A Review on the Application of GIS in Land Use Planning

Bull. Univ. Osaka Pref., Ser. B, Vol. 47,
大阪府立大学紀要, 農学・生命科学, 1995

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Wentao CHE, Daishu ABE, Noboru MASUDA,
Yasuhiko SHIMOMURA, Satoshi YAMAMOTO

Laboratory of Urban Landscape Planning & Design,
College of Agriculture, University of Osaka Prefecture

(Received October 31, 1994)

Abstract

In the last decade, we have seen the rapid development of GIS methods that are capable of being applied to land use planning. This paper tries to give a general review on the past and the near future of GIS applications in this area by the following steps. Firstly, a brief definition of land use planning and GIS, and the reasons why GIS are so widely used in land use planning are presented. Secondly, the history of GIS development in the past three decades is briefly considered. Thirdly, some case studies of the application of GIS in this area in the last decade are summed up by listing them in a table. It shows that GIS are widely adopted and applied in the developed countries since the mid 1980s, because major breakthroughs in cost, speed and storage capacity in hardware (eg. the advent of workstations) and the sufficient progress in GIS software (eg. the success of ARC/INFO) have been made. Finally the prospect of the application of GIS in the next decade and some key issues which will determine the successful application of GIS in the next decade are presented.

Introduction

The reasons why GIS are so widely used in the area of land use planning are presented after a brief view of the definition of land use planning and GIS.

(1) *Land Use Planning*

The land use planning is such a system that can be used to provide a strategic and long-term approach to manage the environmental changes caused by the land use development for achieving the objectives of sustainable development. According to Jacobs[1], the sustainable development means such a level of development that the environment should be protected in such a condition and to such a degree that environmental capacities (the ability of the environment to perform its various functions) are maintained over time: at least at levels sufficient to avoid future catastrophe, and at most at levels which give future generations the opportunity to enjoy an equal measure of environmental consumption.

Land use planning is a form of spatial decision making which involves the detailed analysis of a complex set of geographical information. The planning system consists of a set of procedures for formulating plans and determining applications for development. The objectives and scope of the system are determined by government policy and local interpretation,

underpinned by legal review. The system is centrally concerned with the amount, location and characteristics of development, and with the extent of its impacts on the environment.

According to Dueker[2], a ideal planning process involves the following steps:

* Defining the problem
* Determining objective
* Inventing alternative solutions
* Evaluating alternatives
* Selecting the best alternative
* Implementing the system or plan
* Monitoring the results.

The regulatory land use planning systems, potentially, have a critical role in (Healey and Shaw)[3]:

* Dealing with a whole range of local site-related matters, notably conservation of resources and environments, and in fostering locational patterns which minimize energy use and pollution generation.

* Ensuring that development does not exceed ecological capacity thresholds.

* Balancing the details of environmental, social and economic considerations in relation to specific development projects.

* Promoting and managing the maintenance and enhancement of the quality of local environments.

* Dealing specially with the locally adverse impacts of development.

The breadth of this task implies that achieving the strategy of sustainable development involves entrenching the new environmental agenda within the planning system, rather than the treatment of environmental issues as merely a topic or subject in plans.

(2) *Geographical Information Systems (GIS)*

In general, a GIS may be defined as a computer-based information system which attempts to capture, store, manipulate, analyze and display spatially referenced and associated tabular attribute data for solving complex research, planning and management problems (Fischer and Nijkamp)[22]. GIS can provide tools for the entry, editing, manipulation, management, analysis, display, and output of geographic data.

(3) *The Reasons Why GIS Are so Widely Used in the Field of Land Use Planning*

The land use planning is, in fact, a data business because almost all kinds of planning data are intimately related to spatial location. This nature offers GIS a good opportunity and a perfect stage to demonstrate their ability to manage a diverse set of spatial information and to form the information in a manner that can be efficiently operated. At a minimum, a set of GIS tools linked to an integrated database of the basic social, economic and environmental information enable the planners to conduct exploratory spatial analysis for land use development. In an optimistic viewpoint, GIS offer the possibility of supporting a sophisticated decision-making system on land use planning.

The Development of GIS Technology in the Past Three Decades

The history of the development of GIS has been about thirty years since the first true GIS, the Canada Geographical Information System (CGIS) was created in 1966 (Tomlinson)[4]. It is the fast development of computer hardware and new types of software which has made these systems so popular and wide-spread at the present time. GIS have moved from the phase of concerning with geographical data processing in the 1960s, to the phase of managing the geographic information in the 1970s, and to the first step of supporting a spatial decision-making systems in the late 1980s. In the 1990s, GIS are supported by powerful relational database management systems and powerful graphics algorithms, offer elementary spatial operations such as buffering, overlaying, interpolating, zoning and network analyzing, and are operated in a user-friendly environment through interfaces such as windows, icons, menus and mousses (Fischer and Nijkamp)[22].

The development of GIS hardware, software and data types used in the past three decades is summed up briefly as follows.

(1) *The hardware*

The hardware includes computer platforms, input, storage and output devices (Goodchild)[23].

* Computer platforms:

The platforms may be personal computers, workstations, minicomputers and mainframe computers. The mainframe computers were dominantly in the 1960s and 1970s. In the late 1980s and early 1990s, the trend is towards workstations or networked workstations running under the UNIX operation systems.

* Input devices:

Digitizing and scanning are the two main methods of input in the 1990s. Map-size digitizers were developed in the 1960s. Software for intelligent management of digitizing process and interactive editing of the results was developed in the late 1970s. Generally speaking, Digitizing is error prone, tedious, time consuming and expensive.

Scanning captures the entire contents of the document automatically. However, the process of interpreting features from the scanned image of the map is error prone, requiring frequent human intervention. Map-size scanners are large and expensive, and unlikely to become much cheaper. The most important factors in the development of scanning technology is the software for feature scanning.

* Storage Devices:

The primary storage medium is currently the fixed magnetic disk (hard disk). The magnetic tape is also a useful storage medium for geographical data, however, long time are required to seek data. Optical disks such as CD-ROM (Compact Disk-Read Only Memory) and WORM (Write Once Read Many) can seek data very quickly and are particularly suitable for achieves because of their long-term stability which matches the nature of much geographical data. RAM (Random Access Memory) is the fast access memory used by the central processor.

* Output Devices:

In the early days of automated cartography, The line printer was even used, then pen plotter was put in use. The electrostatic plotter is probably the most popular GIS map output device in 1990s. The output from GIS at present time may take various forms such as statistic

reports, maps and graphics. The output devices may be screens, laser printers, electrostatic plotters, color film recorders, micro film devices and photographic media etc.

(2) *The Software*

Although there are variations in the organization and capabilities of GIS software, three basic designs: the file processing, hybrid and extended design have evolved (Maguire)[5].

* The File Processing Design:

In this design, each data set and function is stored as a separate file and these are linked together during analytical operations. IDRISI and MAP are examples of such design. This is approach adopted in map processing system.

* The Hybrid Design:

In this design, attribute data are stored in a conventional DBMS and separate bespoke software is used for geographical data. ARC/INFO and Deltamap/Genamap are examples of such design.

* The Extended Design:

In this design, the geographical and the attribute data are stored in a DBMS which is extended to provide appropriate geographic analytical functions. The best-known example is SYSTEM9.

(3) *Data*

The geographical data may come from many sources such as analog maps, air photography, remote sensing, census and field survey. Maps are a very important source of digital geographical data, but not the only one source. An increasing amount of GIS data is now being provided by non-map source: remote sensing and Global Positioning System (GPS).

A Brief Review on the Application of GIS in Land Use Planning in the Last Decade

Since the mid 1980s, major breakthroughs in cost, speed and data storage capacity of computer hardware, especially the advent of workstations, and the sufficient progress in GIS software have made GIS technology nowadays available, affordable and accessible to many users worldwide in the field of land use planning. Here, some case studies of the application completed in the last decade are summed up briefly in Table 1. From those applications, what we can conclude is the issues as follows:

1) GIS are widely applied in different levels of administrations in the world ranging from local, regional to national level. They provide a lot of opportunities for integrating graphical, numerical and textual information, for performing spatial analysis and modeling, and for improving the presentation of information to planner and decision-makers in the area of land use planning.

2) The computer platforms used ranges from PCs, workstations, minicomputers to mainframe computers. Among them, the stand-alone workstation and networked workstations seem to be the mainly used types because of its low cost, high performance.

3) A variety of GIS software are applied. It seems that ESRI's ARC/INFO is the most frequently used one because of its hybrid design of data model and its ability of being run across the entire range of platforms from PCs, workstations to mainframe computers.

4) It is noteworthy that no one of the commercial GIS software currently available is so

Table 1 The list of papers (1)

No.	PAPER TITLE	HARDWARE & SOFTWARE	DATA TYPES	AREA SCALE	CONCLUSIONS OF THE PAPER (STUDY RESULTS OR MAIN OUTPUTS)
1	Effects of beaver and moose on boreal forest landscapes (1993)[6]	micro-computer, ERDAS, LOTUS−123	air-photo, field and lab-derived data	regional	The following alternations caused by beavers and its effects on the landscapes were studied numerically, displayed on screen and outputted as maps: 1. length of streams impounded, 2. the location, areal extent, hydrology, and vegetation type of impoundments 3. changes in hydrology and vegetation over time as a results of new dam construction and vegetation succession 4. patch dynamics of pond creation 5. changes in nutrient standing stocks in the landscape
2	The ecological interpretation of satellite imagery with special reference to bird habitates (1993)[7]	Vax 3600 mini-computer, Wyse micro computer, SYSTAT and GENSTAT statistical package, ERDAS	Landsat TM image, field survey and landscape pattern, bird census data	regional	1. rapid and cost-effective mapping of extensive areas 2. the analytical methods employed for relating bird data to habitat information 3. the relationships between land cover and spatial pattern and selected upland bird species
3	Computer-aided regional planning applications for the Perth and Helsinki regions (1993)[9]	mainframe computer for the case of Perth, SUN workstation for Helsinki, ISM system	statistical data (social, economic, natural and environmental)	regional	1. The ISM (Interactive Spatial Planning) system contains the capability of interactively constructing any regional planning and forecasting models. 2. maps and graphics of analyzing, comparing, evaluating, displaying the forecasting results of alternative planning strategies in the area of housing and residential-land demand, workplace location, commuting and other measures of the state of the regional land-use and transport system.
4	Managing environment radioactivity monitoring data: a geographic information approach (1993)[8]	micro VAX and PC, ARC/INFO	radiation monitoring data, medical database, background environmental data, demographic data, infrastructure data	national regional	1. the radiological information and other spatial data sets are integrated with the help of GIS. 2. the development of a variety of application-specific views of the database for management purposes and for descriptive and process studies (for example, the identification of potential restriction zones or 'hot spots') 3. a user-friendly environment for the fast and accurate retrieval of database and making provision for the analysis of spatial relationship of data from different sources.
5	Vegetation mapping with aerial photos and GIS (1993)[10]	not indicated	aerial photos, field survey data	regional national	1. vegetation boundaries were determined by aerial photos. 2. maps showing the distribution of individual species. 3. the preparation of area statements and the statistical evaluation of data take place automatically. 4. a multi-purpose database

Table 1 The list of papers (2)

No.	PAPER TITLE	HARDWARE & SOFTWARE	DATA TYPES	AREA SCALE	CONCLUSIONS OF THE PAPER (STUDY RESULTS OR MAIN OUTPUTS)
6	Use of GIS taking the example of the Reuss Delta (1993)[11]	SUN work-station, ARC/INFO	photogrammetric survey, echo depth sounder surveys, analog planning base maps	regional	1. states of the delta development in different years. 2. automatically generated lake profiles. 3. the TIN 3d perspective presentations of delta. 4. the amount of solid matter deposited by Reuss. 5. deposit plan for the formation of new islands.
7	Use of a geographic information system at Buwal (1993)[13]	workstations, ARC/INFO	maps, statistical data	regional	1. a series of inventories in the field of nature and landscape conservation. 2. valid inventories is available in digital form. 3. the specially developed user interface permits various inquiry possibilities without specific knowledge of ARC/INFO.
8	Use of GIS at a cantonal office for nature and landscape conservation (1993)[12]	PC, workstations ARC/INFO	maps, statistical data, field data, data of species of plants and animals	regional	1. distribution maps of various species of plants and animals. 2. the biological and geographic data can be retrieved not only by GIS specialist, but also by all the office staff, presented graphically and made available for additional evaluation. 3. the GIS serves increasingly as an aid for answering concrete questions in the course of everyday work.
9	Integrated planning information systems (1991)[14]	a network of high performance workstations	Bureau of Census TIGER file, GBF/DIME file, USGS DLG, SPOT satellite data	regional	1. USGS DLG, TIGER files and SPOT data can be integrated into a single system that successfully addresses many of the obstracles associated with the use of GIS in planning. 2. the output are a interrelated spatial database, many different data layers that can be quick reviewed, and a series of maps for planning that are designated to support decisions on infrastructure improvement and industrial site selection.
10	GIS in island resource planning: a case study in map analysis (1991)[15]	IBM PC-AT computer, pMAP	USGS topographic map sheets	local	1. a PC-based GIS was used in a island on resource planning. it demonstrated how a model was built by combining information gained from maps and other sources and, from it, 'best' allocations of land use were generated after making a number of subjective decisions; the sensitivity of the results to these decisions is evaluated by rerunning the model with different parameters.

Table 1 The list of papers (3)

No.	PAPER TITLE	HARDWARE & SOFTWARE	DATA TYPES	AREA SCALE	CONCLUSIONS OF THE PAPER (STUDY RESULTS OR MAIN OUTPUTS)
11	Land resource information systems (the Albemarle Pamlico Estuarine study) (1991)[16]	networked SUN workstations, ARC/INFO, ISM (Interactive Surface Modeling)	soils, land use, land cover, natural resources environmental parameters, Census and demographic data, Landsat TM data, USGS Land Use Data Analysis map	regional	1. the assessment of status and trends in the future of the estuarine area. 2. a land use and land cover inventory were produced. 3. the strategies to preserve and maintain the estuarine environment were identified and recommended. 4. a Water Area Classification System that incorporates a GIS model has been designed as a component of the water use planning and zoning program. 5. three data classification types: Preservation, Conservation, and Development Water Area were designated by the Classification System. 6. a common database used to support technicians, scientists, managers and decision makers alike was created.
12	The Telford Urban Policy Information System Project (TUPIS) (1991)[17]	IBM PS2/80, IBM PS2/70, ARC/INFO, dBase, Lotus 1 - 2 - 3, Pradox, SAS, SPSS/PC	social, economic, census data	local	1. It described how to design a system for incorporating a user-oriented urban management and decision support information system on the GIS base. 2. How to develop a General Information Coordinator (GICO), core of the TUPIS system, to interface PC ARC/INFO with other widely available statistical packages and database management systems in order to increase its functionality and to make the whole system easy to use. 3. How to incorporate the Telford urban database into a GIS framework. 4. How to develop a range of spatial and statistical analytical tools for policy simulation.
13	Database development for decision support and policy evaluation (case of St. Hellens Urban program database) (1991)[18]	IBM PS/ 2 -80, PC ARC/INFO	Demographic social and economic data, urban program, infrastructure and services boundaries data	regional	1. The St. Hellens authority has gained a core of resource managers trained in the concepts, operation and application of GIS methods. 2. The authority has also gained the background and operational data modules, digitized boundaries and a set of computer drawn maps and statistical tables produced. 3. The database has been integrated to identify priority areas within St. Hellens, to measure the spatial impacts of Urban Program Projects and develop priorities for the targeting of future resources.
14	Urban GIS Applications (case study: Finding land for development) (1991)[19]	Prime 9955 ARC/INFO	Land use inventory, aerial photography	regional	1. The general plan, developed land and constrained land for each city in San Diego county was entered into the GIS database through digitizing. 2. The freeways and streets, and geographical area boundary files were overlaid to the three layers mentioned above. The land available for urban development was determined by this overlay process.
15	Integration of Geoscientific Data Using GIS (1991)[20]	PC 80386 SPANS	Geological, geophysical, geochemical data	local	1. A method based on Bayes Rule and an assumption of conditional independence is used to predict points patterns (mineral occurrences and seismic epicenters) from a combination of geological, geophysical, geochemical maps. 2. A GIS is used to build a spatial database from diverse map inputs, to create a multi-map overlay, to generate new maps, to visualize and interactively probe the results.

perfect to meet the needs of practical applications. The most current GIS are strong in data storage and retrieval, and graphic display, but weak in spatial analysis and modeling. An digital atlas created by GIS is not able to provide the planner with the ability to evaluate alternatives and deal with land use conflicts. The software can be selected as a core of the application system, but its analytical and modeling capabilities must be extended to meet the user's needs by establishing links with widely available statistical packages, database management systems and other packages.

5) Land use planning process involves many kinds of data which are expensive to collect, store and manipulate because large volumes are normally required to solve a practical problem, so gathering data from many sources to a digital form and sharing, updating them among different organizations are very important for the application.

6) The user of GIS-based land use planning systems must have the ability, skill and knowledge to exploit the potential that the hardware and software provide. The lack of adequately trained office staffs is often a problem for the governmental organizations in the application of GIS.

7) For solving the problems mentioned in (5) and (6), the cooperation among governmental organizations, research institutes and universities is essential for the successful application of GIS in land use planing.

The Prospect of the Application of GIS in the Next Decade

There is no doubt that GIS will be widely adopted and applied in land use planning process all over the world in the next decade. The successful application will depend on the following issues:

1) The major technical developments and reductions in the price of computer hardware including the input, storage and output devices will determine the scope and extent of applications. The much more powerful workstations or networked workstations, cheaper and effective digitizers, scanners, electrostatic plotters, color film recorders and photographic media are expected to play an important role in this point.

2) If GIS are to be effectively used in a high level for land use planning, the information must be managed and shared both within and between organizations.

3) The spatial and non-spatial data coming from many sources must be stored in a more standard way in order to be retrieved and displayed quickly and effectively.

4) The integratability of GIS must be improved by developing more powerful system designing method to reflect the actual and potential needs of users.

5) It is necessary that more effective process and mechanisms be developed to facilitate the transfer of GIS technology and method into the planning process.

6) New spatial analytical and simulation models must be developed in order to make planners involve in the process of setting scenarios for new development plan.

7) The functionality of GIS software must be extended to meet the needs of planners by establishing effective links to other available software tools. The GIS-based information system must be built in a view of supporting the planning and decision-making processes.

8) The users in administrations must be properly trained to have the appropriated skill and knowledge to operate the system.

9) There is a need to consider reorganizing the organizational structures of public agencies. The existing departmental boundaries and the power relationships should be adjusted to adapt to face the new situations.

In sum, the fundamental issues in GIS applications to the users in the area of land use planning are how to capture a complex and dynamic states of land use development in a digital database, provide access to it, and provide spatial analyzing, evaluating, forecasting and decision-making methods for planners in a useful, accurate and cost-effective manner. The ultimate success of GIS in land use planning depends to a large extent on how well it serves the planning staffs of the governments to meet their planning needs and how well it is integrated into their daily works of keeping the records and managing the data.

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