GEOGRAPHIC INFORMATION SYSTEMS FOR CONSTRUCTION INDUSTRY: A METHODOLOGY TO GENERATE 3-D VIEW OF BUILDINGS

V. K. Bansal and Mahesh Pal[1]

Department of Civil Engineering. National Institute of Technology, Kurukshetra, India.
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Abstract
Geographic information system (GIS) is a computer based tool and being used extensively to solve various engineering problems involving the use of spatial data. GIS technology provides capabilities to solve problems, involving creation and management of data, integration of information, visualization, E-commerce and cost estimation to which most of the construction management software are lacking. In spite of the growing popularity, its complete potential to the construction industry has not been realized. In this paper, a review of the up-to-date work on the applications of GIS technology in construction industry is presented. Methodology to generate a 3-D view of buildings as well as to represent the schedule of construction within the GIS environment is also discussed.

Keywords: Geographic information system (GIS), Construction, 3-D View

LOS SISTEMAS DE INFORMACIÓN GEOGRÁFICA EN LA INDUSTRIA DE CONSTRUCCIÓN: UNA METODOLOGÍA PARA GENERAR VISTAS 3-D DE EDIFICIOS

Resumen
Los sistemas de información geográfica (SIG) son una herramienta computarizada ampliamente utilizada para solucionar diversos problemas de la ingeniería que implican el uso de datos espaciales. La tecnología de los SIGs incrementa la capacidad para solucionar problemas, lo cual incluye la creación y el manejo de los datos, la integración de la información, la visualización, el E-comercio (comercio Internet) y la capacidad para estimar costos de la cual carecen la mayoría de los software utilizados en la construcción. A pesar del renombre cada vez mayor, su potencial de uso en la industria de construcción aun no se ha explotado. En este artículo es presentada una revisión actualizada sobre los usos de la tecnología de los sistemas de información geográfica en la industria de construcción. También se propone una metodología para generar vistas 3-D de edificios así como para representar el cronograma del desarrollo de la obra en un ambiente SIG.

Palabras Claves: Sistemas de Información Geográfica (SIG), Construcción, Visión 3D

1. Geographic Information System (GIS)

GIS is a computer system for capturing, storing, quarrying, analysing, and displaying geographic data. Like any information technology, GIS is a special class of information system. GIS activity can be grouped into spatial and attribute data management, data display, data exploration, data analysis and GIS modelling (Lo and Yeung, 2002). GIS involve in using both spatial and attribute data, spatial data relate to the geometry of the features while attribute data describes the characteristics of the space features. Attribute data are stored in the tabular form, where each row of table represents a feature while

[1]V. K. Bansal and Mahesh Pal. Department of Civil Engineering. National Institute of Technology, Kurukshetra, 136119 Haryana, India. Email: mpce_pal@yahoo.co.uk

column represents the characteristic of features. The intersection of a column and a row show the value of particular characteristics of a feature. Two (spatial and attribute) sets of data files are synchronized so that both can be quarried, analysed and displayed (Chang 2002, Clark 2001). GIS is being used in various disciplines but its application is new to the field of construction industry. Literature suggests a limited use of GIS technology in this discipline. This paper is structured as follows. Section 2 discusses about the various applications of GIS in construction industry. A methodology to create 3-D view of a sample building is discussed in section 3. An approach to represent a construction schedule in GIS environment is discussed in section 4, which is followed by a summary of conclusions.

2. GIS in Construction Industry

In construction industry the information required for planning and design are stored in different form, such as drawing, specifications, and bar charts. In planning process the planner has to repetitively reorganise and interpret the information collected from various resources. This process is tedious and prone to errors (Cheng and Yang 2001). Thus, construction industry require a system which should be capable of integrating various types of data and provide the required information and data timely that will finally support various decision and construction operations. With the advances in the field of information technologies, construction industry has started taking advantages of some of these developments. GIS is a new tool in information technology and can improve the construction planning and design efficiency by integrating locational and thematic information in a single environment. The capabilities of GIS to store large database can be utilized to keep construction data in digital form also (Bansal and Pal 2005).

The construction database can provide a wide range of information to the construction industry with a mechanism for rapid retrieval and manipulation capability. Use of GIS may also satisfy the need of spatial and descriptive information required in different construction process (Jeljeli, Russell, Meyer, and Vonderohe, 1993). The prototype system developed by Sun and Hasell (2002) suggests that instant spatial data capture provides fast and accurate visual information about the progress on the construction site. Integration of spatial database with project management functions provides a powerful and effective management control system. Camp and Brown (1993) suggested the use of database management capabilities of GIS to develop a 3-D subsurface environment from well-log data collected from a series of boreholes. As the surface and subsurface conditions influence the construction methods and choice of equipments to be used, which, in turn, affect the cost and scheduling of projects, therefore it is important that site conditions should be properly assessed. The study by Oloufa, Eltahan and Papacostas (1994) used a database for the storage of descriptive soil data in GIS environment to relate soil data to display the corresponding locations of boreholes on the map.

Cheng and Yang (2001) suggested GIS-based approach for quantity takeoffs and cost estimation. Method involove in dividing the architectural drawing into different layers, called data layers. For quantity takeoffs, area and perimeter are used as the basic parameters. Thus, data layers are created as polygons in AutoCAD and transferred to Map/Info as geometric coverage. Locational information includes spatial features such as coordinate, area, perimeter and spatial relationship, which are derived from the coverage. Whereas thematic information includes identification code, beam number, floor number etc., this information are entered by the user. Locational and thematic information are integrated by using one-to-one, one-to-many, and many-to-many relationships and is achieved by an Open Database Connectivity (ODBC) technique. Spatial operations are performed to identify the required geometric dimensions of the graphical features. To complete the quantity calculation, the user inputs the parameters such as the depth of beam and slab, floor height, and area of door and windows. The Structured Query Language (SQL) is used to retrieve the data for quantity takeoffs from the related attribute tables (Cheng and Yang 2001). Figure 1 shows the detailed algorithm used for quantity takeoffs in this study. The MaterialPlan, developed by Cheng and Yang (2001) integrate material estimates with construction schedule for dynamic materials requirement plan. The system is designed so as to pass on information dynamically to the site for materials planning. Based on the information regarding quantities and locations of the materials required in the project, the proposed methodology identifies the suitable site to store the materials.

In temporary facilities (TFs) layout the project manager has to continuously extract information from various resources and draw it on the paper (Cheng and O'Connor 1994). As temporary facilities should be located as close to their supporting activities to reduce the time for travel, Cheng and O'Connor (1996) developed an automated site layout system called ArcSite using GIS for construction of temporary facilities. ArcSite consist of GIS integrated with DBMS to identify suitable areas for the location of temporary facilities. ArcSite integrate the information required to find suitable location for temporary facilities and perform series of complicated spatial operations and database queries to identify optimal site, which is quite difficult to perform manually.

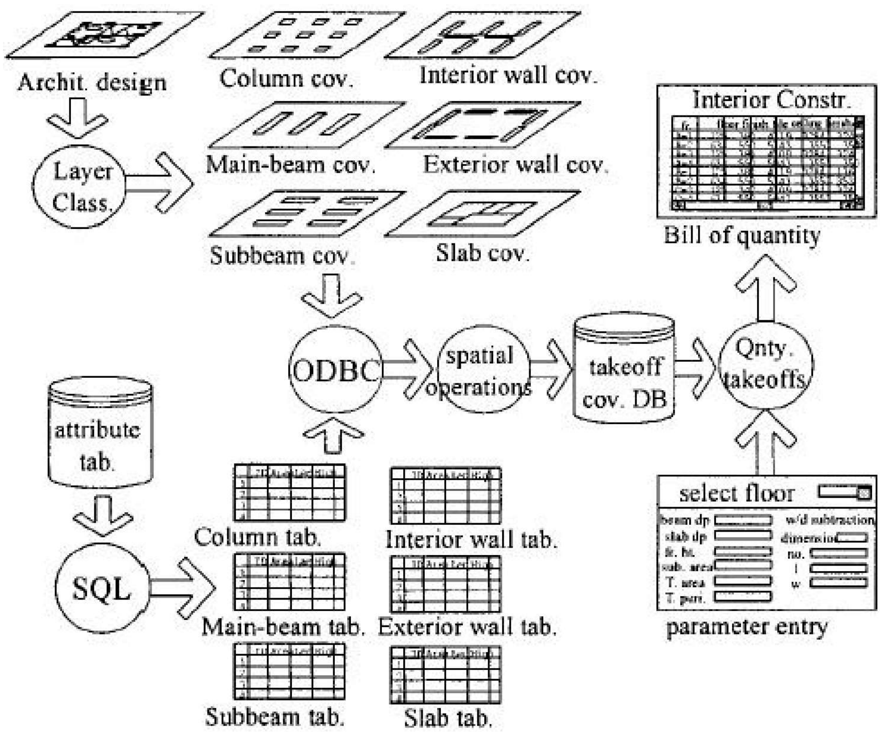

Figure 1: GIS-Based quantity takeoffs algorithm (adapted from Cheng and Yang 2001).

Cheng and Chen (2002) developed an automated schedule monitoring system by using GIS to assist the construction managers to control the erection process for precast building construction. A case study is taken where structural elements were prefabricated in the manufacturing plant and transported to job site for installation. The schedules for prefabrication and transport of the structural elements to the job site are developed based on installation schedule. The study suggested that the use of GIS environment improves the real time schedule monitoring system and construction process as well improves the construction efficiency. The barcode system combined with wireless radio technology for identification of precast member is applied to collect and transmit the job site data to the control center automatically. Through a real time monitoring of the construction process the scheduled components for erection are repetitively tracked and well controlled to assure the lifting schedule is implemented as planned (Cheng and Chen 2002). Study reported by Li, Chen, Yong, and Kong (2005) integrates Global Position System (GPS) and GIS technologies to reduce construction waste. A system was developed from automatic data capture system, barcode for construction material and onsite equipment management, while integrated GPS and GIS technology to material and equipment based on the Wide Area Network (WAN). GPS and GIS integrated construction material and equipment management system is developed in such way that manager from headquarter and construction sites get real-time information to control cargoes on the road to the sites. Comparison of the non-integrated system versus the GPS and GIS integrated system suggests that the GPS and GIS integrated solution improved the construction efficiency by increasing the effective working hour of construction equipment thus reducing the construction duration as well as the cost of workforce.

Li, Kong, Pang, Shi and Yu (2003) presented an Internet-based GIS model for E-commerce business if link between buyers and suppliers is through electronic markets. The E-commerce system, called COME (construction materials exchange) was thus developed which can be used for on-line order and off-line delivery of different construction materials. The electronic market provides platform for the suppliers to provide online information about their products. Buyers can easily search and compare products of different suppliers through online system and contacts the suppliers directly. If required, buyers can also invite agents to undertake certain tasks required in order to complete a transaction. In all E-business activities transportation cost is involved, so spatial information plays an essential role. Thus, internet-based GIS provide an ideal solution to manage costs of transportation and market analysis in the overall E-commercial activities (Li et al., 2003). The costs for transporting construction materials are not only dependent on the distance but it may involve many other variables, such as the locations of local distributors, reduced shipping costs because of combining shipment to various buyers in the same area. The author suggested further improvement could be carried out in the proposed system (COME) by taking care of these problems.

Varghese and O'Connor (1995) developed a system with a platform on which the information required for route planning can be integrated. They successfully demostrated the value of expert GIS for automating the tedious and repetive route planning tasks for large vehicles within the construction site. The study by Cheng and Chang (2001) discusses the development of GIS-based system to automate the process of routing and design of an underground power supply system. In urban areas, obstacles such as existing public utility lines, railways, canals and roads can influence the route significantly as there may only be a limited number of feasible crossing points. Selection of a suitable route to avoid existing obstacles not only reduces the risk of damaging existing utilities, but also minimizes the cost and duration required for construction. In developed system, surface and underground utilities are represented in several coverages. The optimal paths for routing is determined using the network analysis of Arc/Info GIS package. The conflict points between the basic coverages and the selected route are identified and a reallocation schedule is determined through database queries and spatial operations.

The simulation process has proved to be an effective tool for planning and improving the performance of a construction process in many successful case studies. However, these tools lack the capability to represent explicit information involved in the simulated construction process. Zhong, Li, Zhu, and Song (2004) suggested that GIS can be utilized to overcome these limitations. 3-D spatial data is used to represent elements that have physical dimensions in 3-D GIS. By considering time as an attribute of the 3-D spatial model, GIS can depict the simulated operations dynamically in a 3-D environment as being carried out in the same way as they would be in the real world. This process of visualization can help to detect performance inconsistencies and obtain insight into the simulated construction operations.

3.0 Applications

In spite of widespread applications of GIS to construction industry, visualization using GIS has not yet been used to its maximum potential in construction planning. Most of the available simulation tools are capable of optimizing construction sequences and establishing project plans. However, these tools are not having the capabilities to represent information involved in the simulated construction process. Project managers are forced to search for design drawings and data reports that are needed while using simulation tools. So GIS can be utilized to overcome the above mentioned limitations (Zhong et al. 2004). Construction industry uses different tools other than the GIS for visualization, which are not capable to store the huge amount of information involved in any project. As the construction project duration increases, manager receive more spatial and non-spatial data, thus, manager has to take the decisions after careful investigation and analysis of a large amount of data. Researchers have explored the capability of GIS in construction database management, and not much in visualization (Bansal and Pal 2005, Camp and Brown 1993, Cheng and Yang 2001, Jeljeli et al. 1993, Oloufa et al. 1994, Sun and Hasell 2002). A simple application presented here discusses the methodology to generate a 3-D view of building in GIS environment. Although the CAD technologies provide alternative for this, but GIS technology uses data (i.e. non-spatial) synchronized with the 3-D modeling which is not possible in CAD technologies. GIS is a database centric tool, thus, handle spatial and attribute data on a single platform. The CAD layers organize the spatial data only to facilitate drafting process, while in GIS various spatial operations on graphics and non-spatial operation on the attribute data are possible. Present study provides a methodology to represent buildings in 3-D, in which the different information are attached to corresponding components of building.

3.1 GIS-based method to develop 3-D visualizations of building

To develop a methodology for 3-D visualization of a building ArcView 3.2 is used and the procedure involves following steps:

Step 1: As an architectural drawing is not enough to generate a 3-D view in GIS, thus, it drawing is divided into different layers. The purpose of dividing of architectural drawing into different layers is to determine how layers will represent the complete 3-D view in GIS. All features of different layers are created in AutoCAD as polygon. Different layers such as base concrete, footings, walls, slab, doors and windows include number of polygons. Three wall layers are created at different height intervals so as take care of any opening in the wall. Figure 2 show the different layers of sample building created in AutoCAD and used to generate 3-D view in GIS.

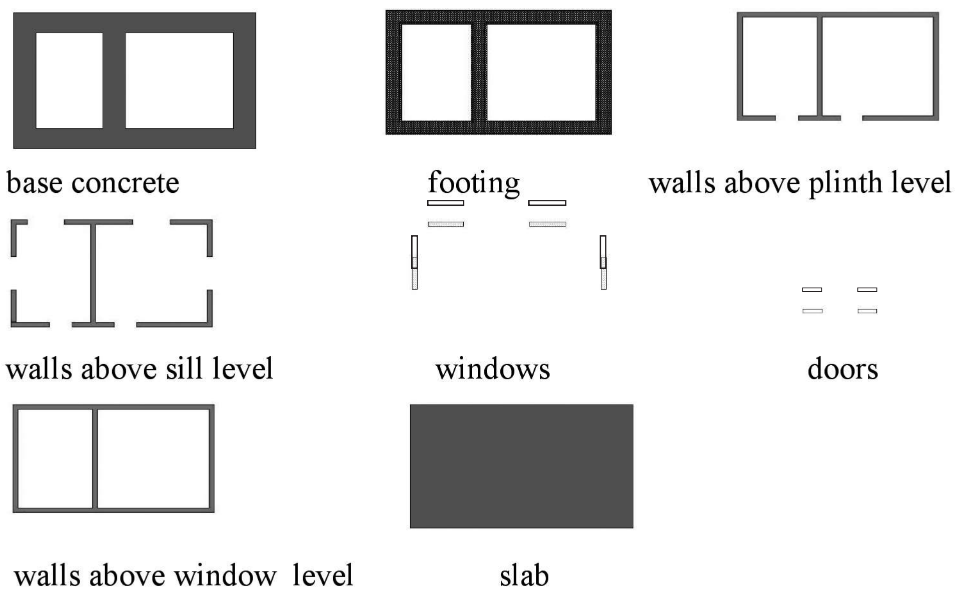

Figure 2: Different data layers of architectural drawing used to generate 3-D view.

Step 2: All the data layers are than transferred into ArcView. Figure 3 shows the different layers of the sample building transferred into GIS. Different polygons in a layer are dissolved to form a single polygon using dissolve of GeoProcessing extension of ArcView. Dissolve is repeated for all data layers. After dissolve, all AutoCAD files get converted as the shapefiles in ArcView. Shapefiles are a simple, non-topological format for storing the geometric location and attribute information of geographic features in ArcView. Vector data model involve in using both spatial and attribute data in a way that spatial data relates the geometry of the feature in layer, whereas attribute data describe the characteristics of layer’s feature. There is always a dynamic linkage between the spatial and attribute data where highlighting a record of the attribute data highlight the corresponding spatial feature in view window of ArcView and vice- versa.

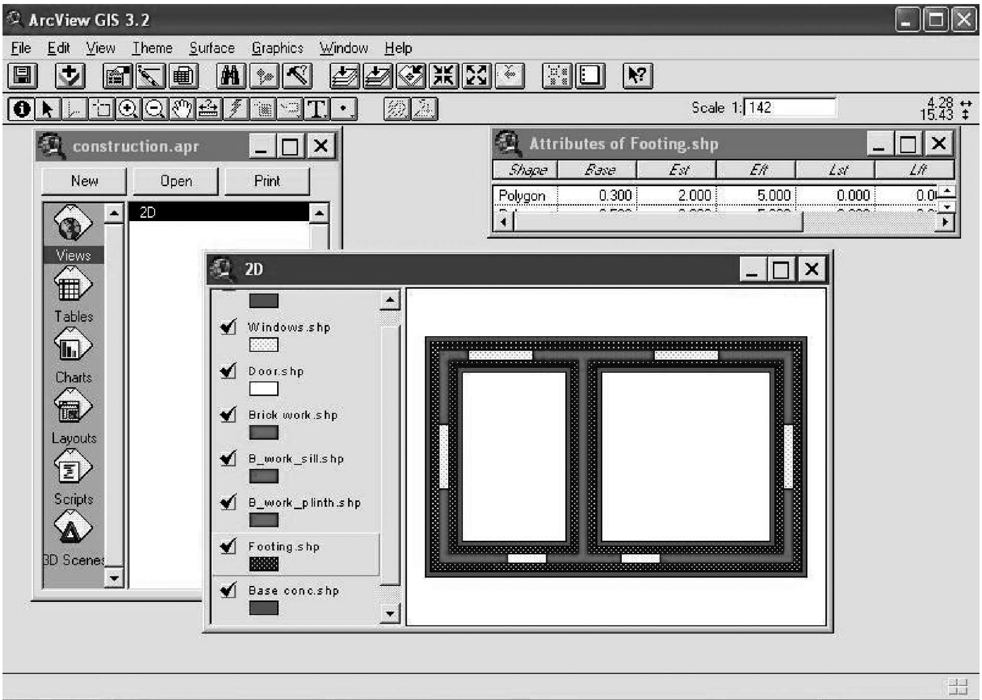

Figure 3: Spatial and non-spatial information stored as 2-D layers in ArcView, which is used to generate a 3-D view in GIS environment.

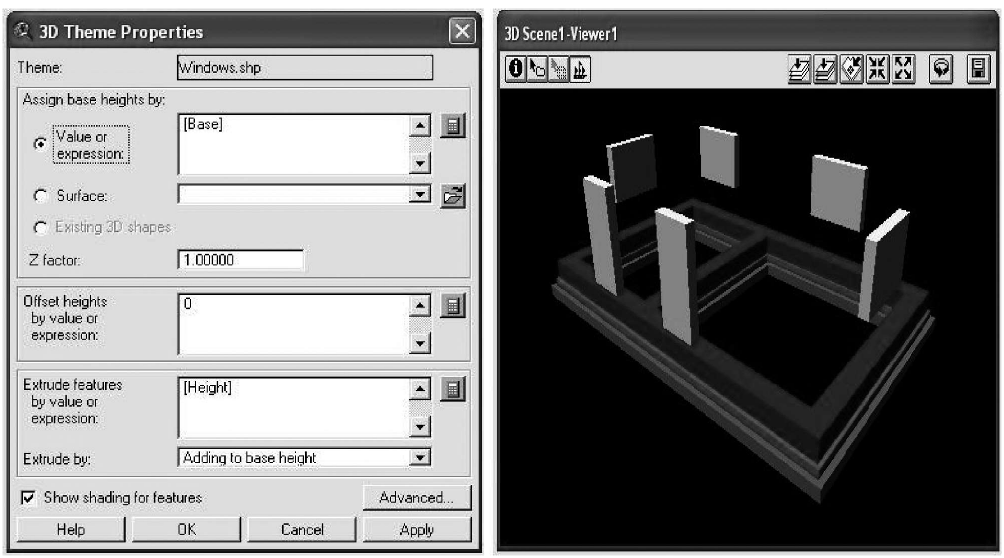

Figure 4: (a) 3-D properties dialog-box in ArcView used to assign the base-height and layer-height and (b) different layers in space at elevation value equals to its base height and extruded upward by value equal to its layer-height.

Step 3: The default sets of attributes are automatically generated when different layers re transferred into ArcView. Attributes needs to generate 3-D view include base-height and layer-height. Base-height is defined as the elevation value for a shapefiles. Thus, field called base is added into the attribute table of each layer that defines the base-height (elevation) and field height is also added into attribute table of each layer that gives the layer-height (i.e. thickness).

Step 4: A 2-D layer does not have the base-height and layer-height information. To display the perspective view, a 2-D layer must be assigned base-height and layer-height from another source. The source will be the fields in its own attribute table. Thus, 2-D theme is assigned the values of base-height and layer-height from its own attribute table. A dialogue-box as shown in figure 4(a) is utilised to assign the fields base and height to the 2-D layers. Extrusion utility in the ArcView changes the form of a feature from points to vertical lines, lines into vertical walls and polygons into 3D blocks. Figure 4(b) shows different layers in space at an elevation equal to their base-heights value and extruded upward to construct a 3-D view, by a value equal to its layer-height. Figure 5 provides different stages of construction process for the sample building, whereas figure 6 shows the 3-D view of the sample building.

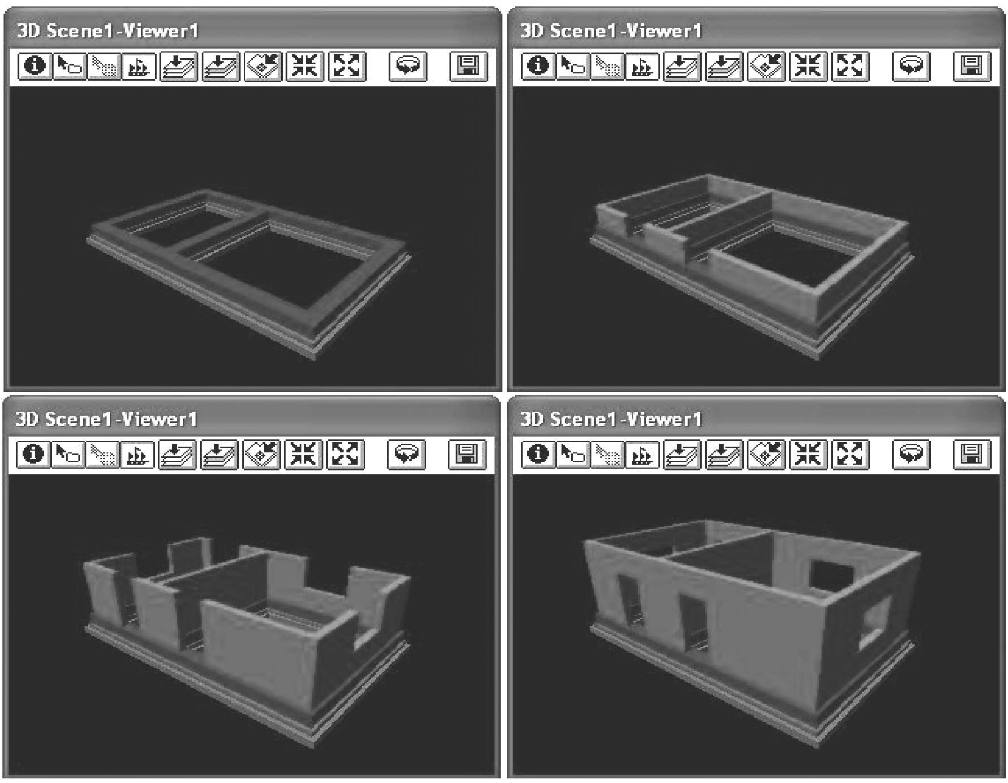

Figure 5: *Appearance of building at different stages of construction using three-dimensional analysis of ArcView*

3.2 Construction Schedule

Schedule is defined as the work program or the time-table for the actions to be taken during implementation of a construction project. Bar-chart method is one of the popular methods used by the contractors for scheduling. In bar chart method, work is first split into different activities. These activities are then listed in the order of construction priorities on the left hand side column, while the time scale is plotted horizontally on the bottom. ArcView can be used to show the schedule using its in-built chart document. Figure 7 shows the ArcView's chart document, utilized to show the construction schedule of different construction activities. The main advantage of the ArcView's chart document is when a bar on bar chart is clicked a window appears which provide the scheduling information related to that particular activity. Thus, with a single click on bar user can obtain the required information from the database.

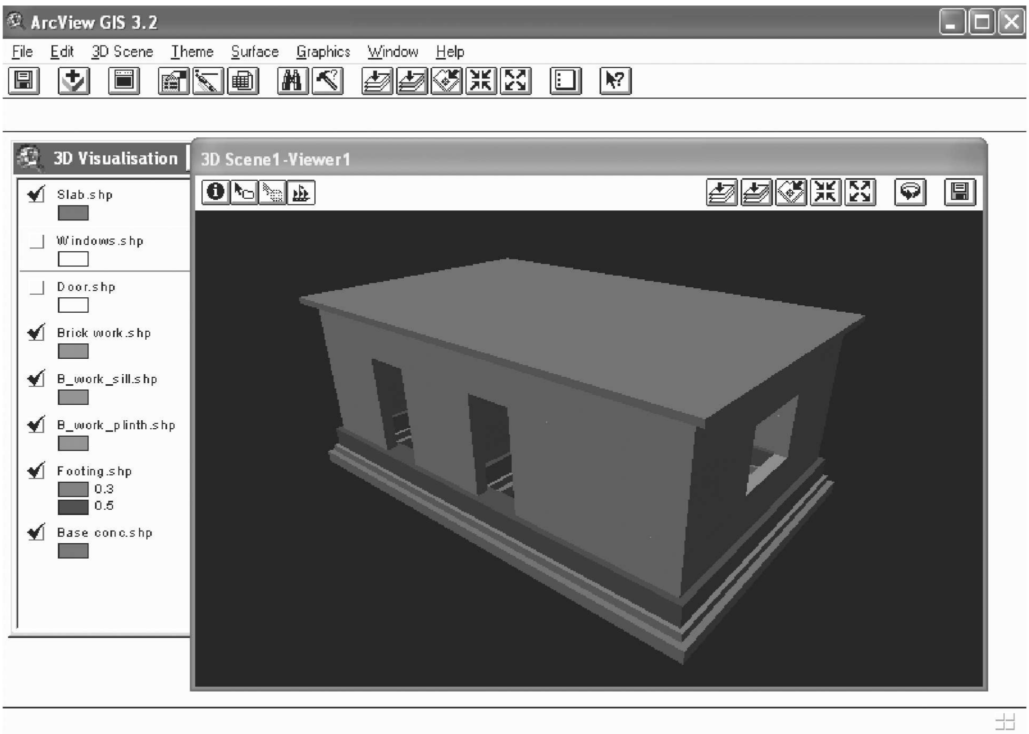

Figure 6: 3-D appearance of building prior to construction using 3DAnalyst of ArcView, relevant information are stored in the attribute table

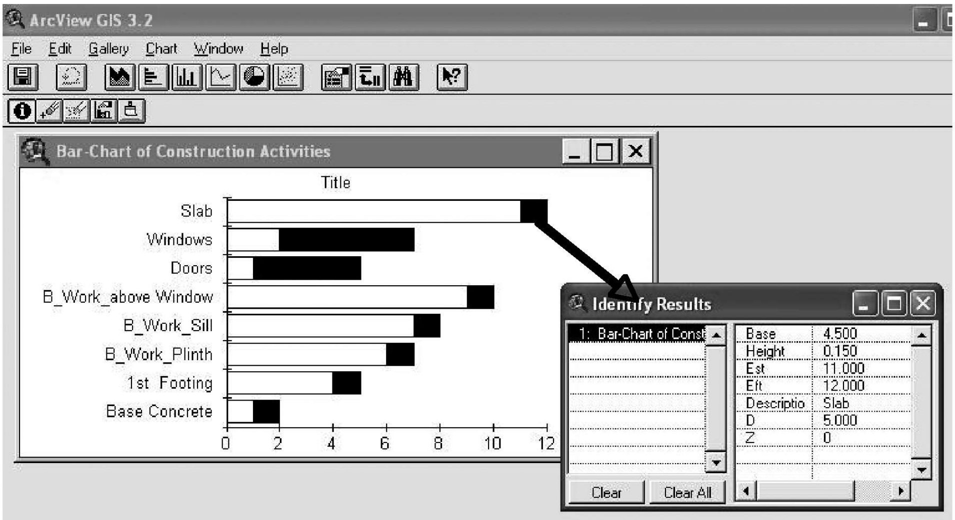

Figure 7: Use of ArcView's Chart Document to represent the schedule of the different activities in sample application.

4. Conclusion

This paper presents a survey of different applications of GIS to construction industry as well as methodology to generate 3-D view and bar-chart to represent the construction schedule. GIS is one of the fast emerging fields being utilized in various engineering projects whereas its complete potential to the construction industry has not been realized yet. GIS provides several benefits to the construction industry, in which most of the construction management software are lacking. GIS may improve the construction planning and design efficiency by the integration of spatial and attribute information in single environment. It is a tool that can effectively be used for quantity takeoffs, cost estimates, and database management. By integrating schedule with material requirement, dynamic material requirements plan can be developed in GIS environment. Database for soil data, foundation analysis and design, construction planning and design-construction integration may be developed in GIS environment.

Database in GIS environment can provide a wide range of information to construction industry with a mechanism for rapid retrieval and manipulation capabilities. Integration of schedule and design information makes it easier for the project manager to monitor and control the construction progress. Several tools for construction industry using GIS are suggested in literature and their applicability has been demonstrated with suitable case study. However, the practical usefulness of these developed tools in construction industry is still doubtful. Tool developed in one study is not utilised in the other study to develop another application and the tools implementation on the real life project in the industry are rare. Further, most of the reported works have used different software in combination with GIS software to develop different tools for construction industry, thus require studies to develop tools that involve in using new inbuilt scripts/codes in the GIS environments itself to replace the use of other software.

The sample application presented here explains the GIS based procedure for 3-D visualization by utilizing the capability of GIS to maintain data in different layers. Data is well stored in the different layers in GIS and features in different layers are constructed as polygons. So these data layers can further be used for quantity takeoff (using procedure provided by Cheng and Yang 2001) also. Thus, GIS can also be used as an alternative visualization tool for construction industry. Although the CAD technologies provide visualization capabilities, but GIS technologies can perform different operation on the attribute data synchronized with the 3-D model, which is not yet possible in CAD technologies.

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