The Technology of GIS For Civil Engineering Profession

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ABSTRACT

The work describes a case study in which Geographic Information System (GIS) technology was used as a tool in developing an existing derelict site into one with new construction purposes and infrastructure. The case study identifies all the necessary available resources and types of spatial information required including topographic mapping, geotechnical data and survey of past land uses. In order to facilitate investigation of modelling and handling problems, data of different resolutions, formats and sources are brought together in a GIS application package. Integration of data in such a manner has been found useful and advantages as proven by the results of procedural measures adopted in the studies. The two procedural measures were namely, (i) to check the appropriateness of some generic GIS functions customised for civil engineering applications and (ii) to check if GIS technology is capable of handling data management for civil engineering purposes.

INTRODUCTION

Civil Engineering is a dynamic profession, which is responsible for constructing and maintaining various types of infrastructure development [2]. Civil engineering usually constructed for the public good involves a wide range of specialists who get involved in a variety of projects such as in the design, construction and management of engineering structures, including environmental or health issues, such as water resource management and waste disposal, and many other forms of structures.

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Current civil engineering activities would be more challenging with sophisticated demand and variety. As a result, other related fields have to be more precise and efficient output. One of the fields, particularly relevant to the work of this profession is GIS. GIS can help engineers solve many spatial and non-spatial problems in each stage of civil engineering work without waiting and working extra days. For example, future civil engineers will not need 'trial and error' methods to find minimum costs for earthwork calculations, instead using the latest approach of GIS, engineers are able to manipulate and analyse data with different approaches either in database or graphical features independently or simultaneously. GIS can produce results with statistical analysis, including graphs and updated features from a selected chainage to another chainage. With a large project, data in each discipline are always related. Strength information from a soil test at the site investigation stage is needed to identify the type of building construction acceptable for the site. The design of the building, such as type of foundation to be used, is only decided after the type of building to be constructed is identified.

This shows that information needs to be collected for each discipline of civil engineering works. The combination of database and graphical information helps engineers to obtain and resolve various problems quickly and accurately. At all times, accurate, up to date information needs to be transferred between these specialist groups.

However, a variety of reasons have forced the engineer to stay apart from other GIS users and take a different path, that of CADD (Computer Aided Design and Drafting). Various attempts have been made to merge the GIS and CADD technologies, some of which have been successful to a limited degree, but in large, the two communities of engineers and other disciplines, have stayed apart and rather wary of each other. Therefore the need for integrating general GIS and engineering applications exists, particularly when the life cycle operation of an engineered project is considered in view of deteriorating infrastructure facilities and shrinking funds and other resources. Some reasons given by many engineers for the separate paths taken by engineering and GIS users, are terminology, graphic form, accuracy, spatial geometry, database cost and mapping [3].

A study on the arising issues and appropriateness of using Geographic Information System (GIS) methodology to help in large scale applications in civil engineering practice is presented herein. The research starts from the premise that a large amount of the information required in many large area civil engineering projects is spatially referenced and required to be shared between a large number of engineers. The GIS methodology is good at integrating and managing large amounts of different sorts of spatially referenced information and making this available to many users and so should benefit this process.

The GIS technology also makes available many generic analysis tools of potential use to engineers and so this should be an additional benefit. Geographic Information System (GIS) is one of the fastest growing computer-based technology of the 1990s, yet their full potential, in the construction industry for example, has not been realised [1]. This provides adequate capabilities for solving problems that involve the integration and analysis of large volumes of descriptive and spatial data from a variety sources. It also supports the interaction of multiple participants who can then approach problems in a more comprehensive and systematic way. GIS is being used in diverse areas related to civil engineering, such as: environmental problems, irrigation management, construction management, ground exploration, transportation and foundation design. The ability of GIS technology to merge map graphics with the management of associate non-graphic data has introduced a multitude of new applications ranging from management of large areas of lands to locating a fire hydrant at a suitable location. This article overviews civil engineering practice, describes the appropriateness of GIS technology to civil engineering professionals and explores the potential applications of GIS in each discipline of civil engineering.

POTENTIALS OF GIS APPLICATIONS IN CIVIL ENGINEERING DISCIPLINES

The civil engineering profession is multi-disciplinary and each discipline is inter-related to the others. These disciplines cover at least eight traditional areas of civil engineering (Fig. 1 and 2) namely, structural, materials, construction, geotechnical, transportation, surveying, hydraulic and hydrology, and environmental engineering [4].

Examples of civil engineering applications which require data of a spatially or geographically referenced nature are network analysis of drain design, terrain modelling of existing land form, superimposition of design and visualisation, volumetric calculations with mass haul analysis and borehole interpolation. GIS applications are unlimited and vary with the type of activities involved. The raw data can be captured by several different methods, depending on the site and the availability of resources.

Structural, Material And Construction Engineering

Before evaluating the general suitability of GIS for a particular proposed work, an investigation of a potential construction work on site is necessary. A comprehensive accumulation of information on the ground and their characteristics, would facilitate an appropriate foundation design, and enables a practical, economic and safe construction process to be planned.

The assessment of a site might be in the form of a feasibility study (e.g. a river crossing where the cost of constructing a bridge might be compared with that of driving a tunnel), or it may be required to determine how a specific form of development can be economically constructed (e.g. a four-storey building).

Although the provisional assumption of the type of foundation for a proposed development may be required before the ground investigation is carried out, the ground conditions may ultimately prove unsuitable for the type of foundation envisaged. Labour and material transportation problems lend themselves particularly well to spatial network type analysis using GIS. The selection of proper equipment suitable for the work conditions at a construction site is another potential application of GIS during the construction phase. Factors affecting the selection of a particular piece of equipment, such as proximity to construction site, soil characteristics, or weather and temperature, possess spatial components. Through the use of topological proximity functions, overlay, and other GIS functions, the suitability of particular equipment to a construction site can be assessed.

Geotechnical Engineering

A point feature, such as a well boring site, is located by a set of coordinates, and may have attributes such as depth to date of boring, groundwater depth, soil and bedrock permeability, and percentage slope. The locations of individual boreholes are maintained on a regular GIS layer and can be used in combination with other layers, to perform the typical types of analyses supported by the GIS. For current application, a street map coverage is included to aid the quick identification and retrieval of borehole data needed by each user.

Visualisation of borehole location can be represented in GIS three dimensional view. Using existing geological information as an aid, the geophysical logs for each well are interpreted to determine the location and type of each formation. Transparent to the user, the GIS procedure constructs a Triangulated Irregular Network (TIN) surface of the well field. Finally, a GIS-based well-log database and procedures for developing a three-dimensional subsurface profile from borehole geophysical logs is constructed. The GIS well-log database contains information on subsurface formations derived from interpretations of borehole geophysical logs [5].

Logical overlays of the soil polygons with other coverages are easily investigated using GIS tools. Soil polygons are frequently overlaid with other coverages such as climatic zones, land use or soil parent material to yield new composite overlays indicating various grades of soil suitability. These overlays can be computed when the graphical data are held in either vector or raster form. Typical applications are in land evaluation and natural resource management.

Transportation Engineering

Important functions in the field of transportation are likely to be those concerned with analysis, particularly in network routing. The routing of vehicles carrying hazardous waste along national road network is commonly practised in many countries. It is unlikely that a generalised, restructured and transformation of route will be required in hazardous vehicle routing. Other examples involve the use of shortest path algorithms where impedances to movement are attached to the roads or road junctions.

Applications using navigation systems include experimental traffic systems, such as traffic congestion reporting and 'sign-post' transmitters and receivers for communicating with on-board navigation systems. Vehicle navigation is in its infancy but promises to be a voracious consumer of digital maps and GIS technology. Already there are commercial systems available in the United States, Germany and Japan offering destination finding by address, street network topology, intersection and landmark and moving map displays. In the future, it seems certain that the vehicle will contain facilities for providing a variety of information related to location of facilities, vehicle position and traffic. Digital maps and GIS will necessarily play an important role in bringing about that situation.

GIS has the ability to determine preferred routes between any two points in the country, based on any network segment attribute. Typical analyses determine routes based on safety, efficiency, or a combination of the two. Using combinations of these routing criteria in a single analysis, solutions can be obtained that attempt to reduce both safety and cost simultaneously [6]. A shipment can be routed from its point of origin to its ultimate destination via a number of additional points. This situation would arise if a specific shipment were comprised of several partial loads that were stored in different locations. GIS can also be used in redirection of traffic flows, on a road that has collapsed following a natural disaster, for instance, an earthquake.

Hydraulic And Hydrology Engineering

In water resource management, GIS can be used to model and monitor water catchment areas and take responsibility for flood analysis, sewage disposal and the provision of recreation amenities on rivers and reservoirs. A polygon encloses a homogeneous area, such as a catchment area, and may have attributes of location and assessed valuation. Surfaces are sometimes represented as collections of adjacent, two-dimensional polygons having vertices of known elevation and attributes of slope and aspect.

As for drainage, an analysis is required of the catchment characteristics and how these will affect runoff from a given rainfall event. GIS can be used for forecasting flood warnings. They are dependent on the use of past records of rainfall events and the resulting runoff and flooding. These records could be conveniently stored in a GIS and the appropriate data will be abstracted when necessary. The production of maps showing the predicted extent of flood waters given the forecast rainfall is not easy, but using a GIS with a full terrain model would make the task a lot simpler. The direction of fall can easily be calculated for the triangles of a triangulated surface and these directions analysed to determine catchment areas. The graphical editing facilities of a GIS allow pipe networks to be designed and the way in which they function can either be modelled using specialised functions provided for GIS or by passing the required data to existing modelling software.

Environmental Engineering

GIS is needed in land management, pollution analysis, forest management, marine ecology or offshore control. Consequently, the capture, analysis, management and display of environmental data are all activities that can greatly benefit from the application of GIS. Moreover, inherent in the solution of many environmental problems is the need to bring together disparate data sets. The complexity and size of these databases makes the requirement for application of GIS technology all the more necessary.

The advantage of holding all the information together is to allow searches and queries to be made on a combination of information. The application of GIS technology in this category uses the fundamental logic and procedures to locate potential sites for the storage of solid or hazardous waste. After determining specific constraints, the necessary cultural and environmental data are gathered. A multiple-theme analysis of the datasets is then used to derive a new land potential theme, indicating areas that meet all the necessary criteria. The analysis involves such analytic functions and boolean operations for combining the intermediate layers to find all raster cells that meet the initial criteria. Finally, a display and statistical analysis of the derived data layer is produced. The final map, indicating those areas in which it is feasible to locate a waste repository, could then be further reduced the search for an appropriate property. It has been shown that the constraints identified in industrial location criteria could be effectively evaluated if the proper information were placed in a GIS and appropriate analysis procedures applied to locate candidate hazardous waste sites [7].

An overview of a GIS case study specifically for whole case study is presented below. The case study used ARC/INFO, a GIS software which has been developed by ESRI since 1969. Other GIS software may also be used for this investigation. The case study was divided into four phases: site selection, data organisation, data modelling and technology organisation.

Phase one relates to the selection of a site with a view to investigate spatial data involved in the development of a prototype GIS and linking this information to a specialised analysis package. The availability of suitable data is a major consideration when selecting a test area for an appropriate analysis. Investigations of spatial data requirements, data models and data processing of some procedures for a Large Area Civil Engineering Project are the main emphasis of a test area. In *phase two*, collection of raw data are involved. The collected data is either in digital or non-digital form. In this project, digital data is obtained in CADD design format. Non-digital data is obtained from conventional paper maps or plans and some descriptive data are available from public authorities. Data are categorised basically on the types of data models namely node, arc or polygon and are stored in ARC/INFO according to its related coverages with its associated text descriptions.

Phase three of the case study features designing of typical spatial data models. This stage also described the development of sampling new tools for upgrading the application of GIS beyond conventional methods. In the *fourth phase,* data processing was undertaken which links graphical features to their appropriate database records. The processes were categorised as database building, performance analysis and result presentation. The building of database involves input of spatial data into GIS, making spatial data usable and getting attribute data into GIS. The GIS performance analysis and result presentation could only be undertaken after the data cleaning process was completed [8].

Example of Data Handling for Optimum Route Analysis Using Standard GIS Functions

Optimum route analysis is required for transport studies and can be implemented in three categories i.e. shortest route, quickest route and preferred route. This utility included solving more complex queries such as, if a user needed to make a journey from a known origin to destination. By inputting the origin and destination, a user can get detailed information along the route, from the map or database such as street names, street codes and any other information available. The user is also able to define stop points between the origin and destination as well as to determine the most efficient way to visit a series of locations. This analysis provides the user with the ability to resolve problems related to changing transportation network links, such as:

a. showing the direction or destination to a site area according to the shortest route algorithm from any origin point.

b. showing the preferred route if there are many in-between stop points in the delivery of construction materials.

c. extending from these queries, so that a user can select his own sequence of stop points from origin to destination. The example applications in sequence order are bus and delivery vehicle routing; the example involving none sequence order is vehicle scheduling.

d. reporting the street name, street code or street id between origin and destination points. Queries can be made from map and database for the above information and more descriptive street information displayed if needed by a user.

Example Of Data Sharing Between GIS And A Specialised Analysis Package

Upgrading GIS software merely for a single purpose or application is potentially costly in time and money to a computer programmer. For an economical solution to a particular project, data from GIS could be transferred to another analysis package for manipulation and adaptation for complex analyses. The output from these packages are then transferred to the GIS software for further application. This process is referred to as data sharing. The sharing of core data for both parties is implemented in a dual-direction. A user can transfer any core data from one GIS to an analysis package, then to be manipulated and the subsequent results passed back to GIS in updating the previous data. A similar process can take place in the reverse direction. Usually, the user works inside GIS software itself; creating database information, generating tools to maximise its application and providing in-house queries for displaying final results either graphically or textually. The same procedure applies to the specialised analysis packages. However, limitations of both packages need to be considered before applying to any particular work.

Some GIS software and analysis packages are of limited use to civil engineering applications such as designing or planning. For example, ARC/INFO does not provide facilities for road designing requirements such as cutting edges, cross-sectioning and longitudinal sectioning and complicated cut-and-fill table and calculation. It is believed that the bridging of the gap between current and future Information Technology (IT) lies in the exploitation of Independent Object Databases (IOD).

The potential benefit of data sharing system is well recognised and the decision to develop a prototype illustrates its importance to ensure efficiency of sharing. In this case, the prototype was developed to:

(i) contain all the necessary core data for design,

(ii) demonstrate the processes of core data manipulation and analysis, and

(iii) demonstrate the processes of data incorporation.

The investigation undertaken on data sharing is based on ARC/INFO, used in conjunction with a specialised analysis package, namely Land Survey System (LSS). LSS is a package specialises on surface modelling and earthwork analysis. The link created between ARC/INFO and LSS provides an interface for use in the prototype. It improves handling of borehole information and development of triangulation irregular networks (TINs) utilising breaklines.

The prototype could be extended for data sharing purposes with a wide range of civil engineering applications (Fig. 3). It does not only function with one-to-one interaction but also available in other forms of combination, for example one-to-several, several-to-several and several-to-one, all of which are reversible. Results of the prototype system shows that there is a possibility of developing a central conducting database, which could be more economical (Fig. 2).

The data sharing system described here in could be integrated between the range of packages available in civil engineering. Such steps tend to reduce cost of any particular project. Sharing of core datasets between GIS software and specialist analysis packages through distributed databases and networks and independent database access is now proving possible and is essential in the management of a large area civil engineering project. The use of such GIS methodology is a small scale example of what may become possible at a national scale.

CONCLUSIONS

A review of GIS applications for civil engineering disciplines has shown that common spatial data are required in the execution of works in the various fields. Additionally, the nature of work often requires interdisciplinary knowledge and background in order to predict the actions and outcomes of the works involve.

In this respect, GIS technology contribute to improve efficiency by enabling spatial data for any location to be stored and integrated. Existing examples have shown that standard GIS functions could be adapted for data manipulations and solving complex problems. The implementation of data sharing between GIS dataset and specialised analysis package resolves the problems of different data manipulation by the individual package.

The advantages of GIS as a tool in implementing civil engineering works is not only recognised for existing and future works but also provides an option for on a more economical solution for any project.

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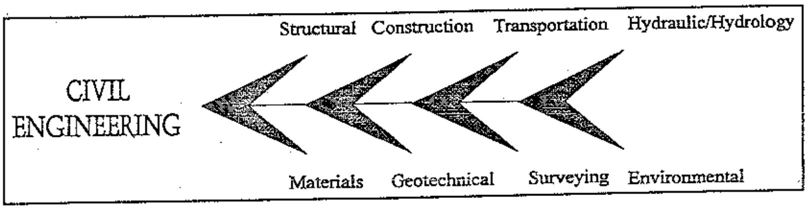

Fig. 1. Typical categorisation of civil engineering disciplines

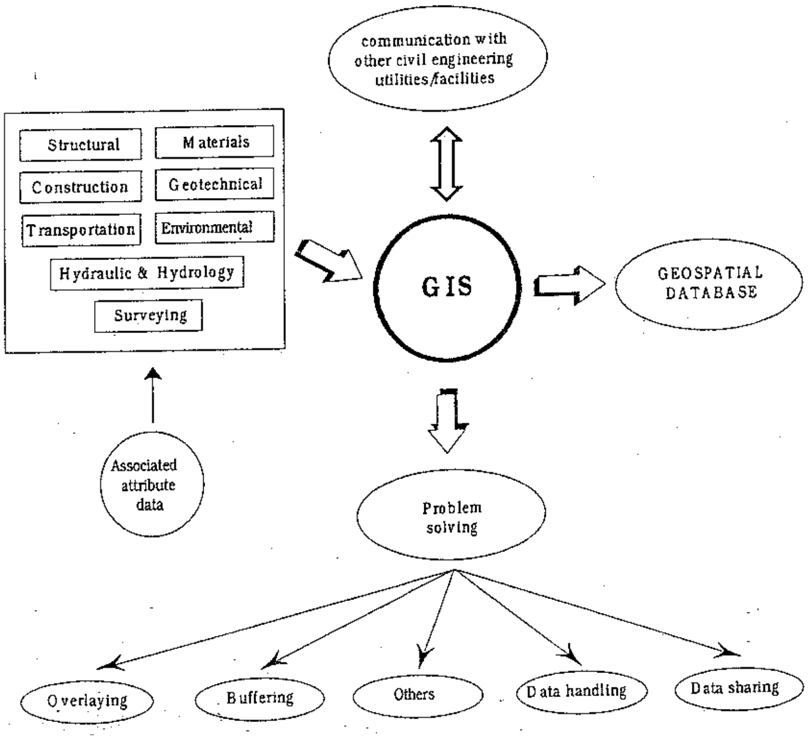

Fig. 2. Data integration methodology

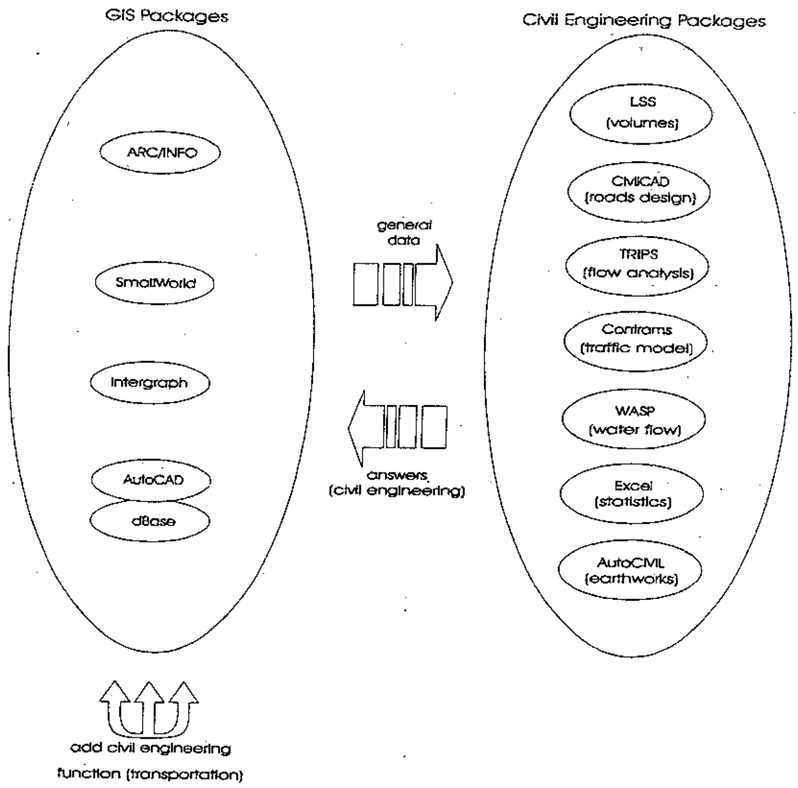

Fig. 3. Linking Operation of GIS and Specialist Analysis Packages