GIS Training in Civil Engineering

Abstract

Geographic Information Systems (GIS) have been used in many fields of science, technology and business. One of these fields is civil engineering. Spatial information and analysis capabilities have been used to assist the planning, modeling, design and implementation of civil engineering projects and activities. There are many GIS-based tools and applications geared toward civil engineering. Proper use of these tools and applications necessitates training in GIS theory, technology and application-specific issues.

1. Introduction

There are many fields in civil engineering where GIS is being employed as a tool to analyze, design, and implement effective and efficient solutions. GIS functionalities have been used to assist in the analysis, selection, prioritization, and implementation of civil engineering projects. In this regard, many GIS applications have been developed in hydrology, hydraulics, water resources, transportation, geotechnical, surveying, environmental and other fields of civil engineering, to facilitate engineering analysis, modeling, design, implementation, management, decision making processes and activities (Wright, 1993; Mitchell, 1998; Jia and Hickam, 2000).

A number of universities have developed courses that concentrate on GIS science and technology in civil engineering or incorporated GIS topics into already existing curricula. Overall extent of the incorporation, however, is still at questionable levels and quality for civil engineering departments. In most cases the incorporation is far less than adequate. This could be attributed to the lack of interest, understanding, prevailing conventional approach in civil engineering teaching/curricula, or other issues. In this paper, the need is underlined for incorporation of information technology and its spatial component, GIS, with its scientific and technological framework to the curricula of civil engineering departments. It is hoped that this information will facilitate efficient, cost saving, comprehensive, integrated and innovative solutions to today's problems in the civil engineering profession. This paper offers examples from civil engineering where GIS could be considered one of the best solutions if accommodated appropriately.

2. Fundamental framework for GIS in Civil Engineering Curriculum

GIS has been used in the areas of land management, transportation system analysis, planning, travel demand forecasting, highway design, infrastructure evaluation, hydrologic/hydraulic analysis and modeling, utilities and infrastructure management, water resources management, environmental monitoring, assessment, analysis and modeling, development and implementation of appropriate techniques/solutions for various environmental issues, site selection, preparation, integration of GIS and Global Positioning Systems (GPS) technologies for surveying, mapping and many other fields of civil engineering (Wright, 1993; Mitchell, 1998; Jia and Hickam, 2000).

Geographic Information Science (GISc) is a multidisciplinary field. It is focused on the principles of GIS, GPS, and remote sensing technology (Goodchild, 1997). The challenging issue in the integration of GIS training/education in civil engineering curriculum is finding a balanced approach that incorporates GIS technology with appropriate background scientific theory to the specific issues/problems of civil engineering (Miles and Carlton, 1999). The approach for GIS education in civil engineering should involve (Figure 1.):

1) Scientific fundamentals of GIS, specifically geographic and cartographic basis. In this respect, the curriculum in GIS should incorporate fundamental definitions related with GIS, GIS concepts such as spatial models, topology, spatial reference, data resolution, data scale, cartographic analysis/design/modeling, regional analysis, network analysis, statistical analysis, spatial data acquisition/quality/errors, metadata and others (Uy, 2002).

2) GIS technology. GIS curriculum in engineering needs to address GIS technologies and its IS framework, such as database theory and practice, relational and object oriented model, data management, queries, spatial indexing, and others (Uy, C. O., 2002).

3) Applications of GIS in civil engineering fields with an emphasis on the application specific issues/concerns and its proper uses on a case-by-case basis. Identification of spatial issues and problems that could be found in the civil engineering practice and demonstrating the appropriate use of GIS technologies to address these problems should be a part of the curriculum. For example, GIS and Engineering Modeling Integration and possible issues (Clark, M. J., 1998), regionalization (Streit and Ulrich, 1996),

errors and error propagation due to spatial data and modeling (Miles and Carlton, 1999; Foote and Huebner, 2000) etc. need to be covered as a part of GIS training for civil engineering.

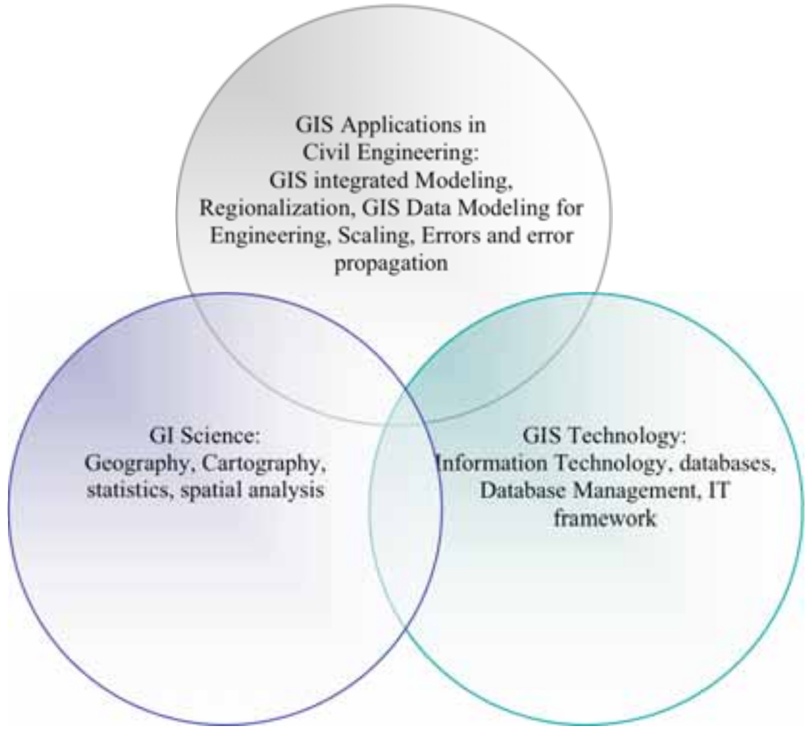

Figure 1. Balanced Approach for GIS in Civil Engineering Curriculum

The balanced approach in GIS training that covers the three basic fundamentals of GIS is necessary to ensure that it has been used in civil engineering practice appropriately with necessary precautions taken regarding its limitations. Approaches that do not address these three foundations in GIS training will yield inappropriate applications, flawed results and lost time and money. Many examples from the civil engineering practice could be given to emphasize the need for the balanced approach. For example, simulation of a flood event through modeling is one of the engineering floodplain management practices where GIS is used to assist in analysis, modeling, design and implementation. The application may involve delineation of the extent of the inundated areas, prediction of spatial and temporal changes in flooding, flood assessment and evaluation and pre- or post-flood planning. Implementation of civil engineering projects/measures to protect lives and property, and to alleviate the environmental, social and economic effects of the flooding may also be involved. The application requires GIS functionalities such as spatial overlay, network analyses, spatial analyses, and may include automation of GIS functionalities and integration of the modeling with GIS for input data pre-processing or output data post-processing and visualization through the custom code, database/file structure development for input and other data storage and retrieval and other processes. Additionally, the application requires digital elevation data in certain forms such as raster or TIN with certain resolution and scale to be used with other basin-related and rainfall event-related data with appropriate temporal and spatial scales. It may be necessary to aggregate (up-scaling, generalization) or disaggregate (down-scale) the existing data with its own quality issues for use in modeling studies. In these processes, spatial relationships between objects should be considered (Streit and Kleeberg, 1996). In other words, the variation of parameters with distance and direction should be taken into account. Otherwise, data quality (degradation) as the data goes through the generalization process for modeling studies could render the results inaccurate and unreliable. Additionally, the hydrologic and hydraulic modeling and GIS integration requires knowledge of data modeling, issues with model (process scale) and GIS data resolution, and data transfer techniques/concerns and possible compatibility issues between these two systems. Furthermore, different uses of GIS data such as for real time modeling (process-intensive), and decision making-management may require different data modeling techniques, storage schemes, and procedures to be applied (Clark, 1998). Therefore, subject matter-related specifics, information systems technology-related specifics and geographic information theory-related specifics need to be addressed in GIS training in civil engineering for an appropriate use of GIS in the floodplain management. Another example of GIS in civil engineering could be given as environmental monitoring, assessment and integrated modeling. In this case, the use requires collection of field data to monitor the parameters of the interest. The application requires use of spatial analysis, geostatistical analysis techniques and modeling for assessment and evaluation. The application necessitates knowledge of spatial data issues such as accuracy, reference and others.

It can be easy to misrepresent data and perform analyses that result in flawed outcomes without proper education and training in GIS that incorporates the theory, technology and application-specific issues (Uy, 2002; Cesur and Burmeister, 2003). A lack of understanding of geography, data quality standards, data modeling, and statistics can lead to the generation of maps or other forms of outputs that mislead policy makers into decisions with potentially costly and/or dangerous consequences with complicated legal, social and economic issues (Uy, 2002). Therefore, GIS classes in civil engineering should address these three fundamental issues in order to be beneficial to engineering students. Additionally, the courses should contain examples from real-life cases and be further supported by internships and projects that deal with actual GIS implementation so individuals will understand both the potential and limitations of GIS technology.

GIS education in civil engineering at a level that could only facilitate basic navigation through GIS software or program applications and scale it down to simple click operations and number-crunching schemes can not be considered sufficient or appropriate to facilitate its proper use in engineering projects/tasks. GIS education in civil engineering should provide understanding of the fundamentals of data management, analysis, integration and customization. In addition to the basic concepts of geography, cartography, spatial analysis and statistics (with an emphasis on geostatistics), application-specific issues should be discussed in GIS education in civil engineering.

GIS Uses and Concerns in Civil Engineering

Data quality issues are one of the major concerns in civil engineering. In this respect, data accuracy and precision are critical factors to consider when using the data for engineering projects. The relative accuracy and precision of a GIS database are considered as measures of data quality (Foote and Huebner, 2000a). Each time a new dataset is imported, the GIS inherits its errors (Foote and Huebner, 2000a). Analytical results can not have a meaning unless a certain standard for minimum quality of data is met. Therefore, GIS education in civil engineering should particularly address data quality problems that can lead to the failure of a civil engineering project.

Accuracy is defined as the degree to which information on a map or digital database matches true, real or acceptable values (Foote and Huebner, 2000a).

Accuracy pertains to the number of errors in the dataset. Precision refers to the level of measurement and the exactness of attribute descriptions. For example, the level of precision for engineering projects, such as utility works, may require data measured to the centimeter, while market/real estate analysis may only need precision to the closest to the census tract.

Sources of errors can be divided into three main categories: obvious sources of error, errors resulting from natural variations or from original measurements, and errors arising through processing (Foote and Huebner, 2000a). Obvious sources of error include age of data, areal cover (data lacking in some areas), map scale, density of observations, formatting, limited accessibility, and constraints on data acquisition/ conversion methods. The second category of errors includes positional inaccuracy, inaccuracy of the content, errors introduced by faulty observations or miscalibrated equipment, and errors due to natural variations such as water quantity and water quality in a stream during different seasons or times of day. Processing errors can occur due to numerical mistakes, logic errors in topological analysis, classification and generalization mistakes, and digitizing and geocoding errors.

Establishing criteria that meet the specific demands of a project, training people involved to meet the standards, and testing the standard throughout a project are required to manage the error (Foote and Huebner, 2000). In this regard, metadata is the principal means of documenting data quality and acquisition methods when sharing the data. It is, therefore, required to assess the use of the data for certain projects. Accuracy, completeness and consistency need to be considered using quality control and quality assurance tests, field verification, and data collection techniques. Potential users can contact the data producer listed in the metadata to inquire about changes, corrections, and caveats associated with the data.

Conclusions

This paper proposes a general outline for GIS education and training in civil engineering. The outline suggests GIS education in civil engineering should address GIS science, technology and application specific issues to facilitate its proper use. The paper exemplifies the necessity of the approach addressing three fundamental issues in GIS education in civil engineering. GIS education that follows this outline is expected to yield desired outcomes regarding use of GIS in civil engineering projects/tasks. This type of GIS education is expected to prepare individuals in the civil engineering profession for the implementation of engineering projects/tasks with time- and money-saving approaches. Additionally, it is suggested that GIS education includes examples from real life cases, and continues with real work exposure and experience in GIS and civil engineering. In preparing students for accomplishing their projects, the approach requires the instructor to organize and discuss the GIS technologies that are needed for the projects. The incorporation of these three fundamental elements into GIS education for civil engineering is a way to strengthen and broaden students' interest in learning and applying GIS in engineering with necessary considerations in its limitation and potential. In conclusion, GIS education can be considered a balanced and appropriate approach that will prepare students to undertake the work of civil engineering with spatial component and concerns.

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