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4D Schedule Optimization for Project Monitoring of Existing Educational Building

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Abstract

Project management is an important domain, especially in the allocation of resources and smooth operation with an assigned budget. To successfully complete a project, it is important to follow effective ways to use available tools, technique, and methods, considering present technology and management. Recently, Building Information Modelling is one of the techniques which creates, manage, or generate a model by taking physical and functional characteristics of building by using digital presentations. Term 4D modeling refers to fourth dimension that associates the 3D model of any construction project with the planned schedule and provides visualization of the actual sequence of construction activities. The study was carried out to understand the uses and benefits of BIM for better proper functioning of the project in accordance with the project schedule. The objective of the study is to minimise the challenge associated with traditional or conventional scheduling process of construction sequences and misunderstanding brought by the lack of visualization. To fulfill the objective of the study, the uses of different dimensions of Building Information Modelling (2D, 3D and 4D) for preconstruction and construction phase was identified. Then a prototype 4D Building Information Model was created and the BIM based schedule was integrated with it and studied. The software used for scheduling, 3D modelling and 4D simulation are Primavera, Autodesk Revit, and Autodesk Navisworks respectively.

Keywords: Construction Planning Management (CPM), Building Information Modelling (BIM), 4D Scheduling, 3D Modelling.

1 Introduction

1.1 General

A construction project involves a lot of activities which needs planning and scheduling properly to ensure the completion of the project on assigned time. Therefore, the study on construction planning and scheduling must be conducted to provide knowledge on this topic and with a view on how it is to be implemented theoretically and in the real case of construction project. This study based on the concept of sequence of work for building construction project, scheduling technique used in the primavera project planner and the development of 3D model of the building. Need of study

3D and 4D modelling of a project is required as it improves the workflow efficiency with proper idea about operations on site. A 3D model is an integral model which involves the process of creating a mathematical representation of any object or surface in three-dimension spacing using specialized software that contains all information in terms of architecture, installation, and construction [1]. When a building is being constructed, multiple teams at once are expected to collaborate on the project a nd come up with the best product. The assigned tasks of each domain (electrical, plumbing, HVAC, etc.) are in some way interlinked so it's essential that every plan is up to date on the changes being made especially with regards to the

- design of the building. 3D modeling makes this easier. A 3D model assists in following ways- Better visualization and understanding of project even to a layman.
- Pre-construction planning.
- Design coordination.
- Efficient pace project delivery.
- Marketing.

A 4D model combines a three-dimensional (3D) model with a project schedule to create a simulation of construction activities. As an inherently visual tool that necessarily aggregates project information from many sources, a 4D model is more accessible to the public and fosters collaboration between stakeholders and engineering professionals in a variety of ways.

4D modelling is also used for –

- Strategic project planning.
- Master scheduling.
- Constructability review (A 4D model improves constructability planning because it helps constructability problems related to access, temporary support, availability of workspace and completion of prerequisite works.)
- Analysis of site operation.

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References: (U.S. Department of transportation)

1.2 Objective

- To prepare 3-Dimensional model of an ongoing construction project which can reduce the complexity of the 2D plan and provide details about actual physical dimensions and distance of the elements.
- To develop an efficient construction project schedule so that overall financial and risk management of the project can be optimized precisely.
- To design a 4-Dimensional schedule by linking 3-Dimensional model with the "TIME" element of project under construction, which can be assist for better visualization and communication of ongoing site work.
- To study comparative results of conventional project scheduling and proposed model-based scheduling.

1.3 Scope of project

This project is based on construction of an educational institute building. Originally the construction of project was done by traditional methods. By implementing the concept of 2D, 3D and 4D the project could have been managed and monitored in better ways [2,5].

In this project, 3D model of the school's architecture was by Revit Architecture software. Structural details of this building were created by Revit Structure. The scheduling of the project was done in Primavera P6. The Architectural, structural and services models were imported into Navisworks software to prepare a 4D video simulation.

1.4 Limitation of project

- The study is limited up to 4th dimension i.e. time scheduling even though it can be extended till 5th dimension (cost and budgeting), 6th dimension (operation and management), 7th dimension (health a nd safety), 8th dimension (energy consumption) and further.
- The selection of software was based on easy availability in market and user friendly and familiar interface. Other software like Synchro, Google sketch up, Tekla, Microsoft project can also be used for this study.

1.5 History

Building information modeling (BIM) has been exposed in construction world in last few years although the technologies and ideas behind BIM evolved since last 50 years.

- In 1957 BIM served their applications as computeraided mechanism (CAM).
- In 1963 used as CAD with graphical interface.
- In 1975 used as (BDS) Building Description System, in1982 served as 2D CAD.
- In 1987 served as a ArchiCAD.
- In 1992 it is officially termed as Building InformationModel.
- In 2000 used in Revit, in 2001 served as Navisworks.
- In 2002 used as Autodesk buys Revit as well as in 2007served as Autodesk buys Navisworks.

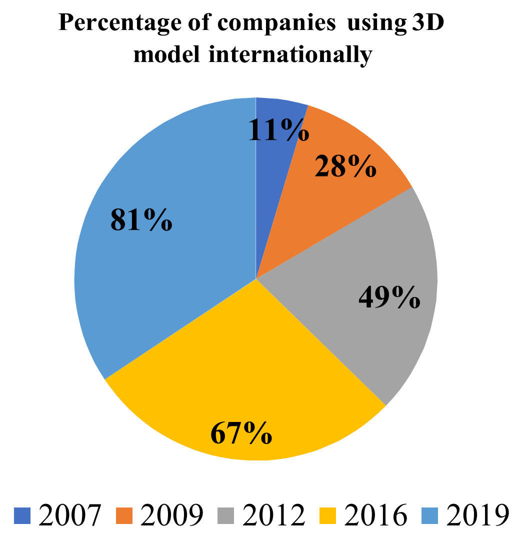


Figure 1.1. Global overall use of 3D models

1.6 BIMS

Building Information Modelling (BIM) is one of the most promising developments in the architecture, engineering, and construction (AEC) industries. With BIM technology, one or more accurate virtual models of a building are constructed digitally. They support design through its phases, allowing better analysis and control thanmanual processes. When completed, these computers generated models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized. BIM also accommodates many of the functions needed to model the lifecycle of a building, providing the basis for new design and construction capabilities and changes in the roles and relationships among a project team.

Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a building in digital form. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. Building Information Modeling (BIM) is a process that begins with the creation of an intelligent 3D model and enables document management, coordination and simulation during the entire lifecycle of a project (plan, design, build, operation and maintenance).

1.7 N-dimensional modelling

An N- D model is an extension of the building information model that incorporates multi-aspects of design information required at each stage of the lifecycle of a building facility; including scheduling, costing, accessibility, crime, sustainability, maintainability, acoustics and energy simulation.

1.8 2D BIM

It all starts with 2D BIM which is where your models have a simple X-axis and Y-axis and these are usually your hand or CAD drawings.

1.9 3D BIM (object model)

3 dimensional (3D) BIM, or a shared informationa l model, adds an additional "Z-axis" to the existing X and Y- axis. 3D BIM is perhaps, the most known kind of BIM, a concept that most people are familiar with. It is the process of creating graphical and non-graphical information and sharing this information in the common data environment, widely known as CDE.

1.10 4D BIM (time scheduling)

Going UP a level to the 4D BIM, is taking a simple 3D BIM model, and applying the 'TIME' element to it. 4D BIM adds an additional dimension of information to a project and information model in the form of scheduling data. This da ta is added to the components that we build, in detail, as the project progresses.

The utilization of 4D-BIM technology can result in improved control over conflict detection or over the complexity of changes occurring during the course of a construction project as information can be used to obtain accurate program visualizations, showing you just how the project will develop sequentially. 4D BIM provides approaches for management and envisioning site status information, alteration impacts, a s well as backing up communication in various situations such as informing site staff or cautioning them about potential threats [3,6].

1.11 5D BIM (cost estimation)

Moving on, the 5th Dimension (5D) takes a simple 3D geometry and applies the 'COST' element to a project. This allows the participants to visualize the progress of their activities and estimates the overall costing associated with it, resulting in greater accuracy and feasibility of any given project.

1.12 6D BIM (sustainability)

6D-BIM (sixth-dimensional building information modelling) helps perform energy consumption analyses. The utilization of 6D-BIM technology can result in more complete and accurate energy estima tes earlier in the design process. Integrating BIM with 6D CAD simulation models leads to an overall reduction in energy consumption.

1.13 7D BIM (operation and maintenance)

7D-BIM (seventh-dimensional building information modelling) is used by managers in the operation and maintenance of the facility throughout its life cycle. The seventh dimension of BIM allows participants to extract and track relevant asset data such as component status, specifications, maintenance/operation manuals, warranty data etc.

1.14 8D BIM (health and safety)

The 8th Dimension is about security on the project site: embedded manuals, emergency plans. It prevents security issues, and so on (8D= Safety). But until now the tools for effectively managing the links between design and safety on site have not been available.

Building information modelling (BIM) is an emerging paradigm in the design and engineering field.

2 Overview of 4D BIM

4D BIM technique is widely used in CAD industry in which 3D CAD assemblies are intelligently linked with tim e scheduled informational work. Each component or assembly in a model gives all information about creation date of model. This process helps in understanding the time line and schedule of construction phase wise.

With the help of BIM Modelling, we can actually link the construction elements across Architectural, Structural and MEP discipline to create a complete sequence of building construction. We can create a 4D simulation that represents the time line and schedule of completion. Based on this we can determine the entire process of on-site construction, check the areas causing delays etc.

4D construction sequencing is also known as "4D BIM Modeling". It is a creative way of presenting the building design and details in a simulation form which helps in design presentation, collaboration meetings, on-site contractors etc. It connects diverse construction phases seamlessly which makes the visualization of building construction processes extremely simple. The next level of construction is planned and scheduled well before it actually starts.

4D BIM plays an instrumental role in linking the construction data with the visual geometry which gives an excellent format presentation along with the data part. The main functionality of 4D construction sequencing is to synchronize 3D geometry, building data and the scheduling of materials together to create a project's phase wise construction simulation. This feature has the capacity to cut costs by 20 to 30% overall. Parties involved in the construction process can suggest on site changes based on the simulation and helps on site construction through a data rich virtual model. Visuals of the work progress makes it convenient to monitor the overall progress.

2.1 Benefits of 4D BIM

- 4D models are helpful to speed up the construction process hence reduces the mistakes and remove them quickly.
- 4D-models identify schedule shortcomings and also detect delays for safety management using visualization.
- 4D visualization create beneficial aspect to overview or visualize entire duration of process properly and also display of progress through entire journey or lifetime of project.
- 4D visualization has a potential to overview all details of project from start to finish.
- Automatically view project work and resources at a given time table without analyzing traditional Gantt charts and important design documents.
- Easy to check interoperability functions with CAD

platforms to evaluate efficiency.

- Provide quick and clear communication through immediate scheduling work updates with intelligent linking process.
- Immediately detect problem against space time clashes and overcome the problem early as possible. [10,11,12].

2.2 Limitations of 4D BIM

- The biggest error or difficulties arises in 4D models is that in 4D visualization internal activities visualization is not possible only external activities or representation of visible activities are possible.
- In large scale interaction with 3D model generally discussed as compared to 4D visualization, 4D Models cannot be spread in wide scale until it is integrated by existing planning and also with some analytical tool that generate decision making automatically in construction industry.
- 4D modelling system did not help the project team to automatically evaluate the feasibility of the proposed schedule or identify potential conflicts. As many activities may be occurring at same time and place resulting in congestion problems and decreased productivity.

3 Methodology

3.1 Scheduling Tools (Figure 3.1)

3.2 BIM Tools

Construction firms use various BIM tools available in market. The percentage of the usage of BIM tools by construction firms is shown in following bar graph. [7,8,9]

For 4D simulation the following software's are available –

- Navisworks Manage (Autodesk)
- ProjectWise Navigator (Bentley)
- Visual Simulation (Innova)
- Synchro Professional (Synchro)
- Tekla Structures (Tekla)

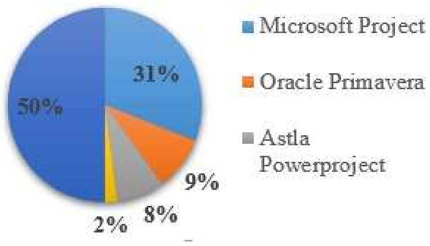


Figure 3.1 Percentage of scheduling software use by firms

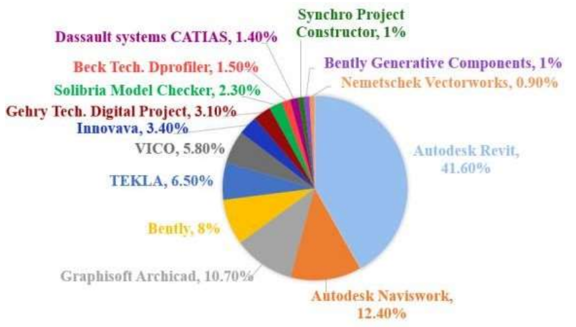


Figure 3.2 Percentage of usage of BIM tools by Construction Firms

- Vico Control (Vico-Software)

3.3 Selected BIM tools

Out of all the BIM tools, the used two BIM tools –

- Autodesk Revit for 3D modelling,
- Autodesk Navisworks Manage for 4D simulation.

3.3.1 Autodesk Revit:

Autodesk Revit is a building information modelling (BIM) software used to create and design Architectural, Structural, Electrical, Mechanical Plumbing projects. Revit contains tools to create intelligent 3D models of buildings using objects and models like, tubes, floors, walls, columns, roofs, footing, etc. It has inbuilt libraries called "families" which contains all the information necessary to simulate real-world construction elements in the simulation. Using Revit, you can visualize your model and can make changes in the design at any stage easily.

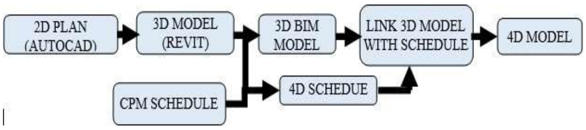
3.3.2 Autodesk Navisworks:

Autodesk Navisworks is a software which allows users to open and Combine design and construction data of all the different formats into a singular model and allows them to viewed, navigated and analyzed all together in one environment and in real-time. Navisworks lets architecture, engineering, and construction professionals review integrated 3D models during preconstruction to better control project outcomes. Navisworks has many advanced tools like clash detection which helps to find and resolve conflicts. Navisworks also allows you to view, naviga te, animate, measure, quantity take-offs, clash detection, clash management, and simulation.

3.4 Sample Modeling (Figure 3.3)

3.5 Methods for development of 3D model using REVIT

To develop a 3d model, firstly template is created. For 4D simulation, to design a basic 3d structural model, a structural template is selected. Once the structural template is selected, the next step is to create grids and based on the grid's columns, beams, analytical levels are created. Slab detailing and concrete detailing is done and finally, a simple structural 3d model is developed using Revit. Once the 3d modelling is completed, it should be saved in rvt, rfa, rtc format, so that it can be export to Navisworks Manage



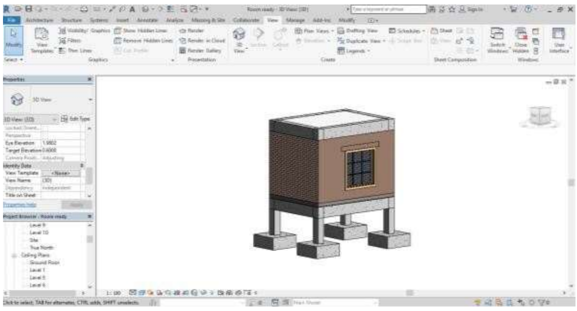


Figure 3.3 Sample revit model of a room prepared in Autodesk Revit

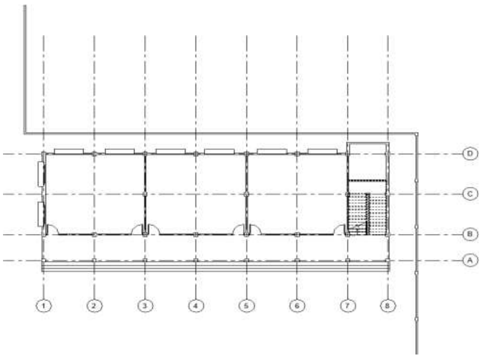


Figure 3.4 Structural Plan of the School building used for study

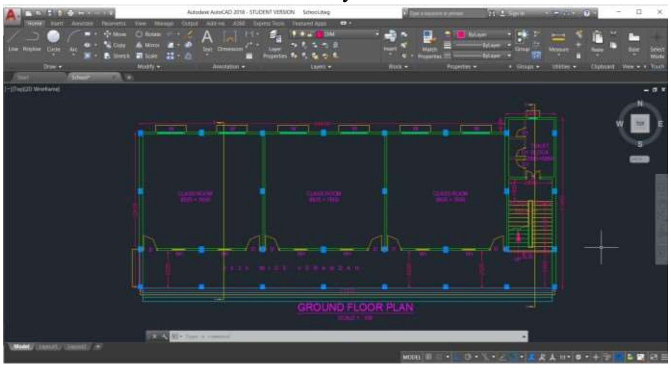


Figure 3.5 Floor plan of ground floor

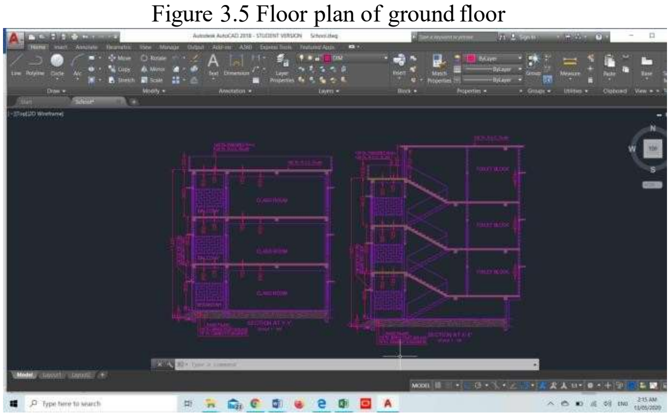


Figure 3.6 Section Plan of the school building

3.6 Method for developing schedule in Primavera P6 The construction industry in the nation phases a lot of issues like budget overruns and time overruns, due to inadequate project formulation, poor planning for implementation and improper management during execution. Proper project management is essential to complete enterprise within time, estimated budget and with allocated resources. Providing good planning, proper organization and sufficient flow of resources to the project can automatically achieve the desired result. Using Primavera P6 above objectives can be achieved.[13,14,15]

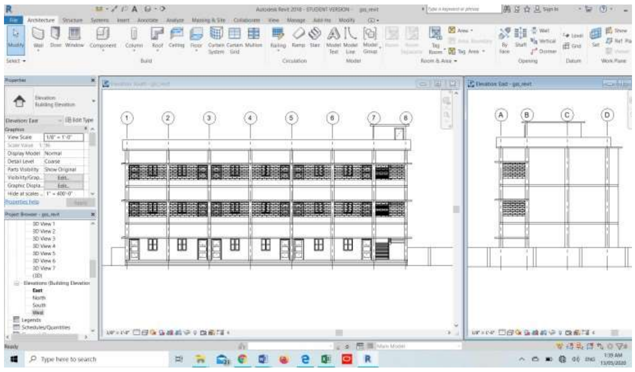


Figure 3.7 Elevations obtained in Revit model

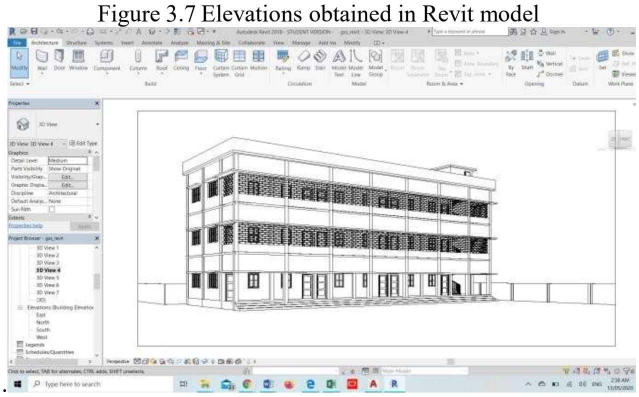


Figure 3.8 3D model (wireframe view)

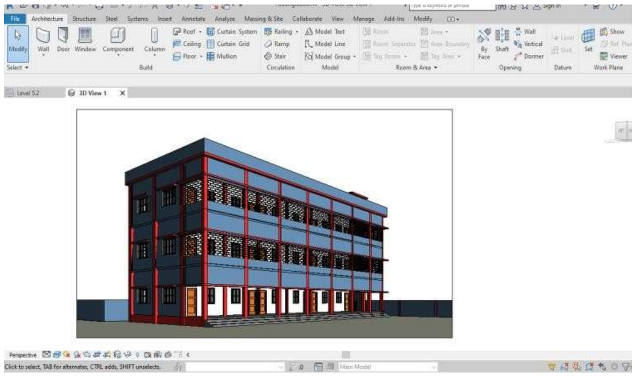


Figure 3.9 3D Model (realistic view)

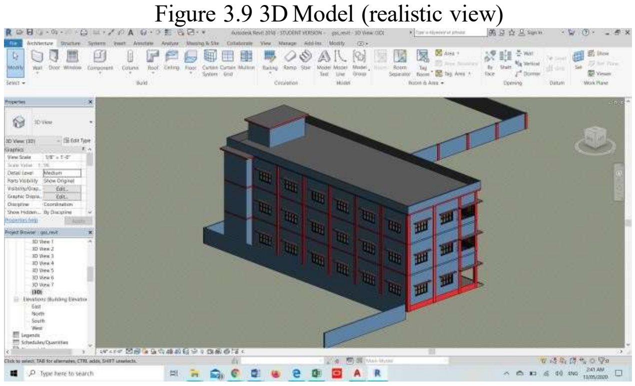


Figure 3.10 Backside view of the 3D mode

Figure 3.11 model in Navisworks Imported 3D

Data like activity sequence, labour output, activityduration and construction resources required for different activities were collected by communication with the senior engineers. The construction on site was already completed so we studied the activities and prepared a schedule showing where time could have been saved in completing the project where

actual time consumed. Steps involved in making schedule:

- The **EPS** (Enterprise **Project** Structure) is a logical, meaningful, hierarchical arrangement of all the projects in your organization. This is a view of the company showing its areas of operations.
- The WBS represents the breaking of the whole project into smaller components.
- Resource Allocation and costing of resource on each day
- The foremost thing is to import the 3d model and the building elements by appending it to Navisworks Manage.

- The next step is to open Time liner in home tab. The Time liner tab has 4 options, and they are tasks, data sources, configure, simulation. Tasks can be added manually in Navisworks Manage or can import schedules from Primavera. The key to create a 4D simulation of the construction process is linking the elements in the building model with these tasks and ca n attach individual elements or sets of elements to each of the tasks in the timeline.
- For creating sets of elements, the home tab is selected in Navisworks Manage, select sets option and then manage sets. Now model elements are attached to specific tasks in the timeline. After individual elements or sets of elements are attached, select tasks option in Time liner bar and activities are assigned as per the construction process.
- While adding tasks both planned start and end time are assigned for the given tasks. Next setup the simulation by looking at the options available under the simulate options. Here the interval size is selected, that will determine which increments are displayed and also can select the playback duration of the simulation.

After selecting all options in the simulation tab, the next step is to run the simulation and watch Navisworks steps through every day/week on the project schedule. It shows the activities that are scheduled for that day/week and in turn brings the different building elements that are associated with those activities creating a 4D simulation.

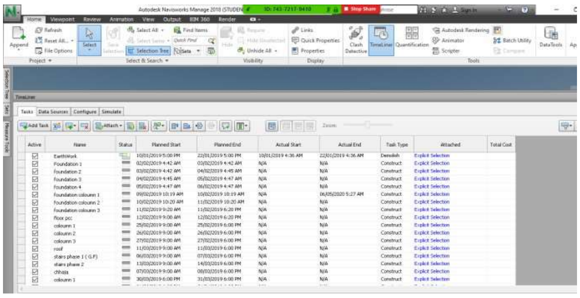


Figure 3.12 The activities added in Time liner with duration

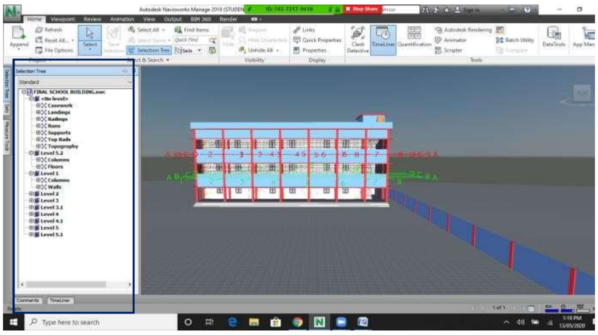


Figure 3.13 Selection tree for selecting elementsand linking to Time liner

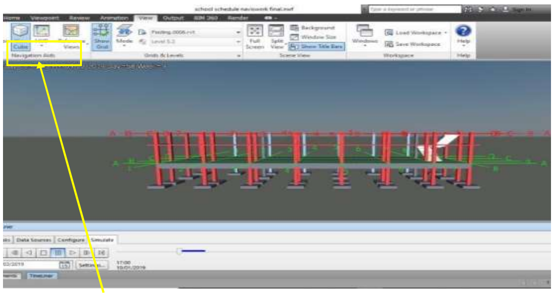


Figure 3.14 The date on which a particular activity is conducted can be seen on top left corner

Figure 3.15 Display of whole project after simulation end

4 Results

4.1 Time optimization in Primavera

The schedule obtained from the site was optimized for early finish of the project by efficient use of resource and better relationships between activities which resulted in 18 days early finish of the project. Points where time could have been saved

In bar chart and relationship, it is observed that after concreting of footing a lag of seven days is given for strengthening purpose of concrete. During those 7 days the construction was at halt as no other work activity could be started before the concrete obtains required strength.

In on-site schedule, activities "Formwork of footing" and "concreting of footing" are done simultaneously, due to which after concreting of footing no other major work activity can be further started until the concrete acquires required strength. To overcome such delay both activities could have been started parallelly within available labor resources on site.

In off-site schedule it is shown that if concreting of footing is started on 2nd Feb date, then by the time of formwork for last footing, previously casted footings would have already acquired enough strength. w.r.t the vertical expansion of building, the duration of construction processes related to higher elevation gets increased simply because of more energy required to transport material on higher floors. Due to this the duration of activity "Reinforcement of column" on ground floor was noted 4 days while on second floor it was 6 days

In off-site schedule, the totally unskilled labors allocated for the activity "Reinforcement of column" at higher elevated floors are increased in number to transport reinforcement bars at the working pla ce. This approach for proper allocation of available labor resources on site results in completion of work activity in comparatively lesser time duration.

The above bar chart taken to shows on site schedule and off-site schedules. Based on the Off-site schedule it was derived that the construction could be completed 18 days earlier compared to the construction durations shown in ON- site schedule. The selected site was a small-scale construction site if this process is properly followed on a large-scale construction site then it will result in saving large amount of time. The On-site schedule shows that commencement of masonry work on any floor was co-related to the casting of slab on the floor above it.

The Off-site schedule shows that the commencement for masonry work will take place immediately after the shuttering for above slab is removed (21 days). This approach will ensure proper utilization of resources resulting into comparatively early completion of work.

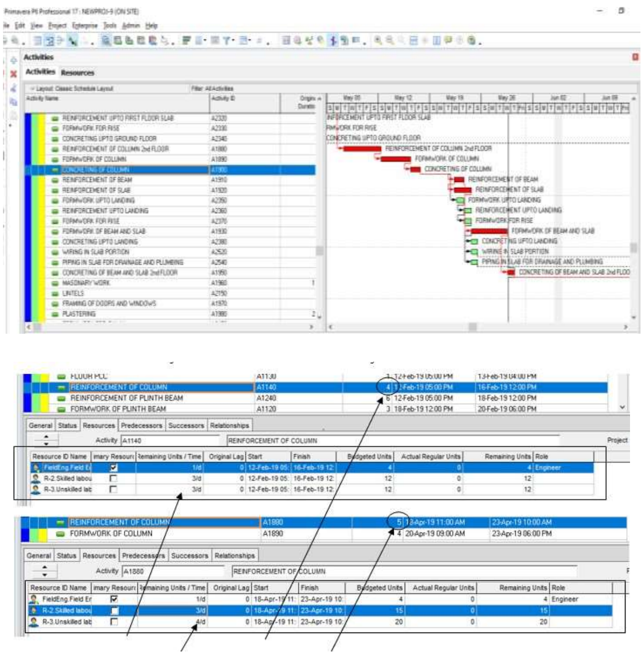


Figure 3.16 Schedule activities allocation in software.

4.2 Quantity estimation

An accurate quantity take-off is the only way to analyze productivity and various costs of a construction project thoroughly and is vital to the financial performance of a contractor. Usually the time spent on quantity take off is project specified but a general research shows that 50 -80% time is consumed on quantification.

4.2.1 Traditional method approach

Based on the 2D AutoCAD drawings the quantity is estimated in Excel Spreadsheet using center line or long wall – short wall approach and a BoQ (Bill of Quantities) is prepared consisting lists of material quantity required. The process is tedious and consumes a lot of time for execution.

4.2.2 BIM solution to re-create 3D BIM model based on original 2D CAD drawings

The 3D model will be re-created based on original 2D design document with methodology shown above. After creating the model go to views and click the schedules as shown in following figure
The required quantities of different materials on each floor can be obtained easily without calculation. Revit automatically generates such quantity data as we generate the model. By doing so the tedious job of quantity estimation in excel can be prevented. Research shows that working with Revit can speed quantity estimation process by

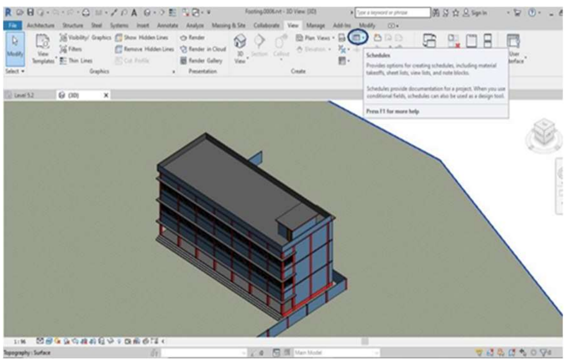


Figure 4.5 Display of Schedule tool

<Wall Schedule>

A	B	C	D	E
Area	Base Constraint	Length	Volume	Width
10.06 m²	Level 2	3.51	2.55 m³	0.25
10.06 m²	Level 2	3.51	2.55 m³	0.25
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.95 m²	Level 2	3.76	1.39 m³	0.13
10.24 m²	Level 2	3.18	1.30 m³	0.13
12.29 m²	Level 2	3.51	1.56 m³	0.13
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10.08 m²	Level 2	3.76	1.28 m³	0.13
10.08 m²	Level 2	3.76	1.28 m³	0.13
12.29 m²	Level 2	3.51	3.12 m³	0.25
12.29 m²	Level 2	3.51	3.12 m³	0.25
3.16 m²	Level 2	0.84	0.80 m³	0.25

Figure 5.6 Quantity Sheet

35%. Proportionally, the training time takes about 23% in traditional method and 65% in BIM method of the total time. However, when it comes to the stage of implementing, the traditional method consumes more than three times of the time than BIM-based method. It is dramatic that the implementation process, which consists of 77% of time consumed for traditional quantity estimation method, becomes much less time-dominant in the BIM-based method, which only takes 35% of the total time. This shows that although BIM is a technology which needs more time on training, it will greatly save time when it is implemented in the cost control process. So once the user becomes competent, the efficiency of BIM method will become obvious.

4.2.3 Virtual visualization in Primavera p6 vs Navisworks

The following figure displays the bar charts generated in Primavera P6 which help in viewing virtual progress in schedule. The top row in the bar chart shows the respective start and end dates associated with particular activity thus duration of activity can be judged by viewing such bar charts. the display of Navisworks 4D simulation video. The virtual progress can be seen clearly in the video with activity progression for which the corresponding duration of the activity is shown on top left corner. By following this process there will not be a need to observe the bar charts created by primavera, live virtual progress can be seen in just a 2-minute video without any tedious processes of viewing the 25 pages of bar charts in case of a large-scale project.

4.3 Cloud storage for BIM

The traditional methods of information exchange cannot meet the mass information processing requirements of modern large-scale construction projects, so to improve the efficiency of BIM storage on cloud come into the picture. Cloud storage is an extension of cloud computing, which collects, stores, and processes data based on services. Cloud storage is the basis for cloud computing systems such as the cloud platform, and cloud services. Some features of cloud which make BIM easy.

- Expansibility.
- Convenience.
- Collaboration.
- Low cost

5 Conclusion

The construction industry is an integral component of a nation's infrastructure and industrial growth. Many problems and issues are being faced by the construction industry, the majority of them are cost overruns and time overruns due to inadequate project formulation, poor planning for implementation and improper management during execution.

The conducted study brought up 4D modeling as a promising tool for construction planning. There are many positive impacts of 4D modeling discovered which are not possible to achieve through traditional planning methods being used. The most significant benefits of 4D modeling are found out to be better visualization of construction work, better communication among project teams and increased planning efficiency, accurate work plans, quantity and managing site logistics.

By this project, it is concluded that by use of 4D schedule optimization, which includes 2D schedule and 3D BIM model along with video graphic simulation and visualization, proper and better functioning of the project is achieved. Altogether 2D schedule, 3D model and 4D simulation does mutually assists in proper work-flow during preconstruction and construction phase, material management with respect to quantity estimation, resource management in accordance of quantity of work to be done on site, better visualization and understanding of the project during preconstruction and construction phase, intended workflow to all stakeholders and communication between all construction teams. Based on the above mentioned results the concept of 4-Dimensional Building Information Modelling can impart a positive impact on project monitoring.

Disclosures

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