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ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Civil and Environmental Engineering
Post Graduate Study Program

Construction Technology and
Management Stream

5D **Planning, Scheduling and Control of Construction Projects
by Integrating Project Management Software & GIS**

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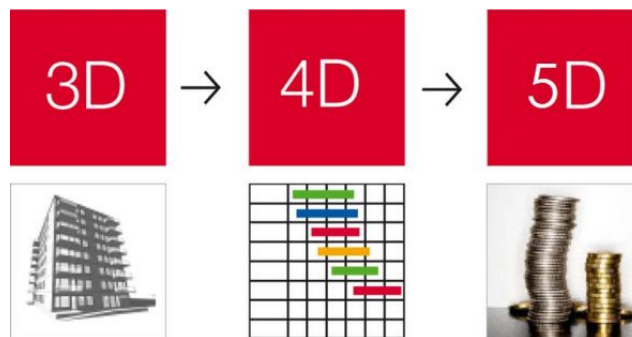
Advisor:
Prof. Abebe Dinku (Dr.-Ing)

December, 2017
Addis Ababa, Ethiopia



AAiT

School of Civil and Environmental Engineering
Construction Technology and
Management Stream



**A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the
Requirements for the Degree of Master of Science in Civil Engineering
with Specialization in Construction Technology & Management**

By
Sitota Girma

Advisor:
Prof. Abobo Dinku (Dr.-Ing)

December, 2017
Addis Ababa, Ethiopia



AAiT

5D

**Planning, Scheduling and Control of Construction Projects
by Integrating Project Management Software & GIS**

"Research is a way of life dedicated to discovery"
(ANONYMOUS)

MSc Thesis

by

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Declaration

I, the undersigned, declare that this thesis is my original and has not been presented for a degree in any other university, and that all sources of materials used for the thesis have been duly acknowledged.

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by Integrating Project Management Software and GIS ”*

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Acknowledgment

Blessed be my God - JESUS! First and for most I would like to give thanks, praises and all honor to **Jesus Christ** – the Almighty God, the source of heavens, the earth, and life; the only one who deserves worship. My Jesus, I will not forget what you have done for me. You were all the way with me from my childhood! My Love, my Savior, my Only One! It is because of you this time I managed to do my 4th degree. I, I myself, know where I came from!! **I will not forget those days!!** Jesus! I trust on you forever and ever!

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Abstract

Construction industry can be deemed as the most vital driving force of a country. Construction of vast projects such as township, stadiums, and dams is a challenging task both in terms of managing complexities of the project and addressing the demands of all stakeholders. Its success or failure largely depends on cost effectiveness, time-bound delivery, quality and amount of resources available throughout the lifecycle of the project. This clearly turns the focus towards effective construction project management.

Today's demand of construction industry requires highly accurate planning, scheduling and management of the process of a project which can enable the overall optimization of cost, time, and resources. With the advances in information technology, its use is being constantly explored in the area of construction planning and monitoring. The aim of this study is to demonstrate the methodology of integrating Geographic Information System (GIS) with construction project management to provide a better solution for *optimization* and *real time* monitoring of the progress of a project.

GIS is a computer based tool and being used extensively to solve various engineering problems involving the use of spatial data. The technology provides capabilities to solve problems involving creation and management of data, *integration* of information, *visualization* and *cost estimation* to which most of the construction management software are lacking. In spite of the growing popularity its complete potential to the construction industry has not been realized.

Integration of GIS and Project management might assist a planner in a better perception of a project as well as in the integration of other parties' activities in the planning process. It will provide a common basis of *understanding* and communication among stakeholders. This helps in reducing construction *errors* occurring on sites and thereby reduces the amount of administrative *time*.

In this research paper a review of up-to-date work on the applications of GIS technology in construction industry is presented. Methodology to generate 3D view of a building and to represent construction schedule within GIS environment is also discussed. With this, integration of GIS and Project Management is developed using AutoCAD, MS-Excel, ArcGIS, and Visual Studio to assist construction managers in controlling and monitoring a construction progress. With

time as the fourth dimension, the progress of construction task can be displayed as 4D (**3D + time**) view. The 5D (**3D + time + cost**) model of progress monitoring is beneficial to all stakeholders and can be opted as the future of planning and monitoring in the fast developing construction industry.

A case study of one story building is selected for the purpose of presenting the integrated tool for progress monitoring. Ultimately, an easy to use Graphic User Interface (GUI) named as “5D Construction Monitoring Application” is developed to enable project participants have an idea of the current status of a project at run-time.

The paper explores the potential of GIS environment in developing a construction project information system for rate analysis; and safety and quality control recommendation. It also suggests that the proposed GIS based methodology may replace manual methods used to extract information from the available database and can be easily updated as most of the information is in digital format. Successful project control is a challenging responsibility, but the job becomes easier when it is complimented with visualization of information. The propositions presented herein could facilitate and accelerate this trend, and as well provide means of measuring the success of implementation of 5D planning in construction projects and be a basis for further research.

Keywords: Construction Industry, Planning and Scheduling, Project Management, GIS, Takeoff, 5D Model, Run-time Application.



Acronyms

5D	– Five Dimensional
BIM	– Building Information Modeling
BOM	– Bill of Materials
BOQ	– Bill of Quantity
CAD	– Computer Aided Drafting/Design
CPM	– Critical Path Method
DBMS	– Database Management System
DEM	– Digital Elevation Model
DWG	– Drawing
DXF	– Drawing Interchange Format, or Drawing Exchange Format
EFT	– Early Finish Time
ESRI	– Environmental Systems Research Institute
EST	– Early Start Time
et al.	– and other authors
FAO	– Food and Agriculture Organization
GIS	– Geographic Information System
GPS	– Global Positioning System
GUI	– Graphic User Interface
HCB	– Hollow Concrete Block
ICT	– Information Communication Technology
LFT	– Late Finish Time
LST	– Late Start Time
N.B	– take note
NGL	– Natural Ground Level
NGO	– Non Governmental Organization
ODBC	– Open Database Connectivity
PERT	– Programme Evaluation and Review Technique
PMS-GIS	– Progress Monitoring System with GIS
Rebar	– Reinforcement Bar
TV	– Television
UF	– Utilization Factor
VR	– Virtual Reality
WBS	– Work Breakdown Structure



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Glossary

3D Model – A representation of three-dimensional surface using specialized software that combines the height, width, and depth of the space.

4D Model – A 3D model intelligently linked with time or schedule related information for a project.

5D Model – A 4D model intelligently linked with cost information for a project.

Annotation – The geodatabase name for map text. With annotation, the position, text string, and display properties are all stored together and are all individually editable.

ArcGIS – A software package that is used for manipulating, presenting and analyzing geographically referenced data.

ArcMap – The main component of ArcGIS package that is used for mapping and analyzing geographically referenced data.

ArcScene – The ArcMap window is for 2D maps, so to work with 3D maps you need a new window, called ArcScene.

Aspect – The direction in which a topographic slope faces, usually expressed in terms of degrees from the north. Many GISs provide functions which generate aspect from continuous elevation surfaces.

Coverage – An ArcInfo vector data storage format.

DEM file – A digital elevation model (DEM) file that contains geographically referenced elevation data in a raster format.

Digitize – The process of converting analogue map features to a digital format.

Feature – A spatial element which represents a real-world entity. Often used synonymously with the term object.

Feature Class – A homogeneous collection of common features, each having the same spatial representation, such as points, lines, or polygons, and a common set of attribute columns; for example, a line feature class for representing road centerlines.

Float – The amount of time that a schedule activity can be delayed or extended from its early start date without delaying the project finish date or violating a schedule constraint.

Hillshading – A technique for enhancing relief depths in 3D displays of spatial data. It attempts to emulate the way natural light low on the horizon illuminates the terrain. It's also known as relief shading.

Key – A field (column) represents attributes in a table whose value can uniquely identify a record (row) in a table.

Pixel – A pixel is represented in a remotely sensed image as a rectangular cell in an array of data values. The term is an abbreviation for 'picture element'.

Raster – A file format where geographically referenced data is stored in cells of a two dimensional grid; each cell is assigned an attribute value.

Relational database – RDB is a collective set of multiple data sets organized by tables, records and columns. It establishes a well-defined relationship between database tables. Tables communicate and share information, which facilitates data searchability, organization and reporting.

Schedule – The work programme or timetable for actions to be taken during implementation of a construction project.

Shapefile – A file that contains geographically referenced data in a vector format; it is composed of several individual files that provide information on feature geometry, position and attributes.

Spot height – A small dot or symbol on a map marking a surveyed elevation, usually according to its height above a particular datum.

Topology – A non-metric (qualitative) properties of geographic objects that remain constant when the geographic space of objects is distorted. For example, when a map is stretched properties such as distance and angle change, whereas topological properties such as adjacency and containment do not.

Utilization Factor – Utilization factor or **use factor** is the ratio of the time that a piece of equipment is in use to the total time that it could be in use. It is often averaged over time.

Vector – A file format where geographically referenced data is represented by points, lines or polygons, and the features' critical points (vertices, end points) are assigned x-y coordinates.



CHAPTER 1: INTRODUCTION

In this chapter the main line of reasoning for the choice of the research topic will be presented and its context to a real world problem. The significance of the research will be briefed and the scope of the study highlighted. The outline structure of the research paper is introduced finally.

1.1. Background

Construction industry plays a vital role in overall development of a country. Construction of vast projects such as high-rise buildings, stadiums, and dams requires management of resources present in large proportions. The success or failure of these projects largely depends on *proper management* of projects throughout their life cycle. This brings about a need for effective and efficient management of materials, manpower, data and time. Good planning, adequate machinery and sufficient flow of resources are the pre requisites of an efficient project. Project monitoring is the process of doing the same. The time available for this process is shrinking day by day as customers need the finished project at the earliest. Efficient project management can help solve this problem.

Construction planning is fundamental and challenging activity in the management and execution of projects. It involves the choice of technology, definition of work tasks, estimation of the required resources and durations for individual tasks, and identification of any interactions among the different work tasks. A good construction plan is the basis for developing budget and 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 timely procurement of necessary materials to 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.

Xing Su and Hubo Cai (2013) proposed a 4D-CPM based graphical scheduling system consisting of a conflict-free 4D model. V K **Bansal** (2008) presented a survey of different

applications of GIS to construction industry as well as a methodology to generate 3D and bar chart to represent the construction schedule. **David** et al. (2004) discussed about the need of 4D CAD (Computer-Aided Design) modeling in the construction industry. The reviewed literature hasn't focused on integration of scheduling in GIS.

1.2. The Need

A host of professions have been in the process of developing automated tools for efficient 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. This rapidly evolving technology has come to be known as GIS. Also, it provides management with a *clearer overview* of data to monitor projects and make decisions; and as well to see the results of those *decisions sooner* and in a more crisper and *comprehensible* format. The system of usage of AutoCAD for drawings, and MS Project for scheduling and explaining the status of projects to clients is very difficult and time consuming. Hence, there is a need for integrating them on a *common platform* to create 5D view of the project using a GIS environment.

1.3. Significance of the Research

The traditional approach for scheduling and progress monitoring techniques like bar charts, Critical Path Method (CPM), Programme Evaluation and Review Techniques (PERT) etc. are still being used by project managers for planning with serious limitations for decision making process, as they fail to provide information pertaining to the **spatial aspects** of a construction project. Hence, there is a dire necessity to come up with some geo-enabled information technology with the capability to present spatial perspective to infrastructure projects so that these projects can be designed, planned and managed more precisely using geo-spatial information analysis and sharing system.

Growing pressure to shorten 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 (**Retik**, 1997). 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 (**Koo** and Fischer,

2000). GIS can play significant role in introducing Geo-enabled Project Planning and Management. Instead of using the traditional methods of CAD drawings and schedule sheets one can integrate them on a platform to create a 4D view of projects using a GIS environment.

Researchers have suggested that project managers can use 4D models and simulation for effective resource allocation (**Fischer n.d**). **Bansal** and Pal (2007) have described the linking of activities in a critical path schedule with 3D model, which makes the project sequence easier to understand. Project managers and client can use the visualization aspects at any stage of the project to *monitor* activities. GIS and project management tools in combination can be used to access *spatial aspects, time* and *cost* involved in the project. This is the overall purpose of 5D modeling.

This research paper aims to provide reasons for incultation of GIS in the construction industry to facilitate the *speed* and *accuracy* of work with the help of 5D models of construction work. It presents the concept of integrating GIS with construction project management to provide a better solution to *monitor* the progress of projects and understand the delay in the work, if any. The integration would help all parties involved in a construction project to visualize the progress in a *natural* way, hence minimizing delays and cost overruns. In addition to monitoring the schedule, the system can also be extended to monitor quantities of *materials, costs, and resources*.



1.4. Objectives of the Research

1.4.0 General

Objectives of a research delineate the ends which the inquirer seeks to bring about as a result of completing the research undertaken. It summarizes what is to be achieved by the research. The aim of this research is to *examine synergies* between GIS and construction project management and compare the outcome to the current practices in the construction industry to reveal its future prospects. It is accomplished with the following objectives:

1.4.1 General Objective

The general objective of the research is to discuss the *methodology* for creating GIS based 5D model of a project and simulate it to *monitor* the work flow on a construction site.

1.4.2 Specific Objectives

The sub objectives to be achieved are:

- 1) To investigate the *potential areas* of the application of GIS in construction project management.
- 2) To develop *construction database* in a GIS environment and use its functionality to replace manual methods to extract information from the available database.
- 3) To identify the state-of-the-art of GIS *integration* in construction project management.
- 4) To develop an easy-to-use GIS based approach for *takeoff preparation*, Bill of Materials (BOM) generation, labour requirement, as well as accurate cost estimation in building construction.
- 5) To integrate *safety* and *quality* control recommendations with various construction activities.
- 6) To *display the progress* and sequence of construction work in 3D while synchronizing this information with a formal CPM work schedule for work monitoring, hence minimizing delays and cost overruns.

- 7) To develop *run-time application* that displays the output of the model. This is accomplished by using Visual Studio software.

1.4.3 Research Questions

This thesis will provide answers to the following research questions:

- How can a prototypical GIS database for construction project management be *assembled*?
- Where does the *functionality* of GIS fit construction project planning and scheduling? What can these tools do?
- How can GIS *techniques* be involved in the process of construction project management?
- How can construction industries *benefit* from the integration of GIS with construction project management and what are the *limitations* of a GIS database for construction project management?
- What are the *prospects* for GIS adoption in construction project management?

1.5. Scope of the Research

The thesis aims at the development of concepts and their validation by prototyping key aspects. The functionality of ArcGIS is tested on small residential building to show its feasibility.

1.6. Limitation of the Study

Some constraints faced by the researcher in the process are:

1. Comprehensive studies, to refer from, on the topic related to “5D Construction Project Management” could not be found by the researcher.
2. Some of the rates set in the BATCODA’s excel template are not found to be practical in real situation. The hourly output for the 3rd coat Gypsum, for example, is too small to accept it. It is 1.25 m²/hr with a crew of one foreman with UF of 0.25, one plasterer, and one daily laborer. As a result the time estimate for this work item has become 45 days. Despite all these, the same value is taken for the model as the purpose of the study is not to set standard for productivity rates.

3. The locations of electric plugs are supposed to be shown in the model. But, it is not incorporated due to the lack of electrical drawings of the subject building. In addition to this the progress of construction was not recorded by the owner to be able to show the percentage of executed works in each milestone.
4. The research doesn't intend to inventory all the construction resource data needed in an operational GIS database, since it is not considered feasible for the time schedule of one research project such as this one. To support GIS based planning and scheduling there is a need to develop a common construction resource database within the GIS itself.

1.7. Road Map

The thesis is divided into six main chapters:

- Chapter One puts the scene of the research through *introduction*. In this chapter, an overview of the research topic and its background has been presented, leading to the formulation of the research work, and its significance. It also involves on the purpose and objectives this research seeks to meet, and highlights the research questions to be answered in the process and the research paper outline.
- Chapter Two outlines on theoretical and conceptual *review of literature* relevant to the subject under study. It discusses about the various applications of GIS in construction industry and its integration with project management software.
- Chapter Three, *Problem Statement*, presents the gaps identified on the field of study, and the significance of the study in detail.
- Chapter Four is a practical reference of the choice of *research methods* used to conduct the study and to create 5D view of the sample building. A state-of-the art study is conducted in the same chapter.
- Chapter Five is all about the *results* and *discussions* of the modeling output.
- In the last chapter, Chapter Six, *conclusions* are drawn with highlights of the *limitations* of the model, and finally *recommendations* are made for relevant future studies.



CHAPTER 2: PROBLEM STATEMENT

A study from Rischmoller et al. (2006) showed that the great expectations from thirty years ago of the assimilation of construction and ICT have not realized the benefits due to the lack of a framework for its application context. The focus has been too much on the core technology.

2.1 Gaps Highlighted

Construction Industry has a huge number of tasks involved and the cost involved in these projects is also very large. Project Managers have hard time monitoring projects between site and office. 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, interested parties normally look at 2D drawings and conceptually associate components with related activities. They have to come to site to know the progress of work and decide the sequence of work. Different project members may develop inconsistent interpretations of the schedule when reviewing only the CPM schedule. This causes confusion in many occasions and usually makes efficient communication among project participants difficult. So the cost involved becomes large and it varies with respect to the completion of the project, i.e., time.

Various traditional techniques for scheduling and controlling are still being used in the construction industry which fail to provide the spatial (layouts, drawings) and non-spatial (specifications, cost estimates etc.) aspects of information in a construction project. The conventional method of project scheduling and planning using CAD and MS-project does not provide complete progress of the work in synchronized manner in a single platform.

It does not satisfy clients in making them understand the project status and also found time consuming.

In contrast with the past, presently construction industry is concerned about optimal execution of projects. There is pressure on project managers to shorten the delivery times and thus the current scheduling and progress reporting practices are in need of substantial improvements in *quality* and *efficiency*. For this to achieve, the industry needs systematic planning, scheduling and management process which in turn permits the overall optimization of cost, time and resources.

Integration of GIS and project management software with visualization is recognized as one of the most important tools for achieving this goal. Hence, an efficient method is proposed in this study implementing GIS as a platform to link the plan of building and its corresponding schedule of executing the construction of a building.

2.2 Benefits to be Secured

The main advantage of 4D/5D modeling is that it helps in visualization of the project, with both the 3D model and the schedule, hand in hand in a single platform. Integrating project schedule data with GIS technology presents a 4D model which can be utilized for the visualization of progress at different stages and timeline. This method helps engineers in proper visualization of construction project and thereby helps in taking clear cut decision at site and reduces delay in work progress. All the project members can be able to visually observe the progress, which will help in effective communication of the schedule. It will provide common basis of understanding and communication among these people. This helps in reducing construction errors occurring on sites and thereby reduces the amount of administrative time (Dierkes & Howard, 2008).

“**5D Construction Monitoring Application**” will be developed to be able to inform project participants about the details of projects’ status.

The use of GIS immensely benefits all stakeholders of a construction project – project managers, site engineers, consultants, clients and end users as well. Some of the benefits are:

- The **project manager** will get up-to date information about the progress of the work and this helps in *controlling* project sites. He comes to know about the *cost* incurred and the *quantity* of materials used on site on each day activities. If the project site is big, it reduces complexity. By the progress view, he would know the exact time **when** the resources are required in which **location**; thus helping manage the cost and quantity of materials being used. This definitely *reduces the time for decision-making* as all information is in one system.
- The role of a **site engineer** is controlling project sites. By displaying the progress of work the system helps in easy decision making for procurement of funds or materials. It helps in knowing how much more material is required to complete the work. A 4D view would

let him order the ideal *quantity of materials* by reducing over-ordering of materials thus helping in reduction of wastage. Time component would allow him to know beforehand about the requirements, so he can inform the contractor before the work actually commences.

- The ***client***, who probably cannot understand the building structure or is not well versed with drawings, can easily know the exact *status* of the project just at a glance to the 4D model. The project owner is able to monitor the progress of the project from one location, which helps in spending more time in chalking out the action plan for minimizing delay.

Therefore, as the construction industry expands, there is a greater requirement of GIS to be adopted for *effective* and *efficient* progress monitoring of construction projects.

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CHAPTER 3: LITERATURE REVIEW

A research paper is not a list of findings; it is the coherent communication of a meaningful pattern of information.

RICHARD COE

A research paper presents and argues a thesis, the writer's proposition or opinion.



3.0 General

The literature review has been defined to serve three main purposes:

1. *Map-out* and establish the state-of-the art in the subject area surrounding the topic.
2. Draw attention to the *gaps in knowledge* or concerns about existing understanding.
3. *Support arguments* advanced by the researcher in making his own case for the chosen topic and research response.

The focus is to identify how issues connect, find out if there is emerging trends and what might be missing. The proposals and findings by various researchers in the areas associated with project management and modelling have been duly reviewed and discussed in the following paragraphs.

3.1 Construction Project Management

Irrespective of the area of application, any management system governs the efficient functioning of an organization. The term management covers two main elements: *resource* management and *time* management. As the nature of the target field is, for example, the construction field, management can be in terms of construction materials, labor, construction site, progress of work, supply chain network, and etc.

According to Taylor, "Project management is the art and science of managing relatively short-term efforts having finite beginning and ending points, usually with specific budget, and with customer-specified performance criteria." It includes developing a project plan, which includes identifying tasks and how goals will be achieved, quantifying the resources needed, and determining timelines for completion. It also includes managing the implementation of the project plan, along with operating regular 'controls' to ensure that there is accurate

information on ‘performance’ relative to the plan, and the mechanisms to implement recovery actions where necessary.

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

3.2 The Role of IT in Project Management

The construction project cycle involves all aspects of problem solving, from problem recognition to the implementation of a fully operational solution. Consequently, civil engineers need information technology to support their endeavors through all phases of the project cycle.

Before the IT revolution, the hand written planning method was the only way to accomplish success in project management. In the 1980s, the microchip and personal computers caused a major revolution in the computer industry, which caused a major revolution in the construction industry as well. The vast amount and variety of data in construction projects makes IT an important tool to be utilized in the planning process. Now, after the huge growth of available IT tools such as AutoCAD, MS-Project, and GIS software; leading or managing projects is easier and more reliable (**Biehl**, 2007).

The use of computer systems, such as a computerized construction project management and scheduling system, is the new way of managing construction projects with many applications. A number of visualization techniques such as 3D modeling, animation, multimedia and virtual reality (VR) have found application in areas related to transportation planning (**Liapi**, 2003). Of these, 3D and 4D modeling are more often used in construction planning. Visualization

and database management capabilities are the two most significant contributions that IT has made in project planning.

3.3 Geographic Information System

3.3.1 Development of a GIS

Several developments in the field of computer science during the last few decades helped the realization of the GIS concept. GIS evolved from centuries of map-making and compiling registers. **Coppock** and Rhind (1991) stated that “computer-based GIS has been used since at least the late 1960s”. However, during the 1840s, the procedure was used manually when, in London, Dr. John Snow used a map of London to determine the location of the most deaths caused by Cholera and then to pinpoint the location of the contaminated water pump from which the Cholera was spread. While the basic elements of topography and layers existed previously in cartography, the John Snow’s map was unique in using cartographic methods not only to depict but also to analyze clusters of geographically dependent phenomena for the first time.

When GIS was introduced in the early 1950s, its early use was limited to small group of researchers. Botanists, meteorologists, and transportation planners began automating the process of thematic mapping. The researchers’ efforts represent the early attempts at computerized cartography (**Editorial**, 1998).

GIS has grown out of a number of technologies, including cartography, information management, computer science, photogrammetry and remote sensing. Advancements made in these fields correspond to advancements in GIS. In 1963, the introduction of software and hardware system gave birth to CAD, which had much influence on the development of automatic map drafting systems (**Ibraheem**, 1997). Next, the influence of database management systems appeared during the 1970s. The rapid developments during recent years, in areas such as distributed processing systems, continue to shape GISs of the next generation.

3.3.2 GIS Defined

Because of the very nature of GIS and the rapid growth of associated disciplines, many definitions of this technology exist. According to the Environmental Systems Research Institute (ESRI), a GIS is defined as

“an organized collection of computer hardware, software, data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographic referenced information.”

It is useful definition, because it addresses functionality as well as components. Thus, a GIS is both a database system with specific capabilities for spatially referenced data as well as a set of operations for working with the data. Activities of GIS can be grouped into spatial and attribute data management, data exploration, data analysis, modeling, and data display as mentioned by **Clark** (2001).

Others have attempted to use the name itself to better understand the functions and components of GIS. Hence, it can be viewed as:

- a) **Geographic**: The system is concerned with data relating to geography and geographic scales of measurement. This is referenced by some coordinate system to locations on the surface of the earth.
- b) **Information**: The system allows for the storage and extraction of specific and meaningful attribute information. Spatial and aspatial queries are made possible with it.
- c) **System**: It is an automated system that includes an integrated set of procedures for the input, storage, manipulation, and output of geographic information.

Hence, it is an information system, a set of interrelated data parts operating together to provide appropriate feedback to decision makers in a way that entire information is available on time and when needed.

3.3.3 Components of a GIS

GIS is a special class of information system, which can be divided into five components involving a computer system, software, human expert, methods and the data.

- **Hardware:** GIS technologies include input/output devices such as Global Positioning System (GPS), digitizer, and etc.
- **Software:** Many GIS software packages are on the market, each offering different levels of functionality. Some of these are ArcGIS, ILWIS, QGIS, MapInfo, and etc.



Figure 1: Components of a GIS

- **Users:** The true GIS professional needs to be well versed in many disciplines. Basic geography, map reading, computer science, database management, programming, and spatial analysis are disciplines in which a thorough grounding is required. A balanced education in GIS (theory and practical experience) is also essential.
- **Data:** GIS is relatively an emerging field of information technology for managing *spatial* and *non-spatial* data. In other words, a GIS answers questions about *where* things are or *what* is located at a given location.

3.3.4 Spatial Vs Non-Spatial Data

2.3.4.1 Spatial Data:

Spatial data describes the location and shape of geographic features, and their spatial relationship to other features. The information contained in the spatial database is held in the form of digital coordinates, which describe the spatial features. Normally, the different sets of data will be held as separate layers, which can be combined in a number of ways for analysis or map production. The ability of GIS to handle spatial data makes it a *special category* of information system.

Entity Representation: GIS systems typically represent entities as *vector* features or as a collection of cells in a *raster* (an array of grid cells). In any geospatial platform, there are three primary types of feature geometries: *points*, *lines*, and *polygons*. The **vector** data model uses points with x, y, and z coordinates to construct these spatial features; where features are treated as discrete objects in the space.

- **Points** are used to represent features that have insignificant area compared to their surrounding or the scale of the map. For example, houses, trees, even cities on small scale maps can be represented as points.
- **Lines** are used to represent ordered set of connected points. These could be boundaries of countries, rivers, roads, and etc.
- An area feature called **polygon** is a region enclosed by line features. *Building polygon* is one of the most common types of vector data used in 3D GIS applications.

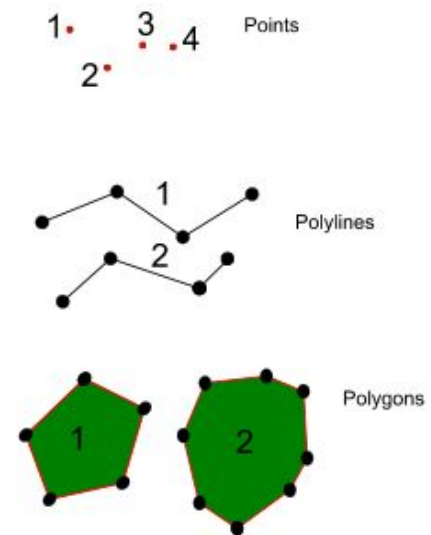


Figure 2: Representation of point, line and polygon

It should also be noted here that the scale of the map is one of the determining factors as to how to represent features on the map.

This study makes use of the vector data model (non-topological) represented by simple graphical objects.

2.3.4.2 Attribute Data:

Attribute database (i.e., descriptive information) is of a more conventional type; it contains data describing *characteristics* or *qualities* of the spatial features: land use, type of soil, distance from the regional centre, type of road, types of building materials, and etc.

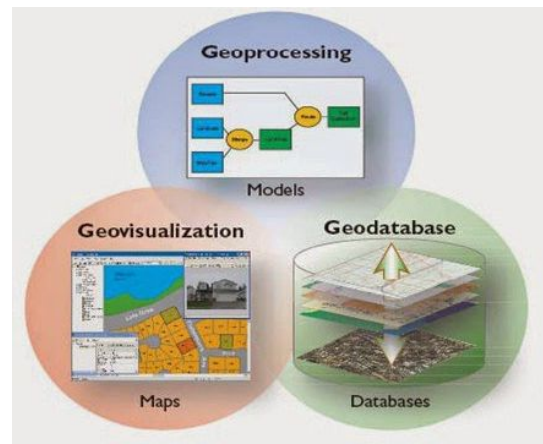
2.3.4.3 Entity Organization

GIS *links* geographic information (where things are) with descriptive information (what things are). All reports, information layers, and maps are simply *views* of the database. If something is changed or updated in the database, all of the views containing those changes are instantly updated.

3.3.5 GIS Views

A GIS can be viewed in three ways – database view, map view and model view (GIS, 2010):

- 1) **The Database View:** GIS is a unique kind of database of the world – a geographic database (geo-database). In the *geo-relational* data model, split data system is used to store spatial and attribute data in separate files and linked together by the feature ID. These two (spatial and attribute) sets of data files are synchronized so that both can be queried, analyzed and displayed (Chang, 2002).
- 2) **The Map View:** GIS is most often associated with a map. A map, however, is only one way that can work with geographic data in a GIS. GIS can provide a great deal more problem solving capabilities than using a simple mapping program. GIS is a set of intelligent maps and other views that show features and feature relationships on the earth's surface. Maps of the underlying geographic information can be constructed and used as “*windows into the database*” to support queries, analysis, and editing information.
- 3) **The Model View - Spatial Analysis:** GIS provides tools for modeling information to support more intelligent and faster decisions; discover and characterize geographic patterns; optimize network and resource allocation; and *automate workflows* through a visual modeling environment. The geoprocessing functions take information from existing datasets, apply analytic functions, and write results into new derived datasets.



(Source: Solutions for Civil Engineering, ESRI)

Figure 3: The three views of GIS

In other words, GIS relies on integration of three areas of computer technology: A *relational* database management system to store graphic and non-graphic data; *cartographic capabilities* to depict, and plot geographic information; and *spatial analytical* capabilities to facilitate manipulation and spatial analysis. It provides a mechanism by which information on feature's

location and geographic relationship can be assessed and viewed in moments. GIS provides an opportunity to efficiently view and access geographic data to improve decision-making process.

3.3.6 Paper Maps Vs. GIS Layers

GIS, unlike a flat paper map where "what you see is what you get," can present many layers of different information. Digital map is much more *convenient* to use than a paper map with an added functionality to zoom in and out. All this information - where the point is located, how long the road is, and even how many square kilometers a lake occupies - is stored as layers in digital format. Think of this geographic data as layers of information underneath the computer screen. Each layer represents a particular feature of the map. One layer could be made up of all streets in an area. Another layer could represent hydrograph in the same area. Yet another could represent elevation as seen in Figure 4. These layers can be laid on top of one another, creating a stack of information about the same geographic area. Each layer can be turned off and on, as if peeling a layer off the stack or placing it back on. Users can control the amount of information about an area that they want to see, at any time, on any specific map (**Geography Matters?**).

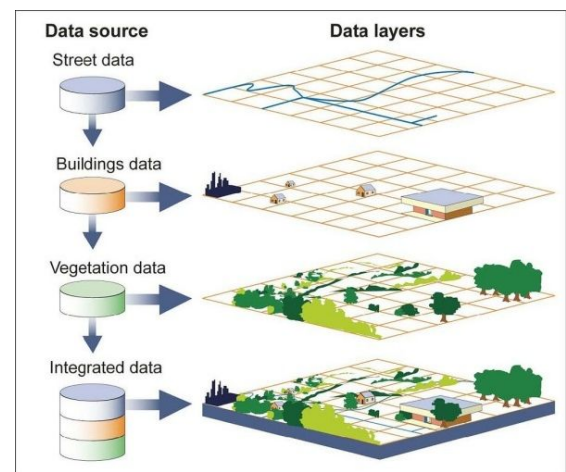


Figure 4: Representation of data as layers in GIS

Why is this layering so important?

The power of a GIS over paper maps is the ability to select the information needed to see to what goal the user is trying to achieve. A business person trying to map customers in a particular city will want to see very different information than a water engineer who wants to see the water pipelines for the same city. Both may start with a common map - a street and neighborhood map of the city - but the information they add to that map will differ (<http://www.gis.com>)

GIS overlays and *integrates* graphic and textual information from separate databases. The end result is a customized and reliable tool that can support decision making and problem solving and provide almost instantaneous answers to complex questions.

3.4 Extent of Use of GIS in Ethiopia

GIS has already gained momentum in Ethiopia. It has gained tremendous popularity in this nation by attracting a great number of governmental institutions: the private sector, institutions of learning and NGOs. The GIS technology has become an essential tool for urban land administration, for land use studies and planning, for transport and other infrastructure planning and management, and for a variety of other disciplines.

Ethiopian Mapping Authorities website (www.ema.gov.et) reported the following:

“The Ethiopian Mapping Agency, being the foremost agency for the government in this field, has been an early adopter of GIS and ESRI products in the country. ... Use of GIS started in Ethiopia early in 1984 when they first started the home developed geographic information for land evaluation system solution with the support of FAO at the then Ministry of Agriculture. This was then later replaced by ESRI product and the current statistics shows that the number of users is growing rapidly, including diversity. The technology is very multi-sectoral technology, and many organizations were using it here for their multi-sectoral activities. Various ministries, regional planning bureaus and municipalities are among those users”.

The potential application of GIS technology in construction sites in Ethiopia **can** be phenomenal.

3.5 Why a GIS Based Project Management System?

Information systems, including GIS, have gained importance because of the increase in complexity of many projects. In this age, a simple Project Management Software does not give clear picture to the management about the state of projects going on at multiple locations. It is said, ‘*Pictures are worth a thousand words!*’ Why not then integrate site images on maps with project management software? This will visually show the user the exact *location, time*

and *state of the project* at any given time. The ability of GIS to search databases and perform geographic *queries* has revolutionized many areas of science and business.

GIS allows users to view, understand, question, interpret, and visualize data that reveal relationships, patterns, and trends in the form of maps, reports, and charts which would be difficult to identify and visualize from the use of numerical representations alone. Also GIS helps the user to answer questions and solve problems by looking at data in a way that is *quickly understood* and *easily shared*, allowing decision makers to focus on the real issues rather than trying to understand the data, since visually depicted details are far more easier to understand than just the raw data itself. Because GIS products can be produced quickly multiple scenarios can be evaluated *efficiently* and *effectively*. Also spatial representation of the query results would help the user immensely in identifying location specific information such as locating defective equipment for maintenance, identifying areas within the facility which need to be modified, and etc. The user does not need to travel and check the project sites. This will not only save substantial costs to the user but will also enthuse a high level of confidence about the progress of the project. He will have a pictorial map based records about the state of multiple projects done and can easily generate reports for the same. In short using pictures and maps will give management a sense of peace and save costs doing the same. A win-win situation!

With the advances in the field of information technology, construction industry has started taking the advantages of some of these developments. Use of a computer based information system may help in reducing *redundancy* as well as saving *time* and *cost*. GIS, not only speed up the modelling process and data extraction from the various resources but ensures data *integrity* and *accuracy* also.

Other Benefits: Additional benefits that the GIS technology could offer in the area of construction management are:

- Proper representation of spatial aspects.

- Ease and speed of map revision and map scale changes.
- Changes in the database immediately reflected in digital map
- Elimination of miscommunication when moving through the planning, design, construction, and operation stages (**Sandip**, 2013).
- Flexibility: Planning maps are no longer static images, but flexible and dynamic system.

Also, GIS can perform geographic *queries* in a straightforward, intuitive fashion rather than being limited to textual queries. For this reason, in today's world, the ability to use GIS is increasingly important.

3.6 Application Areas of GIS

3.6.0 General

GIS has a broad range of applications. Some of the prominent examples are in Research and Education, Forestry, Agriculture, Climate Science, Emergency Management, Insurance, Landscape Architecture, Communication, Natural Resources, Real Estate, Redistricting, Cellular Network, Tourism, Defense and Intelligence, and etc.

3.6.1 The Domain of Civil Engineering

GIS is now being used by civil engineers in every application. Some of these are (**Solutions** for Civil Engineering):

- a) *Public Safety*: Civil engineers assisting this sector of public life are serving on the front line of defense for keeping our communities safe from disaster. GIS is used in public safety for weather-related disturbances, fire department operations, and etc.
- b) *Surveying*: Using ArcGIS Survey Analyst, surveyors can easily incorporate their

The Domain of Civil Engineering

- Public Safety
- Surveying
- Asset Management
- Energy Systems
- Geology
- Mining
- Land Development
- Urban and Regional Planning
- Environmental Management
- Air Quality
- Marine and Coastal
- Petroleum and Pipelines
- Utilities (Electric and Gas)
- Transportation
- Traffic and Streets
- Port Facilities
- Hydrology
- Water/Wastewater management
- Solid Waste Management
- Construction

measurements and calculations into GIS.

- c) *Asset Management*: GIS is a powerful framework with which asset management organizations can track location, condition, and age of capital assets and *infrastructure*.
- d) *Energy System*: GIS has long played an important role in energy system planning, design, construction, operations, and assessment. Power plant siting, transmission routing, and power management are all supported by various GIS functions.
- e) *Geology*: GIS technology has been used for many years for making geologic assessments as related to geologic surveys, mapping earthquakes, determining the effect of tsunamis, assessing *slope stability*, and even *foundation design*.
- f) *Mining*: To be profitable without being disruptive, mining companies use GIS to map mineral locations and other pertinent information about terrain, geology, *accessibility*, the environment, and human populations.
- g) *Land Development*: GIS can be used to greatly enhance the optimum use of land, the functional efficiency of the *proposed design*, its marketability, and the overall cost-effectiveness of the project.
- h) *Urban and Regional Planning*: Visualization of 3D urban area is required for effective urban development planning, utility management, and environmental impacts studies. Most of the issues, such as planning for smart growth (land use, *transportation*, and *infrastructure*), and economic vitality are inherently spatial in nature. This has led to the extensive, almost pervasive, use of geographic information system.

Example applications (**Tekalign** and Andualem, 2012):

- Physical and Natural Planning Constraint Analysis: Identification of stream buffer zone, flat and steep slope, high tension line buffer in a city, and etc.
 - Creating 3D of a Study Area
- i) *Environmental Management*: A GIS combines layers of information about a place to give a better understanding of that location. The type of layers of information combined depends on the project theme.
 - j) *Air Quality*: ArcGIS Geostatistical Analyst extension can be used to analyze point-based air quality data to create statistical surfaces showing the spatial distribution of that data

over a wide area. It can also be used to determine time-based air quality data to forecast the dispersion of that data over an area, projected over time.

- k) *Marine and Coastal*: The oceans and seas provide some of the earth's most important and dynamic resources. From oceanography to hydrography, navigation to defense, and the coastal shoreline to the bathymetric bottom, marine GIS has been adapted and utilized to assist researchers and organizations in achieving their goals.
- l) *Petroleum and Pipelines*: Where to drill a well, route a pipeline, build a refinery, and reclaim a site are all questions that rely heavily on an understanding of GIS to make intelligent decisions.
- m) *Utilities (Electric and Gas)*: GIS technology offers utility organizations a method for quickly accessing and producing maps, and leveraging database information.
- n) *Transportation*: Diverse areas of transportation, including highway and railway infrastructure management, international shipping, airport management, fleet logistics, transit bus and rail service planning, and transportation modeling professionals increasingly rely on GIS to manage equipment and infrastructure. Whether it's monitoring train locations, tracking flight paths, planning for highway maintenance, or improving bus routes, GIS helps improve operations and reduce costs.
- o) *Traffic and Streets*: Traffic and design engineers are engaged in the use of GIS for roadway design, circulation analysis, parking studies, pavement management, operations, and maintenance. They are also engaging GIS to assist them with issues related to public safety including visibility, signage, congestion management, and citation tracking.

Traffic safety is a measure of a community's quality of life and infrastructure. Maps indicating the location and characteristics of vehicle collisions provide a primary source of information for traffic safety studies and identification of corrective measures to *improve streets and intersections*. Comparative information about different locations within the city is imperative in *prioritizing construction* and enhancement projects.

- p) *Port Facilities*: Port facilities (airports and shipping ports) around the world host a vast array of complex operational, logistical, and management activities. Port planners, design engineers, managers, operations staff, and regulators all use GIS to improve the quality

and efficiency of their activities. Air traffic control organizations use GIS for both its 2D and 3D capabilities to maintain safe flight paths and *efficient rerouting* when severe weather conditions interfere with normal operations.

- q) *Hydrology*: GIS technology has been used to develop solutions to water resource problems—determining water availability, assessing water quality, managing water resources, preventing flooding, and understanding the natural environment.
- r) *Water Resource/Waste water Management*: GIS is a powerful tool in helping engineers to track the location and condition of water mains, valves, hydrants, meters, storage facilities, sewer mains, and manholes.

Water/Wastewater management tasks that can be aided by using GIS include

- Population and demand projections,
 - Well log and data management
 - Water distribution system master planning
 - Facilities inventory and automated mapping
 - Water quality monitoring, Hazardous materials tracking
 - Network tracing and reporting
 - Surface flow analysis
 - Sewer collection
 - Sewer TV inspections
 - Operations and maintenance
 - Customer service
- s) *Solid Waste Management*: Solid waste services involve the *location* and management of landfills; defining and managing service routes; and managing hazardous materials. GIS is being used to develop and maintain a wide variety of *service routes*, manage requests for service, and perform trend analysis. It is also being used for parcel identification and ownership for the enforcement of city litter codes. Using the geoprocessing tools in ArcGIS, planners are able to create suitability models to help them assess various factors that need to be considered when determining the optimum location for a new *landfill site*.
 - t) *Construction*: Building contractors, water and wastewater organizations and highway departments are often responsible for constructing and/or overseeing the development of new facilities and replacement of old facilities. GIS can aid in tracking information related to projects, construction work order management, inspections, as-builts, and so forth. [See details of this in the following unit, Chapter 2.7].

3.7 The Use of GIS in Construction Industry

3.7.0 The Trend in the Construction Industry

Civil engineering is about developing and sustaining infrastructure. The profession covers many areas of interest and a broad range of expertise. As discussed in the previous paragraphs, GIS is being used in diverse application areas related to construction such as infrastructure management systems, land resources management, water resources engineering, watershed management, utilities, transportation, surveying, urban development and etc. As a result, civil engineers work with a voluminous amount of data from a variety of sources.

The 1988 GIS core business is estimated to have been \$529 million. This amount has been projected to grow by 32% annually through 1993 (**GIS markets and opportunities**, 1989). This trend has not been reflected directly in the construction industry. Most of the computer technologies investigated by construction professionals focus on *descriptive* aspect of data, though vast amount of construction data can be *spatially referenced*. GIS is one of the fastest growing computer-based technologies of the 1990s, yet, its full potential in the construction industry has not been realized. In fact its 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** and Ethan, 1994).

GIS allows civil engineers to manage and share data and turn it into easily understood reports and visualizations that can be analyzed and communicated to others. Thus, it is playing an increasingly important role in civil engineering companies, supporting all phases of the infrastructure life cycle.

Several researches suggest the usefulness of GIS in construction industry to effectively handle various construction project requirements including data management, integrating information, construction planning and scheduling, site layout, construction visualization, and cost estimation (**Bansal** and Pal, 2008). **Vijay** et al (2009) presented the use of GIS in construction management. It can be used for site and client distance location, networking solutions, 3D data analysis, construction scheduling, and progress control with 3D visualization.

Applications related to 5D visualization and utilization of GIS for construction project database management have been briefly discussed in the following sections:

3.7.1 Storing Location Data

The collection and management of various types of information efficiently and on demand is seen as the key to successful management of 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. Some construction projects, especially highway and street projects, use geocoding process to manage the project. Geocoding is a GIS analysis tool that can be defined as “the mechanism that allows using addresses to identify locations on a map” (**Pine**, 1998). This tool helps to create maps to show locations, *query features*, and search for the target group. This helps organizations with large databases locate their projects, customers, or suppliers. GIS can expand decision making on repair strategies and project scheduling by incorporating such diverse data as accident histories, and vehicle volumes.

Oloufa et al. (1994) stated that GIS is used to create a database for storage of descriptive soil data pertaining to boreholes and link the descriptive data to the corresponding geographic locations of the boreholes.

3.7.2 2D/3D Visualization

Researchers have explored the capability of GIS in construction *database management*, and not much in *visualization* (**Camp** and Brown, 1993). GIS can generate graphic maps, which could be very useful for engineers, including bar charts, pie charts, histograms, and scatter plots (**Jeljeli** et al., 1993). Through the use of 2D and 3D, you can experience a more interactive way of seeing data, visualizing change over time and space to identify patterns and trends, and disseminate knowledge to engineers, clients, regulators, and field-based personnel.

3D visualization allows a construction manager to view construction activities during any stage of the construction process. Visualizing assets and the surrounding environment when you build, upgrade, and repair infrastructure helps you decide how to prioritize your work, convince others of its importance, and make good decisions about how to move forward with your plans. Having an accurate, clear picture of the project helps you better understand needs,

reduce problems, and mitigate costs and environmental impacts. These processes are improved when GIS is the core system for data management and visualization.

Many civil engineering applications require 3D characterization of a site. It is very easy to communicate information about complex objects when represented as 3D Models instead of representing it on a group of 2D drawings. With a 3D Model, even an amateur layman can easily grasp the shape and details of an object by looking at the realistic images of the virtual model, instead of trying to visualize and imagine the possible shape of the object by looking at the 2D drawings. This is very important as such images are directly *understandable* not only by the engineers, but by all the project participants who come from a wide variety of backgrounds. It makes presentation, evaluation, and decision making substantially easier. The 3D model created is very useful during the design and construction phase of a construction project. It can be effectively used by contractors to explain their understanding of projects to clients. The importance of visualization is especially big in customer-oriented companies, as *visual evaluation* of the products can be done together with the clients even if no physical prototype exists (this is especially true in the construction industry). A visual model of a facility will be much more effective in helping the client/user *understand the project* and the satisfaction of his needs by the project.

The great advantage of 3D models is that they eliminate the drawing translation process – the time it takes to make sense of a 2D drawing. Complex *drawings* can be so difficult to read; only their designers understand them. In contrast, users only faintly familiar with a product modeled in solids (3D) know exactly what it is.

A variety of VR technologies are being used to create 3D models. The program called “**3D Analyst**”, an extension to ArcGIS, within GIS, is developed to support fully interactive 3D visualization. The goal is to extend the GIS interface with a 3D view correlated with the 2D information presented in ArcGIS. Within this extension, the user is able to navigate in real-time the photo-realistic 3D database and interactively query information in both 2D and 3D. It enables users to create, analyze, and display surface data.

GIS facilitates the understanding of 3D model and topological relationship between different components in many ways (like zooming, pan, fly forward or backward, navigation, and etc.).

The users also have the option of rotating 3D components around the x , y , or z -axes to observe the developed 3D model. Further, the element can also be viewed from any direction and angle. Any component can be set *transparent* that makes it easier to visualize the model.

With 3D Analyst, users can:

- Create realistic perspective imaging.
- View a surface from multiple viewpoints.
- Examine the visual impact of building new structures.

It also provides tools for 3D modeling and analysis, such as:

- **Hillshade creation:** Hillshading, which is cartographically called shaded relief, is a lighting effect which mimics the sun to highlight hills and valleys. Some areas appear to be illuminated while others lie in shadows.
- **Viewshade** and line-of-sight (visibility) analysis. It is all about Viewshed Modeling (Intervisibility Analysis). Viewshed modeling uses elevation layers to indicate areas on the map that can and cannot be viewed from a specific vantage point. The ability to determine viewshed (and how they can be altered) is particularly useful to national and state park planners and *landscape architects*. For example, it depicts areas within a park where a proposed radio antenna can be seen.
- Spot height interpolation
- Contouring, profiling, slope, aspect, and steepest path determination
- Performing surface area and volumetric calculations

Zhong et al. (2004) utilized visualization capabilities of GIS to show the construction of a concrete dam. **Oloufa** et al. (1992) developed an interface to construct a 3D representation of soil strata that would represent boreholes as complex 3D objects and include such data in a regional geotechnical database. **Camp** and Brown (1993) materialized GIS based well-log database and devised procedures for developing 3D sub-surface profile from borehole logs.

3.7.3 Data Integration

In construction industry information required for planning and design is stored in different forms, such as drawings, specifications, and bar charts. In planning process the planner has to

repetitively reorganize and interpret the information collected from various resources. This process is tedious and prone to errors (**Cheng** and Yang, 2001). Moreover, the failure or success of a building contract largely depends on *quality* and *timing* of the information available to contractors from the database. Thus, the industry requires a coordinated system which should be capable of integrating the whole data and provide the required information timely that will finally support various *decision making* and construction operations (**Hegazy** and Ersahin, 2001).

GIS is found to be helpful in *improving* construction planning and design *efficiency* by integrating spatial (locational) and non-spatial (thematic) information in a single environment. This technology supports the interaction of multiple participants such that they can approach problems in a more *comprehensive* and systematic way. It provides adequate capabilities for solving problems that involve the *integration* and analysis of large volumes of spatial and descriptive data from a variety of sources with a mechanism for rapid *retrieval* and manipulation capability. GIS can be used to *combine* and interpret data from many different formats. It allows integrating satellite images, CAD drawings, and parcel maps to create visual overview of a project and turn it into *easily understood* reports. It accepts CAD data without conversion and includes it as a layer.

Data management tools scale to meet your needs, from individuals to workgroups, and at large in multiuser enterprises. In addition to managing large volumes of geographic data, it also implements sophisticated business logic that, for example, builds relationships between data types such as *topologies* and geometric networks, and as well *validates* data, and *controls access*.

The database *management* capabilities of GIS to maintain construction database and its utilization for rate analysis are discussed by **Bansal** and Pal (2006b).

Seo and Kang (2006) proposed a GIS-based system for highway planning by integrating the design and construction information. CAD drawings, topographic maps and aerial photographs were fed into the system and integrated with the non-spatial attributes such as activity sequences, unit costs, production rates, and durations.

Jeljeli et al. (1993) identified potential applications of GIS in the construction industry and explored the benefits of using GIS technology in the contractor's prequalification process: the design phases, the bidding phase, and the construction phase.

- In the contractor's *prequalification* process contractors will have the capability to find the information they need by using massive amount of data stored in the GIS software as layers. Once the data layer is constructed, spatial and descriptive *queries* can be done through the GIS. For example, owners can select a contractor based on *specific criteria*, such as contractor's office location, labor type, and number of engineers.
- In the *design phase* topological overlay and proximity functions are very important in optimizing the construction site. In addition, site investigation in GIS can be done by finding "where a *geological structure* needs to be examined".
- In the *bidding phase*, the contractor needs information about such things as water, *access roadways*, utilities, and soil. All this information can be stored in the GIS, ready to be queried. Therefore, use of the GIS makes it possible for the contractor to gather the information needed to estimate his bid easily and at a lower cost than if the GIS was not used.
- The GIS tools and techniques can be also used in the *construction phase*. **Jeljeli** et al. pointed out that "different GIS techniques such as classification, *measurement*, *proximity*, overlay, and retrieval operations can be used to assess the suitability of particular equipment to a construction site."

Hence, integration of spatial database with project management functions provides a powerful and effective management control system.

3.7.4 Supply Chain Management

Jadid (2014) proposed a supply chain management (SCM) system meant to locate suppliers, manufacturers and distributors; and determine the *shortest path* from point of origin to the final destination so as to reduce construction costs, minimize time, and enhance productivity by means of mapping technology. GIS is incorporated to provide decision support in

successful monitoring of the movements and storage of materials, and to ensure that finished products travel from the point of origin to the construction destination site.

3.7.5 Construction Equipment Management

GPS and GIS integrated construction material and equipment management system is developed in such a way that a manager from headquarter and construction sites get *real-time* information to control cargoes on the road to the sites. Comparison of the non-integrated system versus the GPS and GIS integrated system suggests that the GPS and GIS integrated solution improves the construction efficiency by increasing the effective working hour of construction equipment thus reducing the construction duration as well as the cost of workforce.

Arrival of mixed concrete at the right place and at the just right time, while maintaining its quality, is very much important (Akintoye, 1995). That is why tracking and monitoring concrete transporting vehicles is important task for planners. For concrete plant operation concrete placing productivity is very much important. Densely populated and heavy loaded traffic conditions with other constraints like neighboring buildings and adjacent roadways make serious difficulties for supplying and placing ready mix concrete by maintaining its quality. Plant management need to know the respective urban area attributes, travel time, and vehicles productivity to deliver concrete. Lu et al. (2003) provided a simulation result for planning concrete production at plant, and later on quantitative analysis for concrete placing rates with its quality control for facilitating batching plant management (Lu et al., 2004).

3.7.6 Terrain Analysis: Cut-fill Estimation

Digital Elevation Models (DEMs) can be used in many engineering projects, especially those in civil engineering, to represent terrain's surface at the site. In addition, Triangulated Irregular Networks (TINs), which can help construction managers read a physical land surface in 3D view, is another GIS tool that can be used in construction projects. These two tools can drive other useful information, for instance *slope* and *aspect*.” The digital model of the construction site terrain is currently being used in several application areas such as volumetric calculations in *cut-and-fill* problems, *route planning* of vehicles for earthmoving projects, visualization of construction operations, and *site layout* planning.

Earthwork consumes significant portions of both cost and time in a highway project and therefore an optimum earthmoving plan is a valuable asset. **Hassanein** (2002) employed GIS to acquire and analyze spatial data to develop an optimum earthmoving plan. Earthwork was planned by analyzing haul routes in 3D using contours from digital topographic maps of the work site. Variations in the type of soil and presence of transverse obstructions such as rivers, valleys etc. along the project length were considered in the plan while optimizing the earthwork. The estimated cut/fill quantities and associated costs were also obtained for an optimized plan. The model employed ArcView GIS to carry out 3D analysis and Microsoft Access for database management.

3.7.7 Land Use /Cover Change Detection

Increasing pollution and natural disasters have become a challenge in our world. Many areas face pollution and deforestation. The unprecedented growth of urbanization has given rise to problems of housing, sanitation, water supply, disposal of effluents and environmental pollution. Systematic mapping and periodic monitoring of urban land use is therefore necessary for proper planning management and policy making. For sustainable development of urban agglomeration, optimal urban land use plans and resources development models need to be generated by integrating the information on natural resources, demographic and socio – economic data in a GIS domain with the currently available satellite data.

Manjula et al. (2011) used Geographical Decision Support System to make decisions for developing specific area. GIS was used to integrate information about an area to reach a solution that would solve complicated problems. Also, image classification was used to identify the changes in the study area. Finally, after collecting data from different sources and calculating the change, they found that “changes such as the reduced vigor of forest vegetation, urbanization, mining, etc. are noticed in the study area.”

3.7.8 Watershed Modelling

GIS improves calculations for watershed characteristics, and facilitates watershed delineation by using DEM. It provides consistent method for watershed analysis using DEM and standardized datasets such as land cover, soil properties, gauging station locations, and climate variables.

ArcGIS and Arc Hydro give engineers the ability to

- Create hydro networks of rivers and streams.
- Define drainage areas linked to a hydro network.
- Represent channel shape using 3D models.
- Connect geospatial features to time series measures at gauging sites.

3.7.9 Site Selection

Land use suitability analysis is the first step of any construction project. GIS quickly incorporates and analyzes many types of information and images for site analysis. Maps such as DEM and land use map, road network and drainage pattern maps, map of natural conservation areas, aerial photos, topographic and soil maps are required for analysis in identifying areas for a project site. Overlays of relevant data on population growth, commercial activity, and traffic flow are combined to rapidly paint a meaningful picture of site's *opportunities* and *constraints*.

Civil engineers use GIS to keep track of multiple urban and regional *indicators*, forecast future community needs, and plan accordingly to guarantee quality of life in livable communities for everyone.

Al-Shangiti (2009) studied how GIS can be used to evaluate environmental impacts of a dam construction. Many information layers, such as physiography and drainage; geology and structure; climate, soil, and land use/land cover were integrated in the GIS software, and a suitable site selection tool was used. By using all these information layers; first, Al-Shangiti determined the soil, land use, slope, and land irrigability, among other things, for the area. The finding was that the Dam could cause submergence of 17.55 square km, which included five villages.

Other example applications (**Tekalign** and Andualem, 2012):

- Identification of natural resource conservation area.
- Best site selection for gravity distribution water reservoirs
- Suitable site selection for urban solid waste disposal

3.7.10 Route Planning

It is a big challenge for engineers to find out appropriate route for minimizing construction cost and avoiding constraints in trench construction. In urban areas, a lot of obstacles come in the way, like existing utility lines (such as water supply, gas distribution, telephone, sewerage etc), railways, canals and roads. The presence of utilities influences the choice of the route significantly as there may only be a limited number of feasible crossing points. Selection of a suitable route from a limited number of feasible options to *avoid existing obstacles* in a path not only reduces the risk of damaging the existing utilities, but also minimizes the cost and duration required for construction. Otherwise, further facility construction damages the existing structure and eventually causes delay on construction work. This problem happens basically because of the lack of spatial information; since superimposing different layers manually to solve conflicting points is very difficult. Nevertheless, GIS can provide spatial and attributes features of locations and so many problems can be solved by using it.

The study by **Cheng** and Chang (2001) discusses the development of GIS-based system to automate the process of routing and design of an underground power supply system. They used network analysis for optimal path determination to select best routes.

Jusoff (2008) studied how GIS, based on decision support system, can be used to select a suitable new road in a forest. Jusoff considered three basic parameters in his research: (a) timber volume, (b) slope, and (c) ground condition. With this information, values were assigned to each pixel (raster cell), and then the Raster Calculator function was used to find the best route with less timber harvesting impact.

3.7.11 Networking Solutions

Networks are used to describe a connected graph of GIS objects. It can be used to model transportation pathways, drainage lines, pipelines, utilities, and many other network-based applications.

GIS can also be used in network analysis like determination of shortest path and route planning of vehicles at a site (**Cheng & Chang**, 2001; **Varghese & O'Connor**, 1995). Other example application areas (**Tekalign** and Andualem, 2012):

- Social infrastructure management: Spatial accessibility to service area centers
- Finding closest fire stations for fire incidents
- Finding best route using network dataset

3.7.12 Site Layout

Construction space is an important part of construction resource—the same as time, labour, material, plants and cost (**Zhang** et al., 2001). A construction site has space restriction for resource management. Deficiencies in space planning result in a congested jobsite, loss of productivity, space conflicts, and schedule interference or delay. Owing to the vast amount of data that is associated with the execution of a construction project, it is practically impossible for project managers to specify spatio-temporal data involved to represent *workspaces* in four dimensions manually. Traditional methods to resolve space conflicts lack features such as topography modelling and geospatial analysis which could enhance space planning. Visual and intelligent management of construction sites has become an urgent need. Consequently, the research in this area becomes a hot spot. The construction industry has acknowledged that its current working practices are in need of substantial improvements in quality and efficiency. To increase work productivity and safety in work place, efficient space management is essential which can be achieved by 3D visualization with the help of GIS.

Topographical features outside the constructed building are important in space planning. For example, space planning for gravity dam construction where topography plays a major role cannot be simulated without geospatial capabilities which are missing in a 4D CAD system, and yet are available in GIS.

A suitable location for material storage has influence on labor *productivity* and can help reduce time, cost and minimize defects and problems of on-site construction (**Rajesh** and Navaneethakrishnan, 2012).

Different studies have suggested effective jobsite layout planning by *minimizing the travel distance* between various temporary facilities. As a mainstream application in the area of construction industries, **Cheng** and O' Connor (1996) developed an automated site layout system called ArcSite that assists designers in identifying suitable areas to locate temporary

facilities in a construction site. ArcSite integrates the information required to perform series of complicated spatial operations and database queries to identify *optimal site*, which is quite difficult to perform manually.

The work of **Guo** (2002) highlighted that space management involves three aspects of research: jobsite *layout* planning, *path* planning and *space scheduling*. Path planning focuses on the path-length optimizations for construction equipment and operations (**Varghese** and O'Connor 1995). They also mentioned that the benefits of 4D CAD system is to visualize assembling steps of construction project and simulate different scenarios before construction and helps engineers for constructability analysis of design.

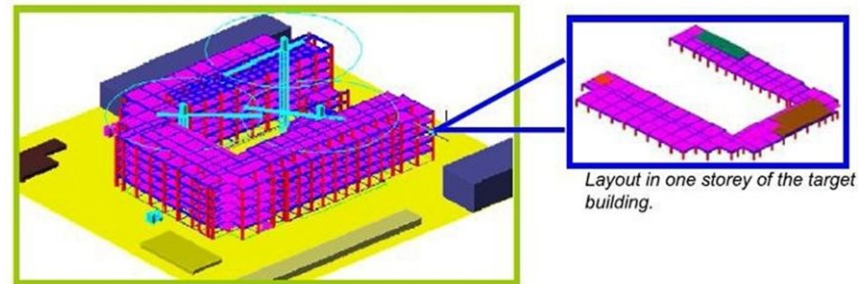
GIS is helpful to estimate the cost of a project by selecting *cost effective* places for material storage at a construction site. **Akinci** et al. (2002) came up with the concept of '*work space planning*' that implies representing various types of spaces required by construction activities in 3D over a time scale. **Cheng** and Yang's (2001) developed proximity index for optimal site selection to manage cost effective space for the material storage; and for this purpose they introduced a GIS based tool called MaterialPlan. Based on the information regarding quantities and locations of the materials required in the project, the proposed methodology identifies suitable site to store the materials. MaterialPlan proves that GIS is a promising tool for solving materials layout problems and opens a new way of thinking in the management of spatial information for construction planning and design using a GIS.

Bansal et al. (2011) used 4D GIS for space planning utilizing its topographic modelling, geospatial analysis and database management functions. They support their reasons for choosing GIS for space planning over other modelling techniques because it has a matured spatial analysis tool.

Determining the location of temporary facilities involves *proximity relationships* among the temporary and permanent facilities. The closeness relationships such as "close to", "far from", and "next to" represent the site layout objectives in *minimizing the traveling time* and improving safety. *Far from* (as opposed to close to) is usually applied for the facilities that have an impact on safety issues (e.g. electrical equipment and possible sources of sparks should be located far from flammable material). Formwork is placed *next to* concrete element.

Also, some relationships can be represented in a quantitative manner such as “*within specified distance*”. It is necessary to locate the supply points within operating radius of a tower crane.

Figure 5 shows examples of the analysis results of the GIS and Building Information Modeling (BIM) for “scaffolding” (as a structural support) and “tower crane” (as equipment).



A sample site layout with storages, mixers and cranes which also contain schedule information.

Source: Zhaoyang et al. (2005)

Figure 5: Site layout management system of a construction project

A concrete batching plant is one of the temporary facilities that has significant impact on production cost (e.g. material delivery cost), especially in the case of large projects requiring high concrete volumes, or when transportation distances are too great for the supply of ready-mix concrete. Ideally concrete batching plant should be located *as close as possible* to their demand points to reduce travel time.

3.7.13 Infrastructure Management

GIS is a powerful framework for monitoring the use and distribution of assets and tracking location ([www.esri.com/ engineering](http://www.esri.com/engineering)).

Jabbar (2011) neatly mentioned the flexibility of GIS in managing civil engineering projects at *all stages*, namely, planning, data collection, environmental analysis, design, construction operation and maintenance stages as follows:

- *Planning*: It contains high-level planning functions for site location including data overlay, economic analysis, alternative site analysis, routing utilities, what-if scenarios, modeling, and cost/benefit alternatives analysis.
- *Data Collection*: GIS provides the tools to collect precise site data, to design and calculate; and as well to document existing conditions.

- *Environmental Analysis*: It provides analysis to support design including environmental impact analysis, hydrological analysis, soil load analysis, slope stability, runoff, erosion control, materials consumption, volume calculations, and traffic capacity.
- *Design*: It allows creation of new infrastructure data for new civil works including grading, cross-sections, design calculations, mass haul plans.
- *Construction*: It provides the management for building new infrastructure including schedules; takeoffs; materials tracking; volume and payment calculations; earth movement; machine control; and traffic management.
- *Operations/Maintenance*: Spatial selection and display tools allow you to visualize scheduled work, ongoing activities, recurring maintenance problems, and historical information.

With an ability to communicate changes to an entire team rapidly, GIS gives your team access to the most current information supporting better decision making.

3.7.14 Critical Infrastructure Protection

Engineers responsible for safety and security of buildings, bridges, utilities, and other critical infrastructure need comprehensive decision-making tool for emergency assessment, preparation response, and recovery activities. One can use GIS tools to combine and analyze specific data needed to meet a required task to add current traffic and weather data, to draw *buffer protection* zones, and share new changes in real time ([www.esri.com/ engineering](http://www.esri.com/engineering)).

3.7.15 Quantity Takeoff

Quantity takeoff is a part of cost estimating process in the construction industry. The automation of cost estimation facilitates in decision-making and creative thinking by allowing designers to quickly recall and review issues relevant to the task at hand (**Saleh**, 1999). CAD systems are also capable of generating material requirement and can be used to produce quantity takeoffs (**Cheng & Yang**, 2001; **Saleh**, 1999).

GIS-Based quantity takeoff methodology *reduces errors* like missing or duplicating various items of work by *visualizing* each component in 2D or 3D space and *calculating* the size of

the work items. Thus, it is helpful in increasing the *productivity* of quantity estimator by reducing the manual work in determining the quantity takeoff.

Cheng & Yang (2001) explored the capabilities of GIS in combination with other software for cost estimation. This study changed the manual process of cost estimating to automatic computer-aided process by taking quantity of materials using GIS and developed dynamic material requirements plan (DMRP) which means requirements of material with respect to construction schedule progress. MaterialPlan uses GIS in combination with CAD systems to compute quantity takeoff as well as to generate BOM based on the dimensions of the design drawings by using MapInfo and Microsoft Access. The user communicates with the components of the system through a customized interface developed using Visual Basic Application (VBA) and MapBasic. Open Database Connectivity (ODBC) was also used to write/read the information to/from the associated database.

Recently, **Bansal and Pal (2007)** suggested the use of GIS for cost estimation in a more generalized way by adding new scripts into GIS environment for various cost estimation operations, which allows users to communicate through an interface developed within GIS environment. ArcView, which utilizes the dynamic linkage between the spatial and attribute data, was used for this purpose without ODBC requirement.

3.7.16 Construction Scheduling

Before starting a construction project the schedule of different activities are prepared to achieve its target deadline. A planner makes schedule in such a way that all components of the project must have related activities. Schedule in GIS displays at ‘what time’ and ‘where’ in the space the components are to be built. This can be achieved easily with user friendly Bar chart technique.

Scheduling results in providing critical path for a project. The duration of the project is the sum of the activities duration in the critical path. Delay in these activities will directly affect the duration of the project. So, resource allocation for the critical activities is very much essential for time management. Thus, it will enable to complete the project under the proposed completion time.

3.7.17 Progress Monitoring

Planners make construction schedule in such a way that all components of a project must have related activities. By viewing the schedule, it becomes quite difficult to determine whether the schedule is complete. Confirming that all components of the project have related activity is a time consuming process because of the large number of activities in the network. **Zhong**, et al. (2004) suggested that GIS can be utilized to overcome these limitations. It will allow construction managers and different people involved in a project with different backgrounds to get information about the progress of the project and support decision making.

Owing to the fact that traditional scheduling and progress control techniques fail to provide information pertaining to the spatial aspects of a construction project, **Poku** and Arditi (2006) developed a system called PMS-GIS (Progress Monitoring System with GIS) to represent construction progress not only in terms of a CPM schedule but also in terms of a graphical representation of construction that is synchronized with the work schedule. In PMS-GIS, the architectural design is executed using CAD program, the work schedule is generated using project management software, and the design and schedule information were plugged into a GIS package. The progress data was regularly fed into the system and compared with the planned schedule.

Similar to this work, **Cheng** and Chen (1997) 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 cost. The system ArcShed was meant to assist engineers in the erection of prefabricated structures which is the most important activity in a precast construction; hence, the manufacturing and transportation schedules were planned based on the installation schedule.

Moreover, **Dierkes** and Howard (n.d) studied integration of GIS into pipeline construction inspection and management. GIS was used to track and manage construction progress so that project-related data could be queried and analyzed. They stated,

“The most important benefit of digital tracking of pipeline construction projects is that integration of GIS and GPS technology will reduce the amount of administrative time

spent by inspectors and management on the project; and better communication will be provided to stakeholders”.

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. **Nejatbaksh** (2008) created a tool that utilized GIS based management in monitoring and scheduling a tunneling job. Hence, visualizing construction progress in 3D provides the construction project manager with a more intuitive view of the construction sequence.

3.7.18 Animation of Construction Process

As the construction projects are becoming more and more complicated, software with ability to convey the physical configuration of the construction project accurately are required (**Songer**, 2001a). With the developments in computer hardware and software, animation is playing key role in the demonstration of these complex processes. Computer animation has the ability to present concepts in a form that *resembles physical and real images* quickly and effectively. It also makes it possible to move through 3D components sequentially according to the schedule.

Animation of construction project sequence may allow participants to improve *communication* as well as exchange their ideas. The visual representation of the construction sequence through animation requires low level of *interpretation* skill than conventional 2D drawings used in construction industry and is expected to help industry practitioners in understanding the schedule in a much better than the 2D drawings (**Bansal** and Pal, 2008). Such effective communication among project participants may also lead to the substantial improvement of *quality* and *productivity* in construction industry (**Songer** 2001b).

It is observed from the actual building information on site and building simulation model that some overlapping and *rework can be avoided* through GIS based 4D model development (**Bansal** and Pal, 2005; **Naik** et al., 2011).

3.7.19 Internet GIS for Construction Material Procurement

With ArcGIS Server technology, you can take maps that you have created with ArcGIS and publish them over the Web; so you, your partners, and your staff in the field can see how a project is progressing. **Doyle et al. (1998)** was of the opinion that modelling and planning was meant to aid the decision making process to assist in the conveyance or *dissemination* of ideas. In this work, the potential of Web-oriented GIS and VR software was reviewed with particular reference to the disciplines of planning and urban design along with the ability of web to serve as a *dissemination mechanism*.

GIS can be used to assist highway departments by tracking multiple construction projects and for providing Internet-based notification of road closures. As to cost, finding economic way of vehicle transport for goods distribution is very important. In all e-business activities transportation cost is involved, so spatial information plays essential role. Now-a-days GIS is proved very important tool for e-commerce in material procurement.

Li, et al. (2003) presented an Internet-based GIS model for e-business of construction material procurement that is used when the link between buyers and suppliers is through electronic markets. GIS has great potential to be made use of in e-commerce systems to provide better services in location-based queries, business area analysis, and transportation facility analysis to proceed with economic procurement of materials. The e-commerce system, called COME (construction materials exchange) was thus developed which can be used for on-line order and off-line delivery of different construction materials. The electronic market provides a platform for the suppliers to provide online information about their products. Buyers can easily search and compare products of different suppliers through online system and contact the suppliers directly.

Yang et al. (2000) found that internet based business provides *efficient* business related information in addition to *effective* way of goods supply. Thus, internet-based GIS provides an ideal solution to manage costs of transportation and market analysis in the overall e-commercial activities. The costs for transporting construction materials are not only dependent on the distance but it may involve many other variables, such as the reduced shipping costs because of combining shipment to various buyers in the same area.

Summary:

From this literature review, the study found that GIS is used in almost all areas of construction engineering and management. It makes the life of engineers and planners easier by saving time, money with ensured quality of project, and also saves human resource from hazards. Most noticeable areas such as, 4D planning, construction space management, labor, equipment and vehicle tracking, and e-commerce for material procurement are found very efficient by GIS based construction management system.

Some of the applications mentioned in this unit are detailed in the research methodology section of the research paper.

3.8 Integration of Software

3.8.1 BIM Vs CAD

3.8.1.1 What is BIM

BIM is an emerging approach to the design, analysis, and documentation of buildings. At its core, BIM is about the management of information throughout the entire life cycle of a design process, from early conceptual design through construction administration, and even into facilities management. By *information* we mean all the inputs that go into a building design: the number of windows, the cost of materials, the size of heating and cooling equipment, and so on. A building information model is a project simulation consisting of the 3D models of the project components with links to all the required information connected with the project's planning, construction or operation, and decommissioning.

This information is captured in a digital model that can then be presented as coordinated documents, be shared across disciplines, and serve as a centralized design management tool. With a tool like Revit, you will reap the benefits of fully coordinated documents, but this represents just the tip of the BIM iceberg.

3.8.1.2 How BIM Is Different from CAD

The key difference between BIM and CAD is that a traditional CAD system uses many separate (usually 2D) documents to explain a building. Because these documents are created separately, there is little to no correlation or intelligent connection among them. A wall in a plan view is represented with two parallel lines, with no understanding that those lines represent the same wall in a section. The possibility of uncoordinated data is very high. BIM takes the opposite approach: it assembles all information into one location and cross-links that data among associated objects. The BIM model, by contrast, is a centralized database model. All documents within the BIM model are interdependent and share intelligence (Tatjana, et al., 2010)

3.8.1.3 Why Revit?

Revit is the most technologically advanced BIM application. Currently, a number of BIM applications are on the market, provided by a host of different software vendors. While most other BIM applications in today's market are based on technology that is 20-plus years old, Revit was designed from the ground up as a BIM platform to specifically address problem areas of the architecture, engineering, and construction (AEC) industry: communication, coordination, and change management.

In CAD, users have to do a lot of manual updating (and remember to do it). By contrast, Revit understands when a change happens and does the entire sequence of changes (updates) automatically without any additional effort on the user's part.

3.8.2 CAD Vs GIS

3.8.2.1 Their Difference and Similarity

Civil Engineering projects involve the management, integration and analysis of large amounts of geographic information to ensure success. This can include a wide range of information such as detailed design drawings originating from CAD solutions. CAD can be described as the use of computers for creating and editing drawings. CAD tools enabled users to create precise geometric objects and edit them with no loss of *precision*. Because CAD comes from a world where engineering tolerances of fractions of a centimeter are important, full attention is given to managing data without losing precision. GIS is a *database centric* tool, thus, handles spatial and attribute data on a single platform. While CAD systems focus primarily on buildings/ structures and the creation of *construction documents*, GIS systems focus on *geographic* (land-based) information and the analysis of that information as a basis for the design and assessment of civil infrastructure.

At their core, CAD and GIS are complementary technologies that have evolved largely independently but in parallel over the past 30 years. ESRI's longtime best-of-breed approach provides value to engineers by building better linkages between CAD and GIS systems (Tim, 2001).

Table 1: Correlation between CAD and GIS Data Organization

<i>Data Organization</i>	<i>CAD</i>	<i>GIS</i>
Layers:	CAD software saves the data in a layer model in order to create data groups of the same distinction – such as color, line thickness, etc. as vector objects such as, line, arc, hatch etc.	GIS data are mostly kept in a layer (roads, buildings, etc.) as geographic features such as a point, a line and a polygon.
Database	CAD data is saved mostly in files (such as DWG files).	One of the most common methods of saving GIS data is in a "Geo-Spatial Database".

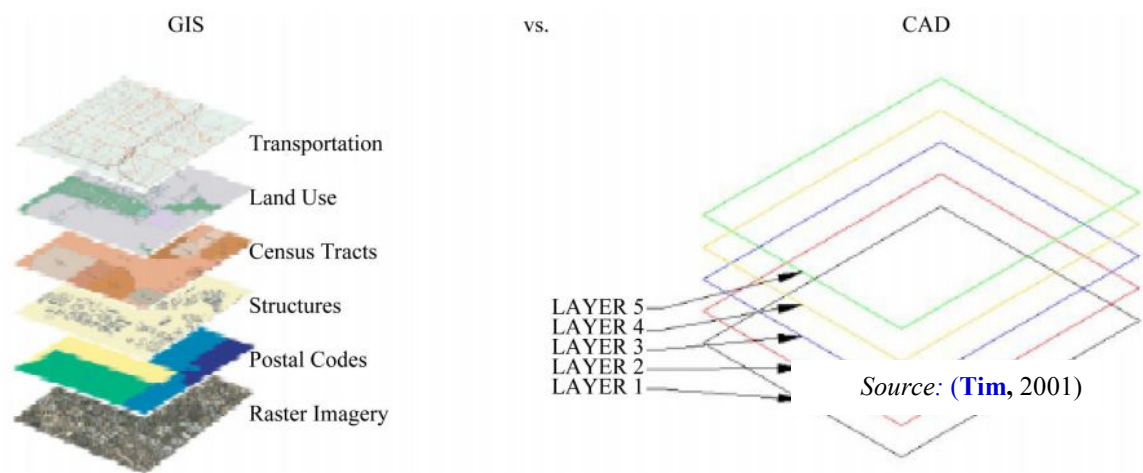


Figure 6: GIS Vs. CAD

Table 2: Differences between CAD and GIS

<i>CAD</i>	<i>GIS</i>
CAD is a graphics program	GIS is a database program
It's the lines that are important, i.e. the drawing is the information.	The lines are just a representation of the data behind it (Figure 6)
CAD developers consider their work as engineering based with powerful precision entry and editing tools for design.	GIS staffs often view their work as small-scale and cartographic in nature rather than being focused purely on engineering.
CAD models artifacts yet to be produced	GIS models the world as it exists.
The CAD systems are unable to aggregate and distribute the information between spatial and non-spatial databases.	GIS can perform different operations on attribute data that is synchronized with 3D model, which is not possible in case of CAD technologies.
Traditional CAD packages lack the	GIS systems provide only some basic

<i>CAD</i>	<i>GIS</i>
capability of truly analyzing spatial data provided by GIS (checking the connectivity, adjacency, proximity, buffer, etc.).	drafting and designing capabilities as compared to the CAD systems.
CAD technologies do not have project management capabilities and are used primarily for planning and design phases of the project.	GIS is used in all stages of project management [See Chapter 2.7.3]

Despite its many capabilities, a standalone GIS is insufficient to meet the demands of the latest crop of infrastructure design projects. While it would clearly meet the informational needs of such applications, it lacks the *graphical design* functionality of CAD. The CAD layers organize the spatial data only to facilitate the drafting process, while in GIS various spatial operations on graphics and non-spatial operation on the attribute data are possible. GIS technology uses data (i.e. non-spatial) synchronized with the 3D modeling which is not possible in CAD technologies.

3.8.2.2 Need for Integration of CAD and GIS

Despite their distinct roles, planners and engineers very much depend upon each other to conduct their work. Planners (GIS users) need accurate information on as-built conditions, while engineers and architects (CAD users) need the context of plans to create their designs. Operational staff needs access to all of this information. The work is not static but *synergistic*, dynamically integrated, and recursive (“**Bentley** ESRI AEC GIS Interoperability”).

This *integration* of CAD with GIS can thus help solve many of the issues regarding *interoperability* between different project participants. An integration effort in this direction will help project participants in *understanding each other’s role*, as well as work in the direction of creating complementary ideas which will fit each other’s plans, and ultimately helping the end-users and decision-makers who are best served by integrated information systems.

3.8.2.3 Complementing the Software

How Does GIS Integrate with CAD? On the surface, the two technologies go together like “cookies and milk”: each has something that the other doesn't, but together they make perfect

combination. In recent years, there have been a number of efforts on the software front to facilitate CAD/GIS integration. In addition, some traditional CAD packages have taken on certain aspects of GIS functionality, such as database-management capabilities, and some GIS tools have added such CAD functions as 3D projection. Such CAD systems pretending to be GIS suffer from poor handling of object attributes, limited and slow database links, and rudimentary spatial analysis and cartography capabilities. GIS trying to be CAD systems are often accused of having *limited* drafting capabilities.

Software developers are now creating tools which are crossing the border between CAD and GIS but enable both disciplines to continue working in a familiar way providing direct access to data, regardless of how it is stored, and enabling the use of CAD tools for maintaining a variety of geospatial information.

☛ **CAD Integration:** Data Interoperability extension of ArcGIS provides additional functionality for integration of the software. ESRI provides two solutions for CAD interoperability (**Solutions** for Civil Engineering) - CAD direct read and bidirectional transition. As to CAD **direct read** functionality, ArcGIS has the native ability to read a variety of CAD data formats without conversion, including DWG, DXF, and DNG files, as layers in ArcMap. ArcGIS symbolizes the data as defined in the CAD file.

Bidirectional translation involves the conversion of CAD data to a GIS data format and vice versa which facilitates data sharing, and assist with the migration of CAD data to multiple users. It can also export selected GIS features (points, lines, polygons, and annotation) to CAD. This enables organizations to incorporate CAD data into an existing GIS and deliver spatial information in a CAD format.

☛ **ArcGIS for AutoCAD:** ArcGIS for AutoCAD allows you to visualize and query GIS data in AutoCAD without conversion. With ArcGIS for AutoCAD, you can:

- Include GIS base maps in your CAD products.
- View live GIS maps and display GIS symbology of all underlying GIS data structures in CAD.

- Define the coordinate system within AutoCAD to automatically project maps on the fly without transforming CAD drawings or converting GIS data.
- Include GIS analysis results in your CAD designs

In the methodology suggested by **Poku** and Ardit (2006), drawings generated in AutoCAD can be utilized in GIS. In addition to this, the system is made more user-friendly by utilizing the drafting capabilities of GIS itself. The major advantage of the editing capabilities of GIS is that, if during the schedule evaluation stage the constructed 3D components do not comply with the desired construction, the editing can be done in GIS itself.

3.8.3 MS-Project Vs GIS

The most popular software for scheduling and management is MS- Project. It provides many functions such as scheduling, network analysis, critical path determination, and data sorting among others. And also it has sufficient functions to help users plan for *time*, *resources* and *cost*, and then *monitor* them later.

In most of the construction projects, CPM networks and bar charts are widely used to represent schedule. Different activities of the network are related to one or more components of the project under consideration. However, the construction schedule prepared using MS-Project is not capable of pictorial representation. Bar charts and networks provide *non-spatial* information that lacks in spatial aspects of the construction activities. Thus, to have spatial aspects of the project, a construction planner uses a 3D drawing and associates its different components with the related activities present in the schedule (**Cherneff**, 1991).

The pieces of information such as drawings, specifications, and CPM networks required during planning are in different forms, which make it difficult to *mentally integrate* them during the planning phase. Further, there is no *dynamic linkage* between the schedule and its spatial aspects in the commercially available scheduling tools. Interpretation of the schedule without any link of its activities with the corresponding spatial components is cumbersome because the actual project may contain hundreds of activities. This makes the CPM schedule difficult to check for completeness. Interpretation of the schedule may vary with the experience of persons involved due to the difficulty in mentally linking each element in a 2D

drawing with the corresponding activities of the schedule, thus making it difficult to understand, communicate, and discuss whether a problem exists in the schedule or not (Koo and Fischer, 2000). This creates a gap in effective communication among different project participants. Hence, there is an increasing need for a modern method for planning and scheduling of a project with real-time monitoring.

Koo and Fischer (2000) suggested that the construction industry requires a tool that can manipulate the schedule and 3D components in a single environment. Few attempts have been made in the past to interlink project management software and GIS so as to reap the benefits of both applications, as visualization of information is an important benefit for any project. MS-Project gives us a detailed plan & schedule of the works to be accomplished. If this schedule is complimented with a pictorial representation from GIS it can create very effective platform for executing as well as monitoring projects (Raiyan, 2016).

3.8.4 4D and 5D Models

3.8.4.1 What is 4D?

Usage of conventional project management software tools for explaining the status of a vast project to parties involved in construction is not up to the mark. Direct usage of schedule sheets prepared from conventional tools with drawings is difficult to follow the schedule activities. In project planning phase, most of the discrepancies creep in due to misconception of reality, misinterpretation of the design and progress in 3D. A solution to interpret the 3D is offered by different 3D modelling software packages - like AutoCAD.

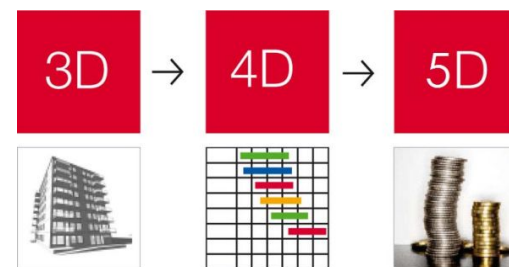


Figure 7: 3D Vs 4D Vs 5D

The concept of 4D modeling is proposed as the traditional instruments of project management had very limited linkage with the spatial aspects of construction works. The 4D modelling concept is all about four dimensional modelling, that directly refers to 3D of **space** (a 3D model) and one dimension of **time** (progress of the work), which makes possible to visualize how the building and site would look like at any point in time by simulating the construction

process. 3D model of a project with schedule which is termed as **4D** management system has been proved beneficial for construction project management.

Platt (2007) generated surface model of existing land conditions and overlaid it by the design of an interchange keeping both horizontal alignment and vertical profile intact. The 3D model and the construction schedule were imported to the 4D software. One of the major limitations of the 4D is the *manual linking* of components of the 3D model to the schedule activities. Its automation would be a great help for future research and implementation. **Staub-French, Russell, and Tran** (2008) partially addressed this challenge by allowing two-way flow of data between the schedule and the 3D model.

Jongeling and Olofsson (2007) developed a 4D model using Line of Balance (LOB) as the scheduling method. The developed 4D visualization could provide a clear insight into the spatial configuration of scheduled activities helping in uniform distribution of activities in different locations of the project for enhanced efficiency.

3.8.4.2 4D CAD Model

The limitations of the CPM schedule forced researchers to combine construction schedule with 3D CAD model that leads to the development of a 4D CAD model. It provides the ability to represent construction plans graphically, by adding temporal dimension to 3D CAD model, i.e. linking a 3D graphical model to a construction schedule, through a third party application. **Koo** and Fischer (2000) suggested that a 4D model *increases comprehensibility* of the project schedule and allows users to detect potential problems such as scheduling conflicts prior to the construction. The use of 4D CAD assists planners in examining constraints, and evaluating alternative construction methods (**Akinci et al.**, 2002).

Heesom et al. (2004) highlighted the fact that most of the earlier 4D CAD simulations concentrated in visualization and aesthetic purposes only and very few packages offer ability to carry out *analytical tasks* on the developed simulation. The existing CAD systems are unable to aggregate and distribute the information between spatial and non-spatial databases and so far there is *no standard procedure* for using 4D CAD technologies (**Heesom & Mahdjoubi**, 2004).

Liapi (2003) developed a 4D CAD model by linking 3D models of highway geometry with construction schedule and traffic control plan. Three-dimensional models of highway elements and the surrounding area were developed and linked with activities of the construction schedule. Such a model helps project engineers and contractors to plan the construction process in the presence of prevailing traffic conditions. **Shah**, Dawood, and Castro (2008) developed a 4D visualization model for earthwork operations in highway construction. The earthwork was scheduled using the calculated cut/fill quantities and the productivity rates of earth moving equipment. The work progress was visualized in terms of the heights at various sections at different times in the developed 4D model.

3.8.4.3 4D GIS Model

Four-dimensional planning system is a powerful visualization, simulation and communication tool that provides simultaneous access to design and schedule by visualization, graphical simulation of work plan and communication tool to facilitate decision making by identifying problems at early stages (**Williams**, 1996). **Poku** and Arditi (2006) used AutoCAD and P3 to generate construction design and schedule, respectively, and both were linked in ArcView. The proposed methodology can also read the schedule generated in P3 but if the resulting 4D model does not comply with the actual construction sequence, the schedule generated in P3 cannot be corrected in GIS. To get rid of this problem an in-house script to develop the CPM schedule within the GIS environment is used in the proposed methodology.

The study of **Bansal** and Pal, (2008) created a dynamic relationship between schedule and corresponding 3D components which ensure problem detection in *logical errors* in work sequences. In this GIS based study they developed a facility that enables to manage spatial and non- spatial data of construction projects in a single platform which is only possible by introducing a GIS application. [See Chapter 4 for details].

3.8.4.4 5D GIS Model

Five-dimensional model (**3D + time + cost**) requires project cost to be integrated with the 3D model (*space*) of the building, making it possible to forecast and track the project *cost* throughout all the *phases* of construction. The researcher could not find a thorough discussion of 5D GIS modeling in the reviewed literatures; nevertheless, it is the **main purpose** of the research paper [See Chapter 4].



CHAPTER 4: RESEARCH DESIGN AND METHODOLOGY

In this chapter, research methodology is reviewed to find the methods that fit the purpose of the research at hand. First, types and approaches of research are identified, explaining the methods chosen in this research project. It concludes with a description of the process of collection and analyses of data.

4.1 The Research Design

4.1.0 General

The *purpose* of a research determines the type of research and the type of design to adopt. Appropriately chosen method is important to guarantee creation of knowledge and validation of effective research. It enables to set a system which is defendable and reproducible. In this thesis the research approach to the solution of the research problem is systematically tracked from Literature Review.

4.1.1 Research Method

The research method used employs a *quantitative* research approach by using different data collection methods to measure dimensions of building elements.

4.1.2 Study Population

The population under study is small residential buildings. As the study is in its infant stage, the proposed methodology is implemented on a single-story residential house.

4.1.3 What Data is Needed and How to Collect It?

Traditionally, the common data collection methods are literature search, document analysis, surveys, visiting a state-of-the-art project, interviews, and others (**Preisner**, 1985). For example, civil engineers or surveyors collect property boundaries, contours, and existing structures. Many site features may be obtained by digital data by using GIS tools.

The following are among the documents used for the study:

- AutoCAD drawings used as the base for measuring dimensions of the building.
- Specifications for BOQ preparation.

- Excel templates for estimation of materials and labour requirements with known productivity rate, and also for cost estimation (Source: **BATCODA**).

4.1.4 Data Input and Conversion

Different kinds of data such as graphic, non-graphic, and existing digital data is required to develop and reformat in the database. These graphic attributes in AutoCAD include layer name, entity type, entity color, etc. A layer's name is used to determine the graphic elements, which means all the graphic elements with the same layer name in the CAD file will be converted to a certain *feature class* in ArcGIS. Elements representing building's fence, for example, are classified in the layer named as "fence".

4.2 Software Used for the Study

Major software such as AutoCAD, MS-Excel, ArcGIS and Visual Studio are used to implement the methodology.

- *MS Excel*: Advanced functionalities of MS-Excel (such as VLOOKUP, HLOOKUP, Roundup, IF conditional expressions) are used for scheduling purpose among others.
- *AutoCAD*: Civil engineers, drafters and surveyors use AutoCAD software for civil engineering design and construction documentation. The plan, elevation, section view; and as well side and rear views of the drawings are used with their respective dimensions.
- *Arc GIS 10.3*: This software package with its extensions like 3D Analyst provides varieties of interoperability modes. ArcGIS allows one to view spatial data, create maps and perform basic and advanced spatial analysis.
- *Visual Studio Ultimate 2010*: Visual Studio which allows different programming languages such as Visual Basic, C#, and etc. can be further used create the run-time application named as "5D Construction Monitoring Application".

4.3 Spatial and Non-Spatial Operations

4.3.0 General

Location information includes spatial features such as coordinate, area, perimeter and spatial relationship that are derived from shapefiles (or feature class). *Thematic information* includes

identification code, beam number, floor number, etc, and is entered by the user. Location and thematic information are integrated by using one-to-one, one-to-many, and many-to-many relationships.

4.3.1 Spatial Operations

4.3.1.1 Editing Features

ArcGIS also contains tools to handle editing session (ArcGIS 9, 2004). The editing functionalities of ArcGIS used in this study are:

- The in-built functions such as *copy parallel*, *move*, *delete* and etc. that can be applied to one or more selected features.
- The *vertex edit tool*, *sketch tool* and *midpoint commands* can be used for drawing and reshaping lines and polygons.

4.3.1.2 Splitting Features

The ability of GIS to maintain data in separate layers which can be superimposed spatially based on the same geographic reference system is utilized in this study.

The *split* tool may be used to subdivide a polygon into two or more polygons. The *Erase* tool removes overlapping areas of input feature classes. The output feature class only contains features or parts of features that do not intersect with the erased feature class.

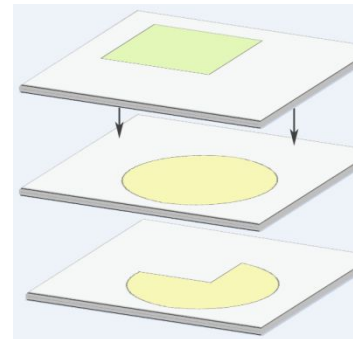


Figure 8: Erase Tool

4.3.1.3 Grouping Features

The *dissolve*, *append or merge*, and *union* functions group features of a layer into one feature.

a) Dissolve

A dissolve combines features within a data layer if they share the same attribute. This process is used to remove boundaries between adjacent polygons that have the

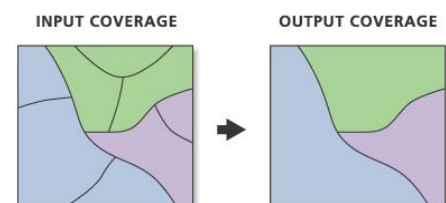


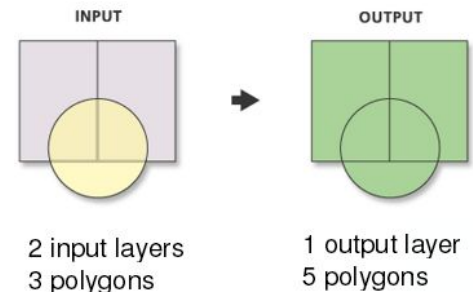
Figure 9: Dissolve Tool

same values for a specified attribute as in Figure 9.

Dissolve also combines selected features of the *same layer* into one feature. When features are non-adjacent, a *multipart* feature is created. For example, you could dissolve individual islands to create a multipart polygon feature.

b) Append or Merge

Append and merge allow feature classes with the same feature type to be combined as a single feature class. **Appending** operation allows appending the data of one layer with another. The append function is used to combine the features of two or more layers and place them into an existing target feature class.



Merging is used to create a new layer by piecing together *two or more layers* of the same geometry type (e.g., points, lines, or polygons) as in Figure 10. The output layer encloses fields from the input layers. When merging, you choose which feature's attributes are preserved during the operation.

Figure 10: Merge Tool

c) Union

Union does preserve the entire feature of the different layers. The output of the tool contains features and/or parts of features representing areas of unique intersection, as well as features and/or parts of features representing no intersection among all the features in the input feature classes. Union produces a new layer containing features and attributes of two input polygon layers.

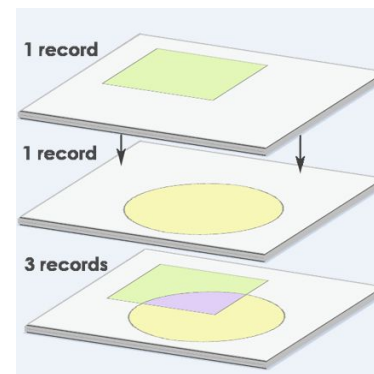


Figure 11: Union Tool

Note that where there were overlapping polygons, new polygons are created for each sub-region. It only works with polygons.

Sample Applications:

■ Figure 12 contains five walls (polygons) having the same attribute value (thickness), which are dissolved into one using the *dissolve* option, where thickness (written in the attribute table) would be the attribute on the basis of which dissolve works. Dissolve creates a new layer with one wall, where each wall being dissolved has the same thickness. Dissolve can also join non-adjacent features to create one feature. For example, non-adjacent windows in a layer, if dissolved, create a *multipart polygon* feature.

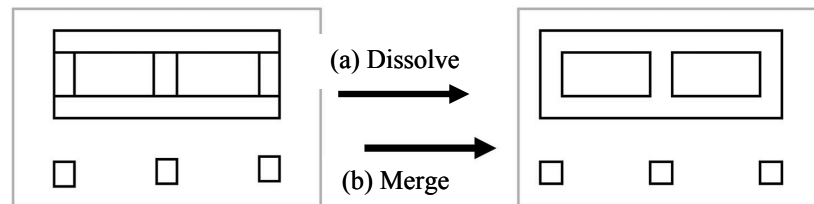


Figure 12: Dissolve and Merge

In Fig. 12 (a), dissolve removes the boundaries between adjacent polygon features, and in (b) the three non-adjacent columns (square polygons) in the same layer are merged to create a multipart polygon feature.

■ In Figure 13, two polygon layers combined by using union are walls (four polygons) and door (one polygon). The result will be a new layer that contains the spatial combination (six polygons) of information.

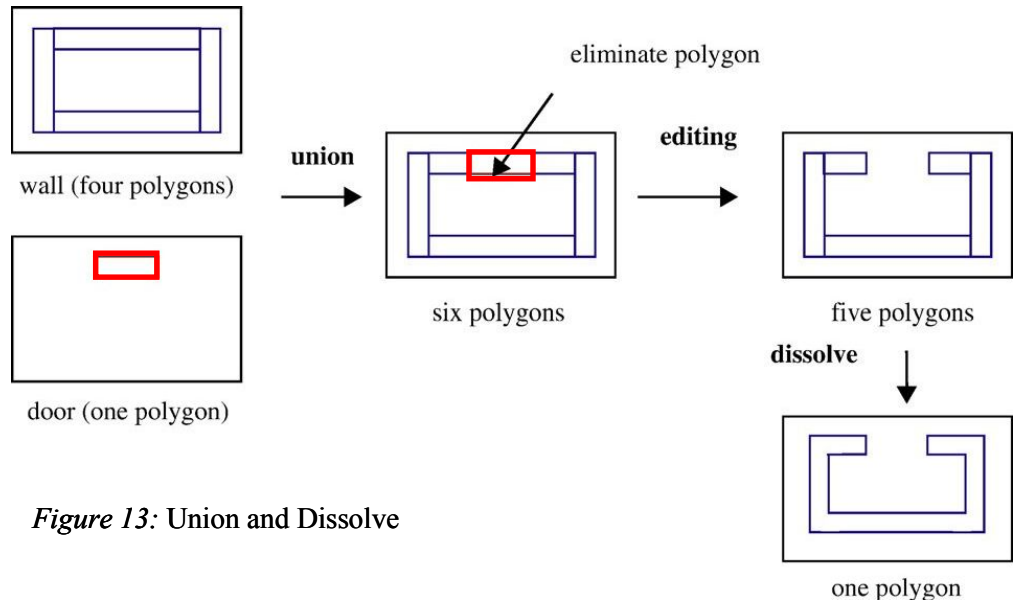


Figure 13: Union and Dissolve

4.3.1.4 3D Display Functions - Extrusion

The 2D layers do not have base height and feature height information, where *base height* is the elevation value and *feature height* is the height of features of a layer in 3D space. To display the 3D perspective view, all features of a 2D layer must be assigned base height and feature height from fields of its own attribute table or from another source.

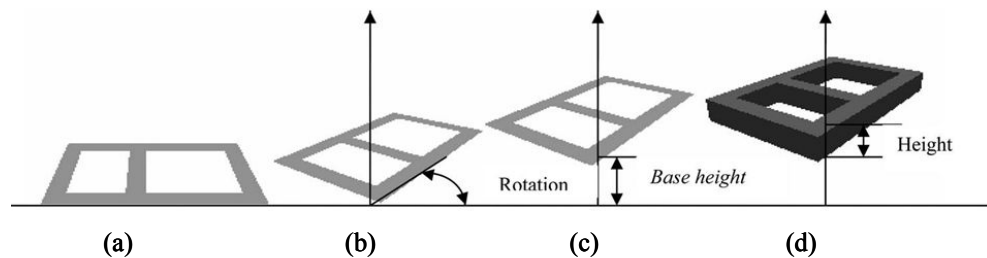


Figure 14: Extruding Components

Fig. 14 (a) shows 2D layer; (b) 2D layer at a suitable orientation; (c) feature of a layer in the space at elevation value equal to its base height; and (d) feature is **extruded** upward by value equal to its height.

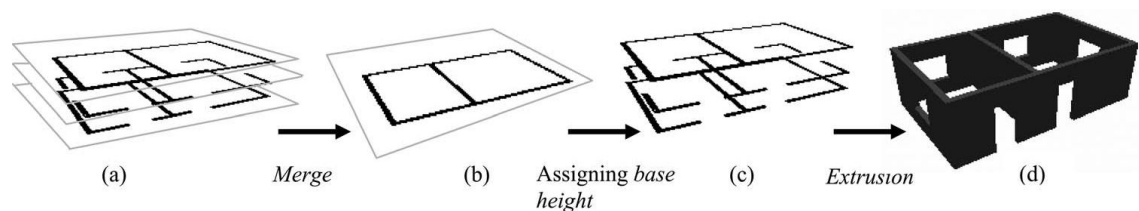


Figure 15: Merge and Extrusion

Fig. 15 (a) shows three 2D input layers; (b), three layers merged to one, in (c) different features of a layer shown in a space at elevation value equal to their respective *base height*, and (d) all features extruded upwards by the value equal to their *feature height*.

4.3.2 Non-spatial Operations - Join and Relate/Link

The characteristics of spatial features are represented by non-spatial data stored in the *attribute table* of a layer. Each row of the table represents a feature, while each column (field) represents the characteristic of that feature. The intersection of a column and a row shows the value of a particular characteristic of a feature.

Sometimes storing the entire attribute information in a single attribute table makes it difficult to maintain and update. An alternative to this is to store the attribute data in separate tables called *database tables*. These database tables can be managed by a database management system. The proposed methodology maintains construction resource data in such tables, so as to relate (link) them with the activities in the construction schedule and BOQ tables. Some feature attributes are created in Excel and ArcMap offers the Add Data command so as one would be able to import the Excel table into the GIS database and join with associated feature. The basic features of ArcGIS such as JOIN and RELATE are used to develop the proposed model of construction project information system.

JOIN: Join is a type of query that extracts selected data from two tables that have at least one common field and combines it into a new table. This allows users to create a relationship between two feature classes so that attributes of each can be shared between them in a single query. Users specify which feature classes to join, which attributes within those feature classes to join on, and what type of join operation to perform.

The field **key**, common between two tables is used to establish the connection between components and corresponding activity. Entries in the field *key* are to be entered manually and should be unique in both tables. Thus, the attributes required to join or associate the rows are the entries in the field *key* of the tables. The name of the field does not have to be the same in both tables, but the data type must be same (allows joining number-to-number or string-to-string) in both tables being joined.

The contents of the *destination* table reflect the changes by including the joined attributes from the source table, while the *source* table remains unchanged. To explain the relationships, one needs to define the *source* (from) and the *destination* (to) tables. For example, if the purpose is to add data from the database table to BOQ table, then the BOQ table will be the destination table and the database table the source table.

RELATE: When tables are **related** with the help of field *key*, they are just related to one another and different input tables remains unchanged. After *link* is established, selecting a record in the destination table will automatically select the record or records related to it in the source table.

4.3.3 Table Relationships

Three types of relationships between tables, i.e., *one-to-one*, *one-to-many*, and *many-to-one* (Figure 16), are used in this work to join and relate different tables together.

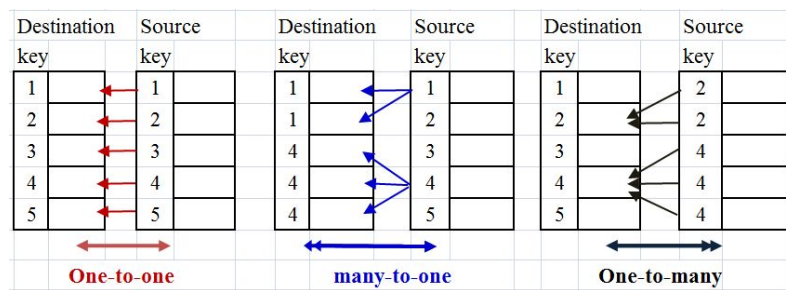


Figure 16: Types of relationship between tables connected through field *key*

The three types of relationship used between tables:

- The *one-to-one* relationship means that one and only one record in the destination table is related to one and only one record in the source table.
- The *one-to-many* relationship means that one record in the destination table may be related to more than one record in the source table.
- The *many-to-one* relationship means that two or more records in the destination table may be related to one record in the source table.

The **JOIN** function is used to establish a *one-to-one* or *many-to-one* relationship between the destination table (the active table) and the source table. The **RELATE** function establishes a *one-to-many* relationship between the destination table and the source table.

4.4 Methodology to Integrate the Software

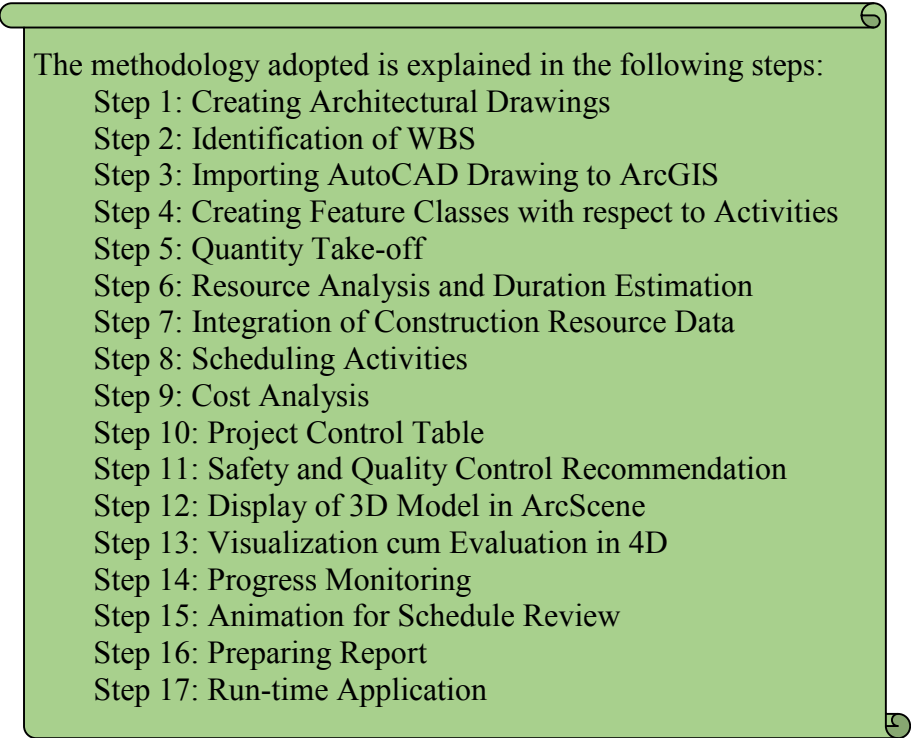
4.4.1 General Highlight

The intent of this section is to *demonstrate* the benefits of using GIS with construction project management. 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 addition to monitoring the schedule, the system can also be extended to monitor quantities of materials resource, labour, and cost. Realizing this goal would require addressing a wide range of requirements such as, interoperation and data exchange between different function-specific software tools.

The methodology developed utilizes functionalities of the software mentioned in Chapter_4.3. In this integration, drawings are created for each activity mentioned in the schedule and then imported to ArcMap (module of ArcGIS) in which all the drawings are georeferenced and then finally imported to ArcScene for 3D representation.

Here, the files are extruded to the desired height to obtain the 3D model. Construction schedule is prepared using MS Excel. After the creation of 3D model, the schedule is imported to ArcGIS and is linked with the 3D model to obtain 4D model of the building.

4.4.2 Step by Step Procedures



The methodology adopted is explained in the following steps:

- Step 1: Creating Architectural Drawings
- Step 2: Identification of WBS
- Step 3: Importing AutoCAD Drawing to ArcGIS
- Step 4: Creating Feature Classes with respect to Activities
- Step 5: Quantity Take-off
- Step 6: Resource Analysis and Duration Estimation
- Step 7: Integration of Construction Resource Data
- Step 8: Scheduling Activities
- Step 9: Cost Analysis
- Step 10: Project Control Table
- Step 11: Safety and Quality Control Recommendation
- Step 12: Display of 3D Model in ArcScene
- Step 13: Visualization cum Evaluation in 4D
- Step 14: Progress Monitoring
- Step 15: Animation for Schedule Review
- Step 16: Preparing Report
- Step 17: Run-time Application

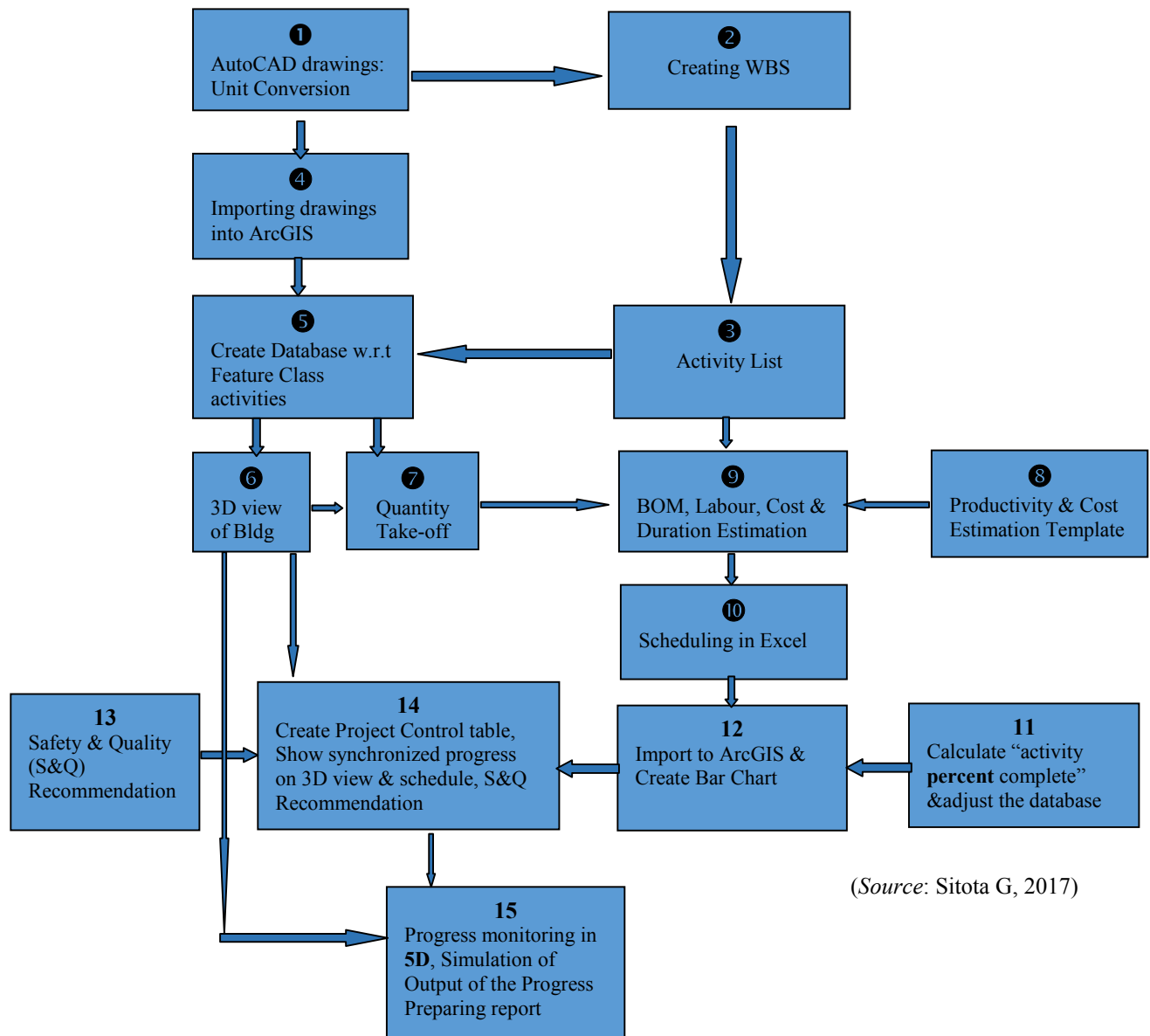


Figure 17: A flow chart describing the process of integrating the 5D Model

Step - 1: **Creating Architectural Drawings**

The first step in the process is the creation of plans (floor plan, elevation, section, etc.) of the subject building. The plan is drawn using AutoCAD and differentiated with layers. For a better model, it is required to have the plans at different stages of the project, i.e., different plans for foundation level, pedestal level etc. Layers in ArcGIS are the equivalent of overlays used in paper-based drafting. The drawings consist of various components such as columns, walls, doors and etc. Therefore, separate layers are formed for all structural elements.

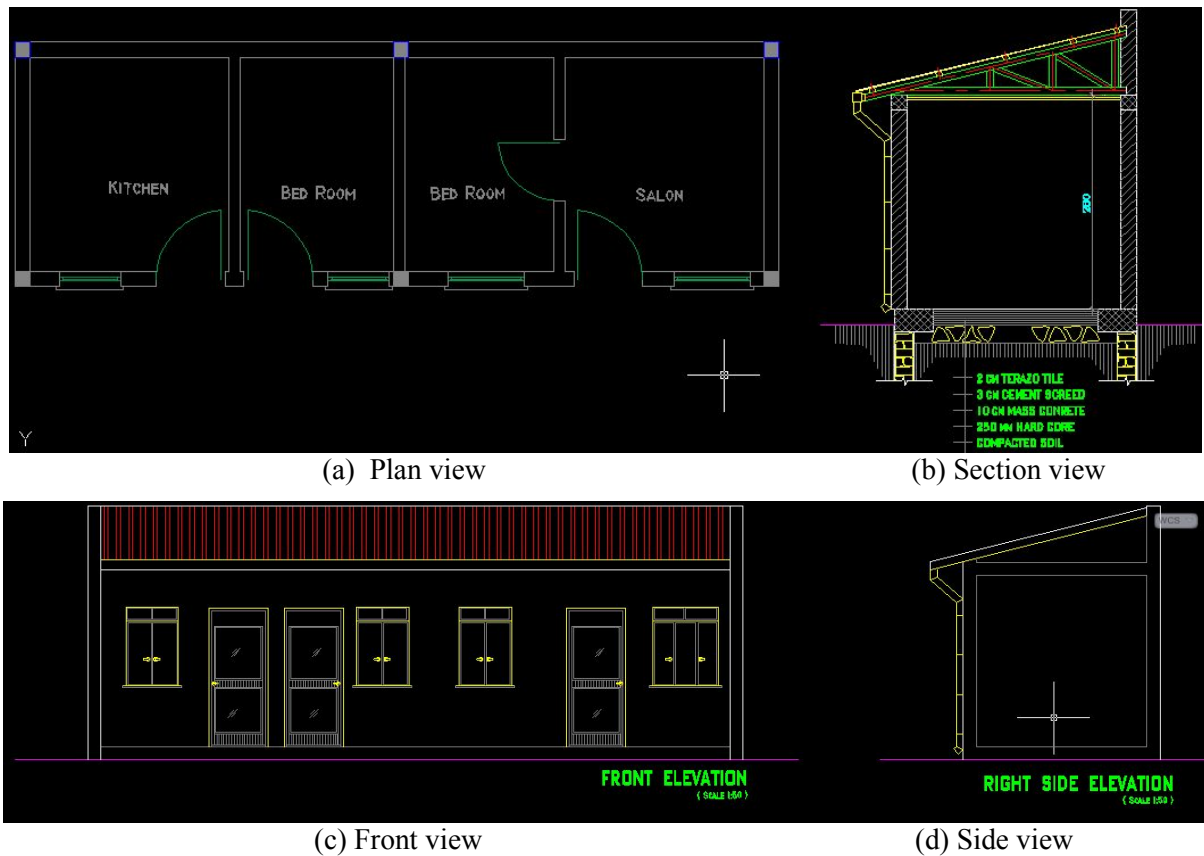


Figure 18: 2D views of architectural drawings

Note: The AutoCAD drawing should be converted to an *appropriate unit* before importing it to ArcGIS window.

Step - 2: Identification of WBS

Project schedule requires the task to be broken down into smaller trackable events. A Work Breakdown Structure (WBS) is a hierarchy of work that must be accomplished to complete a project which defines a product to be produced. The WBS is structured in levels of work detail, beginning with the *deliverable* itself and is then separated into identifiable work elements.

When creating a project, the project manager typically develops WBS first, defines activities for performing the element's work and then assigns resources to each WBS element. When the big components of a structure are broken down into various smaller components, it makes the project less complicated to deal with. It is done to make the project control effective and manageable. Also, this would allow *monitoring* to be done with accuracy and ease.

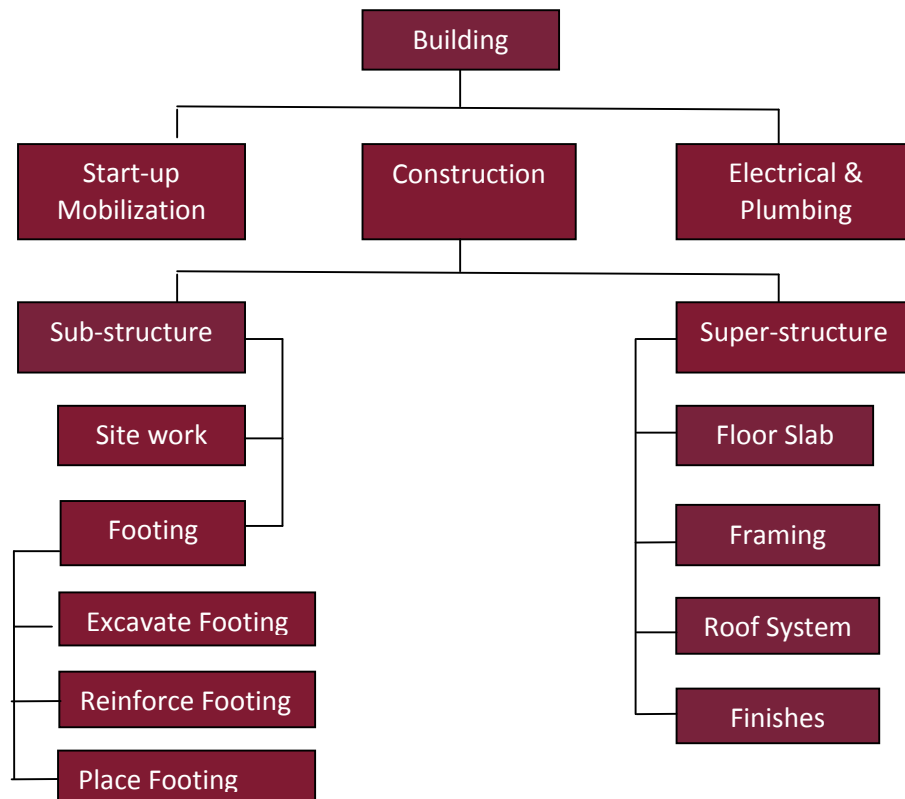


Figure 19: Work Breakdown Structure

Each activity for column, beam, slab, and wall are divided into components and they are further divided into individual activities. Activity Information of the building is shown in Table 4.

Step - 3: **Importing AutoCAD Drawings to ArcGIS**

Step – 3A: Data Transfer

ArcGIS allows working with drawings generated in AutoCAD. It offers its users a variety of interoperability modes including file conversion, and direct read/write mode. All layers created in AutoCAD are transferred to the GIS environment, which automatically adds default legends in the Table of Contents of ArcGIS user interface. To differentiate layers, the user may assign different colours to them. However, to edit or modify a CAD drawing layer's features the layer first has to be converted into a *shapefile*.

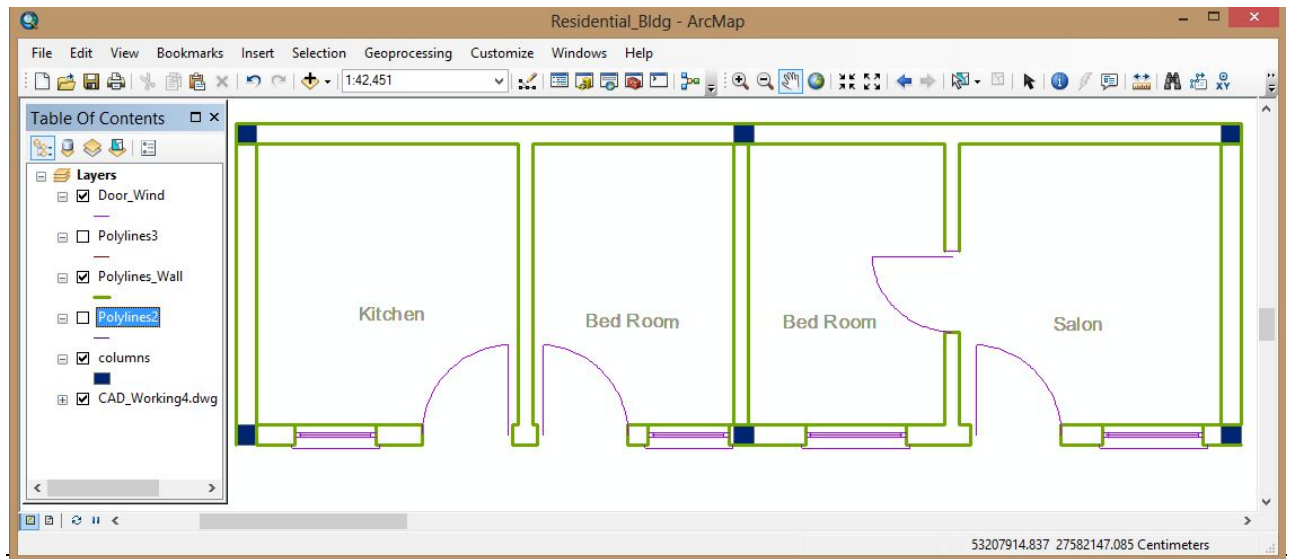


Figure 20: Imported floor plan of the building in ArcMap

If the CAD file is simple, for example on one layer, you are finished. As with many CAD files this file is not simple being composed of several layers of data. ArcMap combines all these layers, including *annotation*, into one group layer composed of 5 categories: *point*, *polyline*, *polygon*, *annotation*, and *multipatch*.

Step – 3B: Georeferencing:

When CAD files are created, there is no coordinate system defined. Therefore, the vector data in the CAD file is not always positioned correctly in relation to its real-world location on the ground when imported to GIS software packages, explaining why features imported from property map do not fit aerial images when displayed simultaneously. Georeferencing means to *associate something with locations* in physical space. This lets users define a new registration using control-point pairs that match locations on the feature class to their correct locations on the ground. In this study, georeferencing has no significance since the location of the building relative to a reference point is not of much importance.

Step – 3C: Editing Imported Layers

The imported layer is not editable at this stage and hence it should be exported as a shapefile and the exported file should be added to the Table of Content of ArcMap window for editing. Exporting converts the file into polyline shapefile whose uniqueness can be defined by its

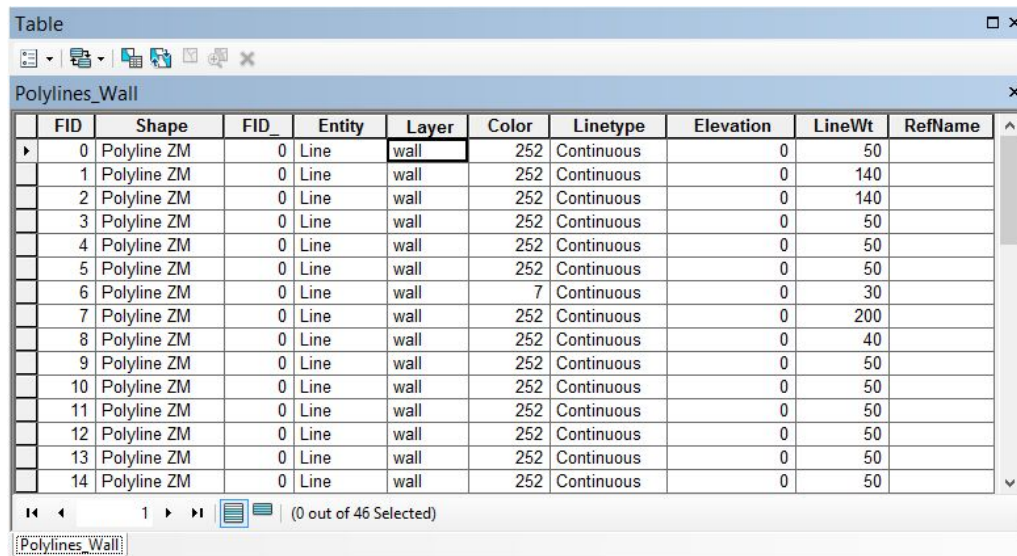
attribute table with columns mentioned as fields. The shapefile is editable and any change can be done in the file through its attribute table.

ArcGIS retains the locations, sizes, and colors/textures of the objects drawn, by maintaining them in a database for subsequent retrieval, analysis, and manipulation. The inbuilt functions such as delete, move, cut, and paste can also be applied to one or more selected features.

Step – 3D: Non-graphic Data Management

The next step is to enter attributes for each feature. Non-graphic attributes are stored and linked with their associated map features to support map display and analysis. Users need to define and add the attributes to the relevant features.

Table 3: Attributes table of the imported layers



FID	Shape	FID	Entity	Layer	Color	Linetype	Elevation	LineWt	RefName
0	Polyline ZM	0	Line	wall	252	Continuous	0	50	
1	Polyline ZM	0	Line	wall	252	Continuous	0	140	
2	Polyline ZM	0	Line	wall	252	Continuous	0	140	
3	Polyline ZM	0	Line	wall	252	Continuous	0	50	
4	Polyline ZM	0	Line	wall	252	Continuous	0	50	
5	Polyline ZM	0	Line	wall	252	Continuous	0	50	
6	Polyline ZM	0	Line	wall	7	Continuous	0	30	
7	Polyline ZM	0	Line	wall	252	Continuous	0	200	
8	Polyline ZM	0	Line	wall	252	Continuous	0	40	
9	Polyline ZM	0	Line	wall	252	Continuous	0	50	
10	Polyline ZM	0	Line	wall	252	Continuous	0	50	
11	Polyline ZM	0	Line	wall	252	Continuous	0	50	
12	Polyline ZM	0	Line	wall	252	Continuous	0	50	
13	Polyline ZM	0	Line	wall	252	Continuous	0	50	
14	Polyline ZM	0	Line	wall	252	Continuous	0	50	

Step - 4: Creating Feature Classes with respect to Activities

To establish a link between components that are feature classes (points, lines, or polygons) and corresponding activities in CPM schedule, components corresponding to different activities need to be identified. Sometimes different layers may be merged together (or split) depending on the activities defined in the WBS. The relationship between the components and activities may not always be *one-to-one*; however, complexity of the project forces to have relationship like *many-to-one* in which many components (which are within the same feature class) correspond to an activity in the schedule. In such relationship, components are grouped (*merged*) together to a

single component and there after linked with corresponding activity. The linking is also possible if there is a single component corresponding to many activities (*one-to-many*) (Bansal, 2008).

If the entire block work is included in a single activity the layers may be merged into a single layer. The components in a layer that belong to the same activity but are located at different positions in the 3D space may also be grouped together.

Components transferred into ArcGIS from AutoCAD may be merged together according to the activities defined in the schedule. Thus, components of a drawing that belong to the same activity but are located at different positions are joined together as one “feature class” to construct the spatial data for each activity. For example all the various components of the Column are dissolved into one feature class called the “Column” activity; and lintels over the doors (if any) and windows sill are not adjacent to each other but can be grouped into a single component, corresponding to an activity of the schedule.

Step - 5: **Quantity Take-off**

The system allows to extract the necessary dimensions from the drawings (prepared in GIS environment) and to perform various calculations for quantity takeoff and easy access to information available in ArcGIS.

Spatial and thematic information:

Various data layers representing architectural drawing and possess accurate physical dimensions have been used as spatial information in GIS for quantity takeoff. The main attributes for quantity takeoffs used in the present study are *length*, *area*, and *perimeter* of various features. Thus, different data layers are created using geographic element either as lines or polygons.

Length, area and perimeter: *Spatial operations* are performed to identify the required geometric dimensions of the graphical features. To complete the quantity calculation, the user inputs parameters such as the depth of slab, floor height, area of doors and windows. *Feature tables* are used to store attributes and shape information of various feature classes. ArcGIS calculates values for length, area, and perimeter based on the *shape* using expressions. For example, *Calculate Geometry* option in the attribute table is used for area calculation.

Work Items: Spatial information of different activities available in the schedule is maintained in the data layers, which form the basis of GIS based visualization. It is **not necessary** to have a 3D component corresponding to each activity in the schedule. For example, in the schedule of the sample building, activities such as *leveling* of construction site using total station, *marking* of the site, and *curing* of the concrete do not have related 3D components. However, there should be an activity in the schedule corresponding to each 3D component.

The second column in Table 4 lists various items to be worked out, while in the third column different layers created to find out quantity of various items of the work have been listed.

Table 4: List of work items

Sr. No. ①	Components Represented by Layers ②	Different Data layers Constructed (Payment items) ③	GIS Element Used ④	Height/ Thickness ⑤	Base-height (cm) ⑥
1	Site clearing (sqm)	Representing clearing of topsoil and trees 20cm depth, a total area of 11m x 4.2m	Polygon	---	-20*
2	Earthwork for foundation (cum)	Representing excavation work for trenching (15+50x2 cm and 20+50x2 cm width). 50cm working space on both sides.	Polygon	103	-20
3	Earthwork for foundation of the fence (cum)	Representing excavation work for trenching (20+50x2 cm width). 50cm working space on both sides.	Polygon	80	-20
4	Masonry work of foundation in cement mortar (cum)	- Representing one step masonry work (25cm width) - Representing lean concrete (C-7) in base foundation (cum)	Polygon	63 30	-30 -79
5	Back fill around foundation and Stone masonry. Backfill up to the lower surface level of the hardcore from the bottom level (cum)	Representing backfill from 45cm to 78cm level from the floor level	Polygon	48	-45
6	Backfill above the bottom lower surface level of the hardcore (cum)	Representing backfill from 20cm (i.e., GSL) to 45cm level from the floor level	Polygon	25	-20
7	Compacted soil surface	- Representing excavation above the compacted soil surface excluding excavation for foundation base - Representing surface area of the compacted soil	Polygon	25 ---	-20 -45

*Negative numbers represent depth below floor level and are measures in centimeter.

<i>Sr. No.</i> ①	<i>Components Represented by Layers</i> ②	<i>Different Data layers Constructed (Payment items)</i> ③	<i>GIS Element Used</i> ④	<i>Height/ Thickness</i> ⑤	<i>Base-height (cm)</i> ⑥
8	Hard Core in foundation (Bottom layer)	▪ Representing Hard Core in foundation at the level of masonry (bottom layer)	Polygon	15	-45
9	Grade beam (C-25)	▪ 30cm depth x 50cm x-section	Polygon	30	0
10	Hard Core in foundation (upper layer)	1. Representing (upper layer) Hard Core in foundation at the level of the grade beam 2. Representing C-25 cyclopean concrete for floor	Polygon	10 15	-30 -5
11	Site work	▪ Representing site work/Leveling the site	Polygon	--	-20
12	Floor: Net floor area	1. Representing cement screed (sqm) 2. Representing Terazzo tile (sqm)	Polygon	3 2	-2 0
13	Columns (C-25)	▪ Columns (cum)	Polygon	260	0
14	Top-tie beam (C-25)	▪ Top-tie beam	Polygon	20	260
15	Roof Slab (C-20)	▪ Representing 10 cm thick R.C.C slab	Polygon	10	280
16	Projection of the slab (C-20)	▪ Representing 8 cm thick projection of R.C.C slab.	Polygon	8	280
17	D.P.C (sqm)	▪ Representing Damp proofing course (2cm)	Polygon	---	---
18	Wall below sill	▪ Representing wall from floor level to sill	Polygon	90	0
19	Wall @ sill level	▪ Representing wall for sill thickness (2cm)	Polygon	2	90
20	Sill (sqm)	▪ Representing Sill	Polygon	2	90
21	Wall @ Window level	▪ Wall at Window level	Polygon	120	92
22	Wall above windows	▪ Representing HCB wall above the door	Polygon	48	212
23	Parapet @ the bottom	▪ Representing HCB parapet at the bottom	Polygon	10	280
24	Parapet @ the top	▪ Representing HCB parapet at the top	Polygon	50	290

<i>Sr. No.</i> ①	<i>Components Represented by Layers</i> ②	<i>Different Data layers Constructed (Payment items)</i> ③	<i>GIS Element Used</i> ④	<i>Height/ Thickness</i> ⑤	<i>Base-height (cm)</i> ⑥
25	Door shutter	▪ Representing Door shutter including frame	Line	210	0
26	Windows shutter	▪ Representing windows shutter	Line	120	92
27	Plastering below plinth	▪ Plastering outside the wall and between ground and floor level for a height of 20cm.	Line	20	
28	Plastering above plinth up to sill level	▪ Plastering inside/outside the wall and between floor and sill level for a height of 90 cm.	Line	90	
29	Plastering @ sill level	▪ Plastering inside/outside the wall at sill level for a height of 2 cm.	Line	2	
30	Plastering @ window level	▪ Plastering inside/outside the wall between sill and lintel level for a height of 120cm.	Line	120	
31	Plastering above window level	▪ Plastering inside/outside the wall and above the lintel level for a height of 68cm.	Line	68	
32	Roof Ceiling	▪ Net area of roof Ceiling	Polygon	---	
33	Excavation for trenching, fencing	▪ Excavation for trenching, to a depth of 50cm and 50cm working space on both sides	Polygon	50	-20
34	Masonry for foundation of fencing	▪ 50cm	Polygon	50	-20
35	Grade beam for fencing	▪ The same cross-section as that of the building.	Polygon		
36	Fencing	▪ Fencing with 20cm HCB, excluding the main gate	Polygon	270	-70
37	Plastering the fence	▪ Plastering inside/outside the fence for a height of 220 cm.	Line	220	-20
38	Main gate	▪ Main gate, a height of 270cm	Line	270	-20
39	Formwork @ the sides of the	▪ Representing formwork @ two sides of the	Line	0.3	

<i>Sr. No.</i> ①	<i>Components Represented by Layers</i> ②	<i>Different Data layers Constructed (Payment items)</i> ③	<i>GIS Element Used</i> ④	<i>Height/ Thickness</i> ⑤	<i>Base-height (cm)</i> ⑥
	grade beam	grade beam			
40	Formwork @ the bottom of the grade beam	▪ Representing formwork @ the bottom of the grade beam	Polygon		
41	Formwork for Column	▪ Representing formwork for elevation column	Line	260	
42	Formwork for Top-tie beam	▪ Representing formwork for the sides of top-tie beam	Line		
43	Formwork for Slab and Projection	▪ Representing formwork below the slab	Polygon		
44	Formwork @ the sides of the slab	▪ Representing formwork @ the side of the slab	Line	10	
45	Formwork @ the sides of the projection	▪ Representing formwork @ the side of the slab projection	Line	8	

Constructed Layers Related with Work Items*Table 5: List of geographic elements used to construct different data layer*

<i>GIS Elements Used</i>	<i>Row</i>	<i>Units of Measurement</i>	<i>Height</i>	<i>Items of the Works</i>
Line	a	Running-meter	zero	Road work (if any), beam etc.
	b	Square-meter	h	Plastering, wood-shutter, parapet wall etc.
Polygon	c	Square-meter	zero	Flooring, damp proofing course etc.
	d	Cubic-meter	h	Excavation, brickwork, concrete work, wood-frame, stonework etc.

As shown in the table, the type of geographic element used to construct the layer will depend on the *unit of measurement* of the various items of work.

- For items of work having units “running meter” and “square meter” geographic feature line is used to create the data layers. For example, in the subject building, line has been used to create layers to find the quantity of plastering [Table 5, Row (b)].
- For “square meter” both line and polygon may be used.
- The entries in the field height will be zero if items of the work are measured in “running meter” and “square meter” represented by line and polygon respectively [See row (a) and (c)].
- For Items measured in “square meter” and “cubic meter” represented by geographic element line and polygon respectively, the values of *height* need to be entered in the field height. [See row (b) and (d)].

Procedures for Quantity Takeoff

The different steps involved in quantity takeoff are shown in the flow chart, Figure 21.

Step – 5A: Preparation of Data Layers

A single architectural drawing is insufficient to calculate quantity; thus, an architectural drawing is divided into different layers, called data layers. These data layers generated in ArcGIS form the basis for GIS-based cost estimate. Only few layers are required to be prepared in AutoCAD, while others can be prepared by editing these layers in ArcGIS. The parameters required for the quantity takeoff are length, area and/or perimeter. Thus, all features of data layers have been created as line or polygon.

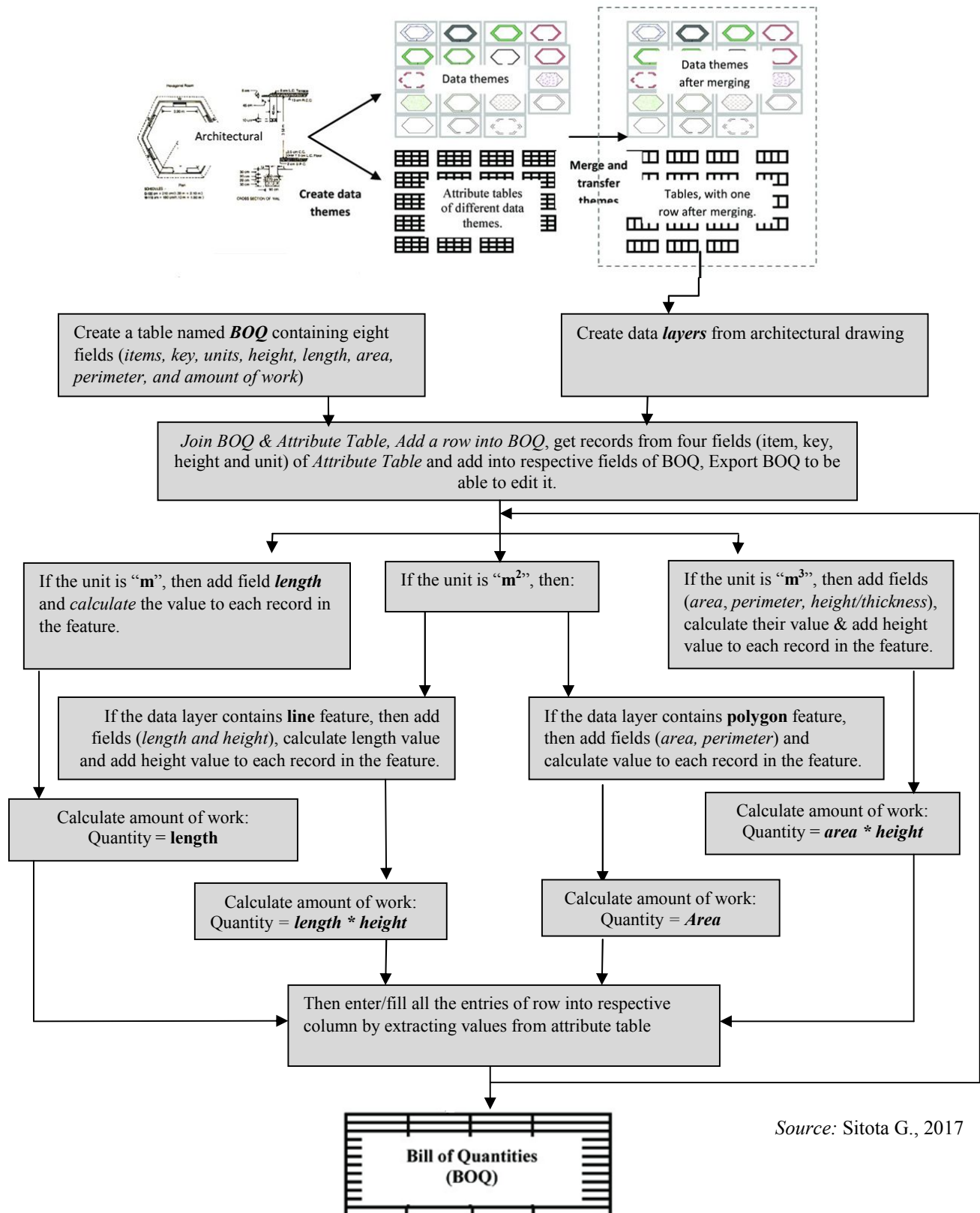


Figure 21: Flow diagram to generate BOQ in ArcGIS

Step – 5B: Dissolve, Merge and Union

The Dissolving, Merging and Union functionality of ArcGIS are used to edit different layers created in AutoCAD so as to get other layers. Polygons in each layer may be dissolved to form a single or multipart single polygon. After using dissolve, new layers are created and saved as a shapefile in ArcGIS.

The number of layers to be constructed corresponding to an activity depends upon the degree of detail (the shape, openings, and thickness) at different levels of the height to be provided in the resulting model.

Step – 5C: Setting Attributes

The default attributes (Shape, ID) are automatically generated when data layers are transferred to or created in ArcGIS. Attributes needed in quantity takeoff include length for line feature, area and perimeter for the polygon feature. Thus, the attribute table of a layer should contain fields: *shape*; *key*; *description*; *length*; *area*; *perimeter*; *height*, and *unit*. Field **shape** is the default field of ArcGIS's attribute table that stores shape information of features in a layer. Fields *key*, *description*, and *height* have been added to an attribute table of each data layer and the values in these fields are then *entered manually*. Field **Key** is the common field in all attribute tables. Field **description** gives the name of task in the data layers. Area, length and perimeter are the basic parameters and *computed* using ArcGIS for each data layer, while the other field's values are entered *through keyboard*.

Step – 5D: Reinforcement Bar Takeoff:

Quantity takeoff for reinforcement bar is **treated differently** from what is presented in the previous sections. Center lines of the grade beams and top tie-beams are drawn using the **midpoint** command available in ArcGIS to use as a base for calculation of total length of the structural elements (Figure 50) by taking care of the overlapping portions of the elements not to be counted twice. Then the quantity of reinforcement bar required is calculated from the information obtained for the section of the structural elements in the drawings (Figure 22). Similarly, the rebar required for roof slab is calculated by using *ratio* as structural drawing is not available for the subject building.

▪ **Beam (for the building):**

- Beam *length*:
= 59m (length of center lines calculated using ArcGIS)
- Length of $\phi 12$ rebar = 6×59 m
= 354m $\phi 12$ rebar
- No. of *stirrup* places (rounds):
= Length/spacing + 1 = $59\text{m}/200\text{mm} + 1 = 295 + 1$
= 296 places

Length of one round stirrup:
= 0.7m (from the AutoCAD drawing)

Length of $\phi 8$ stirrup: 296 places (rounds) $\times$ 0.7m
= 207.2m $\phi 8$ stirrup

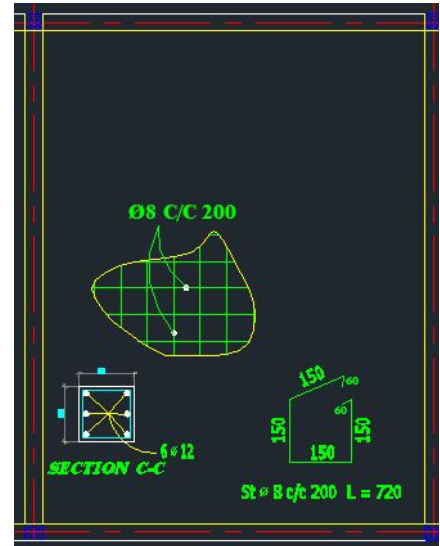


Figure 22: Rebar arrangement @ sections of the beam and slab

▪ **Beam (for the Fence):**

- Grade beam length: 48m
- Length of $\phi 12$ rebar = 4×48 m = 192m $\phi 12$ rebar
- No. of *stirrup* places (rounds):
= Length/spacing + 1 = $48\text{m}/200 \text{ mm} + 1 = 240 + 1 = 241$ places
- Length of $\phi 8$ stirrup: 241 places (rounds) $\times$ 0.7m = 168.7m $\phi 8$ stirrup

▪ **Column (for the building):**

- No. of columns = 6
- Columns's total height = 6 no. $\times$ 2.6m = 15.6m
- Length of $\phi 12$ rebar = 6×15.6 m = 93.6m $\phi 12$ rebar
- No. of *stirrup* places (rounds):
= Length/spacing + 1 = $15.6\text{m}/200\text{mm} + 1 = 78 + 1 = 79$ places
- Length of $\phi 8$ stirrup: 79 places $\times$ 0.7m = 55.3m $\phi 8$ stirrup

▪ **Column (for the Fence):**

- No. of columns = 16 No. [i.e., 1@ 3m spacing].
- Length of a column: 2.2m
Total length: $16 \times 2.2\text{m} = 35.2\text{m}$
- Length of $\phi 12$ rebar = 4×35.2 m = 140.8m $\phi 12$ rebar
- No. of *stirrup* places (rounds):
= Length/spacing + 1 = $35.2\text{m}/200\text{mm} + 1 = 176 + 1 = 177$ places
- Length of $\phi 8$ stirrup: 177 places $\times$ 0.7m = 123.9m $\phi 8$ stirrup

▪ **Column volume** (for the Fence):

- Dimension: 20cm x 20cm x 220cm
- Total volume = 16 no. x 0.2m x 0.2m x 2.2m = 1.408m³ (used for concrete volume calculation)

▪ **Slab and projection**

- Size of slab & projection = 10m by 3.58m

For rebar stretching traverse to the shorter side:

- No. of places to lay down the rebar:
= Shorter side/spacing +1 = 3.58m/200mm +1 = 17.9+1 = 18.9 ~ 19 places
- Total length along the **longer** side = 19*10m = 190m

For rebar stretching traverse to the longer side:

- No. of places to lay down rebar:
= Longer side/spacing +1 = 10m/200mm +1 = 50+1 = 51 places
- Total length along the **shorter** side = 51*3.58m = 182.58m
- Total length at the top: 190m + 182.58m = 372.58m.
- Total length of rebar for the slab and projection = 2* 372.58m = 745.16m

Table 6: Quantity of rebar and stirrup in meters

Rebar Size	Building			Fencing		Length (m)	Unit Wt (kg/m)	Weight (kg)
	Beam	Column	Slab	Beam	Column			
Rebar ϕ 12	354	93.6	-	192.0	140.8	780.4	0.888	692.9
Rebar ϕ 10	-	-	746	-	-	746	0.616	459.5
Stirrup ϕ 8	207.2	55.3	-	168.7	123.9	555.1	0.395	219.3
Total								1,371.7

A simple way to calculate the weight of Steel bar is:

- Weight of Steel Bar (in kgs) = $0.222(\phi^2)/36$
- Where, D is in mm
- So, weight of 8 mm bar = $0.222*(8*8)/36 = 0.395$ kgs

Step – 5D: BOQ:

Accurate BOQ is generated on the basis of the dimensions of different data layers. It is created with eight fields named as: *key; unit; height; length; area; perimeter* and *amount of work*. The field **amount of work** is calculated by multiplying the area with the field height for polygon feature data layer, and by multiplying field *length* with field *height* for line feature data layer. Each record in the BOQ table corresponds to a particular layer used to represent

one or part of the work item. The resulting BOQ table will be like the one shown at the lower left corner of Figure 43 [See Annex – A for details].

Step - 6: **Resource Analysis and Estimation of Duration**

The amount of various resources required, and as well cost and time estimation for each work item involves in determining BOQ, knowing *productivity* rates of machineries and labour engaged in the construction work.

For estimating the amount of resources (equipment and labour) and cost required for each work item the researcher used excel template from BATCODA that consists standard *specifications, productivity rates, utilization factors* and etc. Sample template is shown in Table 7. The numbers of different classes of workers have been calculated from the **man-hour** required to perform the work divided by working hours in a day. The entries in this table can be converted into cost by multiplying them with appropriate labor rate per day. The cost and time estimated based on the stated productivity rate is used for *scheduling purpose* in the coming paragraphs.

Sample Calculation Based on the Template:

Table 7: Calculation with standard productivity rate for a unit work item

Work item: <i>Masonry work</i> Total quantity of work item: $1m^3$ Hourly output: $0.225 m^3/hr$																																		
▪ Duration = Quantity/Hourly output $= 1m^3/0.225m^3/hr = 4.44hr$ (for cubic meter of masonry) Then, the total <i>duration</i> of time required for the work item can be calculated by multiplying this value with the total quantity of the masonry work.																																		
▪ Ingredient's Quantity & Cost, Considering Wastage <i>Material Cost (A):</i> <table border="1"> <thead> <tr> <th>Type of material</th><th>Unit</th><th>Quantity</th><th>Rate</th><th>Cost/Unit</th></tr> </thead> <tbody> <tr> <td>Stone</td><td>m^3/m^3</td><td>1.20</td><td>283.33</td><td>340.00</td></tr> <tr> <td>Cement (PPC)</td><td>kg/m^3</td><td>92.00</td><td>2.40</td><td>220.80</td></tr> <tr> <td>Sand</td><td>m^3/m^3</td><td>0.26</td><td>468.75</td><td>121.88</td></tr> <tr> <td>Water</td><td>m^3/m^3</td><td>0.40</td><td>3.00</td><td>1.20</td></tr> <tr> <td colspan="4">Total</td><td>683.88</td></tr> </tbody> </table> A= Material unit cost = 683.88					Type of material	Unit	Quantity	Rate	Cost/Unit	Stone	m^3/m^3	1.20	283.33	340.00	Cement (PPC)	kg/m^3	92.00	2.40	220.80	Sand	m^3/m^3	0.26	468.75	121.88	Water	m^3/m^3	0.40	3.00	1.20	Total				683.88
Type of material	Unit	Quantity	Rate	Cost/Unit																														
Stone	m^3/m^3	1.20	283.33	340.00																														
Cement (PPC)	kg/m^3	92.00	2.40	220.80																														
Sand	m^3/m^3	0.26	468.75	121.88																														
Water	m^3/m^3	0.40	3.00	1.20																														
Total				683.88																														

Estimated quantity of Cement in a unit volume of Masonry = 92kg (from the template).

$$\text{Cost of cement} = \text{Quantity} \times \text{Rate} = 92 \times 2.4 \text{ Birr} = 220.8 \text{ Birr}$$

The cost of the remaining ingredients (such as stone, sand and water) can be calculated by using the same procedure.

Labour Cost (B):

Hourly output = 0.225m³/hr

<i>Labor by Trade</i>	<i>No.</i>	<i>U.F</i>	<i>Indexed Hourly Cost</i>	<i>Hourly Cost</i>
Forman	1	0.25	41.67	10.42
Mason	1	1	31.25	31.25
Daily Laborer	2	1	10.00	20.00
Total				61.67

$$B = \text{Man power unit cost} = 61.67/0.225 = 274.07$$

Equipment Cost (C)

<i>Type of Equipment</i>	<i>No.</i>	<i>U.F</i>	<i>Hourly Rental Rate</i>	<i>Hourly Cost</i>
Hand tools	1	1	1.25	1.25
Total				1.25

$$C = \text{Equipment unit} = 1.25/0.225 = 5.56$$

- Direct cost of work item = $A + B + C = 963.51 \text{ Birr/m}^3$
- Unit cost of work item inclusive of overhead & profit = $1.35 \times (\text{Direct cost}) = 1,300.72 \text{ Birr/m}^3$

Step - 7: Integration of Construction Resource Data

The proposed methodology utilizes GIS to maintain the construction resource data in tabular form and integrate these data with the corresponding activities of the project using the relationships discussed in Chapter 4.3.2. In **geo-relational** data model split data system is used to store spatial and attribute data in separate files and link together by the field *key*, i.e., feature Identification Descriptor (ID).

Non-Spatial Data Management:

The information needs of a contractor include detail of activities to be carried out, from which the types and quantities of the manpower and the amount of materials can be obtained. The system stores construction resource information for various possible tasks related to construction materials, workers, and equipments in three different *tables* (materials, labour,

and equipment) in GIS. Additional information can be incorporated to all tables to ensure expansion and updating the system at later stages.

■ **Material (BOM):** The Material table in the database contains different fields named as: *key*, *activities*, *quantity*, *units* (i.e., work unit), *cement*, *sand*, *course aggregate*, *steel*, *HCB* and other construction materials. It can be connected to other tables by the field *key*. The field *activities* contains different possible tasks (Table 8). Each record of the table contains amount of different materials required for a task in the corresponding field (column). All entries in different fields of the material table are not for single work unit. Thus, field *quantity* contains amount of work units for which the values have been entered in the respective row. To obtain materials needed for a single work unit of the items, one needs to divide all entries of corresponding row by values in the field *quantity* (**Bansal** and Pal, 2013).

N.B: The material quantity calculated here has taken into account the wastage expected in the construction process.

■ **Labor:** The Labor table contains fields: *key*; *activities*; *quantity*; and skilled and non-skilled personnel. Each row of the table contains number of different class of workers required for a task in the corresponding fields.

Table 8: Resource database developed in ArcGIS

Materials Requirement						
id	Stone_m3	CrushStone	Aggr_m3	Sand_m3	Cement	
10001	0	0	0	0		
10002						
10003	11					
10004						
10005	1.6					
10006						
10007						
10008						
10009						
10011						
10012						
10013						
10014						
10015						
10016						
10017						
10018						
10019						
10020						

Labor Requirement						
id	Forman	G_Chief	DL	Mason	Plasterer	
10001	0.125	0.25	1	0		
10002	0.125	0.25	2	0		
10003	0.5	0.5	6	2		
10004						
10005						
10006						
10007						
10008						
10009						
10011						
10012						
10013						
10014						
10015						
10016						
10017						
10018						
10019						
10020	0.25	0	1	0		

Safety	
OID	precaution
0	Removal of shuttering as per IS norms
1	Start work after the foundation concrete has sufficient strength
2	Soak the brick in the water before use
3	Use the mortar as per specification
4	Use 1st Class concrete
5	Place the concrete properly

■ **Equipment:** The Equipment table contains fields: *key*, *activities*, *quantity* and *rates* for different equipments: Each row contains *rate of equipment* for the amount of the work entered in the field *quantity*. Equipment cost for the tools is considered on hourly rental rate base.

Summary:

In the planning process, the planner has to repetitively reorganize and interpret the information collected from various resources while a GIS can improve construction planning and design efficiency. It allows understanding of the construction process by integrating spatial and non-spatial information together. This approach replaces the manual methods to *extract information* from the database and allows easy updating, as entire information is in digital form. The available information can later be used for correct building cost estimation in the GIS environment itself.

Step - 8: Scheduling Activities

Schedule acts as a *roadmap* for successful implementation of the methodology. A project schedule is essential for making projects efficient and manageable. It



involves *identification* of all possible activities of the project and recognition of their *inter-relationships* to arrange them in proper sequence. Therefore, the building construction project is decomposed into discrete activities and the time needed to complete each activity is estimated and are arranged in sequential or overlapping order. The project is scheduled based on the activities identified on the WBS of the project.

Several tools such as Primavera Project Planner P6 and MS Project are used by the construction industry for scheduling purpose. As the construction project progresses, the network needs to be *updated frequently* and the scheduling computations are carried out many times on the modified data, which is a time consuming process.

Description of elements used in the Excel spreadsheet for scheduling purpose is presented next:

↪ **Activity Precedence**

There is only a rule of thumb used to set activity precedence. It may depend on the availability of construction materials used for specific work or skilled technical manpower. It is up to the scheduler to decide by considering different influencing factors. The activity list description is annexed in Annex B.

↪ **Excel Program**

Spreadsheet programs are widely available now and managers are familiar and comfortable with the software. Spreadsheets (**Kala**, 2001) provide a natural interface for model building; are easy to use in terms of inputs, solutions and report generation; and allow users to perform what-if analysis. This method eliminated the learning curve for a new software application. However, care should be exercised that no errors or gaps are created in the network while deleting or adding a new activity. This paper describes the implementation of the traditional PERT/CPM algorithm for finding critical paths in a project network in a spreadsheet. The researcher used *Excel-GIS integration* to carry out various scheduling computations in tabular form. The spreadsheet written for CPM calculations receives identified activities, their inter-relationships, and durations. The number of rows in the table depends on the number of activities in the network. Finally, it computes *start/finish times*, *floats*, and *criticality* of each activity, and the *project duration*.

▪ “INPUT” Sheet:

The first step of the process is representation of the network with the predecessor-successor relationships as shown in Table 9. We will adopt the convention of representing predecessors in the columns and successors in rows throughout this research paper.

Table 9: INPUT sheet - Matrix representation of the predecessor-successor relationships

Schedule_Bldg - Microsoft Excel

HomeInsertPage LayoutFormulasDataReviewViewLoad TestTeam

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Activity Code	Description	Immediate Predecessor	Duration (Days)	Predecessor Relationships																				
2					A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	
3	A	Site Clearing		11																					
4	B	Trenching and Excavation	A	15	1																				
5	C	Footing	B	7		1																			
6	D	Backfilling and Compaction	C	1			1																		
7	E	Hard core Production	A	1	1																				
8	F	Laying hard core Bottom layer	D, E	6					1	1															
9	G	Rebar Production	A	14	1																				
10	H	Formwork production	A	25	1																				
11	I	Grade beam	F, G, H	2						1	1	1													
12	J	Laying hard core Top layer	I	3									1												
13	K	Mass concrete	J	1										1											
14	L	Columns	K	1											1										
15	M	Top-tie beam	L	1												1									
16	N	Roofing	M	1													1								
17	O	Exterior walls and Interior partition walls	N	15														1							
18	P	Plastering	O	4															1						
19	Q	Installation of windows and doors	P	11																1					
20	R	Placing Sill	Q	1																	1				
21	S	Floor finishes	R	4																		1			
22	T	Painting	S	18																			1		

Input

EST-EFTLST-LFTCPMTableGant ChartDates

Ready

The formulas used to calculate start-finish time, floats, critical activity, and etc are already set in all sheets of the spreadsheet and the user is only required to show the predecessor-successor relationship by typing number “1” as a code in the relevant cells. This code will appear in the conditional statement set in Table 10.

↪ Usage and Extendibility of the Excel Program

The few available approaches that use the well known CPM for solving problems do not permit easy *extendibility* of the model when activities are added or deleted from the network or when the predecessor-successor relationships are altered (Eppen et al., 1998; Hillier et al., 2000; Ragsdale, 1998). Unlike the existing spreadsheet based PERT/CPM approach, which

require rebuilding of the model for each new network through a new linear programming formulation, the model is easily *extendable* and *accepts changes* in the estimated duration of activities, changes in the predecessor relationships as well as the deletion or addition of new activities. If the **range-names** are defined at the initial setup anticipating a larger number of project activities, then the extension from n activities to $n+$ activities takes just a few copy commands (Kala C. Seal, 2001).

▪ “EST-EFT” Sheet:

After entering the input data, the procedure starts calculating the EST and the EFT pairs for the activities in the network. This is accomplished by copying the network matrix into another sheet (named EST-EFT) and then adding two more columns to keep track of the final EST and EFT values of the activities.

Table 10: Application of VLOOKUP function to calculate EST and EFT

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Maximum of All EFTs																		
2	102																		
3		EST	EFT																
4	A	0	11																
5	B	11	26																
6	C	26	33																
7	D	33	34																
8	E	11	12																
9	F	34	40																
10	G	11	25																
11	H	11	36																
12	I	40	42																
13	J	42	45																
14	K	45	46																
15	L	46	47																
16	M	47	48																
17	N	48	49																
18	O	49	64																
19	P	64	68																
20	Q	68	79																
21	R	79	80																
22	S	80	84																
23	T	84	102																

The **EST** of an activity is the *maximum* of all the EFTs of its immediate predecessor activities. The spreadsheet is constructed following that principle. For any activity pair i and j ,

i in the column and j in the row, the cell (i,j) in the matrix contains the EFT of activity i if i is an immediate predecessor of j , zero otherwise. We will look at activity E in the EST-EFT sheet as an example. The cell E8, representing the pair A and E, has a value of 11, the EFT of A, because A is an immediate predecessor of E. The cell F8, on the other hand, contains zero because B is *not* an immediate predecessor of E. *Conditional formatting* is used to make the zero entries appear as shaded/hatched cells to improve the appearance of the EST-EFT results.

Note: Here EST_EFT table refers to range A4:C203 in the EST-EFT sheet. The range up to C203 is used to accommodate up to 200 activities in the spreadsheet without renaming the range.

The formula used for calculating the entries in the cells of the matrix is shown below using the cell E8, representing the activity pair A and E, as an example.

Cell E8:
`=IF(Input_!E7=1,VLOOKUP(E$2,EST_EFTtable,3,False),0)`

The EST for an activity is the maximum of all the EFTs of its immediate predecessors.

Therefore, the EST for activity A in cell B4 is given by the formula

Cell B4: `=MAX(E4:GV4),`

which is copied to the cells B4 through B23 for finding the EST of the remaining activities.

Once the ESTs are obtained, the EFT is found by adding the expected activity time to the EST. For example, the formula used for finding the EFT for activity A is

Cell C4:
`=B4+VLOOKUP(A4,Input_!A3:D203,4,False)`

which is then copied to the cells C4 through C23. The VLOOKUP function is used to extract the expected completion time of the activity from the input data in the range A3:D203 (named as Inputs).

▪ “LST_LFT” Sheet:

The next step in the process is to find the latest start time (LST) and latest finish time (LFT) for each activity. Noting that the LFT of an activity with successors must be the *minimum* of the LSTs of all the successor activities, we can use the same logic that we employed to calculate the EST-EFT pairs for an activity, only in reverse. This is accomplished in the LST-LFT sheet shown in Table 11. Once again a matrix with activities in the rows as well as

in the columns is created. The activities in the rows represent the successors. This is consistent with the predecessor representation followed in the paper. Two extra rows are inserted in this sheet to store the values of the LST-LFT pairs for each activity. In addition, a cell (A2 in the EST-EFT sheet) is used that stores the value of the maximum of the EFTs of all the activities.

Table 11: Application of HLOOKUP function to calculate LST and LFT.

The screenshot shows an Excel spreadsheet titled 'Schedule_Bldg - Microsoft Excel'. The formula bar at the top displays the formula: `=IF(Input_!G6=1,HLOOKUP($A9,LST_LFTTable,2,FALSE),$A$2)`. The spreadsheet has columns A through V and rows 1 through 25. The 'LST-LFT' sheet is active, showing a table with activities A through T as rows and successors A through T as columns. The values in the table represent the LST of the successor activity for each predecessor activity. For example, the LST of successor A is 102 for all predecessors, while the LST of successor T is 84 for all predecessors. The formula bar indicates that the formula is applied to cell E9, which is highlighted in the spreadsheet.

For an activity pair i and j , i in the column and j in the row, the cell (i,j) in the matrix is the **LST** of j if j is an immediate successor of i , maximum of all the EFTs (content of cell A2 in the EST-EFT sheet) otherwise.

Note: The LST_LFT table here refers to cell range C2:GV4 in the LST-LFT sheet. The following formula demonstrates the calculation for the activity pair A and E.

Cell C10: `=IF(Input_!E7=1,
HLOOKUP($A10,LST_LFTtable,2,FALSE),MAXofAllEFTs)`

A *horizontal lookup* function is used here instead of the vertical lookup. The formula is copied to the other cells of the matrix in the LST-LFT sheet. Conditional formatting has been

used again to shade/hatch out the cells with the LST equal to the maximum of all EFTs (i.e., 102 days in this case) to improve the presentation of the results. The cells are shaded with colours to hide formulas/figures that are not so important to be displayed for the reader.

Once all the cells of the matrix are calculated the final LFT for an activity can easily be selected by finding the minimum of all the LSTs of its immediate successors. The formula for the **LFT** of activity A, for example, is given by

```
Cell C4: =MIN(C6:C205)
```

The **LST** is calculated by subtracting the activity completion time from the LFT. The formula used for the activity A is

```
Cell C3: =  
C4-VLOOKUP(C2, Input_, 4, FALSE)
```

which is then copied to other cells in the range C3:V3 of the LST-LFT sheet. The VLOOKUP function is used to extract the activity completion time from the Inputs sheet.

Once the LST_LFT table is completed, the minimum expected project completion time is obtained by taking the maximum of all the LFTs. Cell A2 in the LST-LFT sheet contains that value and the formula for that cell is

```
Cell A2: =MAX(C4:GV4) .
```

▪ **“Critical Path” Sheet:**

The (EST, EFT) and the (LST, LFT) pairs for the activities are extracted from sheets EST-EFT (Table 10) and LST-LFT (Table 11) and the total floats are calculated by subtracting the EST from LST. If the result is *zero*, then the activity is a *critical* activity. Among the network of activities, the set of critical activities form critical path of the project *dictating* project construction.

Table 12: Critical activities identified by using conditional statements

The screenshot shows an Excel spreadsheet titled 'Schedule_Bldg - Microsoft Excel'. The formula bar at the top displays the formula `=IF(G7>0,"-","Critical")`. The spreadsheet contains a table with 21 rows of activities. The columns are labeled: Activity, Duration, EST, EFT, LST, LFT, Tot_Slack, and Remark. Activities A through T are listed. Activities A, B, C, D, F, I, J, K, L, M, N, O, P, Q, R, S, and T are marked as 'Critical' in the Remark column. Activity E has a total slack of 22 and is marked as '-'. Activity G has a total slack of 15 and is marked as '-'. Activity H has a total slack of 4 and is marked as '-'. The status bar at the bottom indicates 'Ready' and '140%' zoom.

	A	B	C	D	E	F	G	H
	Activity	Duration	EST	EFT	LST	LFT	Tot_Slack	Remark
1	A	11	0	11	0	11	0	Critical
2	B	15	11	26	11	26	0	Critical
3	C	7	26	33	26	33	0	Critical
4	D	1	33	34	33	34	0	Critical
5	E	1	11	12	33	34	22	-
6	F	6	34	40	34	40	0	Critical
7	G	14	11	25	26	40	15	-
8	H	25	11	36	15	40	4	-
9	I	2	40	42	40	42	0	Critical
10	J	3	42	45	42	45	0	Critical
11	K	1	45	46	45	46	0	Critical
12	L	1	46	47	46	47	0	Critical
13	M	1	47	48	47	48	0	Critical
14	N	1	48	49	48	49	0	Critical
15	O	15	49	64	49	64	0	Critical
16	P	4	64	68	64	68	0	Critical
17	Q	11	68	79	68	79	0	Critical
18	R	1	79	80	79	80	0	Critical
19	S	4	80	84	80	84	0	Critical
20	T	18	84	102	84	102	0	Critical

It is to be noted that the slack in this table refers to total **float** (or total slack) for an activity as opposed to the free slack. The total slack of an activity is the maximum amount of time the activity can be delayed from its earliest start time *without delaying* the critical path.

GIS and Excel Integrated

ArcGIS reads the schedule prepared in Excel spreadsheet and converts the schedule to “.dbf” data format that is ArcGIS’s standard table format (Table 13). Then, the in-built *chart document* functionality in ArcGIS is used to generate bar chart from the CPM schedule (Figure 23). Bar chart is one of the popular methods used for scheduling. In this method activities are listed in order of construction priorities on the left hand side column, while the time scale is plotted horizontally on the bottom.

Table 13: Schedule table imported to ArcGIS to integrate in the database

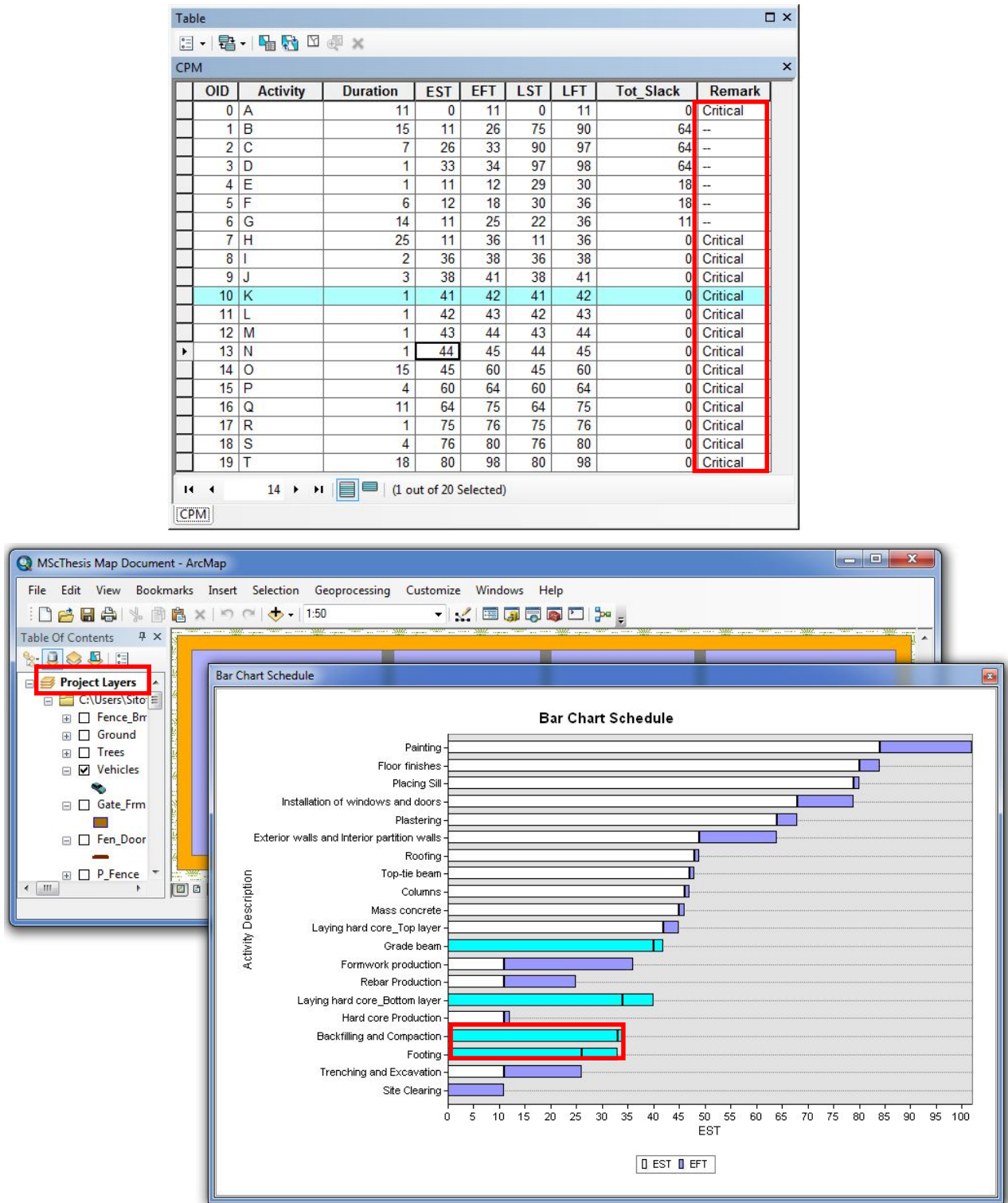


Figure 23: Bar chart in ArcGIS showing the project schedule

Note: EST and EFT of the activities are represented by the *tips* of the bars. Some critical activities are selected in the schedule table and as a result they are highlighted by siyan colour in the bar.

The project activities can be easily stored and listed in a variety of useful ways, such as *sorting* schedule in ascending or descending order on any field (floats, early or late start time) in the table. The selected records could be displayed in the same table by *promoting* them to the top in ArcGIS attribute table.

Step - 9: **Cost Analysis**

This step explores the potential of GIS for building cost estimation. Cost estimation is very essential part of construction management which is required in the whole life of a project - from feasibility study to the end of the construction period. Costs of the different data layers can now be obtained with data integration from the available data tables. The three elements of cost (material, labor, and equipment) are obtained by joining BOQ with three resources tables of the database maintained in GIS (**Bansal & Pal, 2007**). Each element is priced separately in accordance with the stated unit of measurement for each row in the BOQ. After calculating the cost involved, the contractor's profit and overhead cost are added to find out total cost.



Summary: BOQ and Cost Estimation

Failure or success of a building contract depends upon the quality

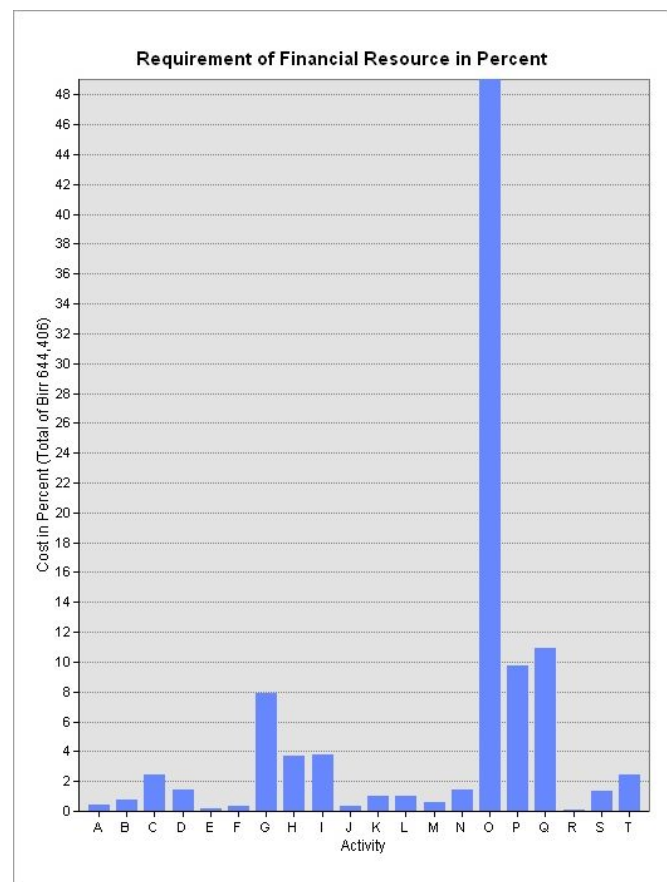


Figure 24: Percentage of cost for each Activity - prepared in ArcGIS

and timing of the information available to contractors from the updated database. The proposed methodology allows understanding of a project by integrating the information such as drawings, schedules, and cost in a single GIS environment (**Bansal & Pal, 2008**). If a digitizer is used for calculation of quantities, digitization errors may also be incorporated in the measured quantity. GIS-based cost estimation methodology eliminates the errors such as missing or duplication of various items by visualizing each component corresponding to the items in 2D/3D space. Thus, it is helpful in increasing the *productivity* of quantity estimator by reducing the manual work in determining quantity takeoff. The quantity takeoff which is based upon the suggested approach is precise as it depends on dimensions in the data layers.

Step - 10: **“Project Control” Table**

The construction project table named as “**project control**” table in the context of this research paper is used to make a summary of the project *status, resource, time, cost* and etc. It includes minimum information about *key, quantity, and percentages complete* for each work package. The *related* (linked) non-spatial information such as schedule, safety and quality control recommendations, and etc. are stored in the attribute tables of the corresponding *components*, which can be extracted from the database maintained within the GIS itself. The Attribute table in ArcGIS has the capability to handle and manage the data, so Ms-Access is not utilized. However, it is possible to prepare all this information as an independent database and later import it to ArcGIS. When a 3D component corresponding to an activity is clicked, a *window appears* that informs users about EST, EFT, floats, and resource information of an activity by extracting it from the related tables such as Project Control table, BOQ and etc. This can be done by linking the tables first (See Step -13). It is also possible to display a work item in the 3D by clicking its corresponding record in the Project Control table to identify where the element is positioned in space.

Step - 11: **Safety and Quality Control Recommendation**

Construction industry is considered to be one of the most hazardous occupations and ranked low in safety standards. Failure of managing construction safety may result in injuries, financial loss, human conflicts, and penalties. Thus, construction industry needs a tool that may help them to integrate safety and health measures into project planning (**Kartam, 1997**).

Linking (relate command) facility of ArcGIS is used for safety and quality recommendations. Selecting a row in the *project control* table will automatically highlight a record or records related to it in the construction *safety table*, and vice versa. So, to access the safety information about an activity from the database, the user only needs to click on activity row in the project control table.

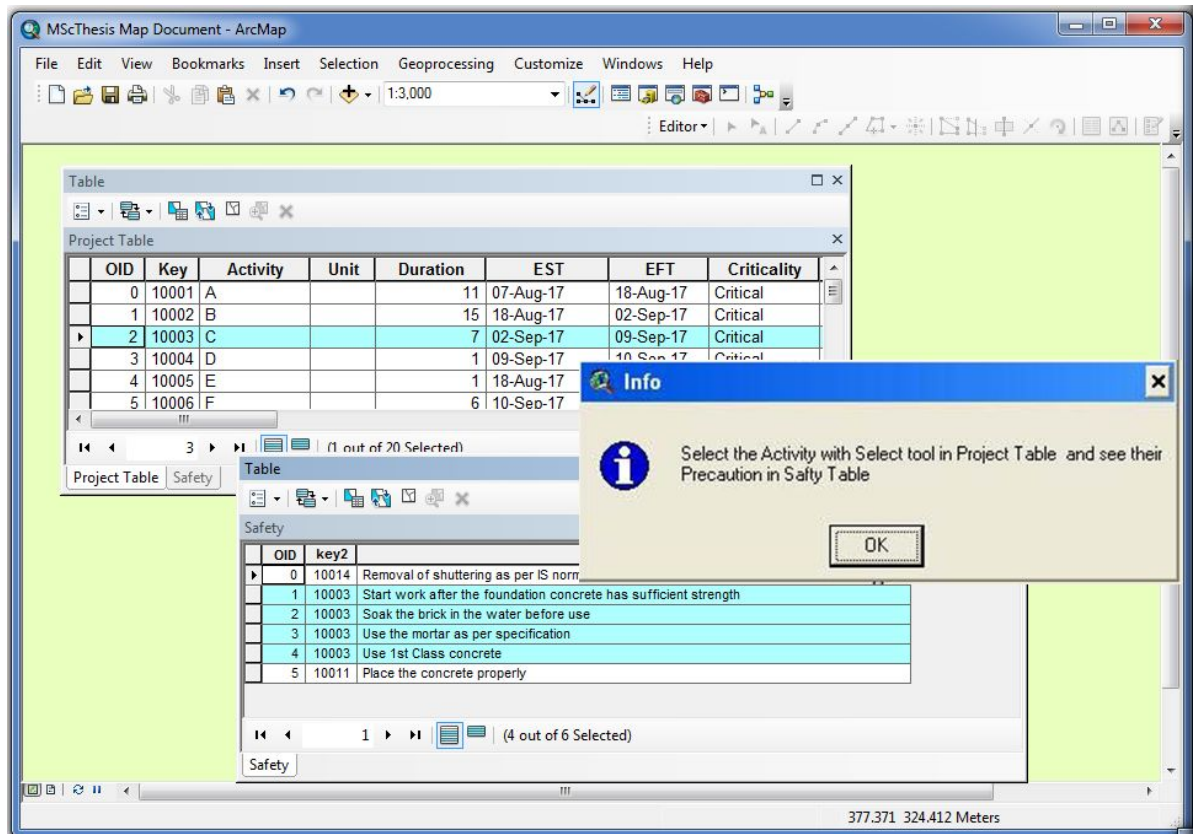


Figure 25: Safety information highlighted for the project activity

Quality recommendation table performs in a similar way as the safety recommendation table and provides information about the quality control recommendations.

Step - 12: **Display of 3D Model in ArcScene**

Extrusion: A field called *base height* is added to the attribute table that defines the elevation, and field *height* is also added that gives the height or thickness of the feature. The **extrusion** tool changes the form of a feature: points into vertical lines, lines into vertical walls, and polygons into 3D blocks.

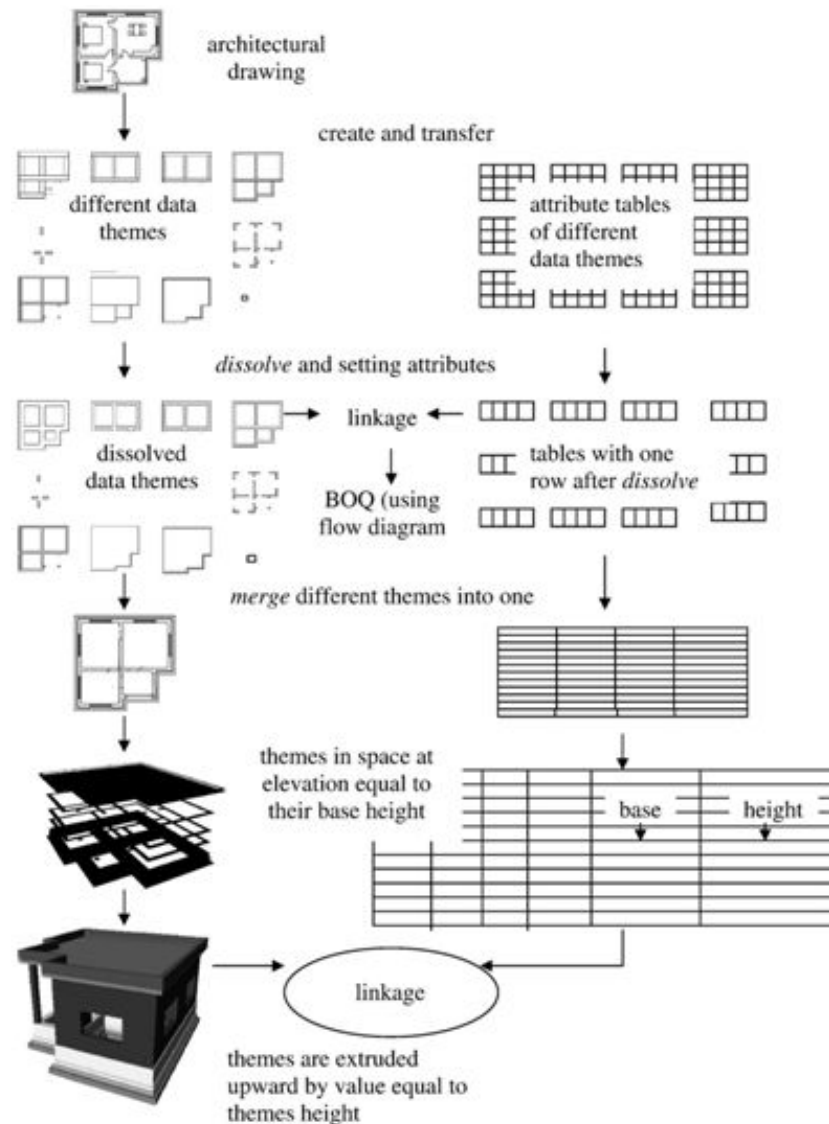


Figure 26: Flow diagram used for quantity takeoff and to develop 3D views by extrusion

The figure shows different layers in space at an elevation equal to their base height value and extruded upward to construct 3D view by a value equal to its height.

ArcGIS's 3D-scene viewer control-bar facilitates the understanding of the 3D model through zooming, pan, fly forward or backward, and navigation. Users have the option of rotating the 3D models around the x, y, or z-axes to observe it more clearly. The models can also be viewed from any direction and from any angle.

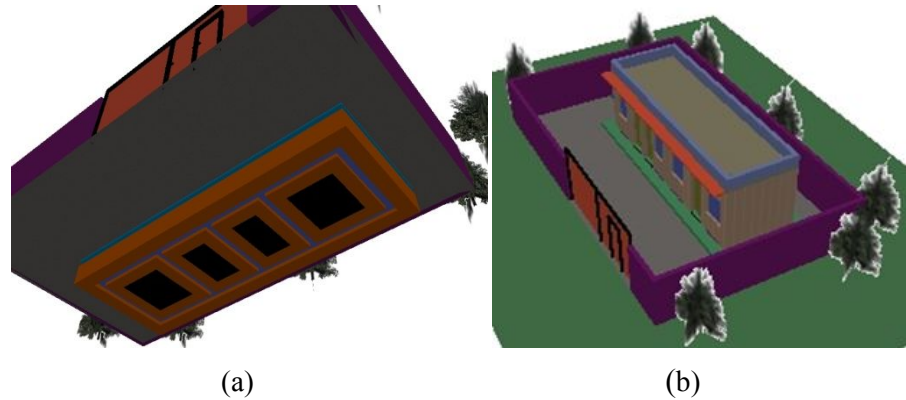
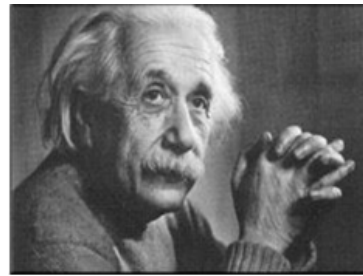


Figure 27: Layers wise 3D views of base heights and extrusions of the building.
 (a) View of Backfill in the substructure (Orange); and (b) Perspective View

Step - 13: Visualization cum Schedule Evaluation in 4D

With non-spatial schedule it is difficult to predict whether the activities are within/out of the construction sequence because the activities with mutual dependencies (i.e., successor and predecessor

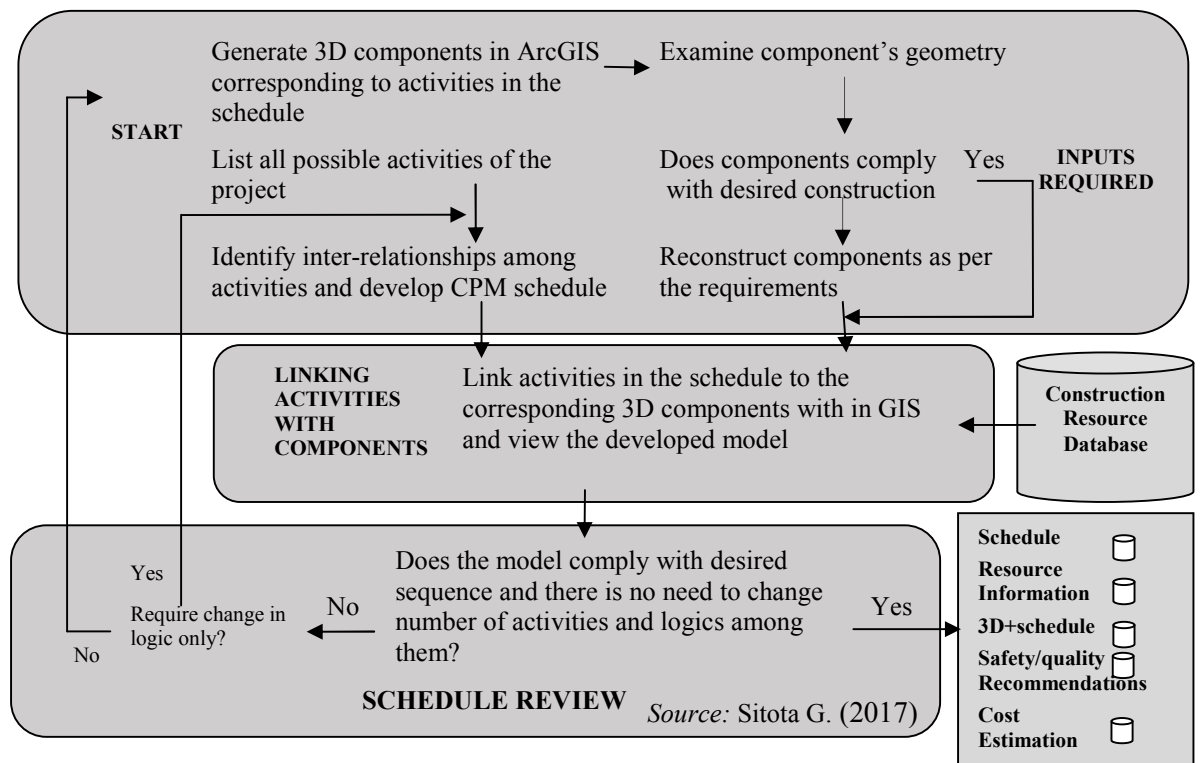


**“If I can visualize it,
I can understand it.”**

Albert Einstein

relationships) may be located in different parts of the schedule. To confirm that all components of the project have related activity is a time consuming process because of the large number of activities in the construction network. Such non-spatial schedule forces multiple participants of the project to visualize and interpret activity sequence individually in their head by associating the activities with the corresponding components shown in a drawing. This interpretation may vary according to the level of experience, knowledge, and individual perspective of the participants. These inconsistencies in the interpretation may lead to miscommunication among the project participants.

In GIS a visual check of schedule is possible, which may help in *preventing omission* of the activities in the schedule. The research paper presents GIS based approach to display at “what time” and “where” the components to be built in the space. Any component can be set *transparent* to make visualizations of the model much easier.



Sub-steps:

- A) Preparation of 3D Model (See Step - 12)
- B) Preparation of Construction schedule (See Step - 8)
- C) Integration of 4th Dimension – Linking

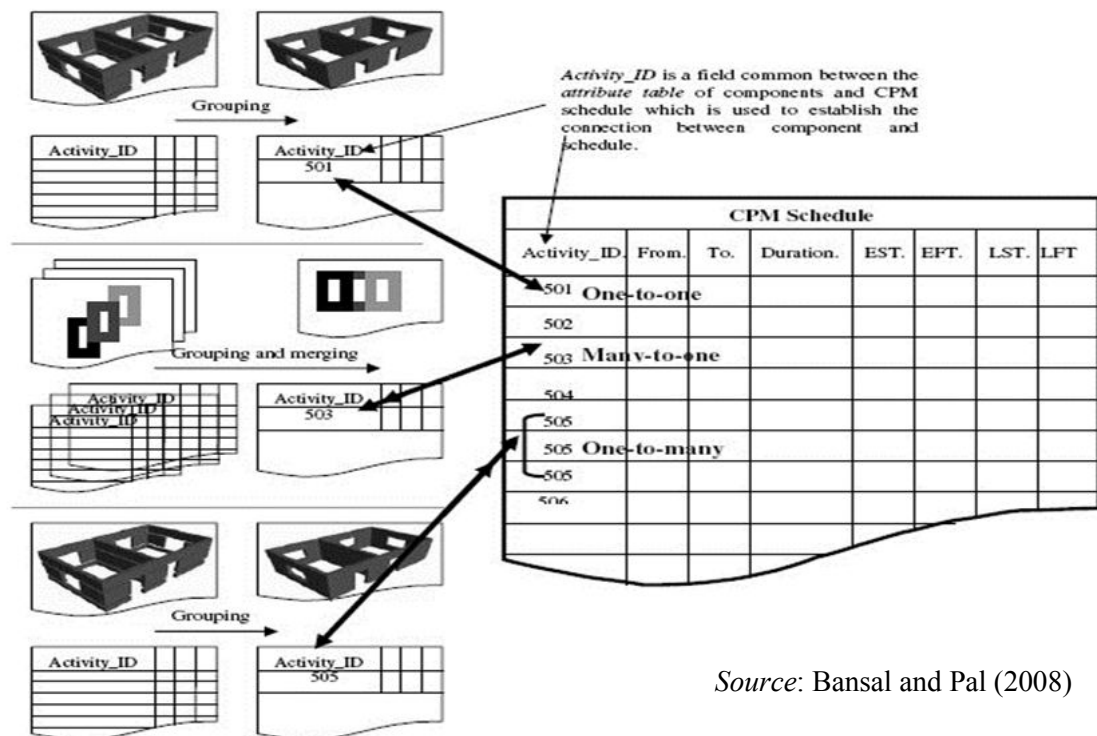
Although some commercial tools allow planners to build a 4D model and create graphical simulation of a construction process it still lacks features like generation and manipulation of a 4D model within a single environment.

The proposed methodology utilizes the dynamic *linkage* between the activities in the schedule and the corresponding 3D components, thus, making it possible to detect the incompleteness and logical errors in the schedule sequence. Linking (relating) activities with 3D components implies *connecting* spatial aspects with the corresponding activities of the CPM schedule.

The schedule prepared in Excel is read by ArcGIS 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. **Linking** involves adding a field *key* in the *schedule* and *attribute table* of each component manually and need to be unique. This forms an input for presenting 4D model of construction project in ArcScene which can then be used to **compare** the progress of work against the planned output.

Integrating information such as project schedules and drawings allows visual understanding of the construction process, and the construction resource data can be linked with the corresponding activities.

The linkage between a component and an activity of the CPM schedule may not always be one-to-one (one component corresponding to an activity of the schedule). However, a relationship like many-to-one may exist in which many components corresponds to an activity in the schedule. In such a relationship, components are merged together and thereafter linked with the corresponding activity. The one-to-many linking is also possible if there is a single component corresponding to many activities (See Figure 25).



Source: Bansal and Pal (2008)

Figure 29: 4D Model in ArcGIS after integrating with time

The figure shows relationships between components of a 3D Model and CPM schedule connected through *Field Activity_ID*.

Benefits:

- Linking of the activities with the corresponding elements of a 3D model in a critical path method schedule makes the project sequence easier to understand.
- The schedule and 3D components are synchronized in a way that can be queried, analyzed, and displayed simultaneously. *Queries* such as, activities starting on the particular date and activities starting between the particular intervals of time can be made from the CPM schedule or Project Control table generated in GIS.

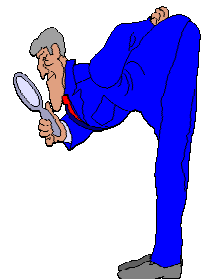
D) Schedule Evaluation and Correction

The link informs the user about those activities in the schedule that do not have corresponding 3D components and also provides a list of 3D components without corresponding activities in the schedule. In the resulting model, the GIS based approach displays at what time the components are to be built and where they will be in the space.

After analyzing the model, if it does not comply with the required construction sequence and needs some changes in the logic (interrelationship among the activities), all activities that are not in the sequence need to be rearranged in the CPM schedule. All relationships among the activities in the CPM schedule that constitute a physical impossibility or can cause major disruption or delay at the construction site need to be corrected at this stage.

Step - 14: Progress Monitoring

The components that are scheduled to be in operation on and before a date will be queried using SQL (Structured Query Language) to make monitoring easier. By clicking on a date in the list, activities that are planned to be in operation on and before a date will be graphically visible in 3D in space by using link (RELATE).



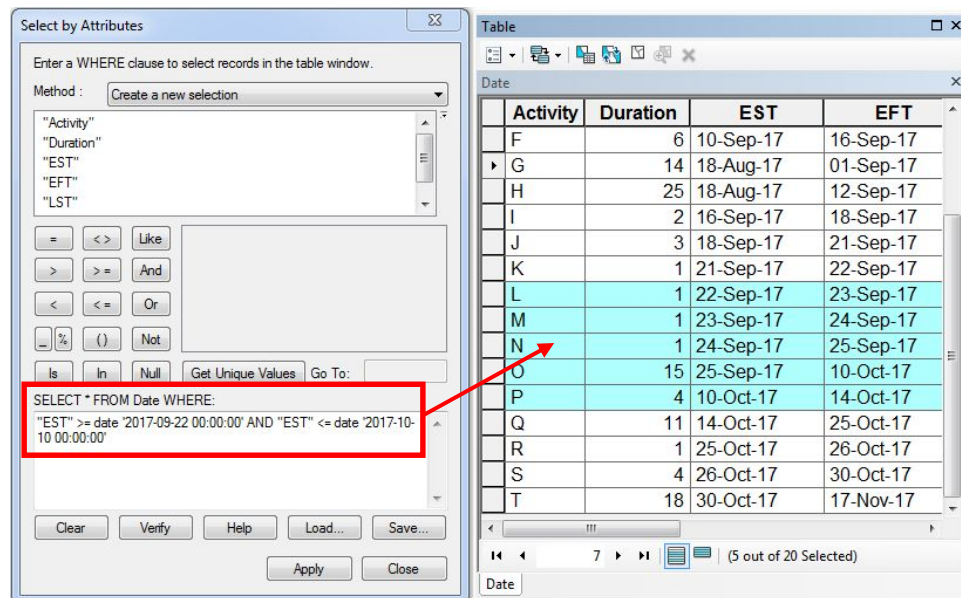


Figure 30: Querying specific activities based on construction date in the project table

A **base version** of the schedule that will be prepared with expected thickness/height is used to construct the planned 3D model of the project. Planned start and finishing dates are fed into the schedule for different activities. A **working version** of the schedule (with height of construction work) is used to update the progress of work on weekly or monthly basis. This working version is used to create the actual work-in-progress in 3D model. The work-in-progress version of 3D model is generated by extracting the height value from *working version* of the schedule. The feature of the file will be a total polygon thus it resembles a developed building. This model is intersected with the base version of 3D model to view the delay in the planned task.

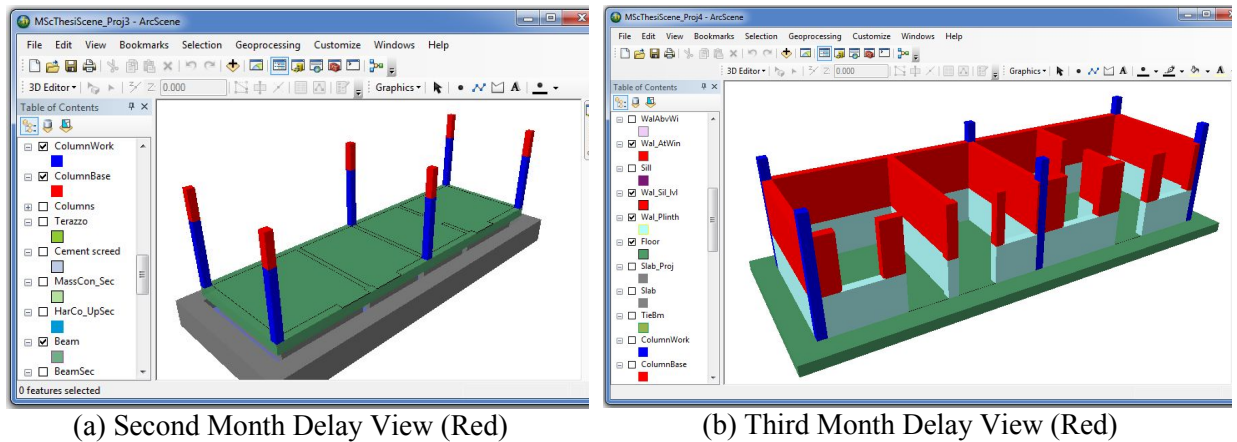


Figure 31: Construction progress in 3D

The Red color represents portion of the work item that is not executed as per the planned schedule.

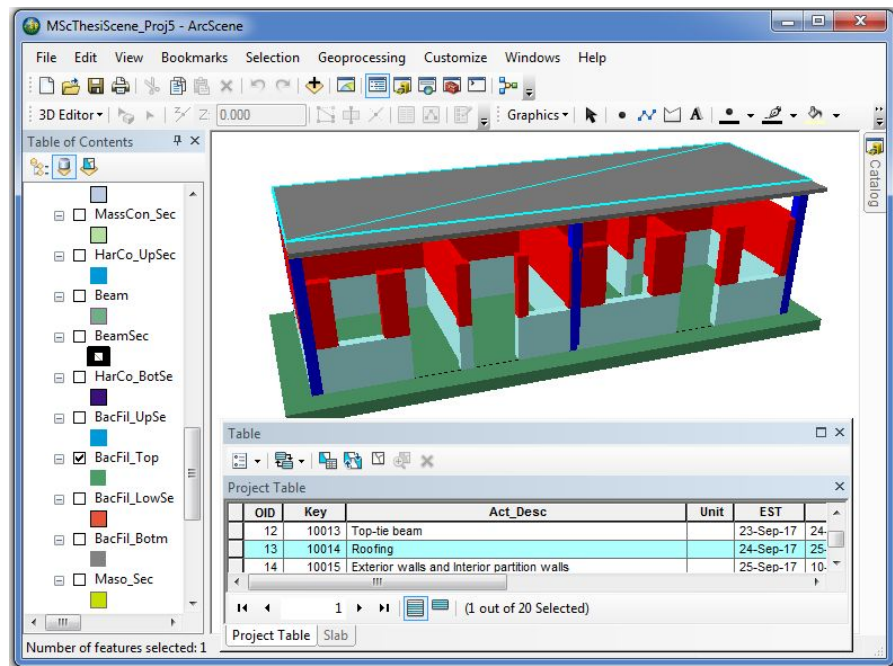


Figure 32: Synchronizing details of components

For Roof Slab, total percentage completion of activities equal to 100%. They are linked to synchronize in both 3D and in the Project Control table, i.e., **4D in Action**. When the work item is selected in the Project Control table the component is then selected in the 3D to enable identify where it is found.

Step - 15: Animating the Construction Progress

What is Animation? It is the rapid display of a sequence of 2D or 3D images in order to create an illusion of movement. It is to visualize how data changes with time and space. The time feature of the spatial data is utilized for simulation of the project. Planners can have a series of images to depict the state of construction on a particular date (Figure 33). As animation advances, an individual component goes on adding at its defined location in space as per scheduled time. The program needs CPM schedule and 3D components as inputs to generate the animation.

ArcGIS offers two methods for animating geospatial data: Animation Toolbar and Time Slider. *Animation Manager* arranges the animation timeline. You can store multiple tracks and mix them, like a recording. However, it is a kind of a pain to use, but powerful since you can bring together many “threads” of a project.

Therefore, the research applies animation created in Visual Studio 2010 by using Visual Basic Programming language, since it has especial facility to create a GUI. It is chosen because the application program named as “**5D Construction Monitoring Application**”, is to be developed by using the same software.

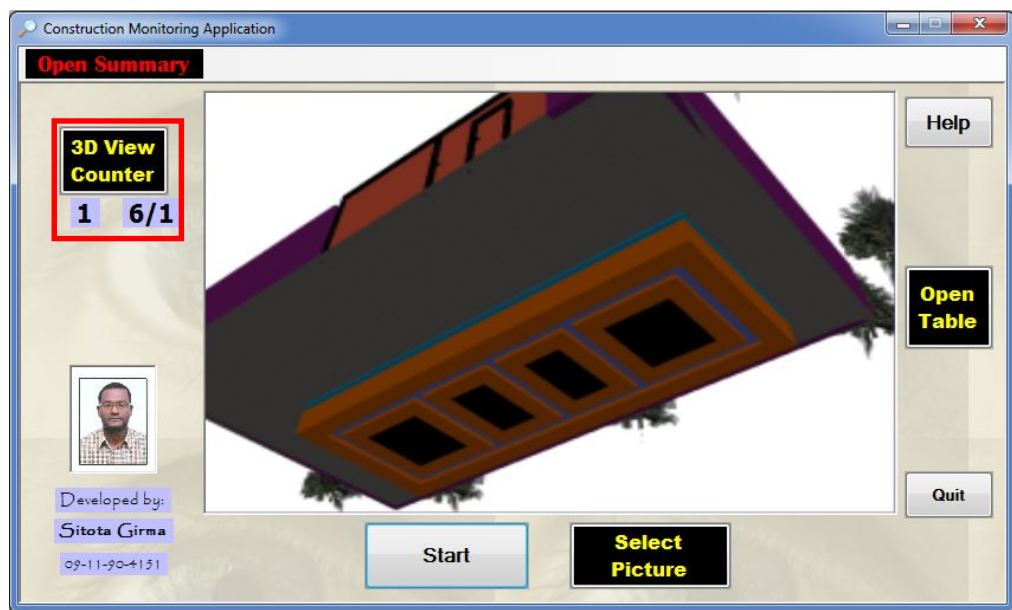


Figure 33: Screenshot of the animated sequence of the construction project using the application

Note:

1. The counter at the left side of the screen shows a sequence of construction.
2. A highlight of how to use the application is displayed by clicking the “Help” button.

Step - 16: Reporting Using the Inbuilt Formats of ArcGIS

At a specific time interval, one can utilize the *planned building* model and the *actual* building model to compare the work in progress. Various formats of reports can be generated as per the user’s requirement. After spatial analysis, the **.dbf** files could be exported to the commonly used file formats such as Excel, .pdf, .jpg, and etc. In addition to this, ArcGIS allows the use of different scales for printing purpose.

Step - 17: The Run-time Application

Data binding and *creating setup* file are the two main sub-activities of this step. The “Project Control” table, Annex-D is imported to ArcGIS “Personal *geodatabase*” to be able to read it in Visual Studio as a MS-Access database.

The application, “5D Construction Monitoring Application” is developed with one *Parent Form* and two *Child Forms*. **Data Binding** facility of Visual Studio allows here to tie a piece (or pieces) of data together with a Windows Forms control. The space in this thesis report doesn’t allow discussing how the *link* between the *geodatabase* and the run-time application is made. Further details related to output is discussed in the Results and Discussion Section, Chapter5. (See Annex – E for exhaustive list of codes used to develop the application).

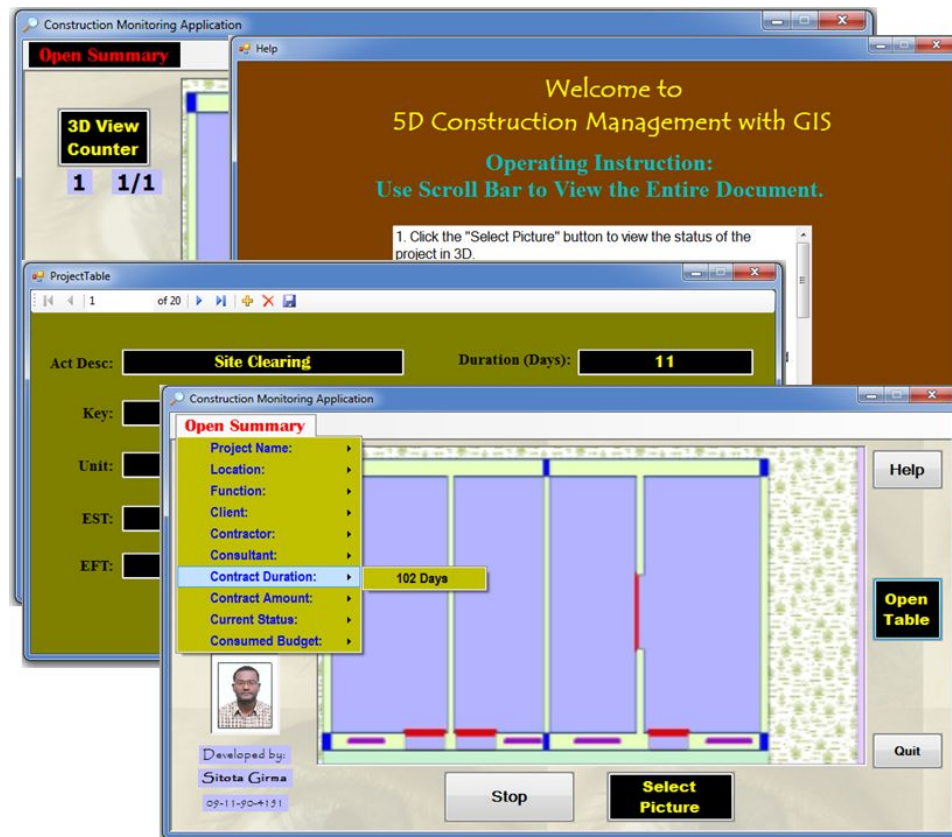


Figure 34: The Graphic User Interface Windows of the Application

The graphic user interface displays:

- A summary of the project details
- The status of the construction progress with 2D/3D animation.
- Details of the status of work items from the geodatabase.

The Project Control table and schedule will be updated as progress information became available from site. The updated schedule shows the progress of all activities as of the new date of the update. The percent complete information on the activities is entered in the Project Control Table, which is accomplished by using the size (height, area and volume) of work item in ArcGIS.

This information is then transferred with the help of the custom run time application every time a progress evaluation is made and the application is run. Hence, the proposed methodology allows users to communicate with a GUI through the run-time application.

CHAPTER 5: RESULTS AND DISCUSSION

In this chapter, a summary of the results of the research will be discussed highlighting relationships among observed facts and demonstrate their significance.

Based on the standard production rates, it is estimated that the building would have taken 102 consecutive days if the productivity rate of the construction work is practical as per the set standard. Nevertheless, the building actually took more than 200 Days for its completion due to financial constraints and some other reasons, according to the information from the owner of the building. By the same token the construction cost is estimated to be Birr 644,406 inclusive of the 35 percent profit margin.

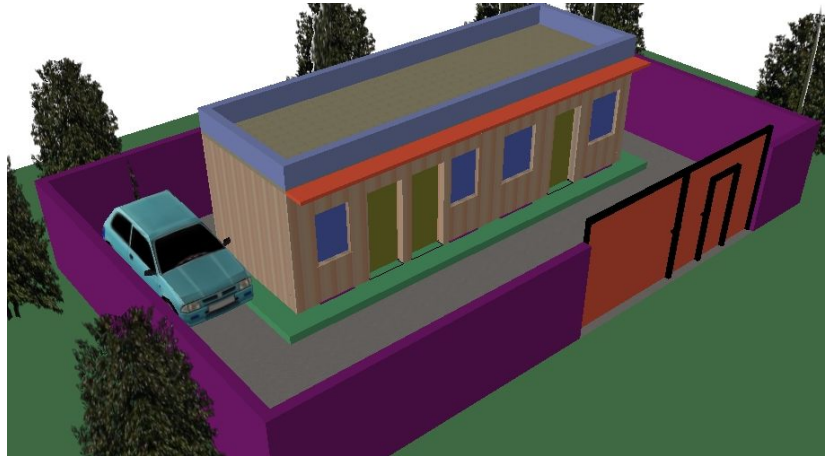


Figure 35: Esthetically attractive 3D perspective view prepared by using ArcGIS

↳ ArcGIS Interface:

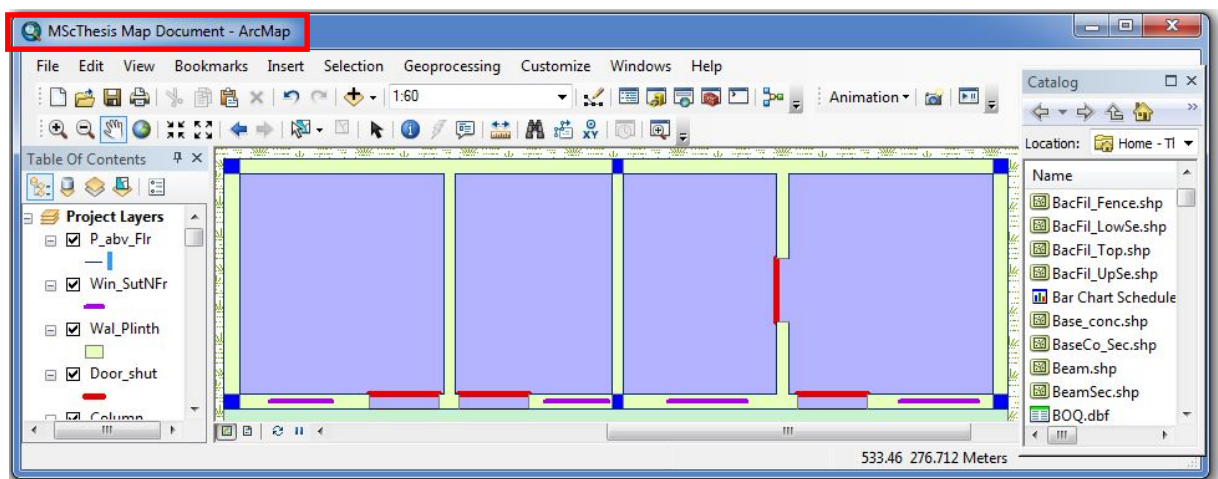


Figure 36: Screenshot of ArcGIS interface – selected 2D data layers

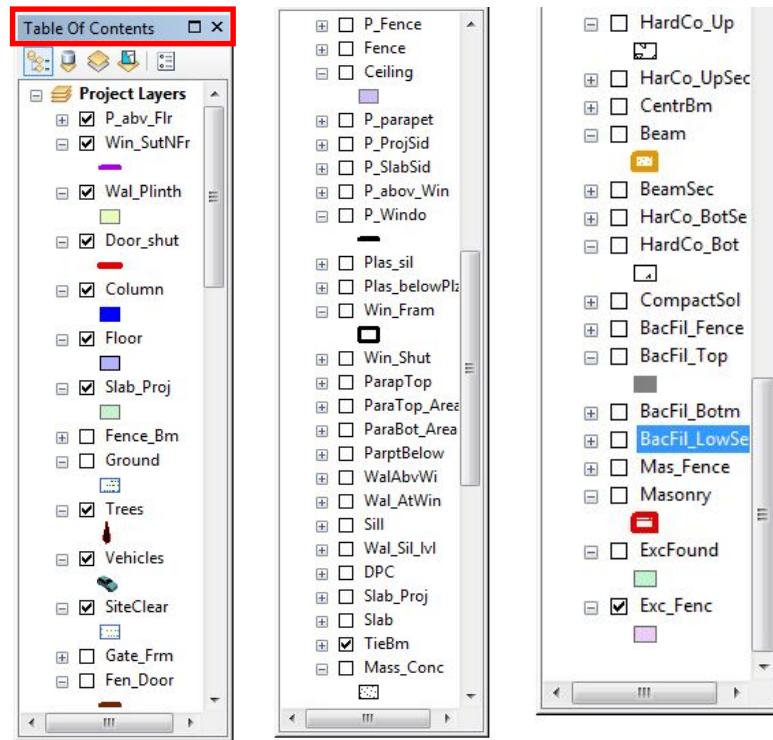
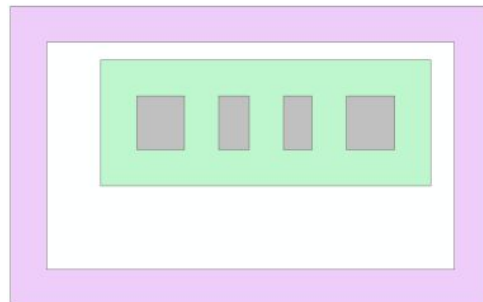


Figure 37: Some data layers in ArcMap Table of Content.

The file names in the figure are abbreviated to comply with file naming restriction in ArcGIS. Each layer corresponds to one or a part of an item whose quantity needs to be estimated. All data layers are stored as shapefile or feature class and their base height and/or feature height has been written in respective attribute tables.

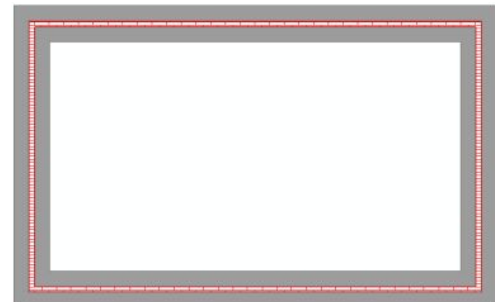
↳ Sample Data Layers from ArcMap Window

The screenshots in Figure 38 (a - p) complemented with the data in Table 4 provide details of layers used to estimate earthwork, backfill, masonry work, plastering and other work items.



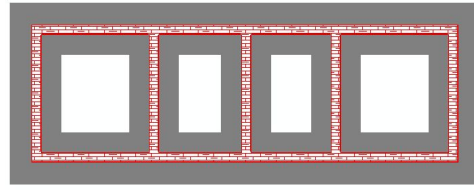
Excavation: Fencing [80cm depth, violet], foundation [103cm, green], hardcore [25cm, gray]

(a)

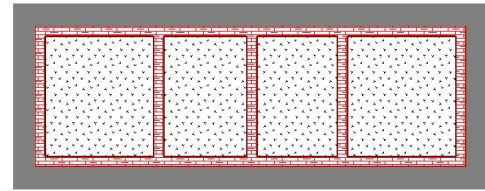


Backfill [80cm, gray] around the base concrete & foundation masonry of the fence [80cm, red]

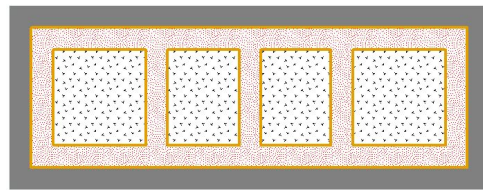
(b)



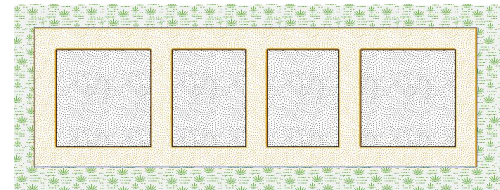
Backfill around foundation masonry (gray) [$@ 45^2\text{cm} - 125\text{cm}$ depth]
(c)



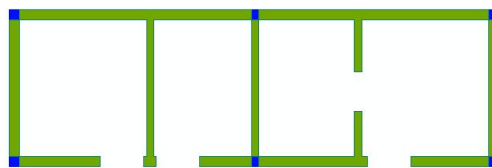
Backfill and hardcore around masonry (red) [$@ 30\text{cm} - 45\text{cm}$]
(d)



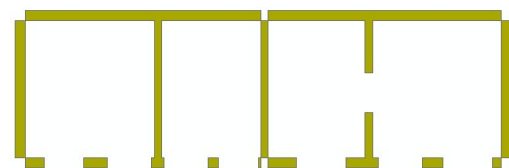
Backfill, grade beam (orange) and hardcore [$@ 20\text{cm} - 30\text{cm}$]
(e)



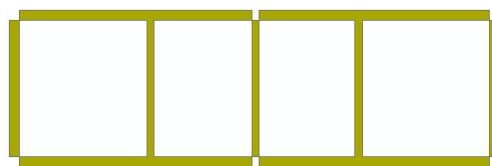
NGL (green), grade beam (yellow) and mass concrete [$@ 0-20\text{cm}$]
(f)



Floor plan (white) above plinth, Column
(g)



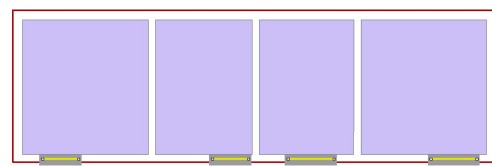
Wall @ window level
(h)



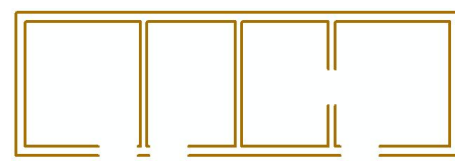
Wall above window level
(i)



Door shuttering
(j)



Outside plastering (red) above NGL to plinth level (20 cm height); Window frame section, sill and ceiling (brown)
(k)



Plastering in/out-side wall from plinth to sill level (90 cm height)
(l)

² Depths hereafter in this figure are measured from plinth level

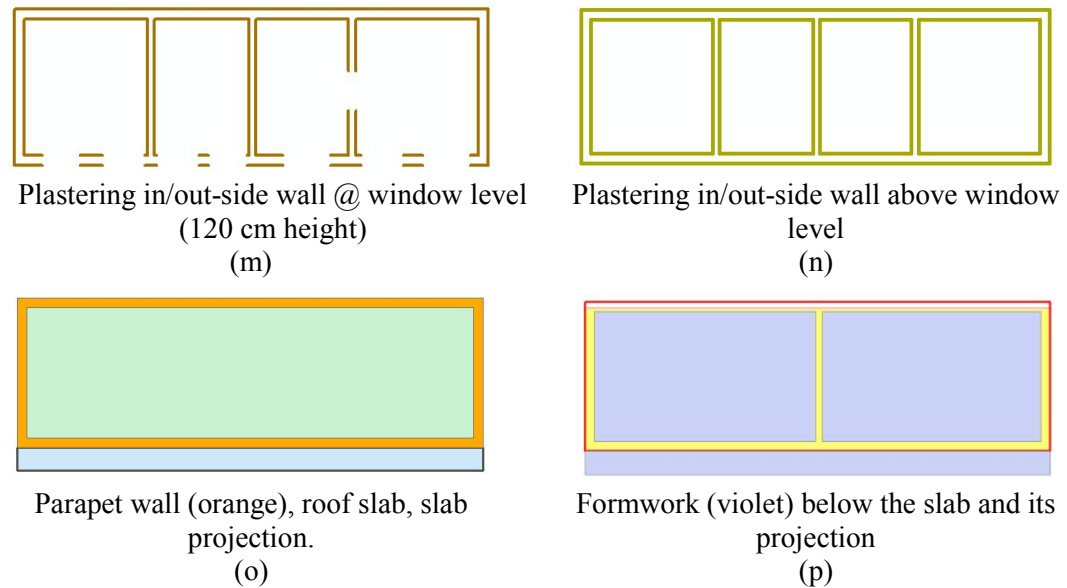


Figure 38: Data layers after merging different features

The Figures show some data layers after merging different features, where each data layer contains single record, as all features in a layer are merged to one polygon or a line.

↳ Constructed Layers Vs Work Items:

In the sample building, more than fifty five different data layers (Figure 37) are generated for quantity takeoff and 3D visualization. Except five layers (i.e., doors, window, plastering for walls, and damp proofing for foundation walls and main gate), those are prepared as line features, all other layers are prepared as polygons. The different data layers include: excavation, base concrete, foundation masonry, backfill, hard core, beam, column, walls, slab, doors shutter, windows shutter, door/window frame section, parapet, and fencing.

↳ Basis for Deciding the Number of Layers Created

The following list describes the approach used to make effective and efficient use of file management in the model:

- a) Two layers are required to estimate the quantity of earthwork since the one excavated to place the masonry is not symmetric in height with the one excavated to place the hardcore. There is also a 3rd layer created to estimate earthwork for fencing (Figure 38 - a).

- b) Only one layer is found to be enough to estimate the volume of masonry work and base concrete in the foundation, because both are symmetric in plan though they differ in height (
 - (c) (d)
- c) - a). Therefore, single layer has been stored in the database by two different names (i.e. masonry and base concrete). To explain it further, if the thickness of the foundation footings changes three times across the height, thus, three different layers representing these changes would have been created for quantity estimation. However, the foundation masonry of the subject building is of a uniform width in this case.
- d) Two layers of hardcore have been generated at different height levels to accommodate the difference in plan surface area of the hardcore sections along the height (Figure 38 – d & e, Figure 45 - a).
- e) The plan view area of the volume of back-fill in the foundation changes across the height, therefore, two different layers representing these changes are created to represent the backfill [Figure 38 (c-d), Figure 45 (a-b)].
- f) Four different layers for different sections of HCB wall have been created at different levels of height so as to take care of the openings in the walls [Figure 38 (g-i)].
- g) One layer for estimation of Reinforced Cement Concrete (RCC) work in the roof slab has also been prepared. For items of concrete in the slab projection and sill, single layer has been generated for each [Figure 38 - (o)].
- h) Two layers have been created for parapet wall considering the irregularity of the building element (Figure 40).
- i) Similarly, six different layers for the quantity estimation of plastering have been created (one for outside surface between the ground and floor level (Figure 38 - k), four for inside and outside surfaces lying between the plinth level and the slab [Figure 38 - (l-n)], and one for fencing).
- j) Also, a number of layers have been created to show the *section* of substructure in 3D and are shown in the next section.

↪ Benefits Secured

A summary of different 3D views and their advantages are briefly discussed hereunder:

- **Allows to Monitor and Report Details**

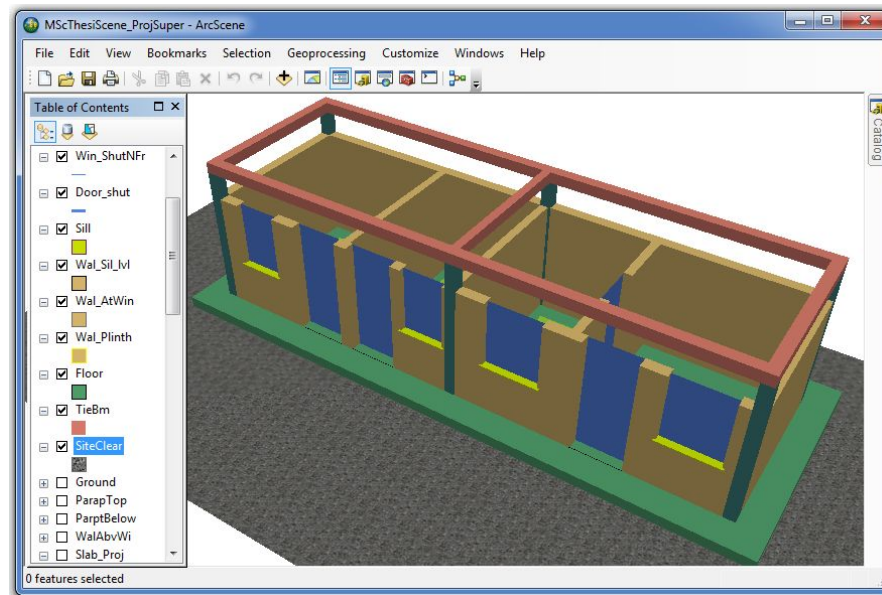


Figure 39: 3D view of the superstructure details

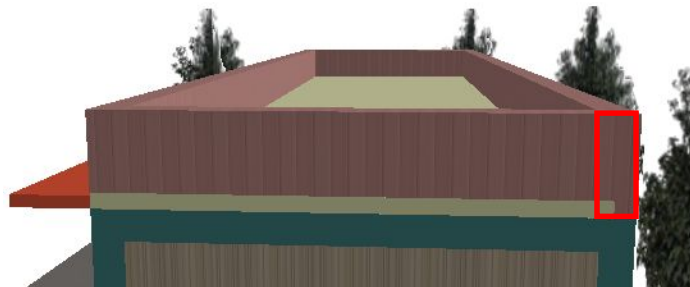


Figure 40: Right side view depicting the profile of the parapet wall

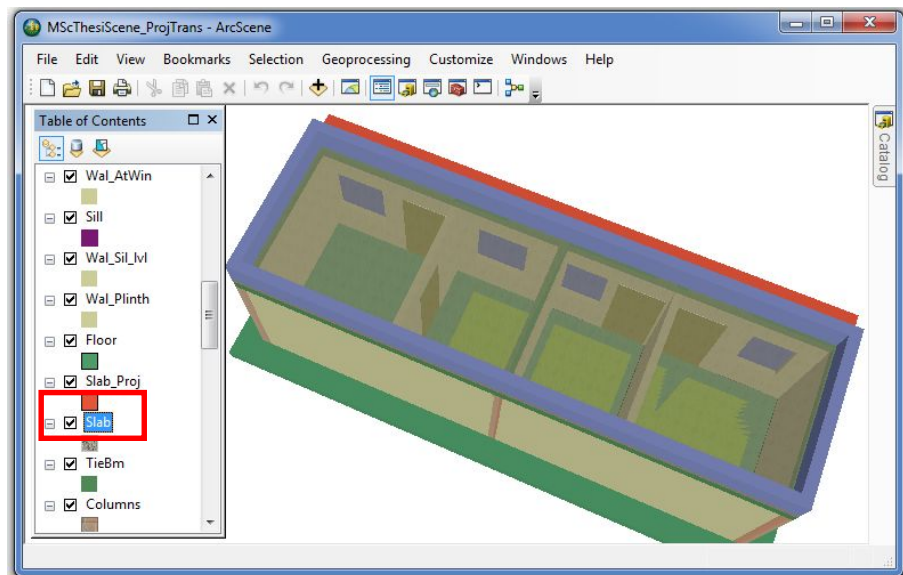


Figure 41: 3D roof slab set transparent to display internal details more clearly.

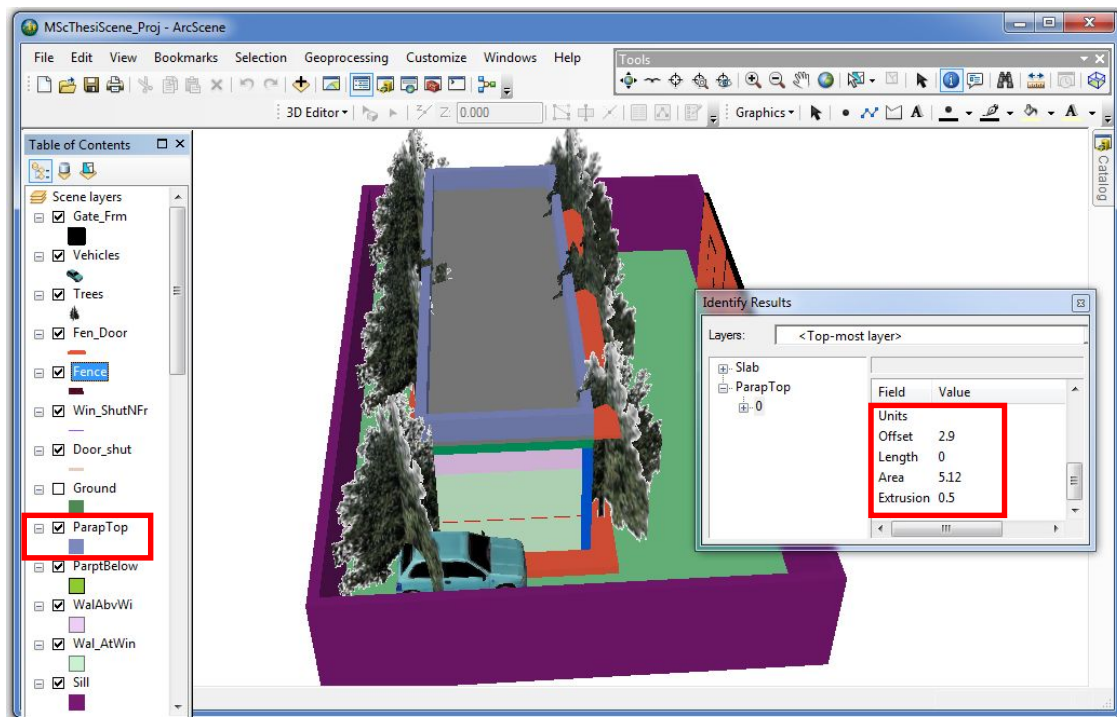


Figure 42: Retrieving details of building components using identify tool

Identify tool is used to check details of As-built components in the 3D by retrieving attributes such as dimensions, material type used and etc. In the figure the details of the parapet are made displayed by clicking on with identify tool.

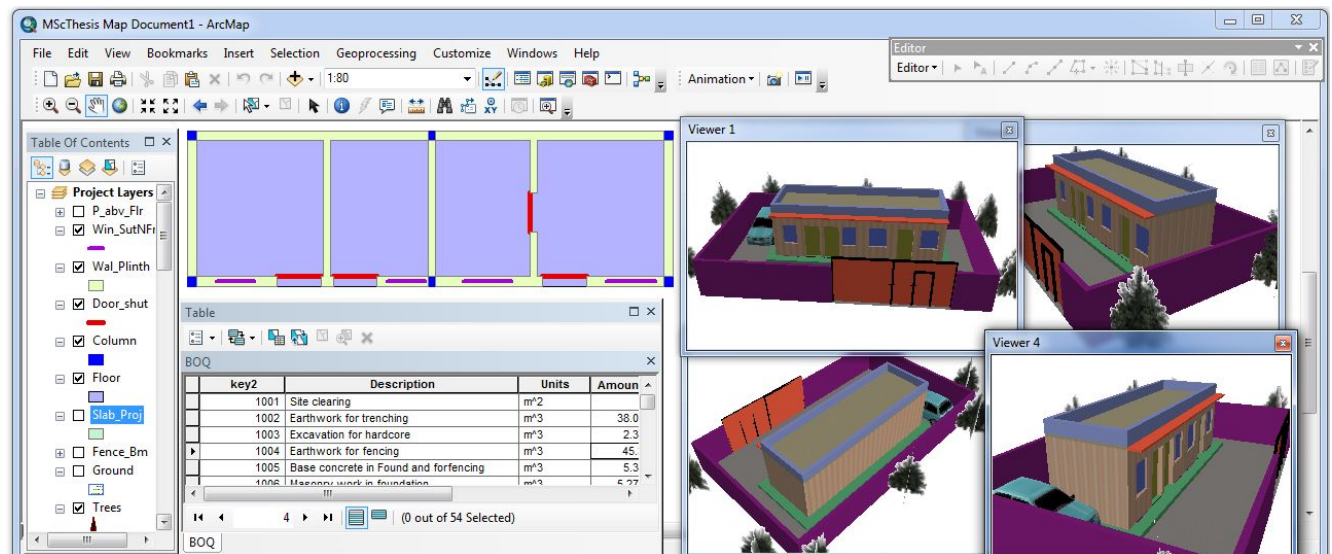
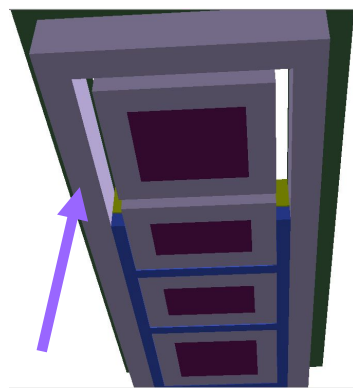


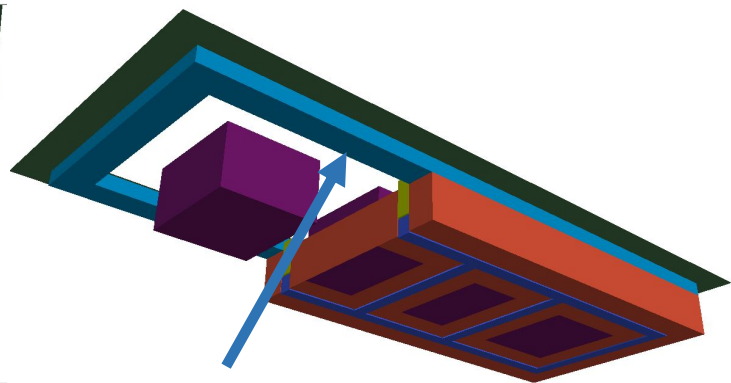
Figure 43: Screenshot of documents of ArcGIS from ArcScene Viewer

The picture is a screenshot of different documents of ArcGIS to display 2D/3D view perspective views and BOQ of the sample building. The 2D at the top left corner of this figure contains different data layers after dissolve, which is the input required to generate the BOQ. The perspective views from different angles are illustrated using 3D Scene documents and provided in viewers 1, 2, 3 and 4 to display the complete building used in the case study. The *Attribute Table* is used to display BOQ of the building and shown in the lower left corner of Figure 43.

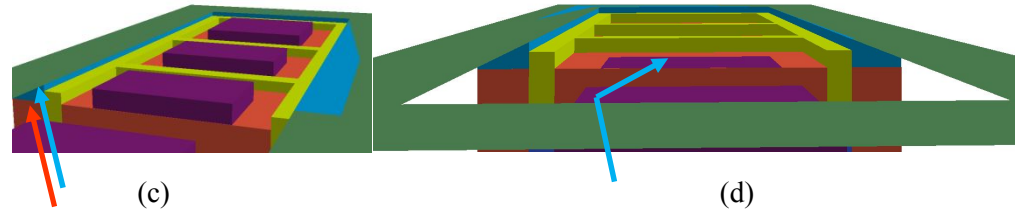
▪ Ease of Viewing Components:



First stage backfill around masonry (lemon), and base concrete (blue)
(a)



Second stage backfill (siyan) around masonry. The suspended portion (brown) is the earth that is left unexcavated.
(b)



The two stages of backfill (Siyan & orange) around masonry (c) before excavation; and (d) after excavation for hardcore placement

Figure 44: 3D views of substructure components

▪ Layer ON/OFF Option:

Components can be turned on/off as required to show the profile of the section view and see the in and out in detail. Some layers on the super structure are turned off to make the sub-structure visible from the top. Layers of terrazzo, cement screed, mass concrete, and hardcore are shown from top to bottom (Figure 45).

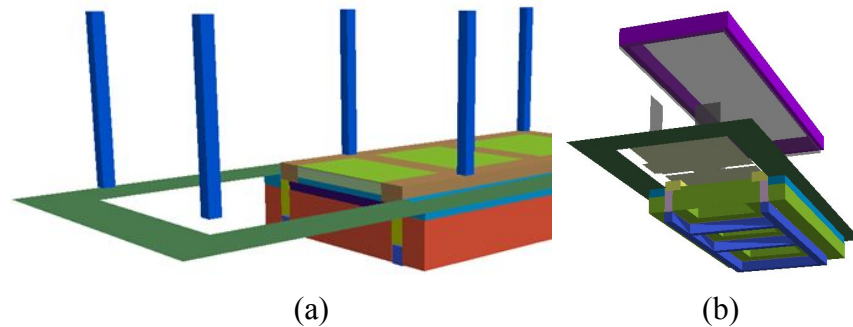


Figure 45: Layers ON/OFF applied on superstructure to display the substructure

▪ Transparency to View Obstructed Objects

This option is also used to make doors/windows transparent as a glass panel is.

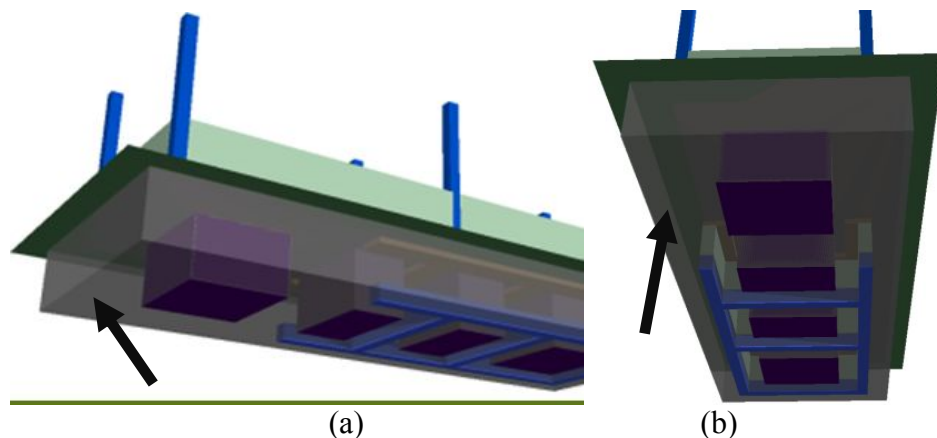


Figure 46: Objects made transparent

Figure 46 - (a) shows the excavated volume of earth made transparent in 3D to show what is behind it; and (b) the back-fill made transparent around masonry & base concrete

▪ **Error Identification:**

By implementing the proposed methodology, incompleteness of the original AutoCAD drawing is detected and correction is made accordingly. For example, cement screed and floor tiles (lemon color) were not shown in their appropriate place (Figure 47 - a). These must be shown above the grade beam.

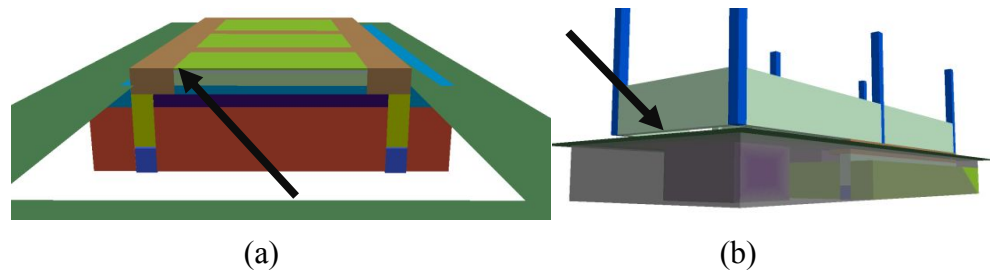


Figure 47: Detailed display to alleviate errors

In Figure (a) Grade beam shown on top of the masonry & the first layer hardcore (violet); and in (b) small gaps identified

Even very small error (in mm scale) expected during approximation of digits could be identified by the help of the zooming functionality, Figure 47 - (b). This seemingly small error will have significant effect on cost estimation especially in the case of massive structures and when the material used for the work item is expensive.

Quantity surveyors often make mistake by incorporating the space occupied by columns (blue space in Figure 48) while calculating the area of the wall. It is committing double count error. This model helps to avoid such intruding mistakes in calculation.

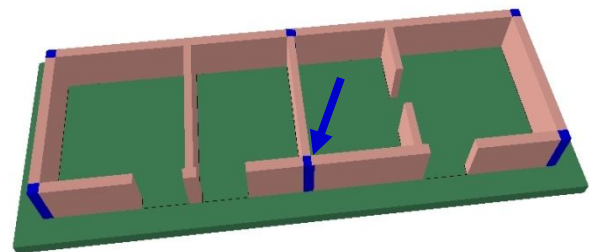


Figure 48: The most commonly committed double count error

In addition to this, the foundation base concrete underneath the foundation masonry were left forgotten in the CAD drawing (See Figure 18 - b). The missing work items are identified only

when *closely* viewed using the ArcGIS functionalities such as zooming and rotating about an axis that is facilitated by the module.

▪ Better Accuracy and Imagination

Note that in Figure 49, the grade beam (orange) is overlaid on top of the masonry (red). Here the masonry is made visible by making the grade beam layer 20% transparent. Hence, it is made easier to understand that the area of the supporting formwork at the bottom is the difference between the plan areas of the beam and the masonry. Otherwise, the quantity surveyor would be most likely prone to make mistake while calculating the area of the formwork by only imagining in his head. This approach may be practical for permanent void formworks installed to avoid uptrust.

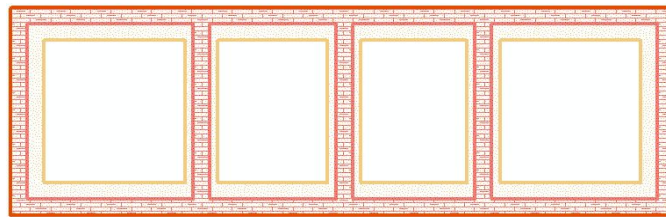


Figure 49: Visualization to calculate net surface area of a formwork

In Figure 50, the center lines of the beam (blue) are used to calculate total length. This length is multiplied by the cross-sectional area of the beam to calculate total volume. The *spacing* between the horizontal and vertical centerlines of the beams is so important not to overestimate the volume of the grade beam. It is used as a buffer to avoid double counting error of overlapping portions because the space (shown by red circle) is already occupied by the horizontal beam.

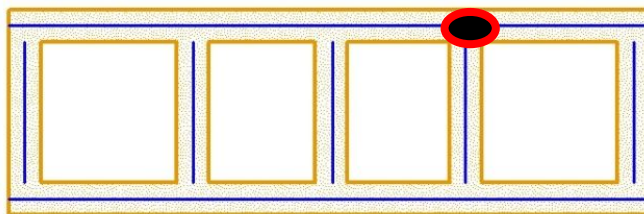


Figure 50: Centerlines used to calculate the exact volume of RCC beam

▪ Efficient Color Selection

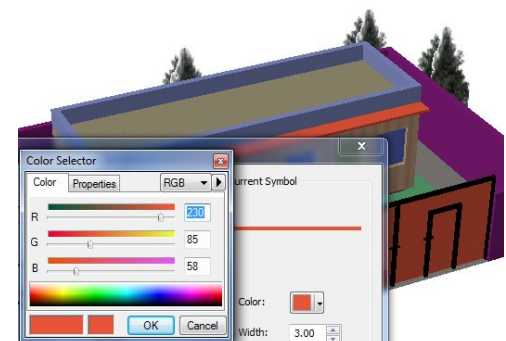


Figure 51: Effective and efficient way of color selection

Esthetically beautiful color combination can be made with trial and error by combining the fundamental RGB (Red, Green, Blue) colors by using color selector option and viewing their real effect or contrast on the building components. For example, the color selected for the gate in Fig. 51 is the combination of RGB: 230, 85, 58. Infinite number of ideal colors can be selected this way.

N.B: Some websites could also be used for best sample color mixes (<http://Paletton.com>).

▪ **The Benefits of Using “5D Construction Monitoring Application”**

The most important features are “Open Summary” Menu, “Select Picture” button and “Open Table” button.

- ☞ The **Help** button – opens a Welcoming screen with operating instructions to be followed [See Annex - F].

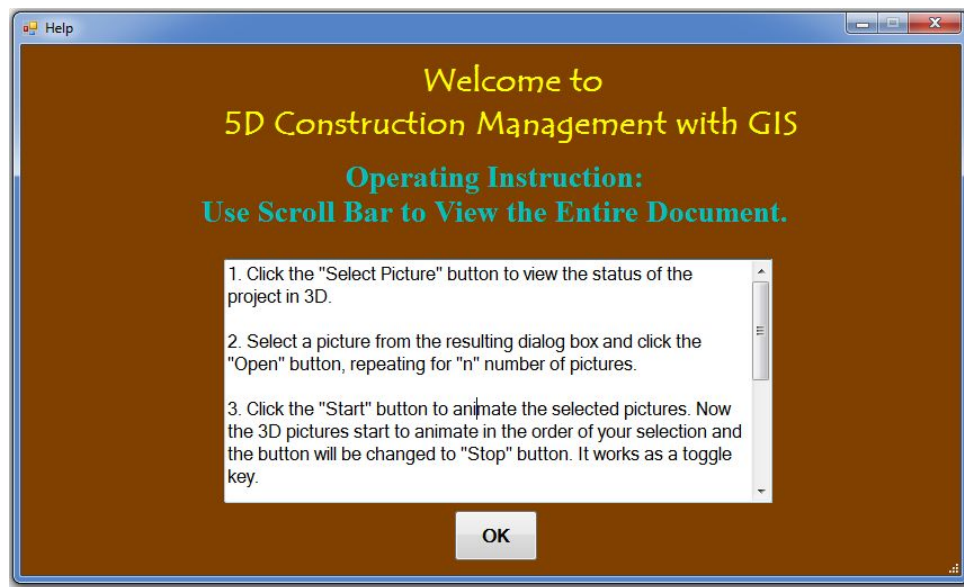


Figure 52: The “Help” window interface

- ☞ The **Open Summary** menu – displays a summary of the status of the project.

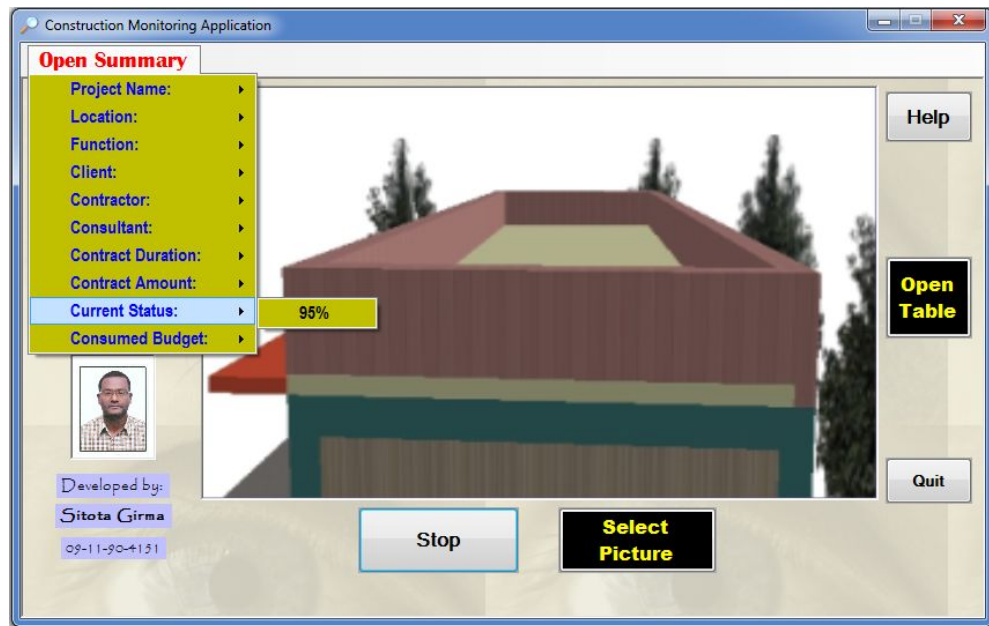


Figure 53: Project Summary Menu in the main window

- ☞ The **Select Picture** button – is used to select pictures to be animated.
- ☞ The **Start/Stop** button – is used to start/stop selection and animation.
- ☞ The **3D Counter** button – helps to view the sequence of 2D/3D pictures being animated.
- ☞ The **Open Table** button – is used to browse the “Project Control” Table placed in the geodatabase and show the content of a row by filtering amongst a huge list of data, (i.e., one work item at a time); and make it convenient to view and get an idea of the status of the building.

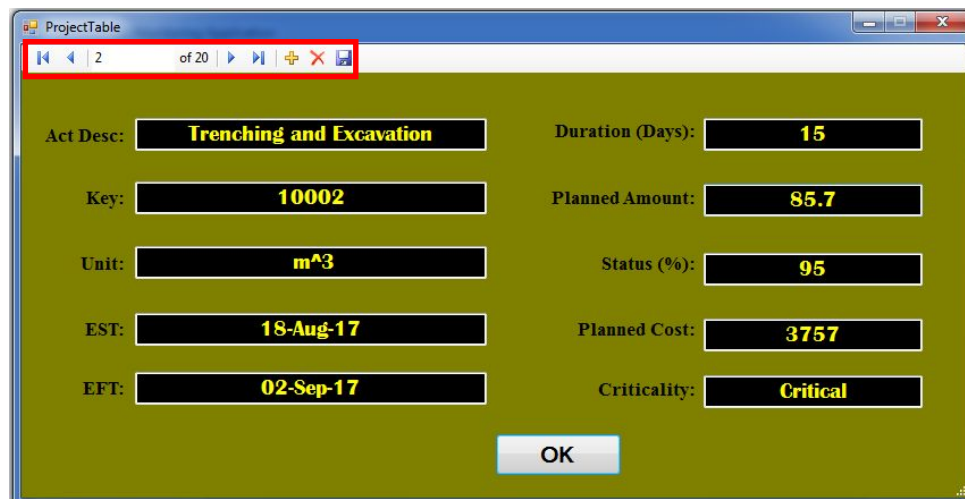


Figure 54: The window to explore the Project Control table



CHAPTER 6: CONCLUSION & RECOMMENDATIONS

6.1. Conclusion

1. In spite of much research in 4D technologies using CAD, their use is not very common in the construction industry. First, they are difficult to use and modify; second, they are unable to *segregate* information as spatial and non-spatial; and third, there is no standard procedure for using 4D technologies. Also, because of the difficulty in updating, they have limited capabilities for collaborative use by contractors.
2. The relationship between the utilization of GIS functions and project management techniques in the construction industry has *not been adequately explored*.
3. Despite numerous advantages of the utilization of 5D models for planning and scheduling of projects, the industry is still dependent on *traditional methods* for scheduling, as integrating GIS with project management tools is time-consuming process though it *pays off* for huge projects.
4. Though some of the earlier attempts made successful utilization of GIS in their works, a work that is *entirely based on GIS* environment is nowhere to be found. Many of the works used a mix of software, working on different tools and environment at different stages.
5. ArcGIS does not have functionality to *extrude* features inclined to horizontal, thus making it difficult to assign thicknesses to flight of stairs and inclined roofs. Hence it makes calculation of BOQ of the inclined roof impossible in this research. Because of this fact horizontal roof slab is assumed for the current analysis. In fact trigonometric relations could also be used as an option to calculate inclined lengths from their projection.
6. Keeping in view the above limitations, the research explores the potential of GIS to handle CPM based scheduling and links the developed schedule with a 3D model in the *same environment*. The various spatial operations on graphics and non-spatial operation on attribute data using a single GIS platform improves and *speeds up*

construction planning process and also ensures data *integrity*. It also makes *updating* of information easier.

7. The studies carried out in this domain proved the flexibility of GIS in the all-round management of construction projects that could truly exploit its *visualization* and *data management* capabilities. The *layout* of the building can be optimized just by viewing at the virtual images before commencing the actual construction work. For example, the area left for the garage or vehicle can be corrected or proportioned by viewing the 3D view (Figure 35). The researcher firmly believes that the chance of making an error in *imagination* while calculating work items buried in the sub-structure (different sections of Hard core in Figure 49 (a), for example) would be of significant amount, if this model would have not been used.
8. Many of the earlier studies have used land-based capabilities of GIS such as, network analysis for routing, construction site layout planning, and sewer/water system design. The current study does not focus on *land-based* information of GIS, rather utilizes its capability to maintain spatial and non-spatial data on a common platform to make *scheduling* and *cost estimation* more realistic.
9. Non-spatial schedules can only convey “what” is built “when”, whereas the schedule in GIS conveys **what** is being built ‘**when** and **where**’. Therefore, with time as the 4th dimension, the progress of construction task can be displayed as 4D view. The 4D drawing helps contractors, consultants and clients providing a clear view of ideas regarding their *work progress*, i.e., the work they have made and the course of work to be done for the mentioned period of time. In GIS a visual check of schedule is possible, which may help in *preventing omission* of the activities in the schedule. That means the link informs the user about those activities in the schedule that do not have corresponding 3D components and also provides a list of 3D components without corresponding activities in the schedule.
10. Developing schedules using Excel leads the scheduler to better understanding of the process behind clicking menus in Ms-project and as a result it takes full attention of the scheduler to do his task without being bored of.

11. The model also integrates construction schedule with corresponding spatial details and presents a GIS based navigable 3D **animation** developed after linking CPM schedule with 3D components. This makes understanding of *construction sequence* easier. The visual representation of the construction sequence through animation requires low level of *interpretation* skill than conventional 2D drawings and is expected to help industry practitioners in understanding the schedule in a much better degree than the 2D drawings. It allows even an inexperienced user to identify errors in logical sequencing of activities and evaluate alternative construction strategies. Such effective communication among project participants may also lead to the substantial improvement of *quality* and *productivity* in construction industry. The main advantage of the system is that overlapping and *rework* can be avoided and thereby *reduces time* for decision making as all information is in one system.
12. The study also demonstrates the significance of GIS-based system for storing and utilizing information related to construction resources to support planning process and quantity takeoffs. GIS-based quantity takeoff methodology reduces errors like missing or duplicating various items of work by visualizing each component corresponding to the items in 2D or 3D space. Thus, it is helpful in increasing the *productivity* of quantity estimator by reducing manual work in determining *quantity*. This is the 5th dimension of the model. Hence, it can be concluded from this work that GIS based approach can be the best alternative to the traditional method for cost estimation.
13. It is also important to handle various project requirements of construction industries such as integrating *safety* and *quality* control recommendation.
14. The 5D Construction Monitoring Application (shown in Figure 34) is developed to help project participants monitor the construction progress. It can be used with no need of installing Visual Studio as a prerequisite. Moreover, an amateur professional can use it easily; and it is user friendly application.
15. Also different queries can be made from the CPM schedule or Project Control table for *project monitoring*. Thus, the research demonstrates effective methodology of *integrating* GIS with construction project management to provide a better solution for

optimization (of material, labour, and time) and *real time* monitoring of the construction progress.

16. It is also possible to **update** the Project Control table in a GIS and retrieve the current status of the project at run-time. The most important advantage of using the run-time application is that it has inherent characteristics to update its database when the input Project Control table is updated in ArcGIS environment to reflect current status.

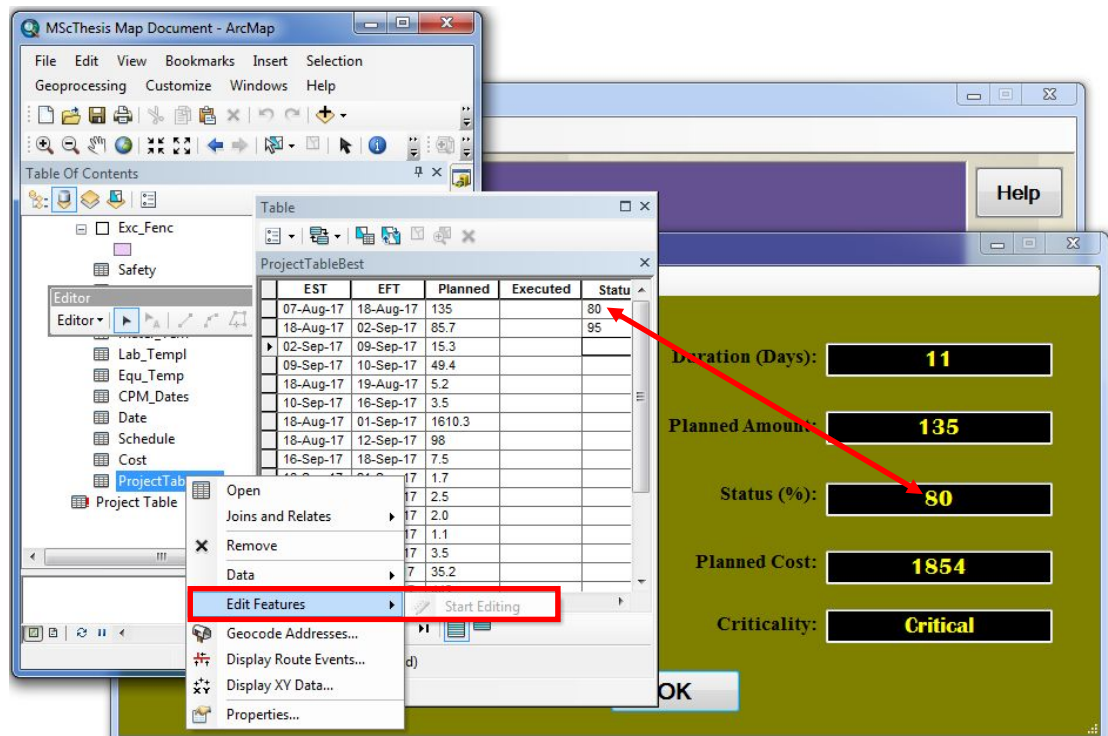


Figure 55: Editing “Project Control” table in ArcGIS & viewing the effect of using the runtime application.

17. On top of that, playing around the software is very much *interesting* as it is not boring as it happens when working on spreadsheets for pretty long enough time in quantifying work items. This approach leads to virtually error free BOQ estimation.

All in all, the model is the best solution to optimize planning constraints – **time, quality** and **cost**. That is why 5D GIS modeling is!



6.2. Limitations of the Model

In spite of all suggested outcomes, some improvements are still needed in the proposed methodology as listed hereunder.

1. Handling the model requires trained staff on AutoCAD and Excel; and also fairly good knowledge of ArcGIS and Visual Studio.
2. Although the study explores the drafting capabilities of ArcGIS to generate data layers, these are a bit cumbersome as compared to graphical editing tools available in CAD systems.
3. Lack of functionality in ArcGIS to extrude features inclined to horizontal, thus making it difficult to assign thicknesses to flight of stairs and inclined roofs.
4. Time-consuming process though it pays off for huge projects.
5. At this stage the researcher is unable to bring the scheduling part of the methodology comparable to the existing scheduling tools, though the Excel version used in the research has its own merits. Therefore, it requires more functionality like those available in MS-Project and P6.

6.3. Recommendations

Some recommendations made for future scope of the work are the following:

1. The current version allows some updating tasks such as transferring information from MS-Excel and AutoCAD to ArcGIS to be performed manually. However, it should be possible for the software to communicate automatically with each other seamlessly.
2. The proposed methodology should be improved by creating and editing data layers in the GIS itself, thus excluding CAD completely. Hence, requires boosting the editing capability of ArcGIS.

3. Future works should include additional functionalities of GIS that would enable to extrude features at an angle to a horizontal reference plane so that to calculate the area and volume of inclined building elements.
4. It would have been easier if the resource estimation that is done using Excel template is handled by interfacing with the model to ease its application.
5. The schedule developed in Excel would be of more beneficial in reducing the learning curve of software if some other functionality such as networking, calendaring, and etc. are incorporated within it.
6. Automation of BOQ preparation, scheduling and other processes by using *python* in ArcGIS (i.e., *ArcPy*) is recommended for further study as this programming language is already incorporated to be called as a module in ArcGIS interface, enabling planners to access and manipulate available database, which finally helps in speeding up decision making process.
7. Lack of understanding the importance of GIS education by civil engineering scholars may be one of the most critical issues that deserve special attention, and hence it should be incorporated in the syllabus of Universities offering Construction Technology and Management courses.
8. Additional codes are recommended to be incorporated in the application so that end users would be able to read a summary of projects from the geodatabase once they are provided with it. This helps to avoid the waiting time while project summary is prepared by office engineers. This would also help to step-up the efficiency of retrieving summary information currently being viewed in the “Open Summary” Menu of the application.
9. To upgrade the application further, the researcher also recommends codes to be incorporated that would enable to add rows (representation of *work items*) in the source Project Control table. This would facilitate data updating (amount of actual work executed, for example) to make it a run-time application.

10. The present study is in its infant stage and further research should be carried out in projects of different scale for calibration and validation of the model.

These recommendations are put to notice and are left for other researchers due to time constraint and because of the fact that the volume of work and scope of the research is being extended beyond its limit.

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Annexes

Annex: A – BOQ

<i>Key</i>	<i>Description</i>	<i>Units</i>	<i>Height</i>	<i>Area</i>	<i>Length</i>	<i>Amount of Work</i>
1001	Site clearing	m ²		135.00		135.00
1002	Earthwork for trenching	m ³	1.03	36.93		38.04
1003	Excavation for hardcore	m ³	0.25	9.27		2.32
1004	Earthwork for fencing	m ³	0.80	56.64		45.31
1005	Base concrete in Found and for fencing	m ³	0.30	17.82		5.34
1006	Masonry work in foundation	m ³	0.63	8.38		5.28
1007	Masonry work for foundation of fencing	m ³	0.50	9.44		4.72
1008	Backfill @ the bottom	m ³	0.78	28.56		22.27
1009	Backfill @ the top	m ³	0.25	14.20		3.55
1010	Backfill for the foundation of fencing	m ³	0.50	47.20		23.60
1011	Hard Core_Bottom layer	m ³	0.15	23.63		3.54
1012	Hard Core_Top layer	m ³	0.10	16.50		1.65
1013	Beam_Grade Beam	m ³	0.30	15.50		4.65
1014	Beam_Grade beam for fence	m ³	0.30	9.44		2.83
1015	Mass Concrete	m ³	0.15	16.50		2.48
1016	Columns	m ³	2.60	0.24		0.62
1017	Column_Fence	m ³	2.20	0.64		1.41
1018	Beam_Top tie beam	m ³	0.20	5.54		1.11
1019	Roof Slab	m ³	0.10	30.75		3.08
1020	Roof Slab Projection	m ³	0.08	5.00		0.40
1021	Wall below Sill	m ³	0.90	5.50		4.95
1022	Wall @ Sill level	m ³	0.02	4.72		0.09
1023	Wall @ window level	m ³	1.20	4.78		5.74
1024	Wall above window level	m ³	0.58	6.16		3.60
1025	Parapet Below	m ³	0.10	1.25		0.12
1026	Parapet Above	m ³	0.50	5.12		2.56
1027	Fencing	m ³	2.20	8.24		18.13
1028	Plastering below plinth level	m ²	0.20	5.26	26.32	5.26
1029	Plastering above floor to the sill level	m ²	0.90	54.11	60.12	54.11
1030	Plastering @ sill level	m ²	0.02	1.05	52.30	1.05
1031	Plastering @ window level	m ²	1.20	63.50	52.92	63.50
1032	Plastering above window	m ²	0.68	45.63	67.10	45.63
1033	Plastering roof Ceiling	m ²		25.62		25.62
1034	Plastering side of roof slab	m ²	0.10	1.64	16.40	1.64
1035	Plastering side of slab projection	m ²	0.08	0.88	11.00	0.88
1036	Plastering parapet	m ²	0.50	25.60	51.20	25.60
1037	Plastering roof top	m ²		37.00		37.00

<i>Key</i>	<i>Description</i>	<i>Units</i>	<i>Height</i>	<i>Area</i>	<i>Length</i>	<i>Amount of Work</i>
1038	Plastering fence	m ²	2.20	181.27	82.40	181.27
1044	Site Work	m ²		29.40		29.40
1045	Main Gate	m ²	2.70	15.93	5.90	15.93
1046	Formwork @ the sides of the grade beam	m ²	0.30	17.70	59.00	17.70
1047	Formwork @ the bottom of the grade beam	m ²		7.13		7.13
1048	Formwork for Column	m ²	2.60	12.48	4.80	12.48
1049	Formwork @ the sides of top tie-beam	m ²	0.20	11.30	56.50	11.30
1050	Formwork @ the sides of the slab	m ²	0.10	2.64	26.40	2.64
1051	Formwork below the slab and its projection	m ²		31.46		31.46
1052	Formwork @ the sides of the projection	m ²	0.08	0.88	11.00	0.88
1053	Formwork @ the sides of grade beam for fencing	m ²	0.30		47.20	14.16
10190	Cement Screed	m ²		26.28		26.28
10200	Terazzo	m ²		26.28		26.28
10290	Sill	m ²		0.94		0.94
10300	D.P.C	m ²		35.75		35.75
10330	Door Shtter	m ²	2.10	7.33	3.49	7.33
10340	Windows shuttering and frame	m ²	1.20	4.32	3.60	4.32

Annex B: Activity Code Description and Specification

<i>Activity Code</i>	<i>Description</i>	<i>Specification</i>
A	Site Clearing	Clear the site to remove top soil to a depth of 20cm.
B	Trenching and Excavation	Earthwork for trenching in foundation, for hard core placement and for fence. Bulk excavation in ordinary soil to a depth not exceeding 150 cm including 50cm for working space.
C	Footing	Lean concrete (C-7) in foundation base and for fencing (cum). Masonry work of foundation and fence in cement mortar: 250mm thick stone masonry retaining foundation wall below ground level bedded in cement mortar mix (1:3).
D	Backfilling and Compaction	Backfilling and Compaction of soil and gravel
E	Hard core Production	Hard core Production
F	Laying hard core_Bottom layer	Hard Core in foundation (bottom layer) (15cm)
G	Rebar Production	Ø8mm and Ø12mm reinforcement bar production (super structure)
H	Formwork production	Formwork for all work items
I	Grade beam	C-25 concrete (Sub-structure) Grade beam footing (including fence)
J	Laying hard core_Top layer	Hard Core in foundation (top layer) (10cm)
K	Mass concrete	C-25 cyclopean concrete (mass concrete) for flooring (10cm)
L	Columns	C-25 concrete Column Columns (260cm), including for fence
M	Top-tie beam	Top-tie beam (C-25)
N	Roofing	C-20 Concrete roof slab with its projection
O	Exterior walls and Interior partition walls	20cm thick HCB wall Class "B"
P	Plastering	Two Coats of Plaster cement mortar Internal & External surface. Also Third (fine) coat Gypsum Plaster
Q	Installation of windows and doors	1*2.70m Metal Door and window Type D2. (Door shutter shuttering with frame)
R	Placing Sill	Sill-Marble
S	Floor finishes	Floor cement screed. And precast Cement Floor Tile
T	Painting	Apply three coat of plastic paint to plastered vertical surfaces

Annex C: Critical Activities in .dbf format

Table

Schedule

	OID	key *	Activity	Activity Description	Duration	EST	EFT	LST	LFT	Tot_Slacc	Remark
	0	10001	A	Site Clearing	11	0	11	0	11	0	Critical
	1	10002	B	Trenching and Excavation	15	11	26	11	26	0	Critical
	2	10003	C	Footing	7	26	33	26	33	0	Critical
	3	10004	D	Backfilling and Compaction	1	33	34	33	34	0	Critical
	4	10005	E	Hard core Production	1	11	12	33	34	22	--
	5	10006	F	Laying hard core_Bottom layer	6	34	40	34	40	0	Critical
	6	10007	G	Rebar Production	14	11	25	26	40	15	--
▶	7	10008	H	Formwork production	25	11	36	15	40	4	--
	8	10009	I	Grade beam	2	40	42	40	42	0	Critical
	9	10010	J	Laying hard core_Top layer	3	42	45	42	45	0	Critical
	10	10011	K	Mass concrete	1	45	46	45	46	0	Critical
	11	10012	L	Columns	1	46	47	46	47	0	Critical
	12	10013	M	Top-tie beam	1	47	48	47	48	0	Critical
	13	10014	N	Roofing	1	48	49	48	49	0	Critical
	14	10015	O	Exterior walls and Interior partition	15	49	64	49	64	0	Critical
	15	10016	P	Plastering	4	64	68	64	68	0	Critical
	16	10017	Q	Installation of windows and doors	11	68	79	68	79	0	Critical
	17	10018	R	Placing Sill	1	79	80	79	80	0	Critical
	18	10019	S	Floor finishes	4	80	84	80	84	0	Critical
	19	10020	T	Painting	18	84	102	84	102	0	Critical

8

▶▶

(1 out of 20 Selected)

Schedule

Annex D: **Project Control Table**

<i>Key</i>	<i>Activity</i>	<i>Activity Description</i>	<i>Unit</i>	<i>Duration (Days)</i>	<i>EST</i>	<i>EFT</i>	<i>Planned Activity</i>	<i>Planed Cost (Birr)</i>	<i>Status (%)</i>
10001	A	Site Clearing	m ²	11	07-Aug-17	18-Aug-17	135.0	1,854	80
10002	B	Trenching and Excavation	m ³	15	18-Aug-17	02-Sep-17	68.68	3,757	95
10003	C	Footing	m ³	7	02-Sep-17	09-Sep-17	15.3	26,701	75
10004	D	Backfilling and Compaction	m ³	1	09-Sep-17	10-Sep-17	49.4	6,816	
10005	E	Hard core Production	m ³	1	18-Aug-17	19-Aug-17	5.2	703	
10006	F	Laying hard core_Bottom layer	m ³	6	10-Sep-17	16-Sep-17	3.5	1,527	
10007	G	Rebar Production	kg	14	18-Aug-17	01-Sep-17	1,610.3	37,660	
10008	H	Formwork production	m ³	25	18-Aug-17	12-Sep-17	98.0	17,745	
10009	I	Grade beam	m ³	2	16-Sep-17	18-Sep-17	7.5	18,177	
10010	J	Laying hard core_Top layer	m ³	3	18-Sep-17	21-Sep-17	1.7	1,735	
10011	K	Mass concrete	m ³	1	21-Sep-17	22-Sep-17	2.5	4,743	
10012	L	Columns	m ³	1	22-Sep-17	23-Sep-17	2.0	4,937	
10013	M	Top-tie beam	m ³	1	23-Sep-17	24-Sep-17	1.1	2,692	
10014	N	Roofing	m ³	1	24-Sep-17	25-Sep-17	3.5	6,667	
10015	O	Exterior walls and Interior partition walls	m ³	15	25-Sep-17	10-Oct-17	35.2	234,070	
10016	P	Plastering	m ²	4	10-Oct-17	14-Oct-17	442.0	46,525	
10017	Q	Installation of windows and doors	m ²	11	14-Oct-17	25-Oct-17	27.6	52,204	
10018	R	Placing Sill	m ²	1	25-Oct-17	26-Oct-17	0.9	433	
10019	S	Floor finishes	m ²	4	26-Oct-17	30-Oct-17	26.3	6,522	
10020	T	Painting	m ²	18	30-Oct-17	17-Nov-17	442.0	11,503	

Annex E: Visual Basic Codes Used in Visual Studio

Annex E1: Visual Basic Codes used in the Main/Parent window:

Public Class PictureBoxParent

```

    Dim I As Integer
    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnSelectPicture.Click
        If OpenFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK Then

            ImageList1.Images.Add(Image.FromFile(OpenFileDialog1.FileName))
        End If
    End Sub

```

```

    Private Sub Timer1_Tick(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Timer1.Tick
        Try
            If I > 5 Then I = 0
            PictureBox1.Image = ImageList1.Images.Item(I)
            I += 1
            Label1.Text = I
            Label2.Text = ImageList1.Images.Count & "/1"
        Catch ex As Exception
            Timer1.Stop()
            MsgBox("Place 10 Photos", , "Error")
        End Try
    End Sub

```

```

    Private Sub Button2_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button2.Click
        If Button2.Text = "Start" Then
            Button2.Text = "Stop"
            Timer1.Start()
        Else
            Button2.Text = "Start"
            Timer1.Stop()
        End If
    End Sub

```

```

    Private Sub Button3_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnHelp.Click
        My.Forms.HelpInfo.ShowDialog()
    End Sub

```

```

    Private Sub Button1_Click_1(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        My.Forms.ProjectTable.ShowDialog()
    End Sub

```

End Sub

```

    Private Sub btnQuit_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnQuit.Click
        Me.Close()
    End Sub
End Class

```

Annex E2: Visual Basic Codes used in the Help window:

```

Imports System.IO
Public Class HelpInfo

    Dim StreamToDisplay As StreamReader

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        Me.DialogResult = DialogResult.OK
    End Sub

End Class

```

Annex E3: Visual Basic Codes used in the Project Table window:

```

Public Class ProjectTable

    Private Sub Button1_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles Button1.Click
        Me.DialogResult = DialogResult.OK
    End Sub

    Private Sub Project_ControlBindingNavigatorSaveItem_Click(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
Project_ControlBindingNavigatorSaveItem.Click
        Me.Validate()
        Me.Project_ControlBindingSource.EndEdit()
        Me.TableAdapterManager.UpdateAll(Me.Project_TableDataSet)
    End Sub

    Private Sub ProjectTable_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        'TODO: This line of code loads data into the
        'Project_TableDataSet.Project_Control' table. You can move, or remove it, as
        needed.

        Me.Project_ControlTableAdapter.Fill(Me.Project_TableDataSet.Project_Control)
    End Sub

End Class

```

Annex F: Hierarchy of Digital Filing

