Potential Applications of Geographic Information Systems to Construction Industry

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Abstract: Geographic Information Systems (GIS) are one of the fastest growing computer-based technologies of the 1990s, yet, their full potential in the construction industry has not been realized. This technology provides adequate capabilities for solving problems that involve the integration and analysis of large volumes of spatial and descriptive data from a variety of sources. This technology supports the interaction of multiple participants such that they can approach problems in a more comprehensive and systematic way. The primary objectives of this paper are to describe GIS technology and explore potential construction applications that can benefit from the implementation of this technology. An example application of this technology to contractor prequalification is provided. One benefit expected from the application of GIS to contractor prequalification is the creation of a comprehensive data base. This data base can provide a wide range of construction users with a mechanism for rapid retrieval and manipulation capability to satisfy their need of spatial and descriptive information required in the process. Practical considerations regarding GIS application to the construction industry are also addressed. Finally, several research areas worthy of further investigation are noted.

Introduction

Geographic Information Systems (GIS) are one of the fastest growing computer-based technologies of the 1990s. They are being used in diverse application areas related to construction, such as: land resources management, environmental problems, utilities, financial planning, transportation, land records modernization, and market research. The 1988 GIS core business is estimated to have been $529 million. This amount has been projected to grow by 32% annually through 1993. The total GIS industry is also predicted to expand about 22% annually, reaching a total of about $11 billion by 1993 (Daratech, Inc. 1989).

This trend has not been reflected directly in the construction industry. Most of the computer technologies investigated by construction professionals focus on the descriptive aspect of the data, although vast amounts of construction data can be spatially referenced. The primary objectives of this paper are: (1) To describe GIS technology to various construction professionals; (2) to explore potential GIS applications to the construction in-

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dustry; (3) to present a conceptual framework to apply GIS to contractor prequalification; (4) to investigate practical considerations that must be taken into account to ensure a successful adaptation of GIS to construction; and (5) to identify areas of additional research. In the subsequent section, data needs and problems in the construction industry are discussed as a justification for this investigation.

Data Needs and Problems

The construction industry involves the interaction and coordination of numerous business firms and individuals. The involvement of these participants during the life cycle of a facility generates a vast amount of diverse data. These data can be categorized as spatial and nonspatial. As much as 75% of the spatial data pertaining to a facility are common to all phases of the facility delivery process (Foster 1989).

The need to share and integrate data among project participants in the various phases of the facility delivery process has been recognized by several researchers in the field (Fenves et al. 1988; Choi and Ibbs 1990; Reinschmidt et al. 1989; and Meyer 1991). The purpose of sharing data is attributed to two main factors. First, to develop and reinforce a common description of the proposed facility, and second, to coordinate the efforts of various participants in the facility delivery process (Meyer 1991).

For instance, a geotechnical engineer, before performing various field tests to determine the engineering properties of soil, needs data (usually in a map format) from multiple sources. Examples of these data include, but not limited to characteristics of the general topography of the project area, geological substrata that underlies the site, and possible subsurface anomalies from previous projects performed near the subject project site. At the end of this operation, the geotechnical engineer is expected to prepare a report containing detailed information characterizing the site, such as soil permeability, shrink-swell factor, skin friction, and compressive strength. This information, in turn, is used by the structural engineer for the foundation design.

Recent attempts by industry enterprises to better manage and analyze construction data frequently involve computer technologies, such as information systems. An information system can be defined as a sequence of operations, from planning the observation and collection of data, to storage and analysis of the data, to the use of the derived information in some decision-making process (Calkins and Tomlinson 1977).

A large number of information systems deal primarily with the selection and reporting of descriptive data, such as Database Management Systems (DBMS), or with the graphic display of spatial data, such as Computer Aided Drafting (CAD). GIS, on the other hand, provide capabilities for spatial and nonspatial data to be collected from different sources, stored, analyzed, and presented systematically. The nature of GIS technology encourages the activity of multiple participants such that they can approach problems in a more comprehensive and systematic way. In the next section, a description of this technology is provided.

Description of GIS Technology

There are different approaches to define a Geographic Information System. Cowen (1988) identified four important approaches: (1) Data base approach; (2) application approach; (3) toolbox approach; and (4) process-

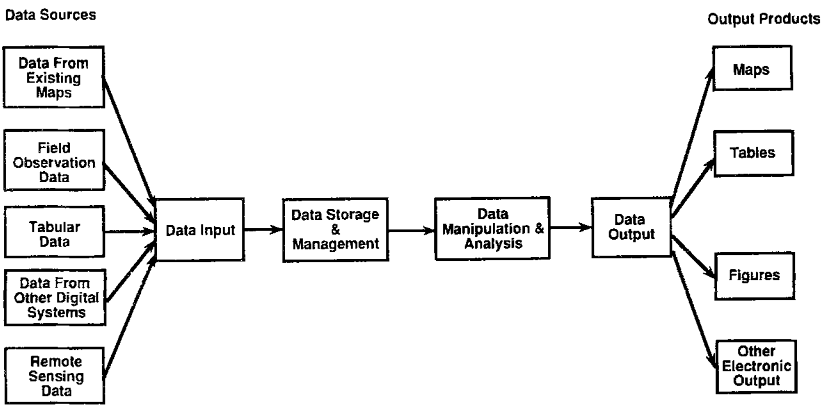


FIG. 1. Principal Modules of Geographic Information System

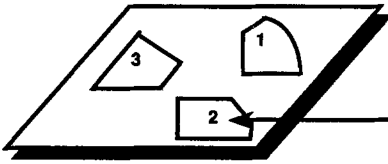
oriented (or technological) approach. This fourth approach, which concentrates on the computer-related aspects of the field, has dominated the literature (Marble 1984; Burrough 1986; Aronoff 1989; and Dueker and Kjerne 1989). The focus presented herein is the technological approach. In this context, a GIS can be defined as "a system of hardware, software, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth" (Dueker and Kjerne 1989). Fig. 1 depicts the various modules of a GIS. In the following, each module is described.

Data input is the procedure that encompasses all aspects of transforming data captured in the form of existing maps, field observations, and sensors (including aerial photography, satellite imagery, Global Positioning System (GPS) receivers, and recording instruments) into computer-readable form and writing the data to a GIS data base (Burrough 1986). With regard to the practical implementation of GIS, input procedures absorb a large share of operating costs.

Spatial data have four basic components that significantly differentiate them from any type of data: (1) Geographical positions; (2) descriptive attributes; (3) spatial relationships, i.e, topography; and (4) temporal relationships. The data storage and management module focuses on the manner in which data regarding these components are structured and organized. Among the types of data base structures that are recognized today, relational structures are commonly used to organize attribute information in GIS. Fig. 2 illustrates the georelational linkage between spatial and attribute information contained within GIS. As shown, relational data are stored in simple records, known as tuples, containing an ordered set of attribute values that are grouped together in two-dimensional tables, known as relations. Users define the relation that is appropriate to the query. The new defined tables may be available or be constructed by a controlling program through the method of relational algebra (Burrough 1986).

GIS recognize three primitive types of spatial objects: points, lines, and areas. Vector and raster data models are two alternate models for representing these objects. The basic logical units of the vector model are points, lines, and polygons. A point is stored as a single X,Y-coordinate pair, a line as a series of X,Y-coordinates, and a polygon (area) as a closed loop of X,Y-coordinate pairs defining the boundaries of the area. Additional

Spatial Data



Attribute Table 1

Project_ID	Area (m^2)	Perimeter (m)	Project Number
1	3,000	220	P-330
2	2,100	200	P-331
3	5,000	300	P-332

Attribute Table 2

Project Number	Contractor	Contract Type	Project Cost ($ million)	Project Duration (months)
P-331	Omni	Cost Plus	0.8	6
P-330	Sharpe	Bid	1.5	12
P-332	Atlantic Cost	Turnkey	1.0	8

FIG. 2. Storage of GIS Attribute Information in Relational Data Base

attribute or descriptive information regarding any given object can then be stored with the data record defining that object.

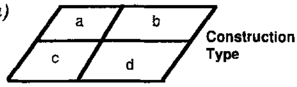
On the other hand, the basic units of the raster model are individual cells. The raster space is subdivided into cells (usually square in shape). Each cell is referenced by a row and column number. Additional attribute information concerning a given cell is stored with the data record for that cell. In this model, a point is represented by a single grid cell, a line by a number of consecutively neighboring cells, and an area by a cluster of neighboring cells.

To extract meaningful information from the GIS data base, appropriate functions must be performed. This process is commonly referred to as data manipulation and analysis. Several approaches to categorize GIS analysis functions have been identified in previous research (Burroughs 1986, Goodchild 1987, and Aronoff 1989). Some GIS analysis capabilities such as those necessary for data maintenance and editing, geometric transformations, or output formatting are common among GIS, computer-assisted cartography, and other information systems. A large body of literature regarding these subject areas exist; here, only the fundamental aspects are addressed and examples provided below.

First, it is assumed that GIS have the capabilities to make scale and projection changes, remove distortion, and perform coordinate system rotation and translation. The analyst must also be able to browse the digital data base, selectively zooming into a region of interest. Once the area of interest is identified, various types of GIS analysis functions can be performed. Some of the most important functions of GIS include topological overlay and connectivity functions, such as proximity and network operations.

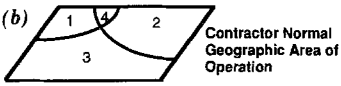
Topological overlay involves the integration of multiple layers to create a new data set. The resultant layer contains new spatial objects with different attribute and topological information. For example, zoning polygons, with

(a)



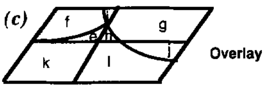
Polygon	Construction Type
a	Industrial
b	Residential
c	Commercial & Institutional
d	Highway

(b)



Polygon	Contractor Name
1	Baker, Inc.
2	Russell, Inc.
3	Miron, Inc.
4	Baker Inc. & Russell Inc.

(c)



Polygon	Combination	Contractor Name	ConstructionType
e	a-3	Miron, Inc.	Industrial
f	a-1	Baker, Inc.	Industrial
g	b-2	Russell Inc.	Residential
h	b-3	Miron, Inc.	Highway
i	4-a	Baker Inc. & Russell Inc.	Residential
j	d-2	Russell Inc.	Highway
k	c-3	Miron, Inc.	Commercial & Institutional

FIG. 3. Example Overlay Operation of GIS

attributes indicating different constrution types, as shown in Fig. 3, overlaid with polygons, indicating the geographical areas where several contractors have successfully completed construction projects, produce a new set of polygons having attributes of the contractor's name and type of construction previously performed.

The main role of proximity functions is to determine if a given point, line, or area lies within a certain distance of another point, line, or polygon. Such information is relevant to the siting of a facility where information regarding adjacency to a transportation system, construction labor availability, and some exclusive areas, such as flood zones or historic sites, is crucial in the selection process. Network functions, on the other hand, can be used to allocate a given resource, such as construction material, or to determine the minimum cost path through a given network between an origin and destination.

Data output is the procedure by which GIS results are displayed in a form suitable to the user. The most common output products generated by GIS are maps of various kinds, such as thematic maps, choropleth maps, isorithmic maps, dot maps, line maps, animated maps, landform maps, and cartograms. For applications such as engineering, other nonmap graphics may be preferred. GIS have the capability to generate several graphic formats. These graphics include: bar charts, pie charts, scatter plots, and histograms.

Potential Applications

The primary considerations in determining the suitability of a particular construction application to GIS adaptation are the significance of the spatial component of the data used in selected application, the diversity of these data, and the need for spatial analysis of application data. These considerations satisfy the technical feasibility of the application. Additional criteria are needed to justify the economic feasibility of the application. The cost of GIS is more easily justified if the data volumes are large, frequently accessed, and used for a wide range of analyses. For purposes of discussion, potential construction applications that can benefit from adaptation to GIS are identified according to the design-bid-build contract type.

Design Phase

In most construction projects, a feasibility study is required prior to the preparation of contract documents. The purpose of this study is to determine the technical, sociological, and economical feasibility of the proposed project. Relevant criteria such as soil characteristics, availability of public utilities, availability of construction resources, equipment access, and environmental constraints, can be represented by location. Through the use of topological overlay, proximity functions, and other GIS functions, an optimum construction site, satisfying various technical and socioeconomic constraints of the project, can be located. A large amount of relevant data in this stage can be obtained from public agencies at the local and federal levels, such as municipal engineers, public work offices, zoning administration offices, land records offices, state departments of transportation, departments of natural resources, U.S. Geological Survey, Census Bureau, and Soil Conservation Service (SCS).

The second potential application during the design phase that can benefit from GIS technology is site investigation. Items that a design engineer selects for investigation are generally local magnification of the items considered in the feasibility study. The use of GIS, for instance, can assist the designer to detect anomalies, to decide where geological structure needs to be examined, where boreholes are needed, and to what depth they should be taken.

The traditional task of design professionals is the preparation of drawings and specifications that define the physical and functional characteristics of a given project. The linkage of GIS and CAD through a common interface can be used to develop the design drawings. The specifications are a verbal description of items contained in the facility and also can be linked to the drawings through the use of relational tables, as previously depicted in Fig. 2.

Bidding Phase

Upon completion of the detailed design in a design-bid-build contract type, the bid process is initiated. In this phase, the owner is interested in qualifying selected contractors based on a set of specific criteria, some of which have spatial components and are amenable to GIS analysis. The application of GIS to contractor prequalification is described later in the present paper.

The contractor, on the other hand, is interested in estimating the total project cost. Such an estimate should be low enough to obtain the job, but high enough to ensure the highest possible profit. To properly prepare the estimate, a contractor should visit the site and carefully analyze the conditions imposed by the site characteristics. For instance, the verification of access roadways, water, electric, and other service utilities in the vicinity of the site can be made. The extent of the top soil to be removed from the site can also be calculated. The spatial data, previously stored in a GIS during the site investigation at the beginning of the design phase may be of assistance to both the design engineer and the contractor in identifying the risk elements that should be accounted for in the estimating process.

Construction Phase

This phase involves the organization and coordination of resources into a sequence of project activities necessary to complete the construction of a facility. Common resources used in constructing a facility include money, time, equipment, labor, material, and management. Unlike these six resources, space is often ignored as the seventh resource. In fact, space is a component of both the action and interaction of project activities. To illustrate this point, the following example situation includes a temporary area on the construction site that is allocated to fabricate and store structural steel components. Each of these actions (i.e., fabricate and store) requires a given amount of space. The interference of these actions with each other, on the other hand, establishes the space conflict.

The introduction of space as a limited resource provides a new perspective to the traditional project management paradigm of cost, schedule, quality, and safety. Some GIS analysis functions, such as network functions may provide assistance in scheduling methods such as critical path method (CPM) and program evaluation and review techniques (PERT). Material and labor transportation problems lend themselves particularly well to spatial network-type analyses using GIS.

Another potential application of GIS during the construction phase is the selection of proper equipment suitable for the work conditions at a construction site. Factors affecting the selection of a particular piece of equipment, such as soil characteristics, proximity to construction site, or weather and temperature, possess spatial components. Different GIS techniques, such as classification, measurement, retrieval, proximity, and overlay operations, can be used to assess the suitability of particular equipment to a construction site. Similar techniques can be employed to examine the suitability of a construction method for a particular project.

The changes of building codes from one geographic area to another can also be structured for GIS application. A spatial data base can be built to store these codes by geographic location. A potential benefit that can be derived from this GIS is interactive querying of the data base with either graphic or text display. GIS capabilities can also be used to easily update these codes as they are modified or deleted from the system.

GIS Approach to Contractor Prequalification

The prequalification analysis of construction contractors has been defined previously as "the screening of contractors by an owner, based on specific criteria in order to determine their competence to complete the work associated with a given project" (Russell and Skibniewski 1988). A large volume of qualitative, subjective, and imprecise information is typically involved in this process. Numerous models have been developed to rationally structure and formalize the prequalification process. Such models vary from ad-hoc approaches to rigorous and formalized methods (Russell and Skibniewski 1990; Russell et al. 1990). However, no attention was given to the spatial aspect of the contractor evaluation problem.

The purpose of this section is to present a conceptual framework to apply GIS technology to the contractor prequalification decision-making process.

An important benefit expected from the GIS approach is the creation of a comprehensive data base. This data base can provide the wide range of construction users with a mechanism for rapid retrieval and a manipulative capability to satisfy their needs for spatial and descriptive information required in the process.

The methodology suggested for this discussion consists of five stages. First, pertinent constraints to the prequalification decision process introduced by the owner, designer, contractor organizations, and the project are outlined. A special emphasis is plased on their spatial aspect as justification for the GIS approach. Then, different data layers that can be incorporated into the GIS data base to support the prequalification analysis are identified. Next, the utility of the prequalification GIS is presented. Finally, potential suppliers and users of this data base are identified.

Construction Contractors Prequalification Constraints

Fig. 4 depicts significant constraints introduced by project participants as well as the characteristics of the project under consideration. In the subsequent sections, selected examples of the spatial aspect associated with these constraints are highlighted. A comprehensive discussion regarding this subject can be found in Russell and Skibniewski (1988). Considering the constraints introduced by the project, two categories can be distinguished, physical and socioeconomic. Each category introduces numerous factors to the prequalification decision-making process.

For instance, the familiarity of a candidate contractor with certain physical characteristics of the project, such as topography, geology, soil, hydrology, utilities, transportation, and local weather conditions, may have an influence on risk associated with the proposed project. This familiarity may also alter the quality of the work performed by the candidate contractor and the time

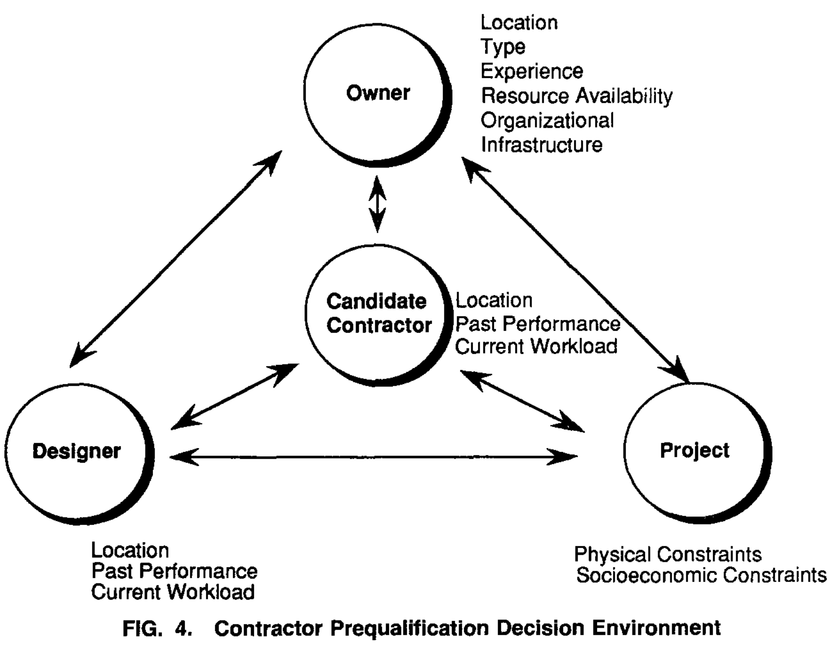


FIG. 4. Contractor Prequalification Decision Environment

required to complete the project. As an example, consider a contractor who has previously completed numerous projects within the area of the project under consideration where similar geological conditions exist. Consequently, they may have become familiar with the subsurface anomalies that might occur and the construction methods and materials that are necessary under these conditions. Hence, the more knowledgeable contractor can arrive at appropriate judgments in an expedient and economical manner.

The location of construction owners with respect to the project site, design firms, and construction firms, can facilitate efficient communication between the project parties, and thus enhance the management and control of the project. Consider, for instance, a construction project where the owner is located in Madison, Wisconsin, the designer in San Francisco, California (another time zone), the contractor in Boston, Massachusetts (still a third time zone), and the project site in Denver, Colorado. All four; owner, designer, contractor, and the project are within different time zones. This complicates the communication process among these participants. The communication process is impacted by the reduction of the working day due to the difference in the time zones. This, in turn, can increase project cost and time. On the other hand, if the same project is constructed in the geographic location of the owner with a local design engineer and contractor, then frequent meetings can be held to resolve problems in a more efficient manner.

The proximity of a contractor home office to the project site generally ensures better management and control. A candidate contractor has easier access to additional resources if their office is closer to the proposed project site. This proximity also reflects the familiarity of the contractor with not only the physical constraints of the project, but more importantly with the locally-favored methods and materials; labor availability, cost, and productivity; prices of standard construction items; labor jurisdiction issues; and local political climate. This does not suggest, however, that contractors with home offices far from the project site should not be prequalified. Based upon discussions with industry professionals, higher risks of failure and losses are normally present when the project site is not within the contractor's normal area of operation.

The performance of a candidate contractor on previous projects is a good indicator of future performance and thus important in the prequalification process. This criterion also impacts the consideration of how the owner subsequently monitors and manages the contractor that is awarded the project. Items such as the construction type, size, and location of these projects can assist owners in evaluating the contractor's past performance. The proximity and geographical distribution of on-going uncompleted projects wth respect to the proposed project along with their percent complete and anticipated completion date can also aid in determining the available capacity of a contractor.

The familiarity of a design engineer with local conditions may also affect project cost, time, and quality. Labor cost, labor productivity, construction materials, methods, and codes differ in various regions of the country. A design engineer is not expected to understand these conditions in all locations throughout the U.S. However, the closer the design engineering firm is to the project area, the higher the chance that they can take full advantage of their prior knowledge and experience when preparing contract documents. The size of the design engineering firm is another important factor that must be considered in the analysis. Design engineers operating at multiple locations can easily access additional resources and expertise when necessary for the project under consideration.

Prequalification GIS

From the previous discussion, numerous data layers that can be incorporated into a GIS data base to support contractor prequalification analysis have been identified. Fig. 5 depicts these different layers. Large volumes of spatial and descriptive data can be associated with each layer, as illustrated

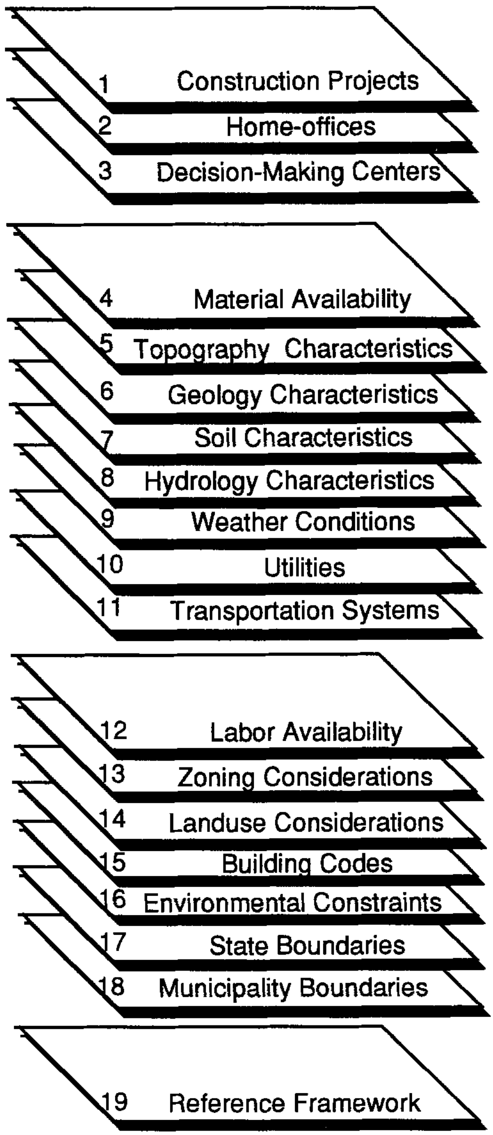
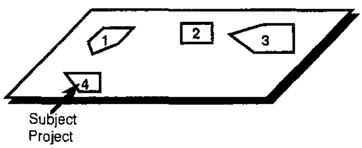


FIG. 5. Proposed Data Layers for Contractor Prequalification Data Base

Project Locations



Basic Project Attribute Table

Project ID (1)	Project Name (2)	Project Status (3)	Industry Sector (4)	Project Type (5)	Project Size ($ million) (6)	Project Duration (month) (7)	Owner (8)	Designer (9)	Contractor (10)
1	Gate Bridge	Previous	Public	Bridge	30	27	DOT	Kaiser Engr.	Baker Elec., Inc.
2	School-Addition	Previous	Private	General Building	16	18	Tom Inc	Parson Inc.	Russell Engr., Inc.
3	I-94	Current	Public	Highway	0.8	3	DOT	Kramer Engr.	Miron Const., Inc.

Related Attribute Table for Incomplete Projects

Project ID (1)	Compl. Date (2)	% Compl. (3)	Proj. Manager (4)
3	3-92	75%	David Michael

FIG. 6. Project Location Data Layer

in Fig. 6. As a practical matter, some of the identified data layers are available at different levels of abstraction, scale, accuracy, and resolution. Therefore, it is the writers' opinion that a useful framework to categorize the data layers based upon these parameters should be established. A more detailed discussion regarding this subject is presented in Jeljeli (1991).

Once the data base is constructed, numerous spatial and descriptive queries can be performed. This data base allows the user to search for records according to specified conditions. For instance, candidate contractors can be selected based on criteria, for example: (1) Labor type must be union; (2) major working construction type of the candidates must be general building; (3) number of construction projects currently under contracts must be less than seven; and (4) contractor's decision-making center must be within 20 miles from the proposed project site. The generated results can then be displayed in the desired report format, such as a table or map.

The user is also able to perform point-and-shoot queries. By pointing the cursor toward an area of interest specified by an owner, an attribute table containing contractors' names, addresses, telephone numbers, and perhaps the labor type they employ or other pertinent attributes can be displayed. Using buffering techniques around a contractor home office, the geographic area where this contractor has a higher change of successfully completing a construction project can be generated. This information can then be used by the contractor to select the spatial configurations that maximize their performance and profits, or it can be used by owners in selecting the most suitable contractors to perform the proposed job. Additional predictive models can also be incorporated into the system to support more advanced queries, such as assessing the effect of the geographical dispersion of the project participants on the cost, time, and quality of construction projects.

Potential Suppliers and Users of Prequalification-GIS

To implement the suggested data base, large volumes of data regarding construction projects, owners, designers, and contractors must be collected from multiple sources. Government agencies at local, state, and federal levels are potential suppliers of spatial data. Examples of these agencies include, but are not limited to zoning administration offices, U.S. Bureau of the Census, U.S. Geological Survey, Defense Mapping Agency, Bureau of Land Management, departments of transportation, and departments of natural resources. Nonspatial information regarding the project and different participants can be obtained from the following sources (Russell and Skibniewski 1988): monthly project progress reports; project close-out reports; questionnaires (e.g., the American Institute of Architects (AIA) Document A305 and the Associated General Contractors of America (AGC) Document No. 40); credit rating services, such as Dun and Bradstreet (D&B) or the National Association of Credit Managers (NACM); Bureau of Labor Statistics (BLS); labor departments of construction labor demand system (CDLS); and other standard industry reports, such as F. W. Dodge report. On the other hand, potential users that can benefit from the GIS data base include private owners; public owners at federal, state, and local municipalities' levels, such as the departments of transportation; design firms (architect, architect/engineering, or design engineering firms); general contractors; construction managers; and surety industry professionals.

Practical Considerations

The particularity of the construction environment and the nature of the required construction data place certain demands and considerations on GIS technology. These considerations are addressed in the following discussion.

Georeferencing System

Coordinates in a GIS should be linked to real-world coordinate systems based on geodetic control. Spatial information, such as project location or home-office location, are meaningless if they are not related to a geographic framework. Such a framework will provide the reference base for all layers contained in the GIS data base. It will also permit the exchange, integration, display, and analysis of the data. Latitude/longitude, state plane coordinate system (SPCS), and the universe transverse mercator (UTM) system are examples of common coordinate systems that can be used for construction applications.

Data Base

Relational data bases have several advantages that make them an attractive solution for GIS application to construction industry. First, the relational structure provides users with a powerful navigation ability to find spatial and attribute relationships as they are needed and perform ad-hoc queries. For instance, using a simple command, a construction user can generate a table or a thematic map showing all heavy construction projects in a defined area and within two miles of a major transportation route. Secondly, the relational data base possess powerful tools that allow for distributed networks. This gives the possibility for multiple construction users to create, update, and maintain their data on their individual servers. At the same time, a full accessibility of these data to other users is possible. This method facilitates the integration of different data, design decisions, and knowledge. It also encourages different construction participants to work more closely and exchange relevant information more freely.

Data Models

The selection of a data model, vector or raster, depends largely on the selected construction application. Traditionally, the two models were seen as competing representation schemes. Advances in hardware and software technologies, however, have gradually made the differences between them less significant. Both vector and raster models are relevant when applying GIS technology to construction. Incorporating raster technology within a vector GIS can help exploit the advantages of the raster model, such as simplicity, low cost, ease of data collection, and image interpretive aspect, without loosing the benefits of the vector model, such as high accuracy and topological capabilities.

3-D Representation

The graphic tools of GIS are typically suited for 2-D phenomena. By contrast, construction industry is frequently confronted with problems involving 3-D phenomena. For instance, a design engineer may desire to determine the extent of removal of top soil and other unsuitable materials, or to balance the cut and fill volumes so that no soil has to be imported or removed from the project site. These calculations are not adequately performed using 2-D representation. Current GIS employ different techniques, such as perspective and stereo views, to create 3-D simulations. However, for more advanced construction applications, an interface with other computer programs, such as CAD may be necessary.

Data Quality

The quality of the results reached through GIS operations is limited by the quality of the underlying data sets. Therefore, quality improvement techniques must be addressed before, during, and after data automation. Several factors can affect the quality of construction data. Examples of these factors include lineage, completeness, currency, logical consistency, scale, accuracy, and resolution among others. A more detailed description of these factors can be found in Aronoff (1989) and Jeljeli (1991). The key issue is to establish proper balance between these factors. Such a balance must satisfy both the technical requirements of the intended construction application and the cost to be invested. For instance, it is not efficient to carry the maximum precision to the nearest micron through GIS operations and print the results to a precision that exceeds the level justified by the accuracy of the data.

Areas for Future Research

Based on existing knowledge and understanding of GIS technology, several research areas worthy of further investigation can be identified. First, more detailed research is needed in assessing the suitability of a particular data model. The possibilities are not limited only to vector and raster models. The object-oriented modeling technique is an attractive alternative to represent spatial objects in a construction GIS. In fact, this model is not new to construction professionals. Previous research has been conducted to assess the potential of this technique in construction automation technology (Keirouz et al. 1988; Grobler et al. 1989; Paulson et al. 1989, among others).

Another research area includes exploring similarities between GIS and other computer systems, such as computer-aided-design (CAD), project management (PM) systems, and facility management (FM) systems, now being applied in single stand-alone construction applications. Communication requirements, such as data interchange standards for GIS and these systems, must also be investigated. The research areas just identified are related to the technical aspect of adapting GIS to the construction industry. In addition to technical concerns, institutional constraints must also be investigated if GIS technology is to be applied successfully. Many of the institutional barriers have been identified by Adams et al. (1992). Barriers include the cost of data, database management issues regarding central versus distributed control, and legal and liability issues associated with ownership, access, maintenance, and reliability of the system data.

Conclusion

The present paper briefly reviewed the four basic modules of a Geographic Information System. Potential construction applications of GIS technology were identified. Specific emphasis was placed on the spatial aspects of these applications as the justification for the use of this technology. A selected application, construction contractor prequalification, was used to highlight the strength of the technology. Practical considerations that the construction industry environment places on GIS were also discussed as well as areas of future research regarding this technology. Like any other computer technology, it is rather difficult to assess the full potential of GIS to construction industry until a prototype system has been developed and validated. Furthermore, as this technology becomes more familiar to various construction professionals, new areas of applications will be discovered, as well as other technical and institutional barriers.

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Appendix. References

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