL for the map. If he or she does, 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 collection of pointers to remote URLs that, when accessed, lets the user grab any map at any of these locations, overlay them, and manipulate them in other ways involving their presentation. In so doing, they add value to the resultant data (as long as the application is meaningful). We show the interface to MapTube in figure 1.10.

In the context of planning support, experts and stakeholders could share their data this way and could take data from remote sources and all have access to it through the Web service. Essentially, storing pointers (URLs) rather than the map data avoids copyright issues, however unwitting. The server will not fall over either as maps are added, for those maps remain on the site where they are currently published. In fact, the data that GMap Creator produces are map tiles from vector data. These can be quite large, which is purely due to the API (application program interface) that Google uses for its maps, and thus we have various stand-alone extensions of this that are Web services in their own right. London Profiler is a server that assembles geodemographic data for London and makes it 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 spatial 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 1.11. We are currently extending the GMap Creator to be able to create 3D pictures that can be displayed in Google Earth; in time the 2D MapTube server will also be extended to 3D.

FIGURE 1.10 **The MapTube Resource for Retrieving, Displaying, and Overlaying Maps**



Welcome to MapTube

MapTube is a free resource for viewing, sharing, mixing and mashing maps online. Created by UCL's Centre for Advanced Spatial Analysis, users can select any number of maps to overlay and view.

Map of the Week

London Building Volumes

The volume of all buildings in London plotted with the size and colour of the dot proportional to the size of the building structure

Click to show the map

London Tube Map

A map of the London Underground with geographically correct station positions taken from wikimedia

English Population

The percentage of the population in London who are English in origin

IMD Total

IMD Total

TFL Travelcard Zones

Rough approximation of the tube travel zones in London

Output Area Classification

Output Area Classification

London Building Volumes

The volume of all buildings in London plotted with the size and colour of the dot proportional to the size of the building structure

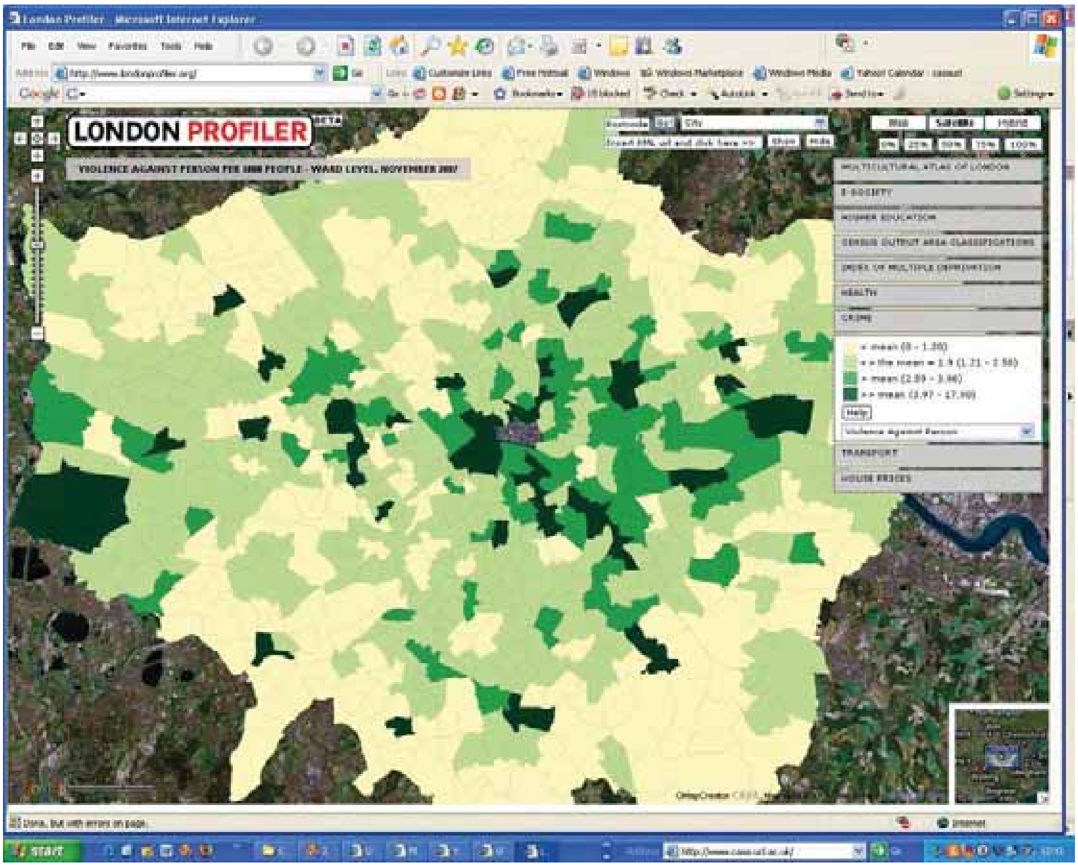
Robbery

London Profiler Robbery

e-Society

London Population Density 2001

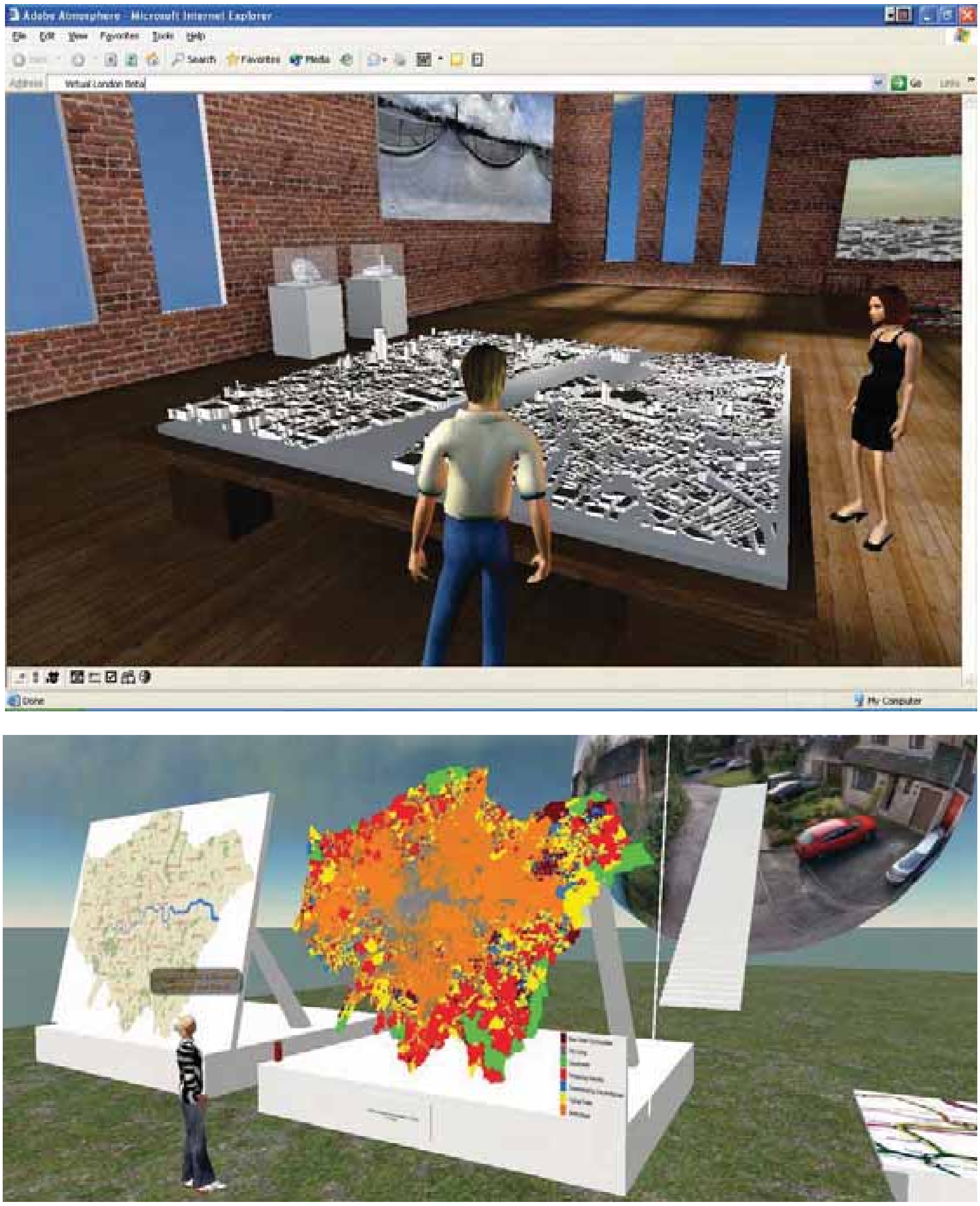
FIGURE 1.11 **The London Profiler: A Web Browser Enabling Users to Examine Different Patterns of Spatial Inequality**



We are also exploring different kinds of environments 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. Several 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 geodemographic 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 many different ways, which is akin to placing the data in a virtual exhibition space through which users can interact.

Figure 1.12 shows a picture of Virtual London in such a virtual space, ca. 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 island, which they use to display scientific outputs. The emergence of such domains, which can also be sustained using real-time feeds, provides new ways of generating informed

FIGURE 1.12 **Spatial Data in Virtual World: 2D Merges with 3D**



support for planning processes. Finally, it is entirely possible that these kinds of digital environments might also sustain more conventional software with models running within them while users as avatars sit, watch, and manipulate such tools in real time (Batty 2007).

The Future

What portents might the key findings of this review 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 tasks in planning with very different combinations of software. Moreover, there now appear to be examples where every kind of software has been linked to every other 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 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 as well as much 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 is shown in movies of the near future such as *Minority Report,* is well on the way to becoming a reality as evidenced 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 dominates 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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Endnotes

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 someone from the Delaware Valley Regional Planning Commission used the term at the 1988 URISA conference. Its precise origin now lies in the mists of time unless the person from Harris's audience can still be identified, or can still come forward.

2. The rules of thumb were coined by Gordon Moore at Intel in 1965; Robert Metcalfe, coinventor of Ethernet, at Xerox Parc in 1973; and George Gilder in his book *Microcosm* in 1989.
3. The paper referred to by Batty (1997b) 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.
4. The "grid" is a euphemism for a new wave of computation that is available in the same sense as the electricity grid delivers electricity, simply by plugging into the Internet and generating whatever software and data resources are required. In essence, the grid is conceptually a system for delivering computational resources—data, software, expertise, etc.—from diverse and remote locations to a user who simply has a device, usually a PC, that controls the way the Internet delivers these resources to the desktop. Usually the grid takes data and software from two or more remote locations and delivers the results of the computation, which possibly takes place somewhere else in the ether, to another remote location, usually the desktop, but possibly to a handheld device connected wirelessly to the Internet.
5. See Janes and Kwartler (chapter 8), and http://www.communityviz.com/. The agent-based model, Policy Simulator, is no longer supported in current versions of CommunityViz, but is detailed in Kwartler and Bernard (2001).
6. See http://www.londonair.org.uk/.
7. See http://www.casa.ucl.ac.uk/software/googlemapcreator.asp.

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