

GIS Based 4D Model Development for Planning and Scheduling of a Construction Project

Gopal M. Naik, Aditya M., and Suma B. Naik

Abstract—Today's demand of construction industry requires a highly accurate planning, scheduling and management of the process of the project which can enable the overall optimization of the cost, time and resources. The older system of usage of MS Project and Primavera for scheduling, AutoCAD drawings and taking a lot of strain and explaining the status of the project to the client is very difficult and time consuming, owing to the fact that the client and the store manager might not be fluent with the technical terms used in the schedules and graphical representations. Instead of using the older, traditional methods of CAD drawings and schedule sheets, one can integrate them on a platform to create a 4D view of the project using GIS environment. The aim of the study is intended to demonstrate the understanding of the methodology to create the GIS based 4D model for optimization and real time monitoring of the project. ArcScene module of ArcGIS is utilized, along with Primavera P3 for this study. Integrated GIS based 4D model has been developed and utilized for the visualization of the construction progress of the project. A case study of factory building of CIGFIL Polymers, located at Hosakote, Bengaluru has been selected for the present study. Different stages of the construction process and activities are generated in different layers using ArcGIS software. Primavera P3 software has been used for creation of the schedules and these are linked with the GIS layers. It is found from the study of actual building information at site and the building simulation model that some overlapping and rework can be avoided.

Index Terms—Planning and scheduling, Work breakdown structure, Geographical information system.

I. INTRODUCTION

The current day demand of construction industry requires a highly accurate planning, scheduling and management of the process of the project which can enable the overall optimization of the cost, time and resources. Planning and scheduling are the important aspects for the successful completion of a project. The proper planning and utilization of resources play important role in cost and time optimization. Construction planning is a fundamental and challenging activity in the management and execution of construction projects. It involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. A good construction plan is the basis for developing the budget and

the schedule for work. Project scheduling is intended to match the resources of equipment, materials and labour with project work tasks over time. A good scheduling can eliminate problems due to production bottlenecks, facilitate the timely procurement of necessary materials and otherwise insure the completion of a project as soon as possible. In contrast, poor scheduling can result in considerable waste as labourers and equipment wait for the availability of needed resources or the completion of preceding tasks. Delays in the completion of an entire project due to poor scheduling can also create havoc for owners who are eager to start using the constructed facilities. The traditional approach for scheduling and progress monitoring techniques likes bar charts, Critical Path Method (CPM), Programme Evaluation Review techniques (PERT) etc are still being used by the project managers for planning. These are a serious disadvantage in the decision making purpose, as they fail to provide the necessary spatial aspects and data. There is a gradual increase in the pressure on the project managers to shorten the delivery time and decrease the costs involved in the process, without a decrease in the quality of the product, i.e. the building. Geographical Information System (GIS) and project management tools in a combination can be used to access the spatial aspects and the time and cost involved in the project. GIS allows project managers and different people involved in the project with different backgrounds to get the accurate information of the project and monitoring of activities. The project manager and client can use the visualization aspects at any stage of the project to monitor the activities and cost flow.

Growing pressure to shorten the project delivery times, new practices and increasing complexity of today's construction projects have resulted in an increase in the number of commercially available computerized planning and scheduling tools [1]. But, the construction industry has acknowledged that its current scheduling and progress reporting practices are in need of substantial improvements in quality and efficiency. Research efforts to incorporate visualization into scheduling and monitoring have been motivated by the failure of traditional methods to provide information related to spatial aspects [2]. Researchers have suggested that project managers can use 4D methods and simulation for effective resource allocation [3]. [4] Bansal and Pal, have described the linking of the activities in a critical path schedule with the 3 dimensional model, which makes the project sequence easier to understand. Some commercial tools allow the planner to build a 4D model and create the graphical simulation, though, it still lacks features like generation and manipulation of a 4D model within a single environment.

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II. GEOGRAPHICAL INFORMATION SYSTEM

In the past twenty five years, a lot of professions have been in the process of developing automated tools for effective storage, analysis and presentation of geographic data. These efforts have apparently been the result of increasing demands by users for the data and information of a spatial nature. According to Environmental Systems Research Institute (ESRI), a GIS is defined as ‘an organized collection of computer hardware, application software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyse, and display all forms of geographic referenced information [5].

Geographical Information System applications have proliferated in the construction industry in recent years. This fact is illustrated by the growing number of articles finding their way into civil publications devoted to GIS. Geographical information system will allow construction managers and different people involved in project with different backgrounds to get the information about the progress of the project and support decision making. GIS does in fact create high quality maps that communicate considerable amounts of information in an efficient and attention-getting manner. GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operation for working with the data. GIS can be used for progress monitoring system in construction, networking solutions, 3D data analysis, site location and client distance, comparison of data, construction scheduling and progress control with 3D visualization. Visualizing construction progress in three dimensions provides the construction project managers with a more intuitive view of the construction sequence. 3D visualization allows the construction managers to view the construction activities during any stages of the construction progress. The intent of this paper is to demonstrate the benefits of using GIS with project management. The methodology developed utilizes the functionalities of ArcGIS, Primavera and Microstation softwares. Visual studio can be further used to assist the project managers in control and analysis, monitoring of work by creation of a frontend application, by synchronizing the construction work in three dimensions and its schedule. This would help all parties involved in a project to visualize the progress in a natural way, hence minimizing the delays and cost overruns. In addition to monitoring of work flow, it can be further used to monitor the quantities, costs and resources. GIS was used by [6] Oloufa et al., to create a database for storage of descriptive soil data pertaining to boreholes and linked the descriptive data to the corresponding geographic locations of the boreholes. [7] Cheng and O’ Connor developed an automated site layout system called ArcSite that assists designers in identifying suitable areas to locate temporary facilities, whereas [8] Cheng and Yang’s site layout system, called Material plan, assisted construction managers in identifying suitable areas in a construction site to locate materials. [9] Cheng and Chen developed an automated schedule monitoring system called ArcShed for precast building construction that integrated bar codes and GIS for monitoring construction progress on a real time costs. Udo-Inyang and Uzoije (1997) developed a GIS –based highway construction, inspection, and management system to

provide construction personnel with easy access to construction data and information with graphical enhancement [10]. The collection and management of various types of information efficiently and on demand is seen as the key to successful management of construction projects. GIS has helped in the communication of information, particularly because the information is always referenced to a geographical location such as a location on a construction site or along a highways network.

III. PLANNING AND SCHEDULING USING GIS AND PRIMAVERA

Geographical Information System applications have proliferated in the construction industry in recent years. This fact is illustrated by the growing number of articles finding their way into civil engineering and construction journals and conference proceedings, in addition to the handful of special publications devoted to GIS (Oloufa et al. 1994). This methodology is mainly intended for the creation of the building stimulation and work monitoring. The steps involved in the process are:

- Progress monitoring system in construction
- Divide the building into different levels, ie., Foundation, Footing, Pedestal, Plinth Beam, Columns, Walls, Beams, Slab, Carpenter fittings etc.
- Draw each and every required level in a different file in Microstation, with the same origin.
- Networking solutions
- 3-D data analysis
- Create a convenient projected coordinate system to measure the values even after creation of the 4D model.
- Site location and client distance.
- Convert the drawings into shapefiles, with the projected coordinate system.
- Enable the z dimension for them.
- Import each and every shapefile into an ArcScene file.
- Calculate the base height of each layer, which is “New Base Height” = “Base Height of Previous Object” + “It’s Extrusion”
- Give the base heights and extrusion values in properties.
- Enable time layer into the layers.
- Link the start time and end time of the activity in it.
- Create a stimulation, based on the start and end times of each activity.
- When a point cloud is obtained, it can be interpolated with the model and analyzed for the work flow.
- Comparison of data.
- Construction scheduling and progress control with 3-D visualization.

The intent of this study was to demonstrate the benefits of using GIS with construction project management. In this study integration of GIS and the Project management is developed using ArcGIS, Primavera and AutoCAD and Visual studio to assist construction managers in controlling and monitoring construction progress. Successful project control is a challenging responsibility for all construction managers. Visualization of the information is an important benefit for any project.

The aim of the project is to display the progress and sequence of construction work in 3-D while synchronizing this information with a formal Critical Path Method (CPM) work schedule. This would help all parties involved in a construction project to visualize the progress in a natural way, hence minimizing delays and cost overruns. In additions to monitoring the schedule, the system can also be extended to monitor quantities of materials, costs and resources. Fig. 1 shows the path of the project among the various applications in the system.

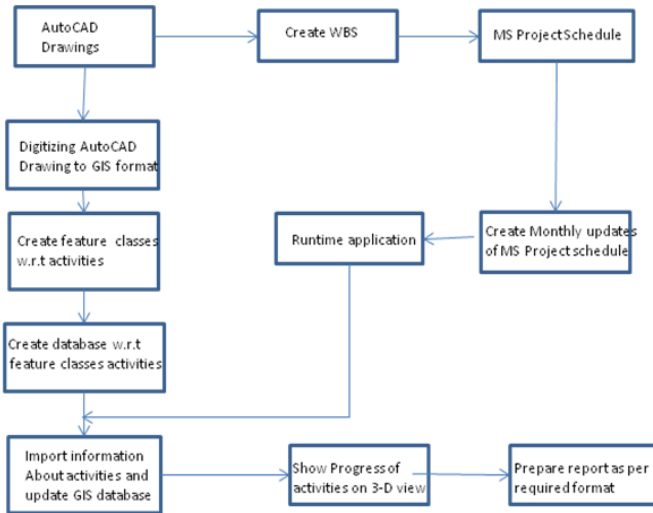


Fig. 1. Flow chart showing the integration of project management and GIS.

IV. METHODOLOGY AND MODEL DEVELOPMENT

There is an increasing need for a modern method for planning and scheduling of a project, with real-time monitoring. Taking the traditional methods as a platform, new methodologies are being developed. The utility of GIS in creation of time enabled data has become a great advantage for planners. The spatial analysis of an area using its remotely sensed data has a greater advantage in site selection of large projects. Site selection is the first step of any construction project. The following data is required for analysis and site selection of the project is identify the area of the project site, generating the road network and drainage pattern maps, creating the Digital Elevation Model (DEM) of the study area and generating land use map of the study area.

This study is to discuss the methodology for the creation of a GIS based 4D model of the project and simulate it to monitor the workflow at the site. Different stages of the construction process and activities are generated in different using ArcGIS software. Primavera P3 has been used for creation of the schedules and these are linked with the GIS layers. A factory building of CIGFIL Polymers, located at Hosakote, Bengaluru has been selected for this study. The steps that are involved in this process of generation of the 4D model are described in the following sections.

- Step 1: Creation of Architectural Drawings
- Step 2: Identification of the Work Breakdown structures
- Step 3: Scheduling the activities
- Step 4: Modelling the 3D model in ArcScene
- Step 5: Integration of the 4th dimension
- Step 6: Simulating the output

A. Creation of Architectural Drawings

The first step is the creation of the plans of the project. For a better model, it is required to have the plans at different stages of the project, i.e., different plans for foundation level, footing level, pedestal level etc. These plans can be generated in Autocad or Microstation. Microstation was used in this present project for the creation of the plans at different levels. The more the number of plans, the more will be the accuracy of the 3d model.

B. Work Breakdown Structure

The process of identification of the WBS involves a different approach for different projects. For the present project, the levels of work identified for WBS are: Footing PCC, Foundation, Pedestal, Plinth Beam, Floor, Columns, Wall Bottom, Wall Top and the Roof. These levels are to be identified based on the elevations of the components. Fig. 2 shows the creation of work breakdown structure of the project. Creating work break down structure was done to make the project control effective and manageable. The first part involves ground work, i.e. activities related to trench excavation, foundation concrete, foundation frame walls, backfilling, compaction of soil and gavel and concrete floor slab. The second part involves the superstructure, i.e., activities related to exterior walls, interior partition walls, doors and windows, floor finishes, plumbing and kitchen appliances. Part three involves activities pertaining to roof construction and part four involves electrical and plumbing ect. Each of these parts is monitored as a different view in ArcView module of ArcGIS Software.

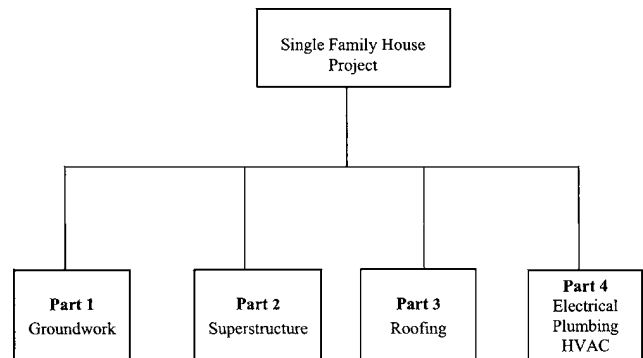


Fig. 2. Work breakdown structure.

C. Initiating Scheduling Process

The activities are scheduled based on the Critical Path Method (CPM). The project was scheduled based the activities identified in the work breakdown structure described the step 2. Primavera (P3) was used to schedule the project , showing the start and completion dates, locating the critical path(s) and float times of activities, and also showing the sequence and interrelationships between the activities. The activities are to be identified based on the work-break down structure for the scheduling of the project.

The list of activities are: Site Clearance, PCC for Foundation, Reinforcement of Pedestal, Shuttering for Footings, Footing RCC, Pedestal RCC, Size Stone Masonry, Plinth Beam RCC, Structural Steel Columns, Internal Plastering, VDF Flooring, External Plastering, Carpenter Fittings, Painting, Cleaning and Handover. Based on the detail calculations and labour requirements, the projected Schedule of the project is given in Table I.

TABLE I: SHOWS THE PROJECTED SCHEDULE OF THE PROJECT

OID	ACT	TITLE	ES	ESA	EF	EFA	AS	AF	TF	OD	RD	PCT
0	1	Site clearance, Mark	10-06-2010	A	22-06-2010	A	10-06-2010	22-06-2010	0	1	0	100
1	11	PCC for Foundations	20-06-2010	A	27-06-2010	A	20-06-2010	27-06-2010	0	1	0	100
2	21	Reinforcement for Pe	14-06-2010	A	28-06-2010	A	14-06-2010	28-06-2010	0	1	0	100
3	31	Shuttering for Footi	23-06-2010	A	05-07-2010	A	23-06-2010	05-07-2010	0	1	0	100
4	41	Footling RCC	25-06-2010	A	10-07-2010	A	25-06-2010	10-07-2010	0	1	0	100
5	51	Pedestal RCC	29-06-2010	A	12-07-2010	A	29-06-2010	12-07-2010	0	1	0	100
6	61	Size Stone Masonry	29-06-2010	A	12-07-2010	A	29-06-2010	12-07-2010	0	1	0	100
7	71	Plinth Beam RCC	02-07-2010	A	15-07-2010	A	02-07-2010	15-07-2010	0	1	0	100
8	81	Columns (SS)	07-07-2010	A	22-07-2010	A	07-07-2010	22-07-2010	0	1	0	100
9	91	Backfilling upto Pl	15-07-2010	A	26-07-2010	A	15-07-2010	26-07-2010	0	1	0	100
10	101	Soiling of Floor and	26-07-2010	A	18-08-2010	A	26-07-2010	18-08-2010	0	1	0	100
11	111	Block Masonry (Windo	17-08-2010	A	21-08-2010	A	17-08-2010	21-08-2010	0	1	0	100
12	121	Block Masonry (Door	22-08-2010	A	25-08-2010	A	22-08-2010	25-08-2010	0	1	0	100
13	131	Block Masonry (Roof	26-08-2010	A	30-08-2010	A	26-08-2010	30-08-2010	0	1	0	100
14	141	SS Roof	21-07-2010	A	30-08-2010	A	21-07-2010	30-08-2010	0	1	0	100
15	151	Internal Plastering	25-08-2010	A	04-09-2010	A	25-08-2010	04-09-2010	0	1	0	100
16	161	VDF Flooring	31-08-2010	A	16-09-2010	A	31-08-2010	16-09-2010	0	1	0	100
17	171	External Plastering	18-09-2010	A	27-09-2010	A	18-09-2010	27-09-2010	0	1	0	100
18	181	Carpenter Fittings	05-09-2010	A	15-09-2010	A	05-09-2010	15-09-2010	0	1	0	100
19	191	Painting	16-09-2010	A	08-10-2010	A	16-09-2010	08-10-2010	0	1	0	100
20	201	Cleaning and Handove	09-10-2010	A	10-10-2010	A	09-10-2010	10-10-2010	0	1	0	100

D. Modelling 3D View in ArcScene

This step involves the exporting of the levels for Microstation drawings into ArcScene. First, a Projected Coordinate System based on the Indian Coordinate system is defined. Using the projected coordinate system as a base, the microstation drawings are then converted into ESRI Shapefiles. The elevation details, which are already identified, are now used as the base heights and extrusions. After the layers are added to ArcScene, base height, i.e., the height of the object from foundation level and extrusion, i.e., its 3D height are given. The current used base heights and extrusions are given in Table II. Layers wise 3D views of Base Heights and Extrusions of the Building are shown in Fig. 3.

TABLE II: EXTRUSIONS AND BASE HEIGHTS OF LAYERS

Layer Name	Base Height	Extrusion
Footling PCC	0.0 m	0.1 m
Foundation	0.1 m	0.6 m
Pedestal	0.7 m	1.5 m
Plinth Beam	2.2 m	0.3 m
Floor	0.0 m	2.5 m
Columns	2.5 m	5.0 m
Wall Bottom	2.5 m	3.0 m
Wall Top	5.5 m	2.0 m
Roof	7.5 m	1.0 m

E. Integration of 4th Dimension

The crucial step of the process is the integration of the schedule with the 3D model of the project. Using the export option in P3, the schedule, along with its details is exported as a database. Each level of the project is then time enabled and then, using the activity codes and the layer ids, both are linked together.

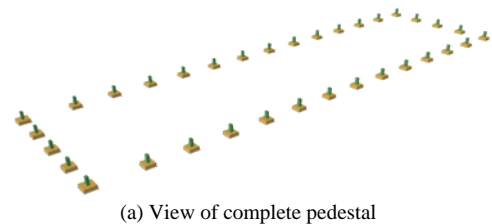
F. Transferring Drawings into ArcViewGIS

After creating the design in AutoCAD, the DXF files were transferred to ArcViewGIS. The topologic data structure of the basic design layers was created as "Themes" based on the work packages identified in the AutoCAD drawings.

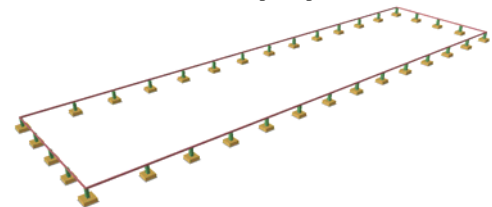
G. Creating Database

The attributes needed for each layers were created in a database. The database includes at a minimum information about identification, quantity, and percentages complete for each work package. In addition the database may include information such as activity, costs, dimensions, types of materials, etc. It is possible to prepare all this information as

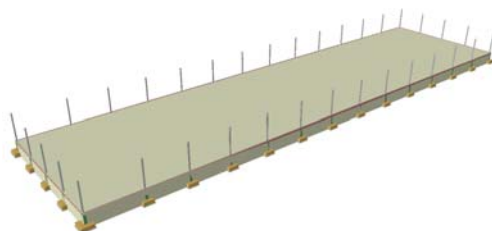
an independent database and later import it to ArcViewGIS.



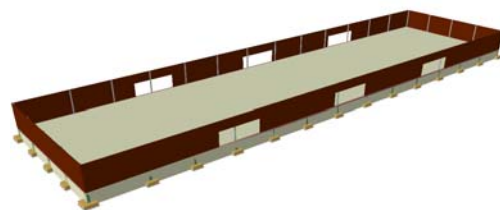
(a) View of complete pedestal



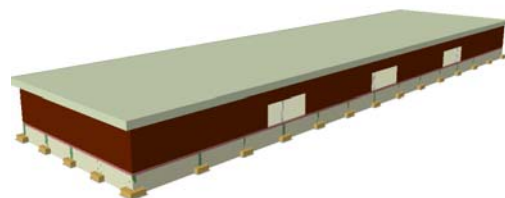
(b) View of complete plinth beam



(c) View of SS Column



(d) View of brick walls



(e) Final view of Factory building

Fig. 3. Layers wise 3D views of base heights and extrusions of the building.

H. Simulation the Output

The final step is the simulation of the project. The time feature of the spatial data is utilized for this process. The process of simulation sequence is shown in Fig. 4. Each

activity is linked with its start and end times. Then, the time zone is changed and required time offset is selected. Thus, the simulation is obtained.

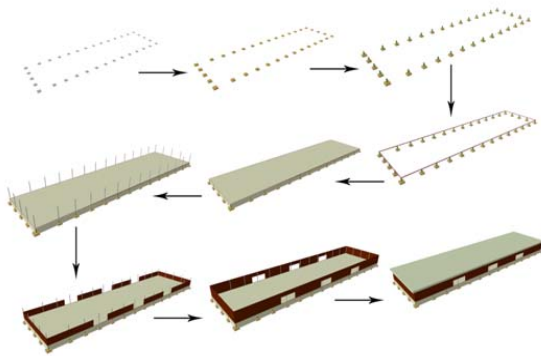


Fig. 4. The process of simulation sequence.

V. BENEFITS AND LIMITATIONS

Despite of numerous advantages of utilization of 4D methodology for the planning, scheduling of the project, the industry is still dependant on the traditional methods. Traditionally, the CPM schedule does not provide any information pertaining to the spatial aspects or context and complexities of the various components of a construction project. Therefore, to interpret progress information, project members normally look at 2D drawings and conceptually associate components with related activities. Different project members may develop inconsistent interpretations of the schedule when reviewing the CPM schedule. This causes confusion on many occasions and usually makes effective communication among project participations difficult. All the project members should be able to visually observe the progress, which will help in effective communication of the schedule. The system has to be run periodically over the duration of the project. This system will benefit project managers, site engineers and the clients. The project manager will get up-to-date information about the progress of the work and it helps in controlling big project sites. The project managers come to know about the cost incurred or spent and the quantity of materials used on site on each day activities.

The role of site engineer is controlling the project site by knowing the progress of the work and helps in easy decision making for procurement of the funds or materials. It helps in knowing how much more materials is required to complete the work. It is also helps in reducing the wastage of materials and ordering the ideal quantity of materials thus by reducing over ordering of the materials. Client can get the information about the project by knowing the exact status of the project and also he has a 3-D view of the progress of work thus knowing where large cost has been incurred.

VI. CONCLUSIONS

Use Integrated GIS based 4D model has been developed and utilized for the visualization of the construction progress of the project. Different stages of the construction process and activities are generated in different layers using ArcGIS software. Primavera P3 has been used for creation of the

schedules and these are linked with the GIS layers. At a specific time interval, one can utilize the actual building model and the scheduled building model to compare the work flow. Major rework has been avoided because of identification of clashes from the GIS Layerwise 3D views of the Building. It is observed from the study that, the actual building information and the building model information, overlapping and rework can be avoided upto 20% for time and upto 25% for material and labour cost of the project. The present study is in the initial stage and further research for calibration and validation of the model for different projects is carried out.

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