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A Review on GIS based Construction Project Management

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Abstract: Construction industry is that area which has indeed experienced tremendous growth over the past decade. As it is, there are numerous challenges that the industry face today. Adequate management identifies itself as a one for all solution to most of the problems faced by the industry. A brief timeline of research and development activities that could be grouped under this title, GIS based 4D modeling for project management, also called Building Information Modeling or BIM popularly has been furnished in this paper. As the traditional instruments of management had very limited linkage with the spatial aspects of construction work, a concept of four dimensional modeling was proposed. With the advent of GIS, enhanced spatial and database management capabilities could be made use of for the purpose. Towards the end, the benefit of carrying out the modelling and management task throughout in a single environment has been discussed, suggesting GIS framework to be an excellent platform that could serve the purpose, stressing out the relevance of an open source GIS package in today's world, recommending an open source GIS environment for the work which would be an added advantage.

Keywords: 4D modelling, 3D visualization, GIS, Construction management, BIM, Planning and scheduling, Open source GIS.

1. INTRODUCTION

The unprecedented rise of infrastructure and construction activities round the globe shaped the world to what it is, today. Infrastructure forms the backbone of the modern commercial world, be it any segment of life. Apart from that, the rapid globalization transcending boundaries demanded quicker development of infrastructure which in turn forced the construction industry itself to grow at an unpredictable pace. Irrespective of the area of application, management system governs the efficient functioning of any organization. The term management covers two main elements, resource management and time management. For an industry like the construction industry that has an immense potential to grow, is considered, there are a lot of challenges that the governing system of management has to face in order to help the organization attain the expected performance. A proper all-round management strategy can offer solution to most of the challenges faced by an organization.

As the nature of the target field is, for example, the construction field, management can be in terms of construction materials, laborers, construction site, progress of work, supply chain network etc. It appears that there exists a lot of factors that are to be given due consideration whilst working on an efficient management scheme like this.

Lot of different methods that help in sequencing different project activities relative to time period has been put to use in the industry, some of the prominent ones being bar charts, network diagrams etc, Poku and Arditi (2006). Owing to the fact that these methods/tools do not take into consideration, the spatial aspect of a project, two main drawbacks have been identified, the former being the difficulty in interpreting complex schedules involving a huge number of activities without the help of a visual aid and the chance of different project members developing different interpretations about an element of the project, latter, the tedious re-planning exercise in the event of a change in plan or lag in the previous plan/schedule, Bansal and Pal (2008). All these facts point towards the need of a methodology that includes the spatial aspect of a project also in the planning process.

2. BACKGROUND

Since the early 1990s, there has been a growing interest in four-dimensional computer aided design (4D CAD) for construction project planning. Commercial 4D CAD applications are becoming more accessible and the use of this technology allows the construction planner to produce more rigorous schedules. At present, there are a lot of different tools/software that comes to use in this area of project management. Some of the notable ones are Primavera Project, MS Project, and Virtual Boss etc. What these tools lack the most is the visual integration of the design with the schedule. In the project planning phase, most of the discrepancies creep in due to the misconception of reality, misinterpretation of the design and progress in three dimensions. A solution to the three dimensional interpretation is offered by a lot of available 3D modelling software packages like AutoCAD. But what is ultimately needed is an integration, more precisely, a real-time integration of the design and the governing schedule, i.e., a four dimensional model of the project, Bansal and Pal (2006).

The 4D modelling concept is all about four dimensional modelling, that directly refers to three dimensions of space (a 3D model) and one dimension of time (progress of the work). This concept can carefully be developed into a one for all solution to the problems faced by the industry. With

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a 4D model, it allows architects, engineers and clients to simulate, visualise and interpret construction sequences as an interactive process. This concept has the potential to bring about radical transformations to the Global Construction Scenario, especially, the fast growing Indian Construction Industry, Naik and Aditya (2011).

3. REVIEW

The proposals and findings by various researchers in the areas associated with modelling and project management has been duly reviewed and discussed in the coming paragraphs.

Generating and maintaining construction schedules from architectural drawings are vital to design and construction professionals for constructability review and project planning. For automating these tasks, it requires combining a computer- aided design (CAD) system with programming and database system for which a system called Builder was developed. Builder is an initial attempt at the development of a representation language for cooperative engineering design and construction, Cherneff et al. (1991). Many civil engineering applications require three-dimensional characterization of a site. Oloufa et al. (1992) developed an interface to HOOPS, an object-oriented graphics library, using the Arc/Info GIS to construct a three-dimensional representation of soil strata that would represent boreholes as complex three-dimensional objects and include such borehole data in a regional geotechnical data base. Camp and Brown (1993) materialized a GIS based well-log database and devised procedures for developing a three dimensional sub surface profile from borehole logs. They developed a procedure for selecting and creating subsurface profiles from the well log data and also to decide upon the basic geometric and hydraulic data for MODFLOW, indicating the flexibility of well-log database and GIS-MODFLOW interface. Different from the then conventional applications, a GIS based system was developed in which the information required for route planning could be integrated. In urban areas, lot of obstacles come in the way, like railways, canals and roads influence significantly. Selection of a suitable route from among limited number of feasible options to avoid existing obstacles like railways, canals etc. in a path reduces the risk of damaging the existing utilities, minimizing the cost of construction, especially in the case of urban areas. Study makes use of two technologies, namely, Expert system to model the human reasoning process through a set of predetermined rules and GIS to provide data display capabilities, Varghese and O'Connor (1995).

As a mainstream application in the area of construction industries, Cheng and O'Connor (1996) built an automated site layout system, ArcSite, for identifying a suitable layout for locating the temporary facilities in a construction site. ArcSite encompasses information relating to construction site layout, TF databases, Arc/Info databases, and algorithms for integrating and automating temporary facility layout design. The system develops a self-learning or heuristic approach to model the process of human like decision-making, followed by framing of an objective function called proximity index to determine the optimal site of each temporary facility, considering all possible quantitative and qualitative criterion. Doyle (1998) was of the opinion that modelling and planning was meant to aid the decision making process, to democratize the planning process and to assist in the conveyance or dissemination of ideas. In this work, the potential of Web-oriented GIS and VR software was reviewed with particular reference to the disciplines of planning and urban design along with the ability of web to serve as a dissemination mechanism. Advantages and disadvantages which these technologies offer will be considered in terms of the level of realism and interactivity available to the end user. The implications for a wide range of potential users including planners, infrastructure managers, built environment students, community groups and interested members of the general public was also discussed. Exploiting even more of the automation capabilities, Cheng and Chen (2000) made use of an automatic schedule monitoring system for precast building construction. The system ArcShed was meant to assist the engineers in the erection of prefabricated structures which is the most important activity in a precast construction; hence, the manufacturing and transportation schedules were planned based on the installation schedule. This method used bar code technique combined with wireless radio technology where each precast element is represented by a barcode throughout the process that would collect and transmit the site data to the control center automatically. The pilot attempt at integrated application of AutoCAD and ArcGIS in progress tracking, enhanced customer service and geospatial analytical capabilities in the area of construction management was made by Dierkes et al. (2000). ArcGIS was used to combine AutoCAD drawings and log data into one location. Proposed gravity lines and manholes were extracted from the AutoCAD file and existing data, such as station number and pipe diameter, as well as future data, such as installation date and testing records were appropriately stored.

In early 2002, a GIS-based visual simulation system (GVSS) was employed in a complex dam construction in China and the simulation was carried out, taking into consideration various influencing factors, configuring every step of construction process and making a reasonable project schedule to achieve the project objectives. The GVSS as a simulation tool that offered powerful planning, visualizing, spatial and non-spatial data management and querying capabilities, and thereby served to understand the complex, difficult to comprehend, modelling and scheduling process in a construction project, Zhong et al. (2002). In the same year, Akinci et al. (2002) came up with the concept of 'work space planning' that implies representing various types of spaces required by construction activities in three dimensions over a time scale. Owing to the vast amount of data that is associated with the execution of a construction project, it is practically impossible for the project managers to specify the spatiotemporal data involved to represent workspaces in four dimensions manually. To overcome this,

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mechanisms that automatically generate project-specific work spaces from generic work space ontology and a project-specific IFC (industry foundation class) is proposed associated with attributes that describe when, where, how long they exist, and how much volume they occupy.

A system called construction materials exchange that operated over a network of 2,000 buyers, 29,000 suppliers, and 1,000 agents, that was implemented in China is an excellent example stating that GIS has a great potential to be made use of in E-commerce systems to provide better services in location-based queries, business area analysis, and transportation analysis. Transporting cost, referring to the costs involved in transporting construction materials, is a complex subject, dependent on many variables, for instance, the locations of local distributors, reduced shipping costs because of combining shipment to various buyers in the same area etc., Li et al. (2003). Li et al. (2005), with an objective to reduce the construction waste, made use of integrated GIS and GPS technology to develop an onsite construction material and equipment (M&E) management system based on automatic data capture system such as the bar-coding system.

The general trend of advancements in the field of 4D CAD in construction management was studied, reviewed and listed by Heesom and Mahdjoubi in the year 2004 and as a result, it highlighted the fact that most of the earlier 4D CAD simulations concentrated in visualization and aesthetic purposes only and very few packages offer the ability to carry out analytical tasks on the developed simulation. They concluded that 4D technologies enabled planners to predict potential problems at the pre-construction stage, which could have considerable costs and time implications, and thereby direct savings and an increased productivity, further highlighting the areas that required further research, Heesom and Mahdjoubi (2004). Owing to the fact that traditional scheduling and progress control techniques fail to provide information pertaining to the spatial aspects of a construction project, Poku and Arditi (2006) developed a system called PMS-GIS, Progress Monitoring System with Geographical Information Systems in which the architectural design was executed using a computer-aided drafting (CAD) program and the work schedule was generated using a project management software, P3, and the design and schedule information including percent complete information were plugged into a GIS package, and for every update, the system produced a CPM-generated bar chart alongside a 3D rendering of the project marked for progress. Bansal and Pal (2006) exploited the capability of GIS to store spatial data in different layers, and eventually manipulated to be used for cost estimation. The generation of 3D view of a construction project were carried out in AutoCAD layer wise and later imported to the GIS framework and extruded to required dimensions using the built in options in ArcView. Scripts were added to GIS for cost estimation and generation of BOQ (Bill of quantities), BOM (Bill of Materials) and labour requirement. The use of single GIS environment for the whole process made the updating of information easy. Two years later, the same team came up with a methodology that utilized the dynamic linkage between the activities in the schedule and corresponding 3D components, as an alternative to the existing 4D computer aided design tools, to build a model and link it with the construction schedule using several in-house scripts written in GIS environment. Bansal and Pal (2008) added that most of the 4D CAD technologies just supported planning and design stage, but not project management stage whereas this system assured an integrated project management, all in a single environment. Nejatbaksh (2008) created a tool, 'Tunnel CS' that utilized GIS based management in monitoring and scheduling a tunneling job and was embedded with tools for project progress, profiling etc. in a simple user interface. Tasks like site selection and fire response management in the construction industry and urban management field are usually managed by using a Geographical Information System (GIS), as these processes required a high level and amount of integrated geospatial information. Two data models were developed – a Schema-Level Model and a geospatial data model. The Schema-Level Model was used in simplifying the information acquired from the BIM, while the geospatial data model acted as the template for creating physical files and databases in the geospatial environment. Software components to transfer building information into the geospatial environment were designed, developed, and validated. The overall research demonstrated that it is possible to transfer information acquired from BIMs into the geospatial environment. The results also demonstrated that BIMs provide a sufficient level and amount of geometric and semantic information for the seamless automation of data management tasks in the site selection and fire management processes, Isikdag and Underwood (2008).

The first study of its kind dedicated to mining sites, Ke-ke and Wei-wei (2010) developed a strategy of visualization of 3D geological bodies and 3D ore-body that served functions like mine planning, mining design, coal seam changes, emergency disaster relief etc. Many functions, such as browsing of dynamic panorama, 3D virtual roaming, spatial coordinate querying, spatial distance measuring, section drawing, direction of slope calculating, etc. were incorporated. The management scheme developed Naik and Aditya (2011) shared some connection with the work conducted by Dierkes et al. (2000) with the Primavera P3 software being used for the creation of schedules that were later linked with the GIS layers. Contrary to the earlier work, stages of construction process were generated in different layers using ArcGIS and Arc Scene module of ArcGIS was utilized for visualization. Jabbar (2011) neatly mentioned the flexibility of GIS in managing civil engineering projects at all stages, namely, planning, data collection, environmental analysis, design, construction, operation and maintenance. The general applicability of GIS in various fields of civil engineering was furnished with specific applications in areas such as water resources engineering, transportation, surveying, and environmental engineering. In contrast to the conventional practice of

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construction safety given less importance, Zhou et al. (2012) conducted research on databases, virtual reality, geographic information systems, 4D CAD, building information modelling and sensing technologies, finding various digital tools for addressing safety issues in the construction industry. Bringing the elementary strands involved in construction practices together, they suggested new kinds of interventions, such as the development of tools to create digital models for project management without compromising on safety. The benefits that the GIS technology could offer in the area of construction management were listed as elimination of: i) proper representation of spatial aspects, ii) data redundancy, and iii) miscommunication when moving through the planning, design, construction, and operation stages by Sandip (2013). GIS could be used for 3-D data analysis, comparison of data, construction scheduling and progress control with 3-D visualization, with due considerations to Government regulations and allowed construction managers and different people involved in project get the information about progress of the project and support decision making. Jadid (2014) proposed a supply chain management (SCM) system meant to locate suppliers, manufactures, and distributors and determine the shortest path from point of origin to the final destination so as to reduce construction costs, minimize time, and enhance productivity by means of a mapping technology, and GIS is incorporated to provide decision support in successful monitoring of the movements and storage of materials, and to ensure that finished products travel from the point of origin to the construction destination site.

4. DISCUSSION AND CONCLUSION

From the reviewed literature, it is clear that GIS has been applied successfully in various potential areas of civil engineering, construction industry being one among them. Construction industry being the area concerned, visualization and simulation of construction projects has been identified as improved instruments of management as compared to the conventional tools. The studies carried out in this domain proved the flexibility of GIS in the all-round management of construction projects that could truly exploit the visualization and data management skills of GIS.

Construction industry has always been taken up all by all classes, ranging from small-scale to large-scale business groups. As such, pricing of the supporting mechanism, whether it be related to the machinery, software used etc., surely acts as a hindrance to a fair competition between the participating groups. Taking into concern the software side alone, we know how relevant the use of an open source software would be in this context. However, any mention of the usage of an open source GIS environment was nowhere found, considering the high pricing of some of the commonly used GIS packages and the growing popularity gained by open source tools at a global scale. Also, although some of the earlier attempts made successful utilization of GIS in their works, a work that was entirely based on GIS environment was nowhere to be found. There has been limited exploration of available tools in GIS. Many of the works used a mix of software for the work, working on different tools and environment at different stages of work. Talking about the complexity of the work, most of the earlier attempts were made on simple projects that involved very limited number of layers and attributes. It is clear that with the excellent data management capabilities of GIS, it could overcome most of the hurdles faced by today's construction industry owing to the imperfect management of resources/time. Keeping all these in mind, the present scenario, available tools in GIS, their applicability, one can make out what more can make a necessary contribution to this segment of the industry. As far as possible, open source GIS packages are recommended to be used in the above work. Altogether, GIS based project modelling and management methodology can facilitate successful execution of the project by reducing construction costs, minimizing time, and thereby ensuring enhanced productivity.

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