Applications of 4D GIS Model in Construction Management

Chowdary Mohanlal, Nagarajan Karthik, Narwade Raju

Abstract*: Construction project involves participation of various stakeholders, contractors, and agencies for timely and effective completion. Each activity and resources of contractors are preplanned to avoid delay of project. Planning, designing and scheduling of structure are done with the help of available software's. But this software's still lack feature of providing related construction information in 3D model and also there isn't any system available which can handle all project related information and documents on single platform. 4D Geographic information system (GIS) model is created by inter-linking schedule of activities and computer aided designs (CAD) drawings on GIS platform for G+4 building located in Navi Mumbai, India. The developed model can handle all project related database on single platform. Proposed methodology helps in determining incompleteness and logical errors in scheduling or designing and helps us to determine feasible route for manpower and material movement from different locations to construction site. 4D GIS model maintains spatial data such as different 3D components of structure in separate layers which is geo-referenced spatially and necessary nonspatial information such as dimensions, materials required, schedule, related documents, persons responsible, safety and quality control recommendations, site expenditure and material inventory are stored in attribute tables. This research concludes that GIS model can create real time building construction information database.

***Keywords*: CAD, Scheduling, Project management, GIS, 4D model.**

I. INTRODUCTION

Construction sector plays an important role in the development of any country whether it is infrastructure or building sector. Construction Sector is second largest employer in Indi but still it is the most unorganized sector. The growth of this sector varies across the nation which means it is more concentrated in urban area [10]. For any project to be successful it is necessary that it should have in detail planning, effective working style of organization, flow of resources as and when required. All these factors can ultimately leads to optimum cost and time utilization [7]. The main aim and objective of project monitoring is to prevent any construction failures or to identify factors in well advance that can increase project cost or its completion time. This is done by collecting and recording inputs receive from project management team and further analyzing it for results [7].

A. Present Scenario

Any Construction project involves completion of number of activities in accordance with its planned schedule. Common methods adopted by project planners for planning are critical path method and bar charts but these techniques cannot be used for decision making as the spatial aspects does not provide the required information. Construction industry needs improvement in project planning and progress reporting. Also there isn't any single platform available for interaction with all project stakeholders and participants. Drawbacks of traditional methods of project management encourages researcher to search for alternatives to develop an information system which can perform project related analysis on a single platform. Due to recent advancement in construction industry, one of the solutions includes combining project schedule with that of 3D models which results into 4D model (3D model + time component). By interlinking 3d models and CPM generated project schedule a 4D GIS model can be developed [11]. As the developed model provides better visualization and graphic of the construction project as it is actually being constructed, it makes the whole project easy to understand.

B. Application of GIS for construction management

[5] Described GIS as a layered system on computer for capturing, storing, querying, analyzing and displaying geographical data. Project monitoring and controlling is the process of collecting, recording, and reporting all information concerning project to bring actual performance to planned performance [17]. Due to recent advancements in GIS hardware and software this concept can be effectively used in construction industry for saving cost and time. The drawbacks of project schedule developed through available planning software's encourages researcher to link it with CAD drawings to develop single platform for handling vast information. Recent GIS oriented developments can be used as a project management tool at all stages of construction project in which the schedule and the 3D components can be shown or edited in a single environment [3]. Also by creation of full network of road layer in GIS shortest possible route for manpower and material movement from different locations to construction site can also be found which can reduce travelling time and can improve productivity.

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C. 4D GIS model

GIS platform can be used as an interface in which all project related information or documents can be used to store and update as per requirements [10]. Using GIS software and building information modeling (BIM). 4D models with some suitable interface can be developed to setup database management system for all phases of building construction [7]. GIS and construction schedule can be interlinked to develop runtime application with the help of Visual Studio to assist project managers in controlling and tracking construction progress for better understanding and ease in decision making [12]. By creating inter-relationship between activities and their respective 3D elements, it can also help to find errors in schedule progress and design of structure by utilizing 3D components in separate layer which can be superimposed on geo-referenced image and non spatial data (i.e., construction schedule, material inventory, unsafe safe spots and quality control suggestions etc.) which can be extracted from database in attribute table [13] and periodic delay of the project can be analyzed [4]. GIS based system can be developed for effectively communicating construction progress status to all stakeholders and participants [14]. [1] Presented managing of construction of a residential bungalow using Microsoft project 2013. GIS can be applied for effective parking system and can be synchronized with mobile phone application [15], [18]. [9] Integrated GIS with project management software and developed a runtime application using C# language where user can get all project related information on developed user interface and can update building information through runtime application. [16] Compared industrialized building system (IBS) concept by using Primavera P6 software with conventional method of planning and concluded time savings of about 42% with IBS concept. [2] conducted research on preconstruction planning stage and concluded that GIS can be used for preconstruction planning, on-site planning, site layout planning and resource planning.[8] Integrated 4D model can be developed using BIM-GIS for understanding flow of materials, availability of resources and map of respective construction supply chain management.

GIS provides support for handling documents regarding construction project such as site layout, structural and non-structural drawings, sub surface details, super structure details, construction specifications, emergency evacuation plans, safety rules, MEP plans through systematic approach. [7] Presented that GIS interface can generate and maintain the spatial information. GIS model stores information about execution sequence, construction site layout, and daily schedule and can help us to predict hazardous situation so as to take necessary early precautionary measures. 4D GIS model consist of vast database which requires balanced control in which all participants are instructed for required input in project system controller which then can be viewed by backend team before forwarding to project manager for their final approval. Construction reports can be created and analyzed in we based management server after authenticating authorized user, which has the responsibility to accept inputs or send back for required changes [7].

D. Research Objective

There was a need to bring CAD drawings, construction schedule, spatial and non spatial data and all document related to construction project on a single platform. Therefore, the objective of this research is to create an building construction information system through GIS interface and explore its outcomes. The objective was accomplished via the following steps:

- Create an construction database by interlinking Computer aided design (CAD) drawings and project schedule on GIS platform to develop 4D model which can be used for:
  1. Updating, monitoring and controlling project.
  2. Making decision through 4D GIS model as it provides good visual appearance of structure.
  3. Linking all project related documents and information.
  4. Finding cause of defects which may occur during or after construction.
  5. Providing information during and after construction.
- Find shortest possible route for manpower and material movement from different locations up to construction site.

II. METHODOLOGY

Methodology has been developed for creating inter-relationship between 3D components of the structure and construction schedule using GIS platform. AutoCAD 2016 was used for 2D drawings and Microsoft Project 2016 for scheduling of activities, both of them was imported in QGIS 2.18. Fig. 1 represents various steps involved for 4D model development. The following method consists of GIS approach and management approach.

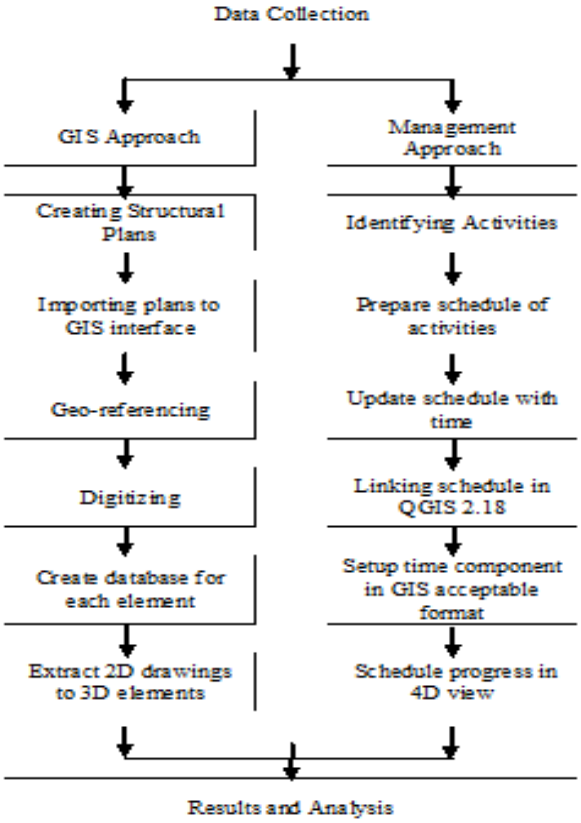


Fig. 1. Flowchart for 4D model development

A.GIS Approach

A.1. Creating Structural Plans

Required structural plans are being collected from Architecture's firm and RCC consultant office. For more accurate detailed model all plans are being collected. The collected plans are being drawn on digital environment with the help of AutoCAD 2016 or soft copy can be simply taken from their office. While drawing, various layers are to be created depending upon the type of structural components.

A.2. Importing of CAD drawings to GIS interface

The AutoCAD 2016 generated drawing with extension *.dwg (drawing) is being converted to *.dxf (drawing exchange format) for importing it to QGIS 2.18. For importing the drawings the co-ordinate reference system WGS 84 UTM ZONE 43N was selected where study area is located.

A.3. Digitizing and geo-referencing

GIS imported drawings are over layered with geo-spatial image with respective co-ordinates of drawing on all sides. After geo-referencing it is converted to digital shape files such as point, line, and polygon. Once it is being digitized it is being converted to vector data.

A.4. Create separate database for each element

Data corresponding to respective shape file is being inserted in attribute table which can be updated as when require. Shape files added by digitization process should be linked with separate attributes which stores all information about each element in it. Information such as id(unique number), layer name, length, breadth, height, g.height (height from ground level), area (m2), area (m3), cement required, sand required, aggregate required,0.15m brick required, 0.1m brick required, plan (pdf), checked by, remark is being added in attribute table in this study:

A.5. Extract 2D drawings to 3D elements

Extraction of 2D drawings into 3D elements is being done with the help of Qgis2threejs plug-in. By using this plug-in, a HTML file is being created which contains the 3D structure of the building. The 3D element extracted has resource data and schedule data which was linked earlier.

B. Management approach

B.1. Identifying activities

For any construction project, numbers of construction activities are required to be completed for completion of project. These activities are being determined as per their completion sequence. Depending on activities which have to be completed a systematic work breakdown structure is being prepared using top to bottom approach. Work breakdown structure is being created to make the project sequence more efficient and manageable. Structural component which are to be completed can be added in Microsoft Project for scheduling of the construction such as footings, underground water tank, plinth beams, PCC, Column, Slab, Beams, overhead water tank, brick wall, MS railing and elevation structure.

B.2. Prepare and update schedule with time

All the activities are being planned and scheduled depending upon the work breakdown structure. For scheduling activities Microsoft Project 2016 was used. While planning the activities importance is to be given to activities name in Microsoft Project which has to be similar with their respective layers name in AutoCAD. Microsoft project prepared schedule shows when the activity is starting, when its ending, its duration, percentage complete accomplished by critical path, its activity sequence and their inter-relationship. The schedule has to be updated whenever there are changes such as completion of activity or delay in activity from time to time. For obtaining accuracy it is recommended that the schedule is being made up to date.

B.3. Linking of schedule

Microsoft project generated schedule with extension *.mpp (Microsoft project) has to be converted to *.csv (comma separated value) for successful linking it with QGIS. It provides inter-relation between structural elements and their respective schedule. After linking, changes such as activity start day, end day, percentage complete have to be updated periodically.

B.4. Schedule progress in 4D view

The concluding work in this model preparation is attaching of 3D model with their project schedules which are imported from Microsoft Project. Linked 2D elements and schedules should have similarity in names for activity layers for successful inter-linking. Developed 4D GIS model could be studied as 3D model along with its real time database through HTML file. The developed final output is being termed as 4D model (3D model along with time component and its database).

III. SITE LOCATION & IMPLEMENTATION

This research was applied to a construction project of G+4 residential cum commercial building located at ulwe, Navi Mumbai, Maharashtra, India as shown in Fig. 2 and Fig. 4. Fig. 5. Shows sector layout of ulwe node. GIS software was used to create a construction model due to its advanced capabilities. It can review and handle multiple project activities and can have track ongoing work at site. GIS stores the database which can be extracted throughout any phase of project. The construction phase is ended in many different phases depending upon project. In this research, we have created three phases of construction project or there are three milestone of our construction project as shown in Fig. 3. For completing any milestone further work is being divided in number of activities which are further divided. The construction of building is concluded in several stages such as site mobilization, excavation, sub structure, super structure, finishing, and closeout.

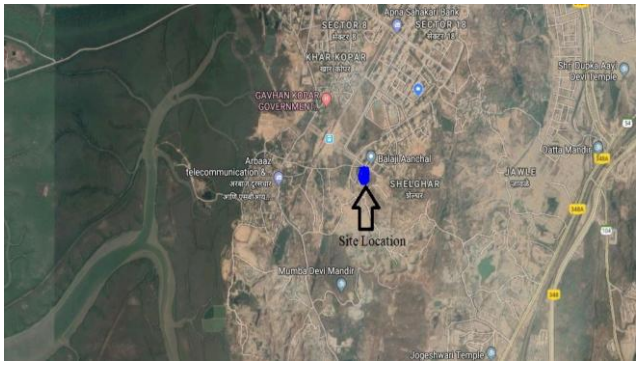


Fig. 2. Satellite imagery of site location (Source: https://www.google.com/maps/@18.9562764,73.0193241,4874m/data=!3m1!1e3)

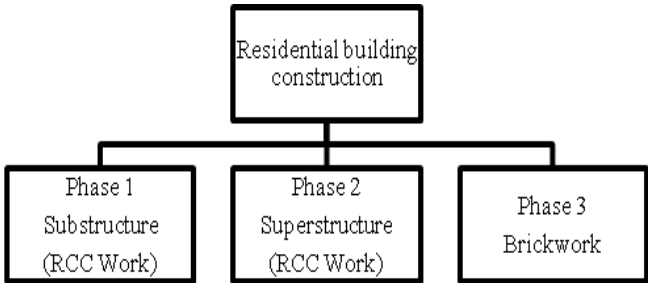


Fig. 3. Work breakdown structure

A. Creating 3D model

The first step for creating 4D model of any construction project through GIS, involves splitting of drawings and then layers. Using the open street map, the location of the building is being marked. The open street map contains layers such as streets name, labels, village boundaries, plot boundary, sector boundary, any existing infrastructure, proposed future infrastructure. The details of map can also be attached to GIS model. Required 2D plans, are being drawn in AutoCAD in required format. For importing it in GIS interface the drawings are being converted in required format. While importing it in GIS, co-ordinate reference system should be precisely selected which is different for different regions. Once it is being imported the 2D elements of the drawing are to be extruded into 3D elements by specifying the height of element from ground and the height of individual element. All the values are to be entered in meter. Fig.6 shows ground floor layout, Fig. 7 shows view up to footing column, Fig. 8 shows ground floor working plan, Fig. 9 & 10 represents part of RCC structure of the building, Fig. 11 shows complete 3D structural view, Fig. 12 shows complete 3D view of the structure, Fig. 13 Represents building along with nearby plot.

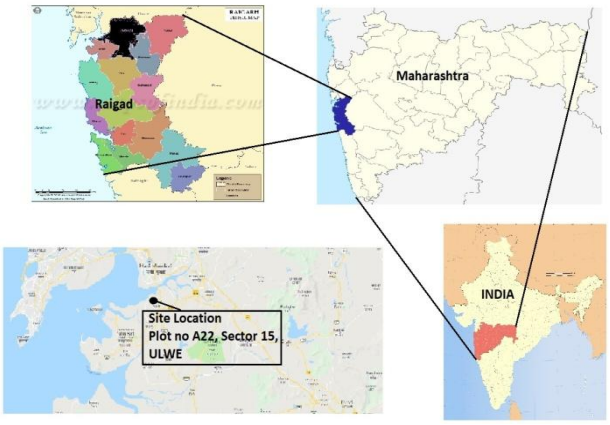


Fig. 4. Study area map

Fig. 5. Maps showing sectors of ulwe

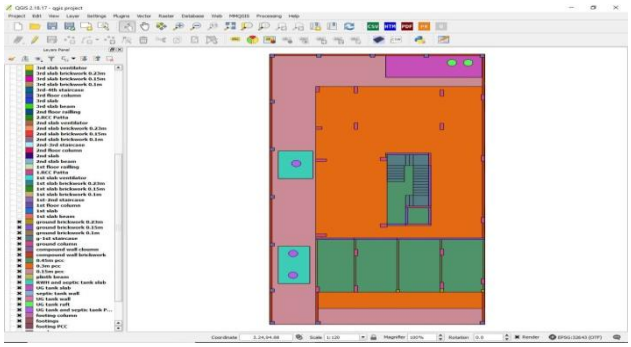


Fig. 6. Ground floor layout

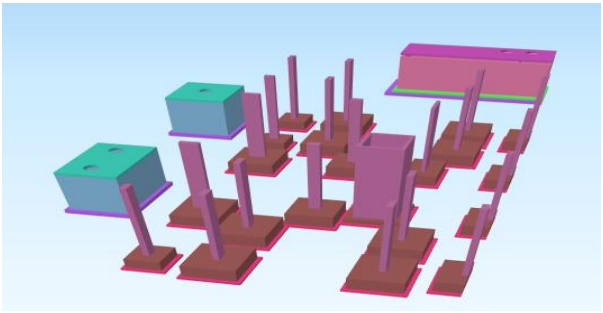


Fig. 7. Footing Layout

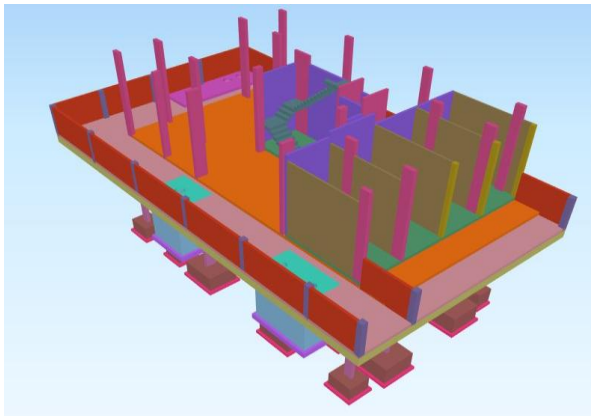


Fig. 8. Ground floor working

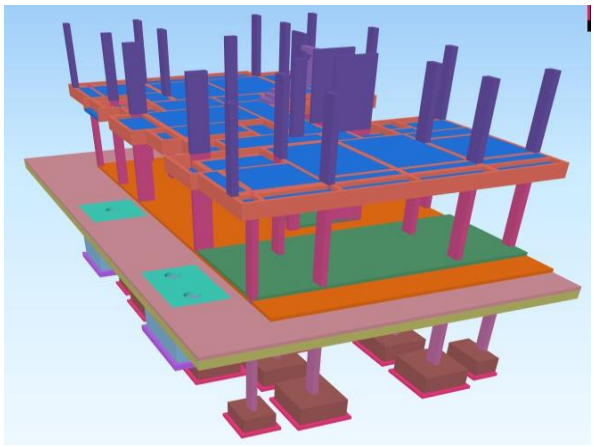


Fig. 9. Part of RCC structure of the building

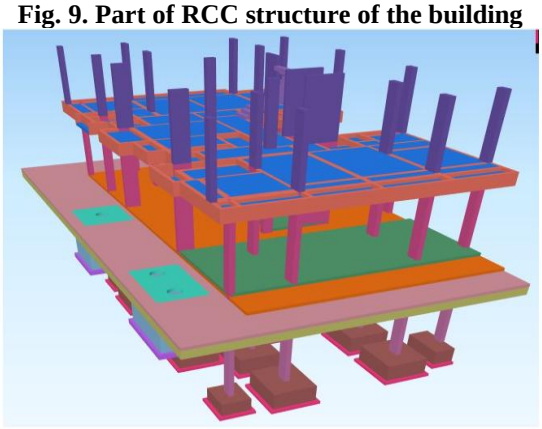


Fig. 10. Part of RCC structure of the building

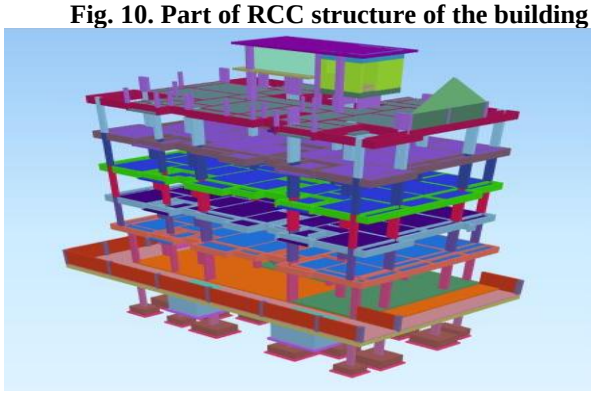


Fig. 11. Part of RCC structure of the building

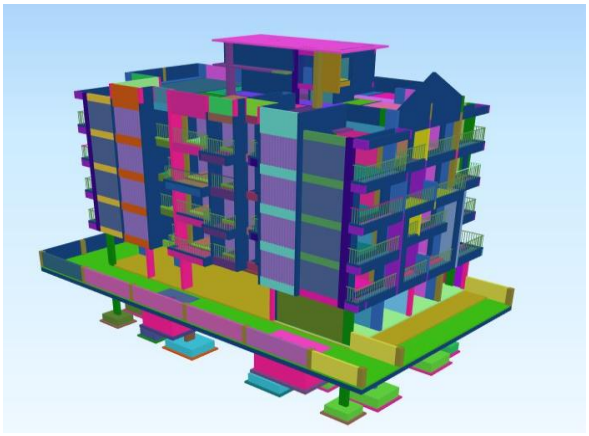


Fig. 12. Complete 3D structural

Fig: 13. Building along with nearby plot

B. Scheduling activities

Depending upon the work breakdown structure different construction activities are being defined and scheduled. Many of construction project schedule are being developed with the help of critical path method or bar charts or program evaluation and review technique. Program evaluation and review technique basically involves calculation of slack time, float time, early start, late start, early end, late end and resource allocation. CPM method has an advantage of completing activities with minimum time with the help of critical path. Factors which can influence project cost and project time are start date, end date and resource flow. For efficient planning whole construction project is being divided into many phases (or setting up of milestone) and for completion of one phase which activities would be required for completion of that phase are being determined and they are given suitable start time, end time and some resources for completion of activity. Similar process is being applied for all phases. For this research scheduling of construction activities are being done with the help of Microsoft project 2016 with input data such as activity name, start date, end date, predecessor, scheduled duration and percentage complete. Once activities are being scheduled it is being converted to comma separated value format for exporting it in GIS platform. While scheduling one thing should be given importance is that the activity names in Microsoft

Project and layers name in AutoCAD should have same names. Fig. 14 shows Microsoft Project generated schedule.

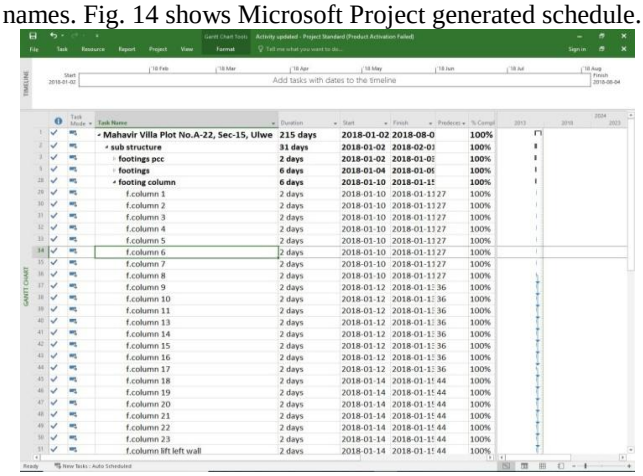


Fig. 14. Microsoft Project generated schedule

C. Creating Database

To obtain all information on finger click on developed user interface a database was created. The imported 2D CAD drawings is linked with their schedule which can show start date, end date, its duration and percentage complete as shown in Fig. 15. This whole process require classification of structural elements in accordance with their activities in CAD system, which includes PCC, footings, footing columns, plinth beams, columns, brick wall, slab, beams, elevations and water tanks. Fields related to structural elements such as length, breadth, height of element, height of element from ground, area, volume, material required, 2D drawings source file, checked by and remark are to be entered for further analysis. GIS matches the inputted activity name and attaches it with the structural component having same name as of the activity name. Similar method is used for linking all information to their respective structural component. Information such as dimensions, area information, material required, daily site diary, material inventory and site expense are created and linked with construction database in GIS interface. In addition to this various information about a project, such as safety suggestions, quality control parameter, cost and material inventory, project schedule, sustainability, safety analysis, resources planning can also be included in database.

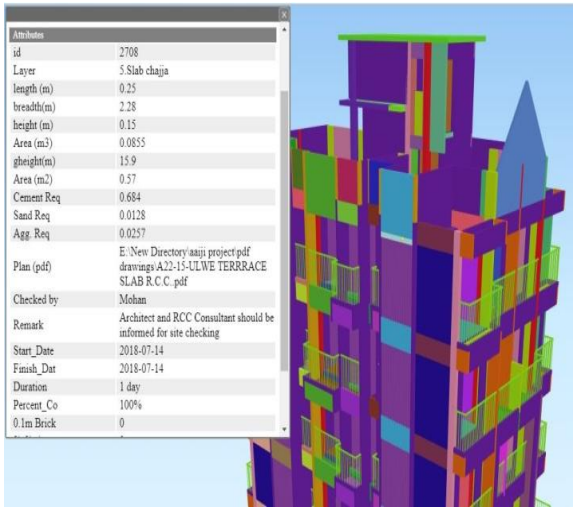


Fig. 15. Information table in 3D window

GIS applications have the capabilities of data managing, its analysis and then creating model based on imputed data. Any information can be included in database be it in document format or data format. Fig. 15 shows information table in 3D window and Fig. 16 shows linked database with linked structural elements.

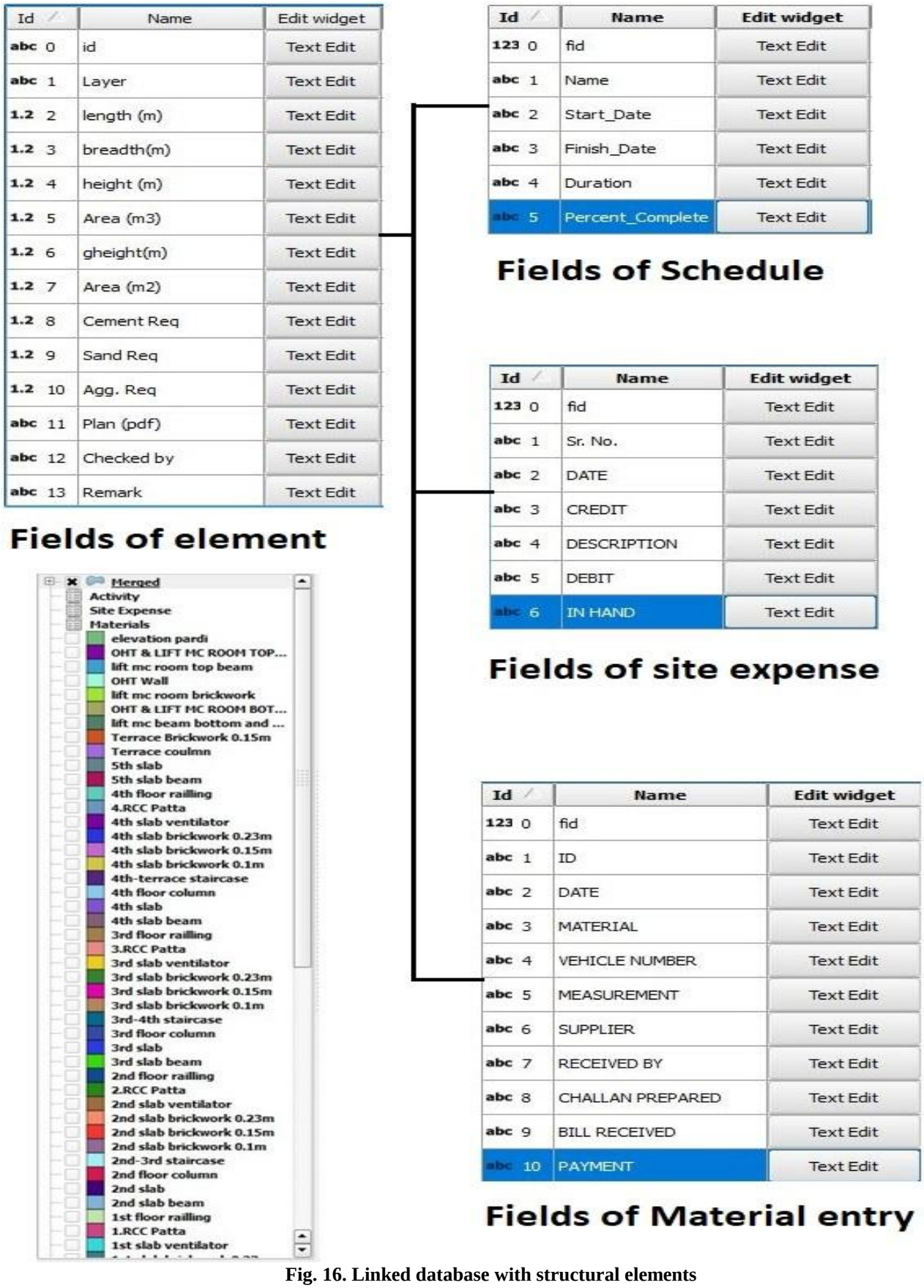
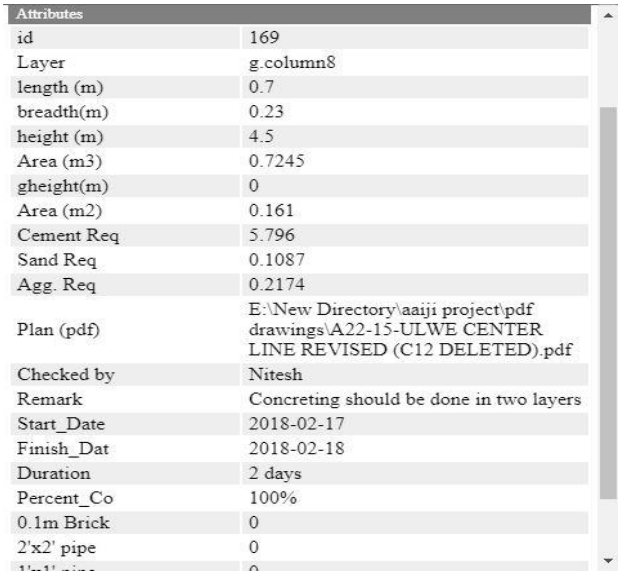


Fig. 16. Linked database with structural elements

IV. RESULTS AND ANALYSIS

A. Problem Identification

Error in designing can be found out with the help of 3D model and also some error in construction schedule can also be brought into notice. The GIS model can detect problems and also can find person responsible for it. For example after casting of ground column, if column is being seen deflected from its original angel, by referencing the attribute table in GIS model there was a remark which was instructed by the consultant that the column must be casted in two layers or two subsequent stages as shown in Fig. 17 . But the persons under whose supervision casting is being done have neglected the instructions and could have casted the whole column in one stage. As the person name that has checked is being shown in attribute table, that person can be held accountable for the defect arising due to his negligence.



Attributes	
id	169
Layer	g.column8
length (m)	0.7
breadth(m)	0.23
height (m)	4.5
Area (m3)	0.7245
gheight(m)	0
Area (m2)	0.161
Cement Req	5.796
Sand Req	0.1087
Agg. Req	0.2174
Plan (pdf)	E:\New Directory\aaiji project\pdf drawings\A22-15-ULWE CENTER LINE REVISED (C12 DELETED).pdf
Checked by	Nitesh
Remark	Concreting should be done in two layers
Start_Date	2018-02-17
Finish_Dat	2018-02-18
Duration	2 days
Percent_Co	100%
0.1m Brick	0
2'x2' pipe	0

Fig. 17. Remarks showing Check By

B. Quantity Analysis

Material required for completion of individual structural component was being calculated with the dimensions of the individual element. Volume of concrete or quantities of different material required for completion of activities can be analyzed. For example ground floor column 1 has length=0.23m, breadth=0.5m, height=4.5m, ground height (g.height) =0m, area (m3)=0.5175m3, area (m2)=0.1150m2, cement required=4.14 bags, sand required=0.0776 brass (1 brass=-2.83m3), aggregate required=0.1552 brass. Table 1. shows the comparison of total quantity of material by theoretical calculation with the actual quantity consumed along with their percentage in error which is also shown by graphical representation in Graph 1 and Graph 2. Accurate results are based on the data entries during the construction of 3D model. The accuracy of this quantity analysis depends upon accuracy of data imputed, greater the accuracy of data imputed greater will be the accuracy of quantity analysis. A similar process can also be adopted for plastering or any other interior work

Table 1. Difference between GIS calculated quantity and actual quantity

Materials	Theoretical Quantity	Actual Quantity	Error in Quantity	% Error in Quantity
Cement	3680 Bags	3780 Bags	100 Bags	2.7%
Sand	277.34 m^3	305.64 m^3	28.3 m^3	10.2%
Aggregates	421.67 m^3	445.73 m^3	24.06 m^3	5.7%
0.15m Brick	45929 nos.	47500 nos.	1571 nos.	3.4%
0.1m Brick	51302 nos.	51800 nos.	498 nos.	0.97%

C. Sharing On Web Based Platforms

Sharing real time database with some web based platforms. GIS application can extract attribute table information in *.pdf, *.html or *.CSV. These files can be stored in local web server, which can be accessed by all the stakeholders on real time basis, who cannot access GIS. All the documents and report related to construction project can be updated and uploaded on local server from time to time.

D. Handover and Closeout

By creating inter-relationship between 3D model and all information and documents, a powerful database was created which helped to find whether all the objectives of the project are fulfilled or not. The linked information through reports and documents helped us to know the work pending status of project. The system can detect incomplete work or some issues that can abort handover. The project will show incomplete work while generating query with % complete syntax. When all incomplete work or issues are solved, project handover and close-out can occur and based on that demobilization work could be started.

E. Analysis using Query Tool

Query tool in QGIS can process and analyze the project based on user's questions and can generate report based on that. Analysis such as till date construction completion model, construction within/before/after specified date, element checked by specific person is being performed under this research but it can display result of many queries. We just only need to type our queries in software accepted syntax.

F. Possible Shortest Route

Road layer can be drawn on the base map which can facilitate in finding shortest route as shown in Fig. 18 and Fig. 19. Only start point and end point are to be provided and the application will show the route which takes less time. Shortest route can help daily movement of labour, machinery or incoming materials which can not only reduce construction time but also can reduce construction cost. For this project 4 options for

temporary labour camp were being evaluated as there was shortage of space at site for labour accommodation for which distance found was:

Labour camp 1 to site: 2.55 Km
Labour camp 2 to site: 1.73 Km
Labour camp 3 to site: 3.29 Km
Labour camp 4 to site: 2.20 Km

From above inputs from Qgis for temporary labour camp it was decided that labour camp 2 would be most suitable.

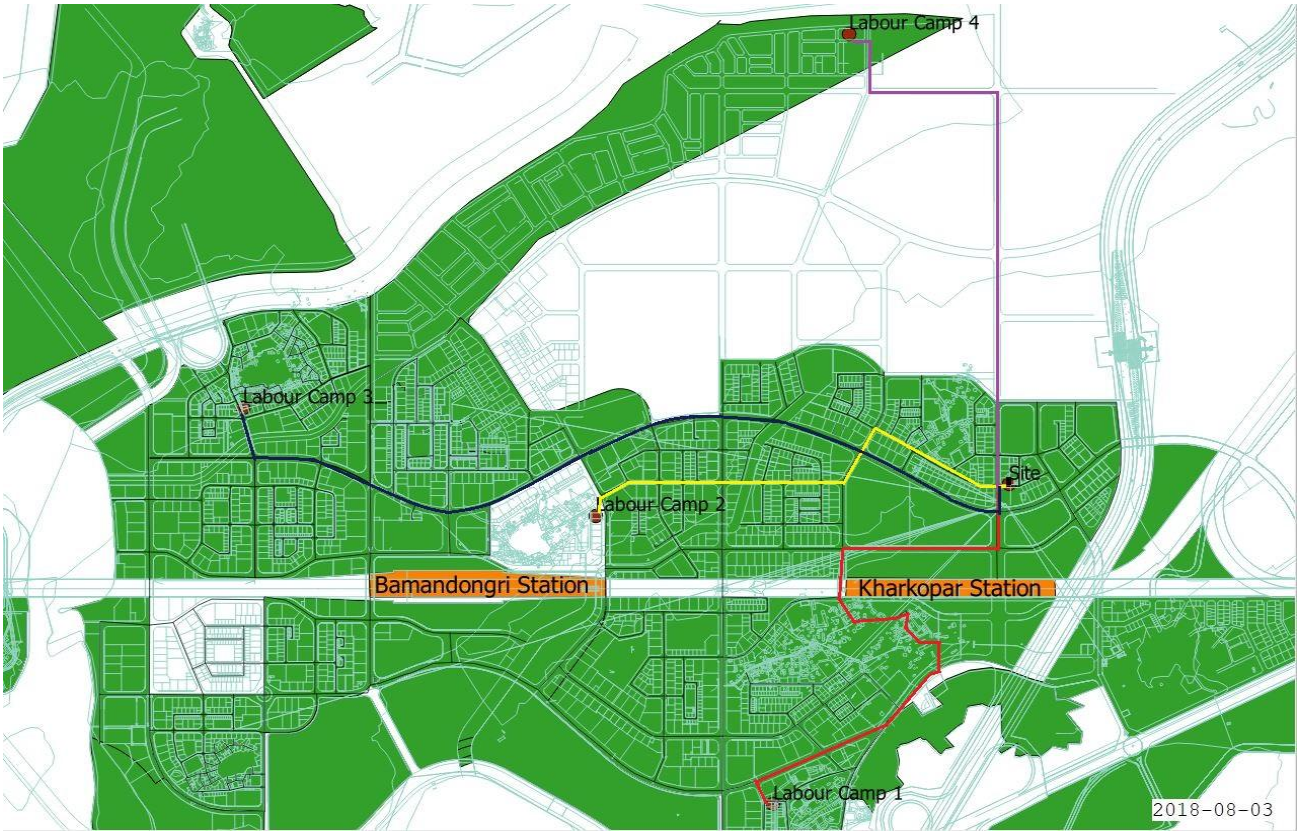


Fig. 18. Comparison of options for constructing labour camp

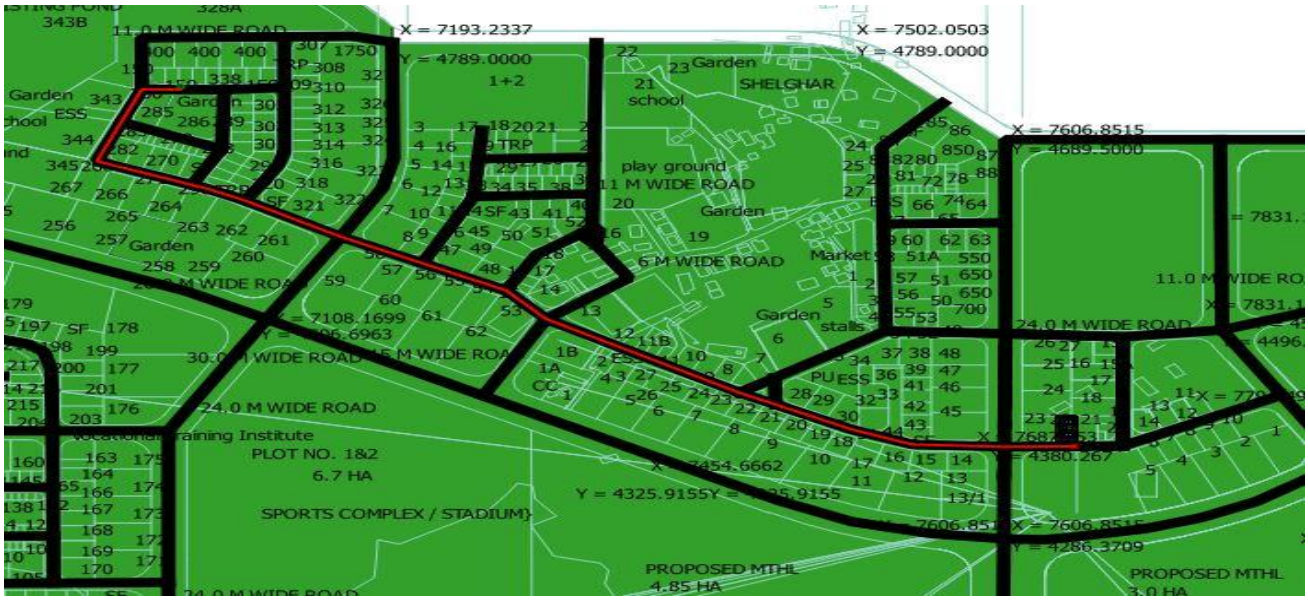


Fig. 19. Shows shortest route between selected start and end point

G. Create hyperlink of any file

In 2D model hyperlink can be created of any file. We just need to click at a point and it will display list of all connected files and by clicking on file name that particular file will open in new window. 2D plans of Architects and RCC Consultants are linked in this research with their respective structural component.

H. Track record of day to day activities

GIS platform can also act as a day to day diary which can store daily site expenditure, material inventory and day to day happenings of the project. Files of format comma eliminated value can be linked with 4D model which can also be further inter-linked with their respective structural component. Any text data which is to be linked, should be entered in excel sheet which has to be further converted to QGIS accepted format.

I. Animation

With linkage between activities schedule and their respective structural element a two dimensional animation using QGIS 2.18 and three dimensional animation using QGIS 3.4 was created which displays construction sequence along with time slider. This animation provides good understanding of construction execution cycle.

V. CONCLUSION

Any construction project has huge amount of information stored in it right from mobilization of site up to demobilization. These information contains minutes of the project happened during its construction. This data has to handled and archieved professionally in a systematic way. At present there isn't any feasible single platform available for accessing this information along with its structural component. Due to advancement in recent GIS applications it was found that GIS applications could be used for handling complete building information in a single interface which later can also be analyzed and visualized. They have the capabilities of handling spatial and non spatial information. Also in past years many researchers have explored extensive applications of GIS which can be applied to construction industry as well. Advanced GIS applications was found useful in construction project right from project planning till project maintenance or in short throughout the whole project life cycle.

GIS interface was used in this research study to develop building construction information system, by interlinking CAD drawings, project schedule, necessary construction information and document. From this integration, a 4D model was developed which contained spatial and non spatial information in it. Spatial information was used for geo referencing and non spatial information was project schedule and wide database which was linked to 4D model. AutoCAD 2017 was used for creating 2D drawings, Microsoft Project 2016 was used for scheduling, Microsoft Excel 2010 was used for creating construction database and QGIS 2.18 was used as a GIS interface.

The developed model can monitor, control, and edit construction sequence of the project which is best suitable for it. By feeding all the construction information in attribute table during and after construction can help create archiving system for project documentation. It can help design the structure from safety and hazard point arising during and after construction and helps in determining solution for it. Apart from developed 4D GIS concept in this research study, no other present available application/software was found to be efficient, economical and simple to use without any pre training.

Project planners have the difficult task of controlling cost and time over run apart from time space conflicts, safety concerns, construction site working place restrictions and many more. By using various plug-in available in QGIS inventory different work can be completed. By drawing inter-connected road layer shortest possible road route from specified start and end point could be found out. Query function was used to analyze structure based on construction completed or pending within or before or after specified period and based on that resource can be arranged. At the time of handover and closeout, model can helped in finding incomplete work or some pending issues. Hyperlink of any file can be created in attribute table for providing ease in viewing related files. Files such as site expenses and material inventory register are being imported in GIS model to provide assistance to billing and QS department. Track record of day to day activities can also be entered. All the contents of the attribute table can be exported to *.pdf, *.html or *.csv format. This research study had considered only important 3D visual structural activities up to all RCC work and brickwork excluding plastering, MEP works, flooring or any internal and external architectural aesthetics.

The defined methodology in this study strongly demonstrates 4D GIS concept for integrating and representing all construction project related spatial and non-spatial information such as drawings, resources, specifications, schedule, documents, cash flow, material inventory and tracking day to day activities in single interface

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2. Karthik Nagarajan, Raju Narwade and Sunilkumar Patel (2017) : "Sustainable Smart Blue Roof Network System with application of Geographic Information System (GIS)", International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE), (2017) Vol: 2, Issue: 3, pp. 423-428 http://technoarete.org/common_abstract/pdf/IJERMCE/v4/i3/Ext_19824.pdf
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