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Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

GEOMATICS AND GEODESY PROGRAM

THE ROLE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) IN

ENHANCING 5D BUILDING INFORMATION MODELING

THE CASE OF RESIDENTIAL BUILDING

By: Bekalu Tsedeke Asfaw

January, 2021

Addis Ababa, Ethiopia

AAiT

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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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Blessed be my God - JEHOVA! First and foremost, I would like to give thanks, praises, and all honor to JEHOVA the Almighty God, the source of heavens, the earth, and life; the only one who deserves worship. I will not forget what you have done for me. You were with me from my childhood! My Love, my Savior, my Only One! I, myself, know where I came from!! I will not forget those days!! JEHOVA! I trust in you forever and ever!

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Bekalu Tsedeke

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Abstract

The success or failure of any construction project largely depends on the cost-effectiveness, time-bound delivery, quality, amount of resources, and information available throughout the lifecycle of construction. Despite the technological advancement of Building Information Modeling (BIM), it lacks a database program, does not consider spatial information, and has low visualization. The objective of the study was to explore the role of the Geographic Information System (GIS) in enhancing the 5D BIM of construction building. The architectural drawing of a case study, focus group, and interviews were used to prepare cost estimation, schedule, develop the 3D model of construction building and assess the similarities and differences between BIM and GIS regarding scope, data type, and standards. The architectural drawing was created and imported to ArcMap; then the feature classes of each activity were created and imported to ArcScene to develop the 3D model and prepare cost estimation of construction building. The finding of the study showed that the integration of GIS and BIM technology enhanced the cost estimation by 2% of birr and the duration by 0.009% days of the cost estimated and time scheduled by BIM technology. Effectively selecting the color and making the 3D model transparent improved visualization of construction building. And hence it was concluded that cost estimation, schedule, and visual aspects of the construction were enhanced through the integration of GIS and BIM technology. Finally, the GIS-based methodology can enhance the BIM technology by extracting the information from the available database, assisting the decision making, and reducing delay in work progress.

Keywords: Building Information Modeling, Construction building, Cost estimation, GIS, and Scheduling.

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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CHAPTER ONE: INTRODUCTION

1.1 Background

People involved in the construction industry claim that in real construction, saving time and money can be done rather than applying simple construction project management techniques such as cost estimating, preparation, scheduling and control (Vijay K. Bansal & Pal, 2006). The current demand of the construction industry requires extremely detailed preparation, scheduling and management of the project process that can maximize the expense, time and resources overall (Naik et al., 2011). In addition, the success or loss of a building design relies primarily on the accuracy and sequencing of the data available to builders from the database. (Vijay K. Bansal & Pal, 2006).

There is a large amount of data obtained during the construction of each and every project that requires careful handling to provide just-in-time access in the appropriate format (Bhandari et al., 2013). This refers to difficulty in the storage, handling, preservation and updating of collected data (Bhandari et al., 2013). The Geographical Information System (GIS) allows the consolidated collection of data that can be accessed by users at any time and everywhere for review and display in the desired format (Bhandari et al., 2013). BIM describes the formation and use of n-dimensions created by computers.

This leads to complexity in storing, manipulating, maintaining, and upgrading collected data (Bhandari et al., 2013). Geographical Information System (GIS) provides for centralized storage of data, which can be accessed by the users at anytime and anywhere to be analyzed and presented in the desired format (Bhandari et al., 2013). BIM represents the development and use of computer-generated n-dimensional (n-D) models to model building project preparation, architecture, construction, and service. Building Information Modeling (BIM) and Geographic Information System/Science (GIS) are greatly encouraged by the incorporation of Building Information Modeling (BIM) and Geographic Information System/Science (GIS) to promote smart and efficient infrastructure growth due to their strengths in data integration, predictive analysis, technology ease of use, and construction management (Song et al., 2017).

1.2 Statement of the problem

Building information modeling (BIM), Critical Path Method (CPM), and Program Evaluation and Review Technique (PERT) only consider the non-spatial information of the construction projects (Karimi & Akinici, 2009). For that reason, they cannot solve complex locational orientation problem, does not recognize where and what is occurring around the site and it cannot give us a full picture of construction in progress which leads to holding back the decision making ability of construction stakeholders.

Compared to GIS technology BIM/CAD technology have low visualization aspects (Liu & Issa, 2012b). Hence different participants of the project may develop inconsistent interpretations of the construction progress due to a lack of quick and clear understanding of information and even cannot identify emerging trends. This creates confusion in various activities and for the most part, makes ineffective and misunderstanding among construction members, the cost involved in the construction project becomes extensive and completion of the project is prolonged than expected and planned time.

The other shortcoming of BIM/CAD is, it does not have a database platform (V. K. Bansal & Pal, 2007). Consequently; construction manager cannot easily edit and update information, difficulty in data integration, prevent data access to users through query languages and increase data redundancy.

There are a lot of earlier studies on Integration of BIM and GIS building information model that mainly focused on Building information modeling in construction conflict management (Charehzehi et al., 2017), 4D Model for Scheduling of a Construction Project (Naik et al., 2011) mainly focused scheduling of construction building using primavera and 4D CAD modeling for construction projects and (Vijay K. Bansal & Pal, 2006) focus on GIS in construction project information system. The above-mentioned studies have their limitation or gaps. Some of the gaps are: - unable in synchronizing cost estimation and schedule on a single platform, do not have a construction database, as result difficult to update, editing, retrieve and display information, failure in

addressing spatial information, low visualization of projects, increase construction error as result increase the delay in scheduling and increase the cost of projects.

All stated gaps lead to construction cost escalation, mismanagement, scheduling challenges, and lack of handover of the project as per the contract and completion period. One of the remaining challenges at a practitioners' level, is that there is also the need to overcome difficulties and misunderstandings that are connected to the little knowledge of the field (geo-information and BIM) where one is less involved in another. For example, it is essential to know the Industry Foundation Classes (IFC) or CityGML standards to avoid preconceptions about their use.

The purpose of this study was to solve the context of the above-mentioned problems by exploring the potential of the GIS environment in developing a construction project information system. By integrating GIS and BIM technology the researcher intends to solve the spatial problem of BIM, the lack of database, and enhance visualization of the construction building. Due to the enhancement of BIM technology engineers and construction managers can view the correct picture of the project and thereby supports construction managers in taking vibrant judgment at the site and reduce delay in work progress.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study was to explore the role of Geographic Information System (GIS) in enhancing 5D Building Information Modeling.

1.3.2. Specific Objectives

The specific objectives to be achieved were : -

1. To develop a 3D model and improve visualization of building using GIS software.
2. To prepare cost estimation and schedule of building using GIS.

1.4. Research Questions

This paper offers answers to the following research questions: -

1. How does a 3D model and visualization of the building can be developed and improved using GIS software?
2. How does GIS prepare cost estimation and schedule of a building?

1.5. Significance of the study

This study contributes to construction managers and engineers to visualize the progress of construction projects. As result it reduces error, minimize construction delay, and increase effective communication among the construction members. This research is vital because it is a relatively new idea that could potentially fill the gap in enhancing cost estimation and schedule by integrating GIS and BIM. More importantly, it tries to answer what are the application areas of GIS in construction projects.

This research paper has its importance as an academic input, social transformation, economic and technological development. The result of the research is based on the facts collected from updated resources and current situations. This in turn adds to the reliability of the information gathered. Scholastically, this paper can be used as a pioneering ground to professionals and other individuals whom in the future may establish too deeply conduct further researches related to this topic.

1.6. Scope of the Research

This thesis aims at the development of concepts and their validation by prototyping key aspects. The functionality of ArcGIS is tested on a small residential building located in Addis Abeba Yeka sub-city wereda 06 to show its feasibility. Despite enhancing and increasing the accuracy of cost estimation and time scheduling for construction projects; yet it is tedious and time-consuming. As a result, a case study was taken to analyze the integration of BIM and GIS.

1.7. Limitation of the Study

GIS systems are used to analyze objects which already exist around us. Some difficulties faced by the researcher on the overall progress of this study includes but not limited to

1. Time-consuming process though it pays off for huge projects.
2. Another limitation of the paper is that GIS incapability to calculate the area of themes drawn inclined to the horizontal plane (e.g. flight of stairs and inclined roof called gamble roof).

1.8. Road Map of Research

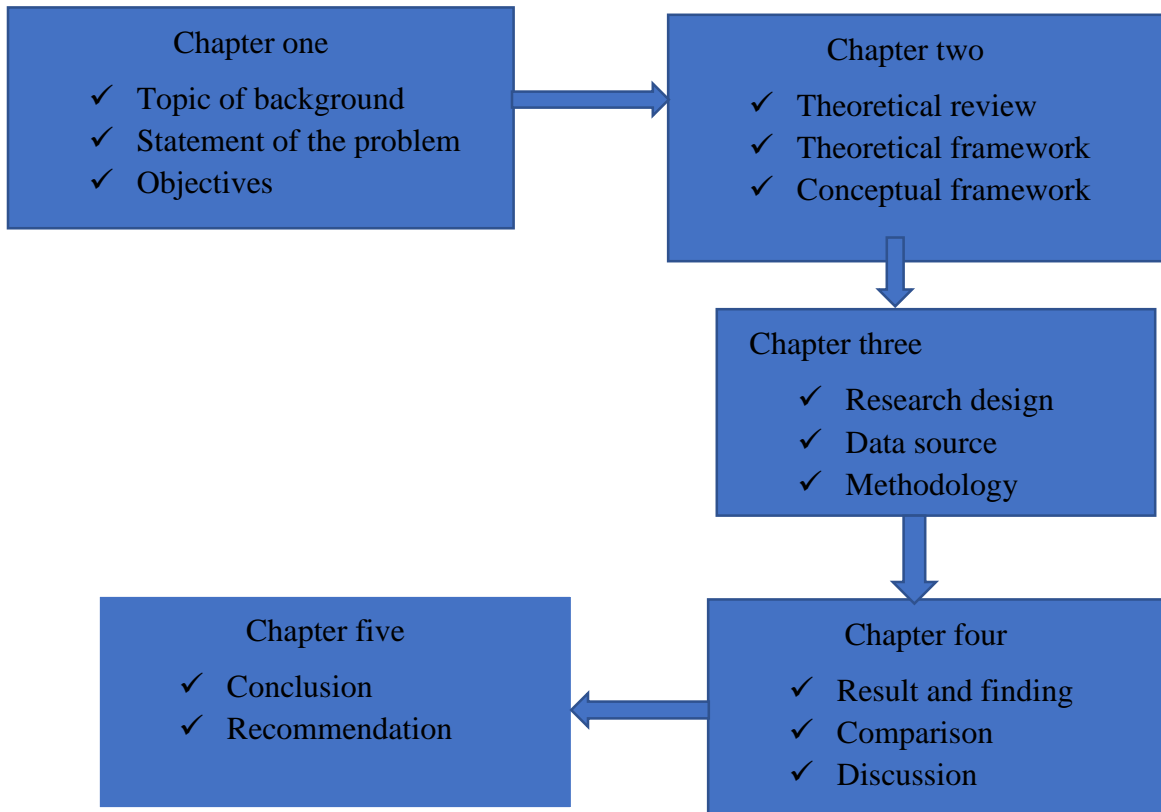


Figure 1. 1: Road map of thesis

CHAPTER TWO: LITERATURE REVIEW

2.1. Theoretical Review

Manual approaches to quantity surveying and scheduling have become obsolete and over the last three decades' digital technology in this regard have transformed the way construction cost estimates and schedule are made and yet development of new software's evolving(V. K. Bansal & Pal, 2010). In decision-making and strategic thinking, automation of construction cost analysis and schedule letting engineers and construction managers to easily remember and revisit problems related to the job in hand(V. K. Bansal & Pal, 2010).

Quantity take-off is part of the cost calculation process in construction projects(Cheng & Yang, 2001). Cost estimators use construction blueprints, either physically or electronically to measure the number of different types of construction work. Computer-Aided Design (CAD) programmers are also capable of producing quantity takeoffs and scheduling(Saeed, 2013). Excel spreadsheets are also used for the preparation of price sheets. Spreadsheets will easily execute all quantitative measures on which the quantity estimator invests hours in preparation of the bill of quantity(Yousif et al., 2020).

Moreover, some commercially available construction cost estimating software such as PandaDoc, Sage Estimating, and Stack can take the quantities determined manually and from a CAD file or with the assistance of a digitizer and apply unit prices to calculate the construction cost(V. K. Bansal & Pal, 2010). GIS has thrived within technology in recent years (Longley et al., 2005). GIS handles various construction project requirements including cost estimation, site layout, route planning, integrating information, construction visualization, and time scheduling(V. Bansal & Pal, 2008). Cheng and Yang explored the capabilities of GIS along with other software for cost estimation and scheduling of construction projects (2020). They developed a GIS-based tool called Material Plan to assist engineers and construction managers in quantity takeoffs and schedule and assessing materials layout design(V. K. Bansal & Pal, 2010).

Nowadays, construction projects require highly accurate planning, time scheduling, management, and the method of the project which may enable the general optimization of the cost, time, and construction resources(Naik et al., 2011). Cost estimation and schedule are the crucial features for the effective completion of a project(Sitota, 2017). The planning and utilization of resources

play a vital part in cost and time optimization. Construction planning may be a major and challenging activity within the management and execution of construction projects (Demeulemeester & Herroelen, 2006).

2.2. Geographic Information System (GIS)

A Geographic Information System is a powerful tool that is used to analyze, manipulate, retrieve and display spatial and non-spatial data (Martindale, 2018). The idea of GIS was first presented in the mid-1960s and it was hence explored and created as another discipline (Longley et al., 2005). The GIS history sees Roger Tomlinson as a pioneer of the idea, where the main emphasis was intended to store, collect, and investigate information about land utilization in Canada (Goodchild, 2018). The second period of improvement in GIS history happened all through the 1970s and by the 1980s, the idea advanced as public offices embraced it and contributed parties started deciding best practice (Goodchild, 2018). GIS is called geoinformatics by some experts and believed it was originated in Canada (Zhu et al., 2020). Others have attempted to use the name itself to understand better the functions and components of GIS (Longley et al., 2005).

Entity Representation: In a Geographic Information System, data representation is classified into two and these are vector data and raster data representation. Vector data are data that expressed geographic features in point, line, and polygon while raster data express information of geographic features in an image format such as photogrammetry images and satellite images.

Points A point consists of one pair of coordinates describing a single location in a set of coordinates (Longley et al., 2005). The simplest geometric primitives, which have no length or field, are points (Walter & Fritsch, 1999). By definition, since it has no field, a point cannot be "seen," but this is not practical if such primitives are to be mapped. Thus, points are represented on a map using symbols for both area and form (e.g. circle, square, and sign) (Ohori et al., 2017).

Lines A polyline is composed of a sequence of two or more coordinate pairs called vertices. Roads and rivers are commonly stored as polylines in a GIS (Yousif et al., 2020).

Polygon A polygon is composed of three or more line segments whose starting and ending coordinate pairs are the same (Wu & Zhang, 2016). Polygons represent both length (i.e. the perimeter of the area) and area. Examples of polygon features are building, Lake, etc.

N.B: data representation of any features depends on the scale of the map.

Non-spatial data

Information or data that is used to express additional information about spatial data is called attribute data or non-spatial information(Tang, Adams, & Usery, 1996). The attribute table is mostly expressed in the form of a table(V. K. Bansal & Pal, 2010). Some examples of attribute tables include rainfall, temperature, type of soil, etc. Attribute data tables are characterized by row and column. The row expresses the name of the entity while the column or field shows the character of the entity. A GIS can be viewed in three ways: –

- Database view
- Map view
- Model view

The Database View: One of the uniqueness of GIS from the construction software is, it has a database program that BIM/CAD lacks(Amirebrahimi et al., 2015). The spatial and non-spatial data is integrated into the geodatabase system. The database is used to edit and update the information in the catalog (Bíl et al., 2012).

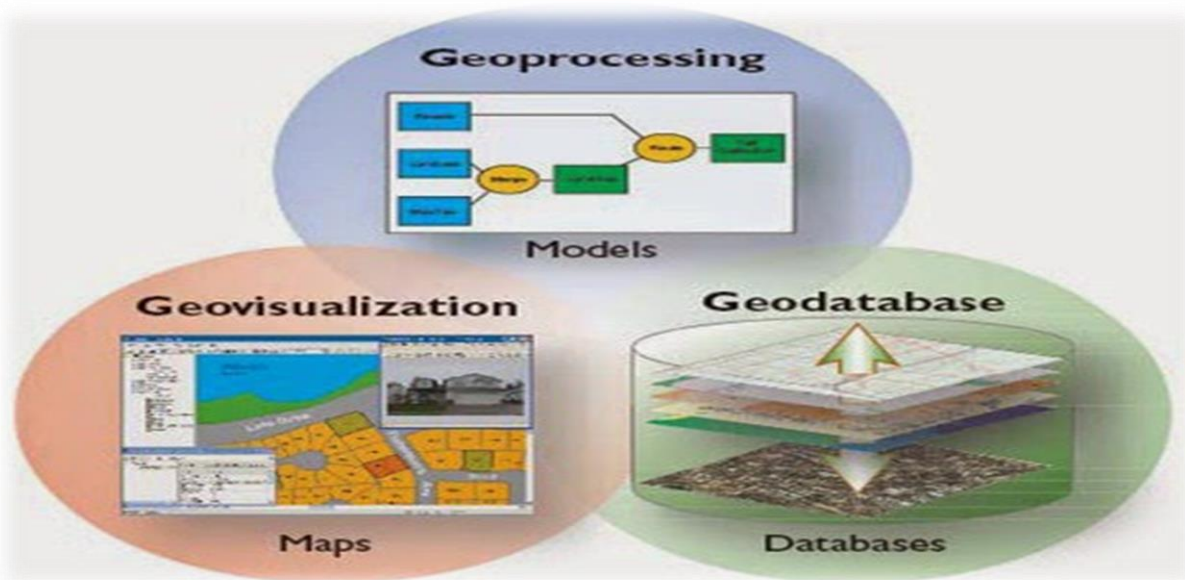


Figure 2. 1: Map view, Database view, and Model view of the GIS(Sitota, 2017, p. 16)

The Map View: One of the primary importance of GIS is the preparation of a map. The map contains spatial and non-spatial information. A map that is prepared by GIS and stored in electronic format is called a digital map.

The Model View –The model view is used in geoprocessing in accomplishing tasks.

2.3. Building information modeling (BIM)

BIM is described as the advancement and the practice of a computer software classical to put on the construction and process of a facility(Irizarry et al., 2013). The subsequent building information model is a digital demonstration of physical and functional appearances of a facility from which views appropriate to various users' needs(Jayasena & Weddikkara, 2013). Building information modeling is the latest technology that is used in the design documentation and analysis of building construction systematically(Sacks et al., 2010). BIM assists project managers and engineers in controlling, monitoring, visualization, and quality management of construction projects in a scientific method (Basir et al., 2018).

Building information modeling is one of the promising technology in the construction sector especially in architecture, engineering, and construction (AEC)(Ma & Ren, 2017). The BIM technology has changed the way of construction process and perspective(Wang et al., 2015). The fundamental change in BIM is the use of digital modeling software that is used for minimizing error, easy visualization of the construction project, and minimize the delay of projects(Saeed, 2013).

Types of BIM

Building Information Modelling (BIM) dimensions refer to levels of detail (LOD) and data entered into a 3D model using BIM software and includes 3D model data, and schedule data(Enku & Wondimu, n.d.). Based on the dimension (D) there are many types of Building Information Modelling (BIM). These are: -

- Three dimensions (3D) contain width, height, and length.
- The fourth dimension (4D) includes construction scheduling and planning.
- The fifth dimension (5D) is the sum of the bill of quantity and 4D.
- The sixth dimension (6D) incorporates sustainability of construction and 5D.
- The seventh dimension (7D) contains facility management of construction with 6D.
- The eighth dimension (8D) include safety of construction with 7D

2.4. Application Areas of GIS on construction projects

Bodies are dependent on geographic and spatial analysis, infrastructure management systems, land resources management, water resources engineering, watershed management, utilities, transportation, surveying, urban development are some application areas of GIS (Facchinelli et al., 2001). GIS has many important roles in construction firms in reducing error, decrease redundancy, and visualization (Koo & Fischer, 2000). Thus, it is playing an increasingly important role in civil engineering companies, GIS support all life cycle of a construction project from starting period up to end (V. Bansal & Pal, 2008). Several types of research suggest the usefulness of GIS in the construction industry for data management, integrating information, construction planning and scheduling, site layout, construction visualization, and cost estimation (V. Bansal & Pal, 2008).

Application Areas of GIS on construction projects

- 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

Figure 2. 2: Application area of GIS on construction (Ma & Ren, 2017, p. 56)

2.5. GIS in enhancing 2D/3D Visualization of construction projects

Visualization, as a form of visual communication, can be described as the process of transforming (non-visual) data into artifacts accessible to the human mind (Liu & Issa, 2012a). With the development of computer and network software and hardware, GIS allows users to

visualize, analyze and manage spatial data that is geographically referenced(Naik, 2011). One of the powerful features of the GIS environment is the ability to overlay spatial datasets for instance infrastructure locations, street widths, building footprints, and tree locations(Longley et al., 2005). It allows users to visualize and understand the relationships between data. The ability of GIS to display and analyze spatial data makes it an effective tool for physical planning (e.g., land use, infrastructure, and transportation planning)(Ohori et al., 2017). In many interactive computer graphics applications, maps in 3D (three dimensions) are central to enabling the exploration, presentation, and manipulation of geographical data(Tang, Adams, & Lynn Usery, 1996).

5D building information modeling (BIM) visualization permits a construction member to easily understand or visualize every activity in a construction project(Ma & Ren, 2017).

Visualization for the construction site helps the stakeholders to understand the overall setting of the site and also plays a significant role in repair, upgrade and build up infrastructure(Yousif et al., 2020). It also helps in having a better accuracy and making a clear image of the construction project for better understanding, minimize the problem and also decrease cost and environmental influence(V. Bansal & Pal, 2008). In addition to the 5D model, both experts and less experienced professionals can conceptualize the pattern and arrangement by inspecting the realistic picture of the virtual model(Longley et al., 2005). This model can be understandable by every stakeholder including the project members who come from different understanding(Bil et al., 2012).

2.6. GIS as a modeling tool for quantity takeoffs

Cost estimation is one part of the bill of quantity in the construction sector. Using a GIS-based bill of quantity increase decision making, help the designer and construction manager(V. K. Bansal & Pal, 2010). A CAD system is used as a program design that helps in designing and drafting different infrastructures(Kemp, 2001). GIS-based cost estimation of building construction minimizes missing or redundancy of many work activities and also make easily visualization of the construction(V. K. Bansal & Pal, 2010). It also increases the productivity rate as it worked in an automation system and replaces the traditional method called manual method(Shekhar et al., 2009).

With different software in the market, the traditional software (manual) for quantity surveying and cost estimation is outdated. In the last four decades the way of a bill of quantity approach is

changed as information technology is progressing(Cheng & Yang, 2001). Computerized technology changes everything about cost estimation and easy to handle data and minimize error in decision making(Cheng & Yang, 2001). Despite CAD capability of generating a bill of quantity, it lacks the functionality in integrating the spatial and non-spatial information which is the most important factor(Naik et al., 2011). However, the GIS tool can handle the spatial and non-spatial data integration that will replace the cad system(Tang, Adams, & Usery, 1996). GIS and BIM applications can improve and speed up cost estimation as well as ensure data integrity and accuracy(Karimi & Akinici, 2009). By integrating both technology GIS and BIM, they can bring spatial analysis in a real-world spatial reference. Through the integration between GIS and BIM, users will use the advantages of the one element (either in GIS or BIM) to complement the weakness from the other parties (GIS or BIM). From this point of view, the integration of GIS and BIM can improve the interoperability function which means data sharing problem and enhance cost estimation among the users(Liu & Issa, 2012b). This data sharing issue' is the critical benchmark to evaluate the effectiveness of BIM. In addition, through interoperability function, the function of reused data can be used for different representation by using the same model without recreate back the model(V. K. Bansal & Pal, 2010). Accessibility of consistent and accurate BOQ data by entire project also be improved.

2.7. GIS as a modeling tool for Construction Scheduling

Today's demand of the construction industry requires highly accurate planning, scheduling, and management of the process of the project which can enable the overall optimization of the cost, time, and resources(Naik et al., 2011). To schedule the construction project, every component must have related activities. This can be achieved easily with the user-friendly Bar chart technique. The result of scheduling and planning gives the critical path of the construction project. The sum of each activity will provide the duration of the construction project. Any delay of activities may have prolonged the construction project schedule. Some factors are utilized to determine the activities duration of the construction project such as availability of equipment, availability of skilled personnel, and resource allocation for the critical activities(Bhandari et al., 2013). A construction project requires highly accurate scheduling, planning, and bill of quantities(V. K. Bansal & Pal, 2010).

The traditional scheduling and planning software such as Primavera and MS Project cannot produce scheduling and planning of construction projects in a synchronized manner with spatial

aspects(Sitota, 2017). There is also the outdated method of determining the scheduling process such as Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) which fail to synchronize the spatial and attribute information in a single platform(Hegazy & Ersahin, 2001) yet they are utilized by the project manager and planners(Charehzehi et al., 2017). There is always pressure on project managers and engineers to minimize the cost of the project and decrease the delay of the project without compromising the quality of the construction project(Song et al., 2017). GIS integrated with different construction software to allow the project manager in solving spatial and attribute information in a single platform(Bhandari et al., 2013).

2.8. Difference and Similarity of BIM and GIS

The difference between CAD and GIS systems is becoming blurred at their core, CAD and GIS are complementary technologies that have evolved largely independently but in parallel over the past 30 years. Environmental System Research Institute (ESRI) longtime best-of-breed approach provides value to engineers by building better linkages between CAD and GIS systems.

One of the major differences of GIS from CAD system is that GIS has a database program that enables to analyses of spatial and non-spatial information while CAD is a design program which uses to create architectural drawing and construction with high precision(Newell & Sancha, 1990). Most of the time, GIS focuses on land use and land-related resources as CAD systems frequently evolve in the construction of buildings, roads, and so on(Newell & Sancha, 1990). GIS and CAD files can integrate by default mode and made it easier for construction members(Karimi & Akinci, 2009).

Table 2. 1: Relationship between CAD and GIS(Karimi & Akinici, 2009, p. 33)

Data Organization	CAD	GIS
Layers:	CAD software saves the data in a layer model 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.
saving	CAD data is saved mostly in files (such as DWG files).	One of the utmost common approaches to saving GIS data is in a "Geo-Spatial Database".

Table 2. 2: Difference between CAD and GIS(Karimi & Akinici, 2009, p. 34)

CAD	GIS
CAD is a design program	GIS is a database program
It's the lines that are important, i.e. the drawing is the information.	In GIS line is entity representation like road, river, etc.
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 rather than being focused purely on engineering.
CAD models artifacts yet to be produced	GIS models the world as it exists.
Spatial and non-spatial (attribute table) data are not integrated into the CAD system. Only consider the spatial information.	GIS can perform different operations on attribute data that is synchronized with the 3D model, which is not possible in the case of CAD technologies.
The spatial operation such as clip, connectivity, and a query is not common in a CAD system.	GIS system provides only some basic drafting and designing capabilities as compared to the CAD systems.

2.9. Data Integration

In the construction sector, information is stored in different ways such as bar charts, specification, and drawing this information is essential for design, implementation, planning, and monitoring(V. K. Bansal & Pal, 2007). The first step in construction building is planning using facts gathered from different resources (Irizarry et al., 2013). The success or failure of construction industries depends on different factors these may include the skill of labor, timing, and quality of information available in the catalog or database.

The construction industries need a coordinated system that is used to integrate information and help different decision-making and construction processes(Longley et al., 2005; Naik et al., 2011). GIS is essential in cultivating construction scheduling and design efficiency by integrating the spatial and non-spatial (attribute information) in a single platform. This technology is very essential concerning not only in the construction of buildings but also in mapping and modeling different information based on their importance. It provides a various solution for the construction project that relates with large data called spatial and non-spatial data.

Integration of BIM and GIS

GIS users require precise information on the as-built form while AutoCAD users require the context of the plan to produce their design. All stakeholders of construction must utilize and access all this information. The integration of geographic information system and BIM help in reducing error and easy visualization of construction projects. In what way does GIS integrate with CAD? On the surface, the two technologies go together like “cookies and milk”.

There have been ongoing efforts and initiatives on the technology front to promote CAD / GIS integration in recent years. Besides, some elements of GIS functionality have been taken on by conventional CAD packages. GIS tools have incorporated CAD functions as 3D projection. The poor handling of attributes data, limited and slow database connections, and primitive spatial analysis and cartography capabilities that CAD lacks, but numerous attempts were made to take these advantages from GIS.

CAD Integration: ArcGIS Expansion of Application Interoperability offers extra device integration capabilities. Two CAD interoperability solutions (Solutions for Civil Engineering)

are provided by ESRI-CAD direct read and bidirectional transfer. ArcGIS has the native ability to read several CAD data formats without modification, including DWG, DXF, and DNG files, as layers in ArcMap, concerning CAD direct read capabilities. As specified in the CAD file, ArcGIS symbolizes the details too.

2.10. International perspective on GIS and BIM integration

Across Architecture, Engineering, and Construction (AEC) industries, many countries around the world developing standards, protocols, and guidelines to support their ambitious strategy towards GIS and BIM integration and implementation (Song et al., 2017). Countries are developing methodologies that regulate pursuit across AEC projects tailored to engage specific requirements of the subcontracting organization, project owners, specialist trades, multi-disciplinary project team, subcontracting organization, service suppliers, insurance, liabilities, users, constructors, and technology (Rafiee et al., 2014).

United States of America

In 2006, the United States through the General Services Administration (GSA) delivered a guideline outlining a BIM-GIS implementation plan to integrate the use of BIM in the AEC of the United States. Consequently, GSA established a mandate demanding BIM compliance from all planners as a condition to a successful application of GSA funding schemes (GSA, 2007) making the US one of the earliest initiators of BIM guidelines and mandates for public sector projects.

The US public sector is the early beneficiary of BIM-GIS implementation due to refined a guideline that transfers and allocates risks associated with BIM-GIS implementation plan, establishing protocols that define the granularity of roles and responsibilities of participating project party and explicitly detailing conflict resolution plans for issues resulting from existing contracts and policies. Stakeholders of the public sector are encouraged to comply with the BIM mandate confirming that about 60% and an increasing number of the US Architects use BIM-GIS integration in their projects (AIA, 2008).

European Countries

UK, Netherlands, Denmark, Finland, and Norway Governments currently demand the use of BIM and GIS integration for their public projects. AEC leaders in the EU supports parliamentary vote with a stance that it will modernize EU public sector processes. This support is possibly viewed to aid BIM-GIS adoption and allowing EU member states to specify

requirements and mandate GIS and BIM for publicly funded construction projects. This is to advance European competitiveness and make construction more efficient.

Africa's experience

The construction sector plays a vital role in the national GDP and economic development of any nation and nationality. It's crucial because of the part it has in the economy, but that role differs greatly from one nation to another. In developing continents, like Africa, the construction sector is a very vital industry that delivers mainly new infrastructure in the form of roads, airports as well as new hospitals, schools railways, housing, and other buildings (Dakhil2013). The construction sector is a promising industry in many countries, usually making up to 6%–11% of the projects to be forwarded within or below budget and time. The Nigerian construction sector helps immensely from the adoption and integration of BIM and GIS to enhance the current crumble and highly uncoordinated way of working among construction(Wang et al., 2015)

The Present Situation of GIS and BIM integration in Ethiopia

A lot of organizations and companies in Ethiopia have started to explore GIS-BIM topics in the last few years(Gurmu et al., 2019). Also, there is an increased demand for the application of information systems in the construction industry(Ofori, 2018). Even though GIS and BIM integration is at its infant stage in Ethiopia(Jayasena & Weddikkara, 2013), The most effective roadmaps are developed supported input from each of the key stakeholder's teams

2.11. Conceptual framework

The purpose of this part is to show the Conceptual Framework of the thesis analysis by integrating GIS and BIM software to enhance a 5D BIM. The procedure started with preparing architectural drawings of a small residential building then importing the AutoCAD drawing to GIS and produce 3D after creating shapefiles or feature class. 4D is produced after GIS software integrated with the schedule using the critical path method. The 5D is the sum of the fourth dimension and cost estimation of the residential building. Building information modeling follow two guidelines one is schedule oriented which control time and resource, the other one is cost estimation oriented that leads to direct and indirect cost control. In most aspects of the construction industry schedule oriented and cost-oriented planning are considered.

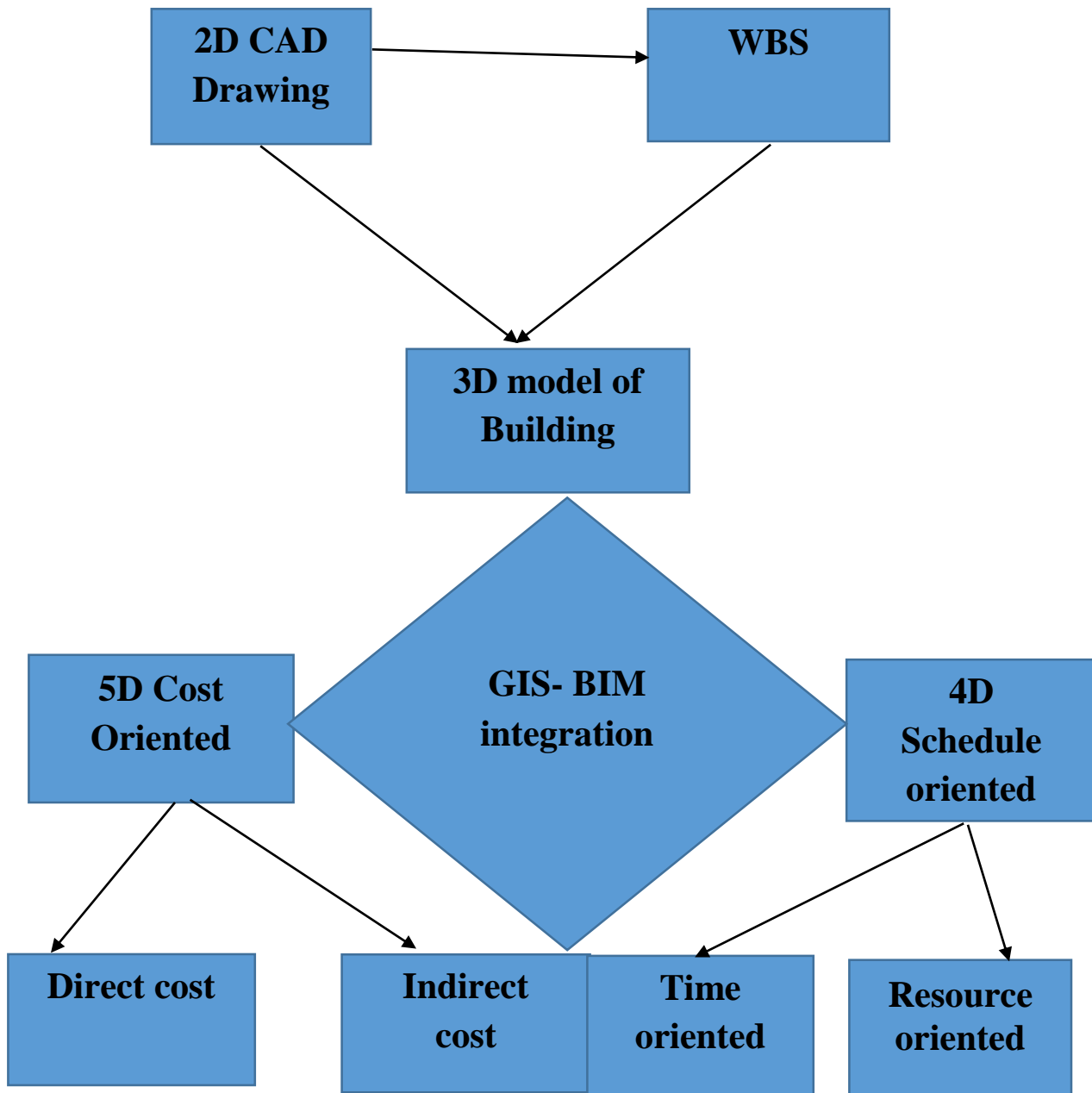


Figure 2. 3: Conceptual framework of GIS and BIM integration

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

This chapter describes the process that was used to collect data to establish knowledge towards 5D BIM enhancement using GIS. The research strategy is defined and its methodology to the subject matter established.

3.1. Description of the Study Area

Addis Ababa is the capital city of Ethiopia located in the central part of the country. Geographically located at the latitudinal extent of $8^{\circ} 22''$ to $9^{\circ} 30''57''$ N and longitudinal extent of $38^{\circ}24''$ to $39^{\circ}21''$ covering an area of 519.52 km^2 . For governance and organization, the city is separated into ten sub-cities and each has on average about 10 weredas under it, and hence the city is divided into more than 116 weredas. This study was conducted in one of the 10th sub-cities of Addis Ababa named Yeka sub-city of a single wereda and located in the northeastern suburb of the city of Addis Ababa with $9^{\circ} 2'14.28''$ N and $38^{\circ}50'6''$ coordinates. As to the recent organizational division, the Yeka sub-city is divided into 13 weredas and each of them is locally subdivided into sections or 'katana and neighborhood.

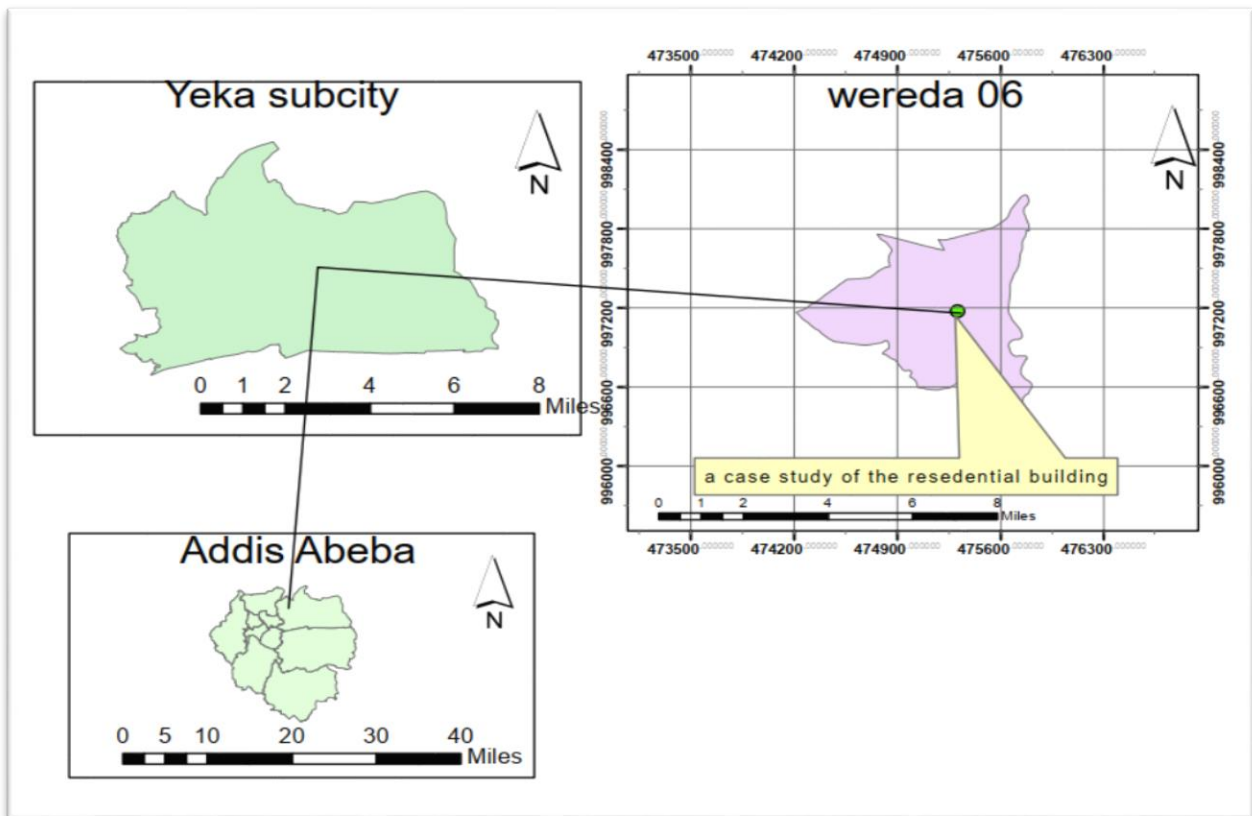


Figure 3.1: Geographical location of the study area

3.2. Research approach

There are two broad types of research. These are quantitative and qualitative research. In numbers and graphs, quantitative analysis is expressed. It is used to verify hypotheses and conclusions or to validate them. It is possible to use this method of study to evaluate generalizable facts about a topic. Experiments, findings reported as figures, and surveys with closed-ended questions are typical quantitative approaches. It is used to comprehend concepts, theories, or interactions. This kind of analysis helps one to gather in-depth perspectives about subjects that are not well known. Popular qualitative approaches include open-ended question interviews, words-described insights, and literature reviews that discuss ideas and theories.

Based on the above research techniques, a mixed approach was used since both qualitative and quantitative research tactics are employed accordingly, the use of unique numerical from the dimension of building to compute cost estimation and schedule make the research quantitative whereas the reviewed report used to be re-checked and triangulated through an informal interview, website online visits make the research qualitative. To characterize this research, a case study is used in a residential building in Yeka sub-city wereda 06 designed by RY consultant P.L.C.

Types of data & materials

For this research, both primary and secondary data sources are used to enhance 5D BIM using GIS and to answer the objectives of the research.

Primary data

Primary data include case study's architectural and engineering drawings, site visit, personal observation, interviews, and small focus group discussion.

Secondary data

These include works of literature in the fields of GIS- BIM integration and other collateral data that were of great help to this research.

3.3. Data sources and collection techniques

The research relied on the data collected from the questionnaire, case study, related literature reviews, site visits, and observations. Since the concept of BIM- GIS integration is relatively new to the study area, it was necessary to rely upon internet search on legitimate websites. Few

experts' discussion consisting of colleagues that had worked on the title of BIM and GIS was of great help to understanding the issue at hand.

Primary data source and collection techniques

Concerned government officials, owners and managers, consultants, contractors and professionals, and Personal observation and experiences were the main sources of the primary data. The following data collection methods were used to collect primary data.

Case study

To characterize this research, a case study is used in a residential building located in Addis Abeba in Yeka sub-city wereda 06 designed by RY consultant P.L.C. drawings and documents were compared with one another and tried to find the difference between them. And tried to find the project delay, additional cost, and loss of quality it incurred.

Interviews and focus group

Drawings and archive documents were re-checked and triangulated through an independent interviews with involved professionals, project's design head and project architect Mr. Neway Semunigus [ArchEng MSc.], structural designer Mr. Milkiyas Mezegebeziker [ST Eng. BSc.], Electrical designer Mr. Elyas Tesfaye [EL Eng. BSc.], Sanitary designer Mr. Leulseged Ali [Water supply and Environmental Eng. BSc.], Mechanical designer Mr. Miteku Negash [Mech Eng. BSc.] and Mr. Iman Abdulaziz Quantity surveyor [Adv. Diploma]. A small focus group discussion was conducted with researcher and instructor on GIS and BIM such as Dr. Denamo Addissie [researcher], GIS and CAD Expert and instructor Mr. Zekeleke Lerango [planner MSc.], RY consultant and Design team Leader Mr. Megersa Biyena [Arch BSc.] and RY consultant and Design team Leader Mr. Neway Semunigus [ArchEng MSc.].

Physical observation method

Own direct observation is used in the case study aided with field notes and sketches.

Secondary data source and collection techniques

The main sources used to collect the secondary data were both hard and Softcopies which includes: - Published books and journals, unpublished norms and standards, reports, brochures from the internet, libraries, and office stacks, and BIM-based cost estimation and schedule of the residential building. The secondary data were collected through reading, note-taking, scanning, and photocopying books, journals, reports, browsing, and extracting through trusted websites.

Software Used for the Study

Software such as AutoCAD, MS-Excel, and ArcGIS is used to implement the methodology.

1. **MS Excel:** Advanced functionalities of MS-Excel (such as VLOOKUP, HLOOKUP, Roundup, IF conditional expressions) are used for scheduling purposes.
2. **AutoCAD:** It is one part of BIM software that Civil engineers, draft man, 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.
3. **ArcGIS 10.4:** This software package with its extensions like 3D Analyst provides a variety of interoperability modes. ArcGIS allows to view spatial data and perform basic and advanced spatial analysis.
4. **Revit:** It is advanced BIM technology used to prepare cost estimation and schedule of the building to compare with 5D GIS-based cost and schedule.

Data analysis and interpretation techniques

Software such as Microsoft Office Word, Microsoft Office Excel was used to write texts, create tables and graphs. These software's are also used to analyze and present the surveyed data from focus groups and interviews. To organize the data different possible techniques are used not forgetting editing and description. Also, for any kind of data that needs confirmation from the source officially, it was sent for confirmation. In the description stage, all kinds of sorted data are reviewed and additional descriptions and explanations of data are undertaken as required. The descriptions are textual, graphs, and numeric findings. In addition to the search for the fact contained in the data the analysis of the organized data aimed at preparing the data for direct use in the evaluation process.

3.4. Method

This sub-topic elaborates the procedures followed or techniques used to identify, select, process, and analyze information about the integration of GIS-BIM technology.

- The method used for this research is summarized here as follow;
- 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: Generating spatial information for the architectural drawing
 - Step 6: Display of 3D building model in Arc Scene
 - Step 7: Quantity take-off
 - Step 8: Resource analysis and duration estimation
 - Step 9: Integration of construction resource data
 - Step 10: scheduling activities
 - Step 11: Cost analysis
 - Step 12: Project control table
 - Step 13: Visualization schedule and cost estimation
 - Step 14: Preparing cost estimation and schedule using BIM

Figure 3. 1: General Methodology

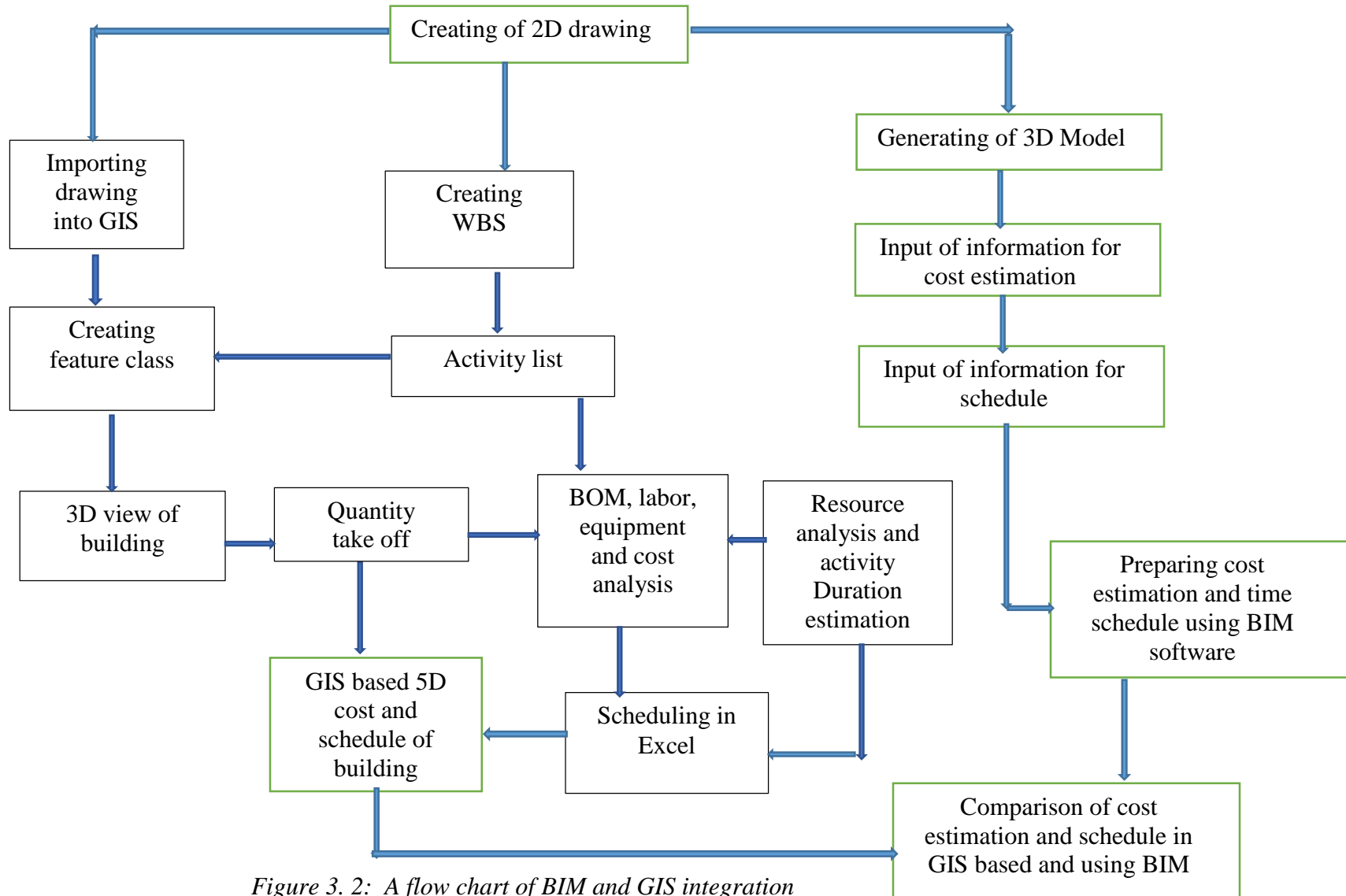


Figure 3. 2: A flow chart of BIM and GIS integration

Validation of research approach and methodology

Reliability and validity are concepts used to evaluate the quality of research. They indicate how well a method, technique, or test measures something (Heale & Twycross, 2015). Reliability is about the consistency of a measure, and validity is about the accuracy of a measure (Heale & Twycross, 2015). It's important to consider reliability and validity when the researcher creates research design, planning methods, and writing up results. In a mixed research approach, there are several techniques and tools to ensure the feasibility or validation of the research method for instance; pilot study, face validation, test-retest, etc. A pilot study was taken for this paper as it is not time-consuming and stable compared to other techniques.

A pilot study is a small study designed to test various aspects of the methods planned for a larger, more rigorous, or confirmatory (Heale & Twycross, 2015). To carry out the pilot study, a sample of two activities from the substructure and three activities from the superstructure of the residential building was selected. From substructure parts excavation for foundation and backfill were selected whereas from superstructure beam, column, and roof slab were selected. The pilot study was carried out using a combination of AutoCAD, ArcGIS, and MS Excel applications. After processing the pilot study, the researcher concludes that the result of the study shows positive towards the selected methodology.

3.5. Data analysis

Step 1: Creating Architectural Drawings

Architectural drawings (such as section, floor plan, elevation, detail foundation) were prepared by using AutoCAD software for the case of a small residential building. Each of the components of the building is identified by using layers. The layer has been used to distinguish one component from other components using different colors.

Step 2: Identification of Work Break down Structure (WBS)

Before scheduling and cost estimation of construction building, each activity needs to breakdown into small activities to manage every task. 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. One of the duties of project managers is creating WBS, then determine each activity, and assigning resources for every

WBS element. In this thesis, the researcher used a top-down approach to create WBS. There are some steps followed to create WBS of the residential building: -

- Identify the major elements of the project
- Identify the supporting activities of major elements
- Repeat until undividable activities are created

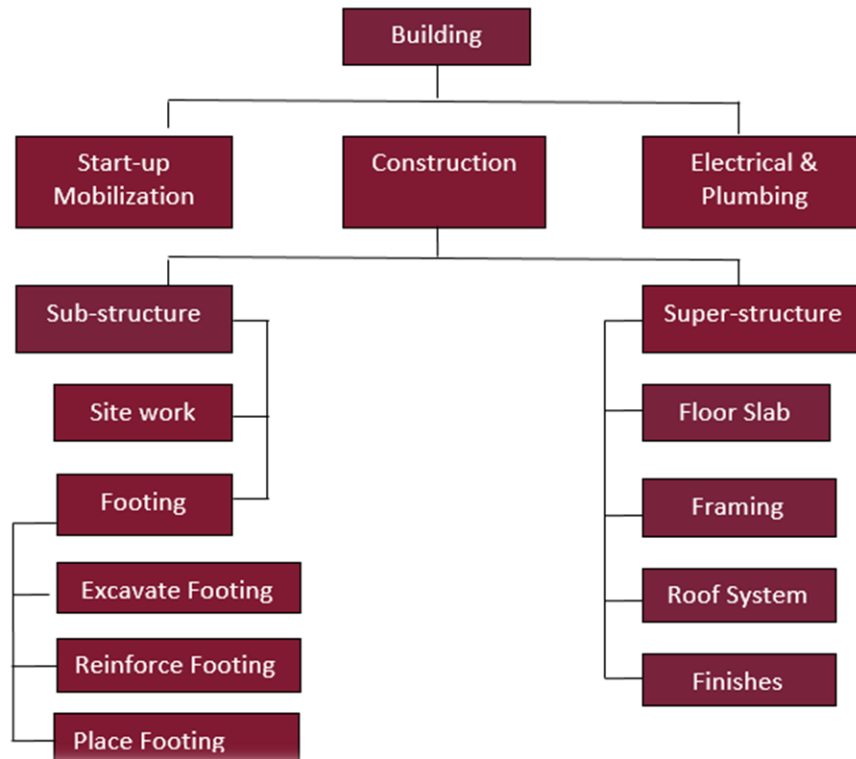


Figure 3. 3: Work break down of the structure(Song et al., 2017, p. 52)

Step 3: Importing AutoCAD Drawings to ArcGIS

Data Transfer

The drawing created in AutoCAD imported to ArcGIS using direct read/write modes. The layers created in AutoCAD are conveyed to the GIS environment by default method where legends have appeared on the table of content on the GIS interface. The imported layers are categorized into the point, Polyline, polygon, annotation, and multipatch data.

Step 4: Editing Imported Layer

The AutoCAD drawing data which are imported to GIS cannot be edited until all features are converted into shapefiles. The shapefile contains both spatial and attributes data integrated within the GIS database.

Step 5: Generating spatial information for the architectural drawing

By default, an AutoCAD file does not comprehend ESRI spatial reference information to define a coordinate system. AutoCAD practice 2D and 3D Cartesian coordinate systems which localize data at fixed coordinates. CAD coordinates are not naturally geographic locations; quite, they are locations comparative to geometric origin (0, 0, 0). Even though CAD data that relates to the x, y coordinates of a projected grid zone, without a supported means to pinpoint which supported ESRI coordinate system was used, the data is not likely to be positioned properly. When CAD data is added to a map or scene in ArcGIS with an undefined spatial reference, the coordinates of the data are assumed to be the same coordinate system of the current map or scene's spatial reference, which is not correct. It is recommended that defining a spatial reference for all data added to ArcGIS so that it can be properly positioned.

Table 3. 1: coordinates attained from owner’s parcel index map or landholding adjudication

Building corners	Easting	Northing
Building corner 1	475308	997173
Building corner 2	475321	997173
Building corner 3	475321	997164
Building corner 4	475308	997164

The Role of GIS In Enhancing 5D BIM of Construction Building

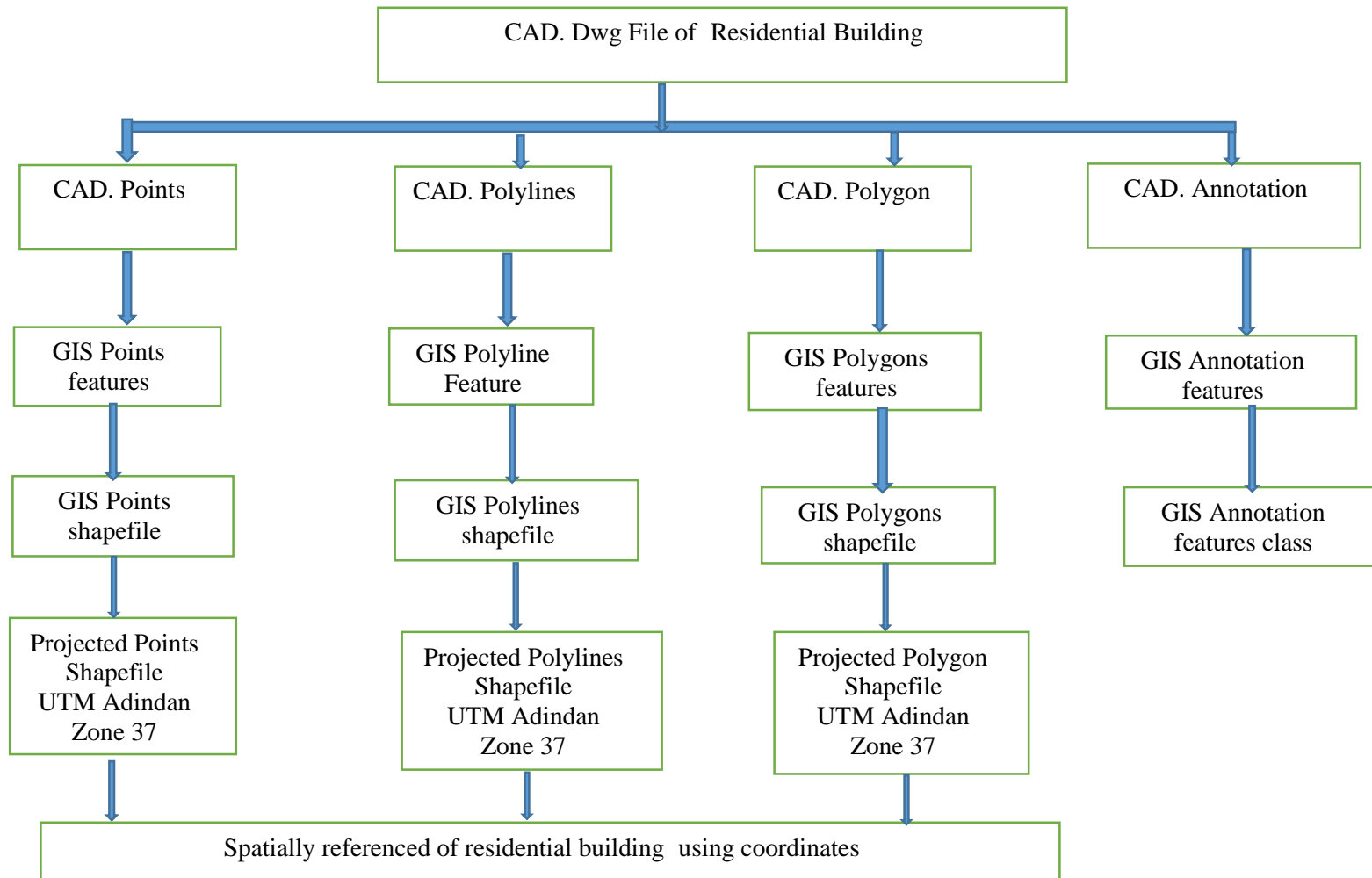


Figure 3. 4: The flow chart of generating the spatial information for a case study of residential building

Giving spatial information to the case study means associating the architectural drawing with locations in physical space. The parcel index map contains coordinates of the building both in paper and digital form based on the national geodetic survey network. The researcher used a case study of a physically existing building in Yeka sub-city wereda 06. The researcher uses the four building corners of the coordinates from the owner's parcel index map. After taking those coordinates the researcher fills them into MS excel and imports them to ArcMap. After importing those points of building corners, a polygon shapefile was created to reference the case study.

Step 6: Creating Feature Classes

After the work breakdown structure task is finished, the next step will be preparing a feature class for each activity by using ArcGIS. Feature classes of each activity will be made to have spatial and attribute information in the form of a table. This combination is important for detailed analysis and investigation of components of project management processes such as a bill of quantity and scheduling of construction projects. The linkage (or relation) that exists among the attribute tables may not only define one-to-one relationships; it may define one to one, one to many, and many to one relationships based on the complexity of the different tables. The activities expressed in WBS be merged to form a single attribute table which is easy to edit and control the information flow. The parts in shapefile that belongs to similar activities in different position or location can be grouped as one by using merge or union tools.

Step 5: Display of 3D Model in Arc Scene

Extrusion: In the architectural design of 2D, there is no base height and object height data. We need to assign height in the 3D space co-ordinate scheme to translate 2D to 3D. As the basis of elevation values, there are two methods to determine base heights. These are: -

- Using an attribute or constant value
- Draping the feature on a surface

The attribute values representing height information are applied to the layer when the first method is used or are used to construct an expression that provides base height values. If a constant value is applied, it can be any whole number that would become the height of the feature in meters above the surface. In essence, the second option, draping, is setting the base heights from a surface. In essence, the second option, draping, is setting the base heights from a surface. Single-

band digital elevation model (DEM) rasters, triangulated irregular networks (TINs), and terrain datasets are used in surface elevation details. The researcher used the height manually entered from the table of attributes to create a building 3D model.

Step 7: Quantity Take-off

The system allows the extraction of 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 are length, area, and perimeter of various features. Thus, different data layers are created using geographic elements either as lines or polygons.

Length, area, and perimeter: Spatial operations are performed to identify the required geometric dimensions of the graphical features. 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.

Quantity Takeoff procedure

Below are the steps to be followed to attain quantity takeoff:

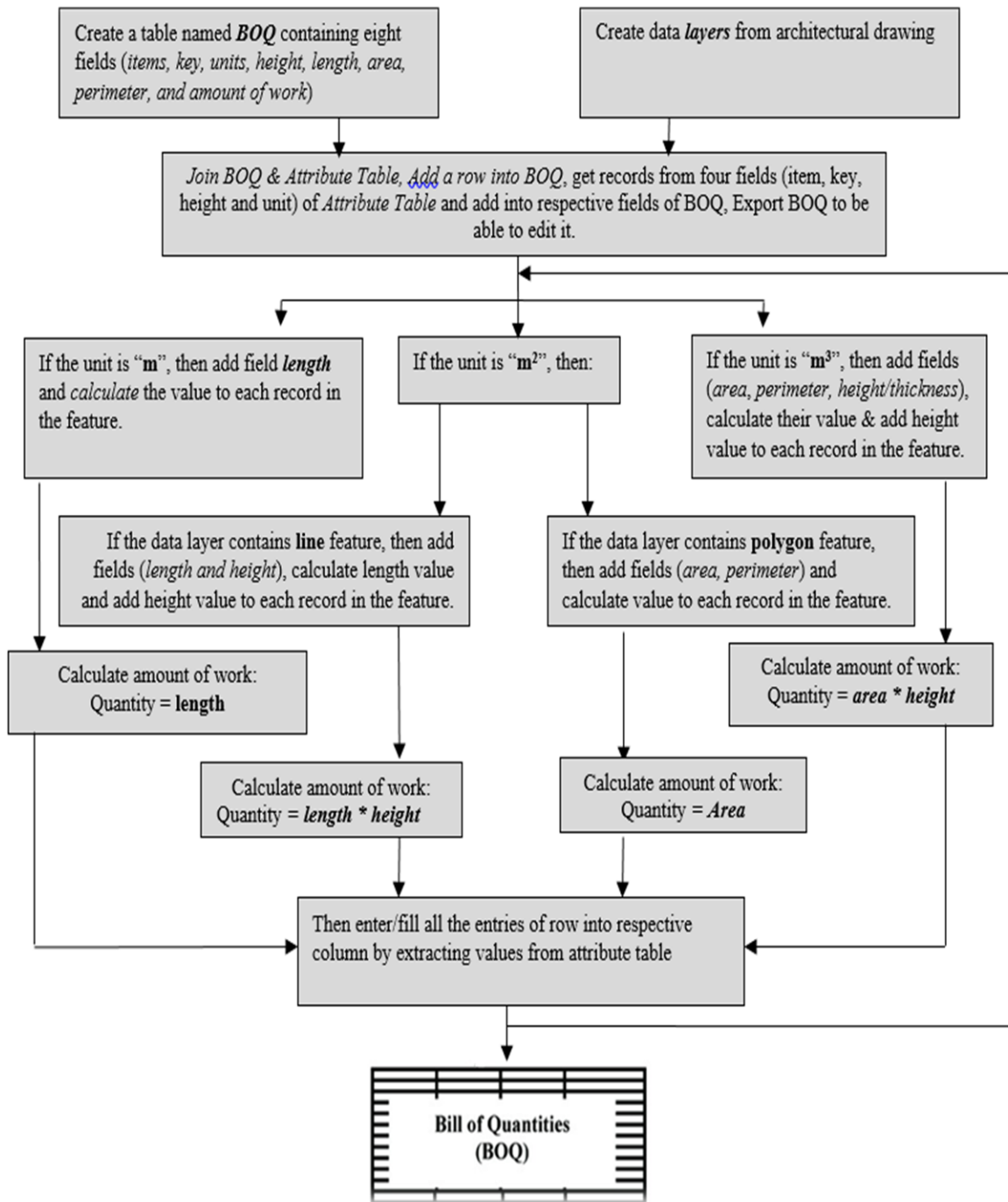


Figure 3. 5: Flow diagram to generate BOQ in ArcGIS(V. K. Bansal & Pal, 2010, p. 7)

Setting Attributes for BOQ

When AutoCAD data are imported to GIS, default field information is created (shape and ID) in the data layer. Information required for the bill of quantity is the length for line feature and area and perimeter for polygon feature. Thus, the non-spatial table of a layer must have fields of shape, key, description, length, area, perimeter, height, and unit. The field shape is stored as an entity representation of each component of activities that are attained by default when feature class is created. Once shapefiles of every activity are created; there are some fields appear such as area, length, and perimeter. In the mean process, the fields like description, height, unit, and key are added to the non-spatial table (attribute table) manually. The basic parameter that required by cost estimation were length, perimeter, and area. The amount of work executed will be computed by multiplying these parameters.

Reinforcement bar Takeoff

Quantity take-off for reinforcement bar was treated differently than other elements. Centerlines of the grade beams and top tie-beams were drawn using the midpoint command available in ArcGIS to use as a base for calculation of the total length of the structural elements by taking care of the overlapping portions of the elements not to be counted twice. Then the quantity of reinforcement bar required was calculated from the information obtained for the section of the structural elements in the drawing. Detailed calculations are shown in annex D.

Step 7: Resource Analysis and Estimation of Duration

The amount of resources available is essential for determining the bill of quantity. Resources may be skilled manpower, machinery, labor, and so forth. The researcher used a standard excel template from BATCODA that consists of standard specifications, productivity rates, and utilization factors. 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 costs by multiplying them with the appropriate labor rate per day for a specific period. Cost and time estimated based on the stated productivity rate were used for scheduling purpose in table 3.2 as follow.

Table 3. 2: Calculation with standard productivity rate for a unit work item

<p>Work item: Masonry work</p> <p>The total quantity of work item: 1m³</p> <p>Hourly output: 0.225 m³/hr.</p>																																		
<p>▪ Duration = Quantity/Hourly output</p> <p>= 1m³/0.225m³/hr. = 4.44hr (for a cubic meter of masonry)</p> <p>Then, the total duration of time required for the work item can be calculated by multiplying this value with the total quantity of the masonry work.</p>																																		
<p>▪ Ingredient's Quantity & Cost, Considering Wastage</p> <p>Material Cost (A):</p> <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>m³/m³</td> <td>1.20</td> <td>283.33</td> <td>340.00</td> </tr> <tr> <td>Cement (PPC)</td> <td>kg/m³</td> <td>92.00</td> <td>2.40</td> <td>220.80</td> </tr> <tr> <td>Sand</td> <td>m³/m³</td> <td>0.26</td> <td>468.75</td> <td>121.88</td> </tr> <tr> <td>Water</td> <td>m³/m³</td> <td>0.40</td> <td>3.00</td> <td>1.20</td> </tr> <tr> <td colspan="4" style="text-align: center;">Total</td> <td>683.88</td> </tr> </tbody> </table> <p style="text-align: center;">A= Material unit cost = 683.88</p>					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																														

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 number of materials can be obtained. The system stores construction resource information for various possible tasks related to construction materials, workers, and equipment's in three different *tables* (materials, labor, and equipment) in GIS.

Material (BOM)

The material table in the database has diverse fields named as key, activities, quantity, units (i.e., work unit), cement, sand, coarse aggregate, steel, HCB, and other construction materials. This field was connected to another table by the primary key. The field activities contain different possible tasks. Each record of the table contains several different materials required for a task in the corresponding field (column). All entries in different fields of the material table are not for a single work unit. Thus, field quantity contains an 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 the corresponding row by values in the field quantity (Bansal, 2005)

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

Equipment: The Equipment table contains fields: key; activities, quantity, and rates for different equipment's each row contains the rate of equipment for the amount of the work entered in the field of quantity. Equipment cost for the tools is considered on an hourly rental rate base

Step 9: Scheduling Activities

Planning and scheduling are very essential to finalize building construction. The construction schedule is important to monitor and track each activity to be accomplished. The schedule determines the relationship among the component and defines the sequence of each activity. Therefore, the building construction project is decomposed into discrete activities and time needed to complete each activity and arranged in sequential and non-overlapping order.

Activity Precedence

In preparing to schedule; the process of selecting which activities is precedence and successor, experts may use the rule of thumb. It may depend on the availability of construction materials and skilled manpower. It is up to the scheduler to decide by considering different influencing factors.

Excel Program

The spreadsheet program is broadly accessible presently and the managers are commonplace and comfortable with this software. The spreadsheet gives a common interface for show model building. It is easy in terms of solution, report generation, and input. Also, it is crucial in using an advanced program like IF analysis, VLOOKUP, and HLOOKUP. While using spreadsheet care should be taken to the Excel program during editing and adding different activities or components. This paper is used the critical path method (CPM) algorithm to compute the critical part of the schedule in the project. This study utilizes the GIS-Excel integration to determine the project schedule in the form of an attribute table. The number of rows in the table depends on the number of activities in the network. Finally, it computes the start/finish times, floats, and criticality of each activity and the project duration.

Input Sheet:

The primary process in preparing a schedule using CPM is showing the network from end to end predecessor and successor's relationships. The thesis accepts the demonstrating predecessors in the columns and successors in rows overall this research paper. These methods are used to compute start-finish time, floats, critical activity, etc. The schedule is already established 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 cells.

GIS and Excel Integrated

The schedule prepared in MS excel spreadsheet transported to GIS and converted into database “.dbf” data format which means a GIS compatible format. Then the software prepares a bar chart from the scheduled prepared by excel. A 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.

Step 10: Cost Analysis

This part discovers the capability of GIS in preparing the bill of quantity. In construction building bill of quantity are very crucial in accomplishing the whole life of a project which include from feasibility stage to the final project. The bill of quantity of different data layers (shapefile) is obtained from integrating the database of attribute tables. The three elements of cost (material, labor, and equipment) are obtained by joining BOQ with three resource tables of the database maintained in GIS (Bansal & Pal, 2007). Each element is priced separately following 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 the total cost.

Step 11: “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*, etc. It includes minimum information about the *key, quantity, and percentages complete* for each work package. The *related* (linked) non-spatial information such as schedule, safety, and quality control recommendations, 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 can 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.

Step 12: Visualization of schedule and cost estimation

In GIS a visual check of the schedule is possible, which may help in preventing omission of the activities in the schedule. The research paper presents a 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. Although some commercial tools allow planners

to build a 5D model and create a graphical simulation of a construction process it still lacks features like generation and manipulation of a 5D model within a single environment.

Step 13: Preparing cost estimation and schedule using BIM

To prepare cost estimation and schedule using BIM software architectural 2D drawing of the residential building is created using AutoCAD which explained in step1. Then importing the 2D drawing into BIM software. 2D drawing is a foundation for BIM projects, hence, it's vital to correctly transfer 2D plans from one software to another A complete 3D building model has three major assemblies: walls, architectural components, and doors and ceilings. Extrusion should handle each assembly differently according to its unique characteristics and the specific application needs. After inputting necessary information for cost estimation and schedule take off and schedule is prepared using BIM software called Revit

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Evaluation of the proposed model to objectives

The major focus of this study was to explore the role of GIS in enhancing the 5D BIM cost estimation and schedule in construction projects. As a matter of fact, after having intensive literature reviewing, focus group discussion and assessing quantitative data of a prototype residential building and eventually triangulating all source data; observed results are discussed here as follow: -

Specific objective 1: To develop a 3D model and improve visualization of building using GIS software.

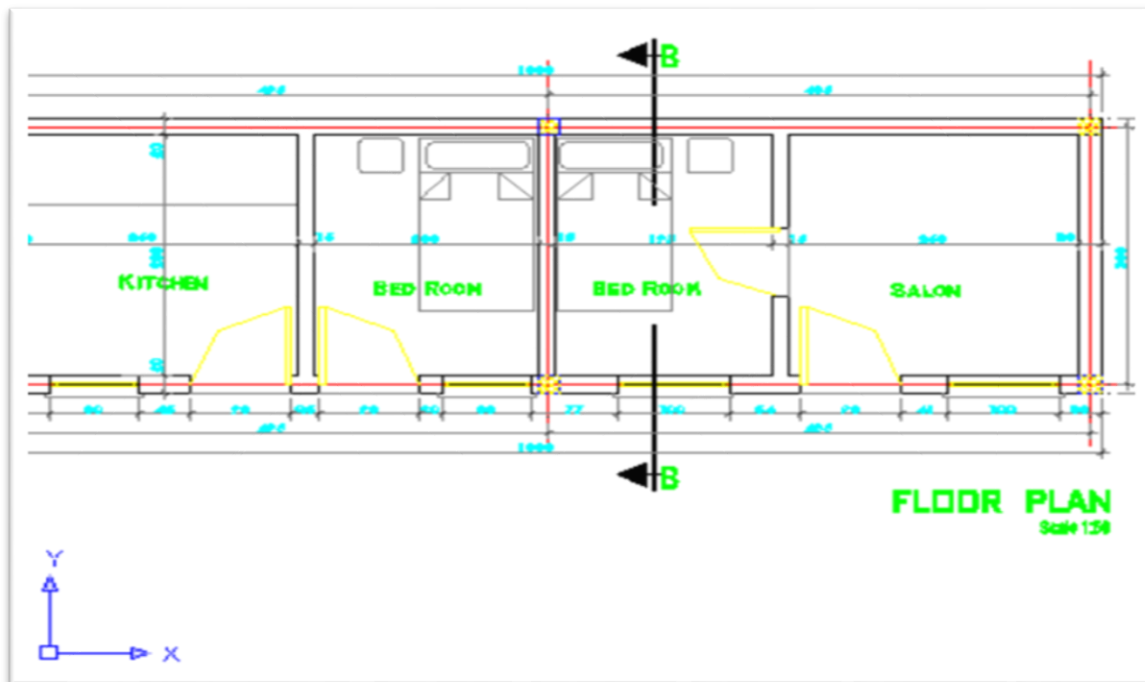


Figure 4. 1: Floor plan

Figure 4.1 shows the drafted architectural drawing of the residential building. It was generated by using CAD software of the existing building. The building has one bedroom kitchen salon and a master bedroom. There are four windows and three doors. The building is located in Yeka sub-city wereda 06.

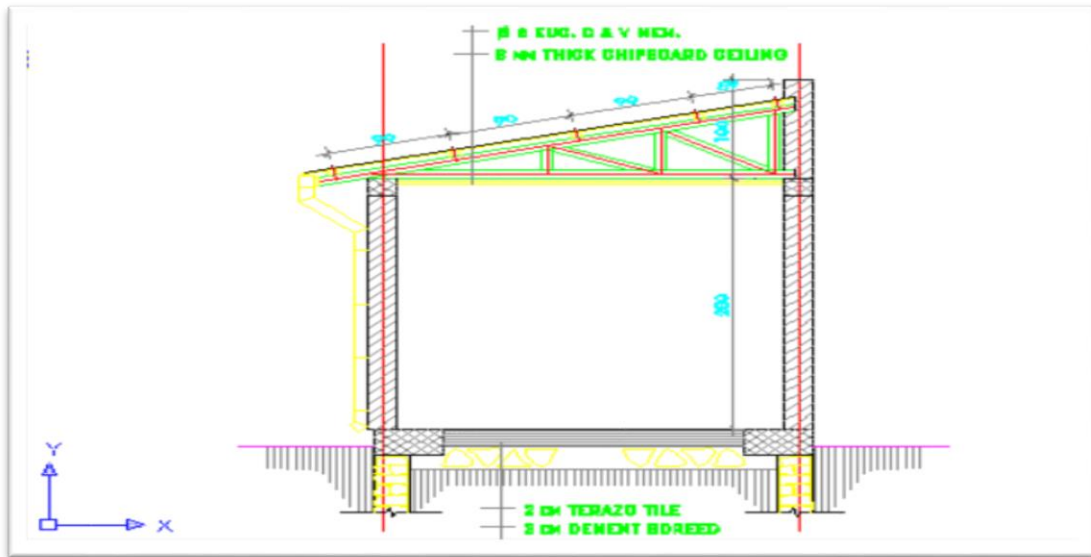


Figure 4. 2: Section plan

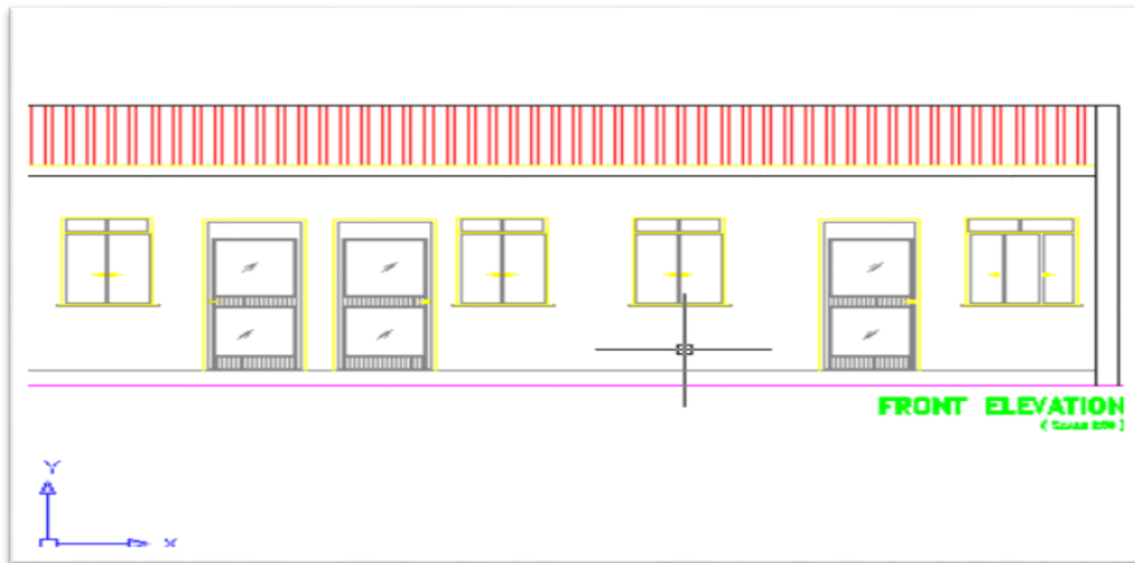


Figure 4. 3: Front elevation

The above three figures 4.1, 4.2, and 4.3 shows architectural drawing used to develop a 3D model and also used for preparing cost estimation and schedule of a residential building. The architectural drawing is created using CAD. As the number of drawings increases the quality of cost estimation and construction building schedule also increase.

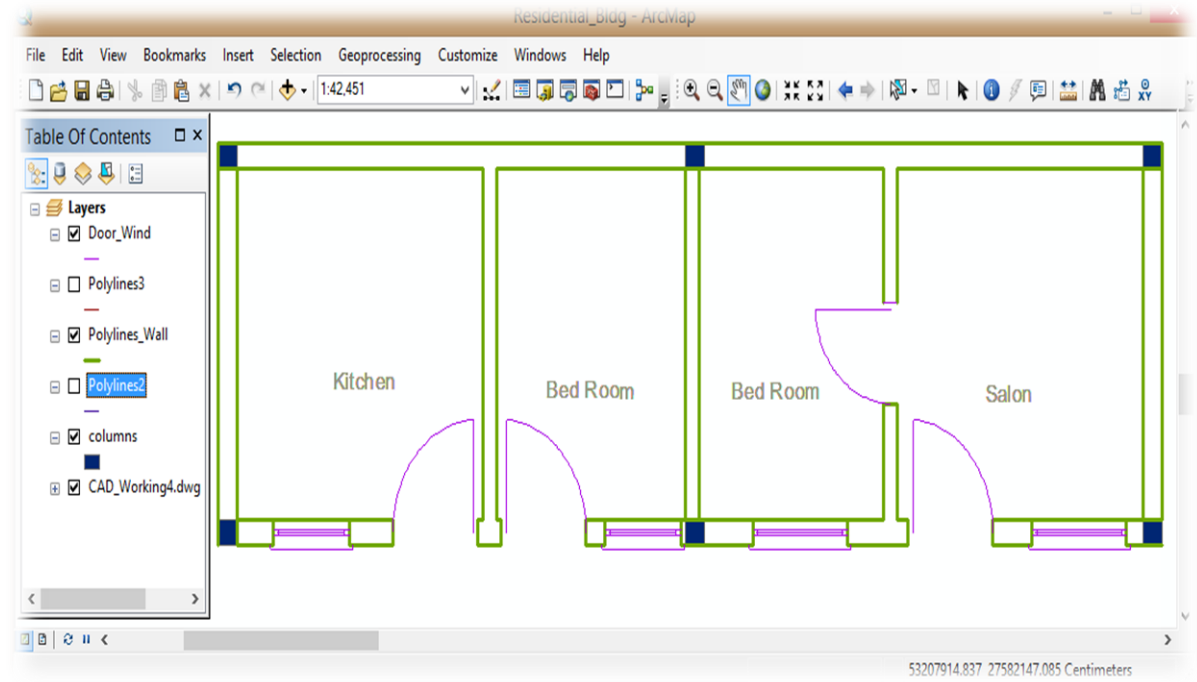


Figure 4. 4: Imported floor plan in ArcMap

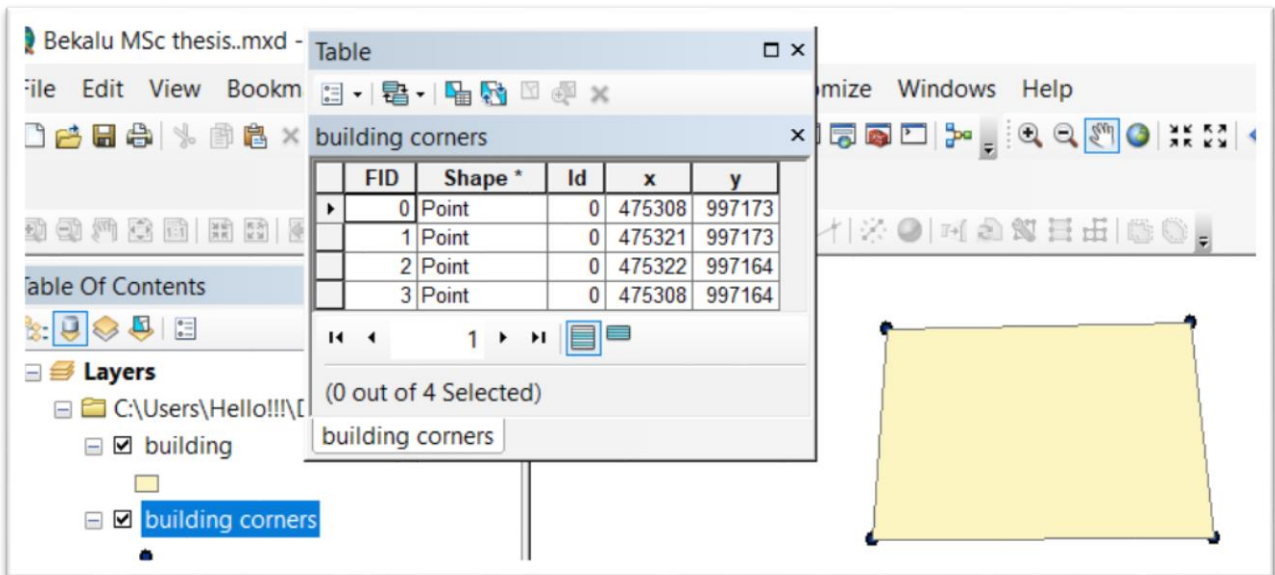


Figure 4. 5: spatial information of the residential building

Figure 4.4 shows the imported architectural drawing using read and write mode. The imported architectural drawing has five pieces of information such as point line polygon annotation and multipatch. All feature classes are emanated from the imported case study.

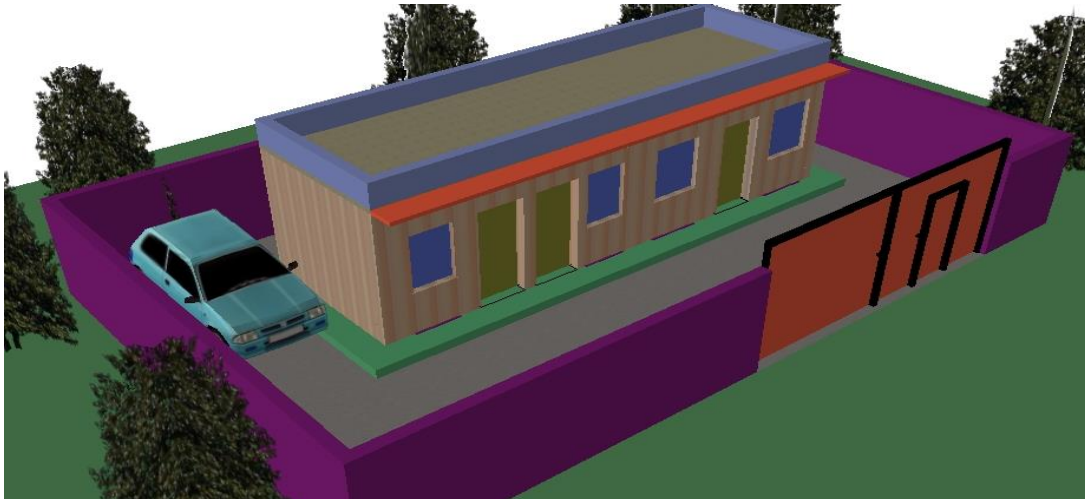


Figure 4. 6: 3D view of the building using ArcGIS

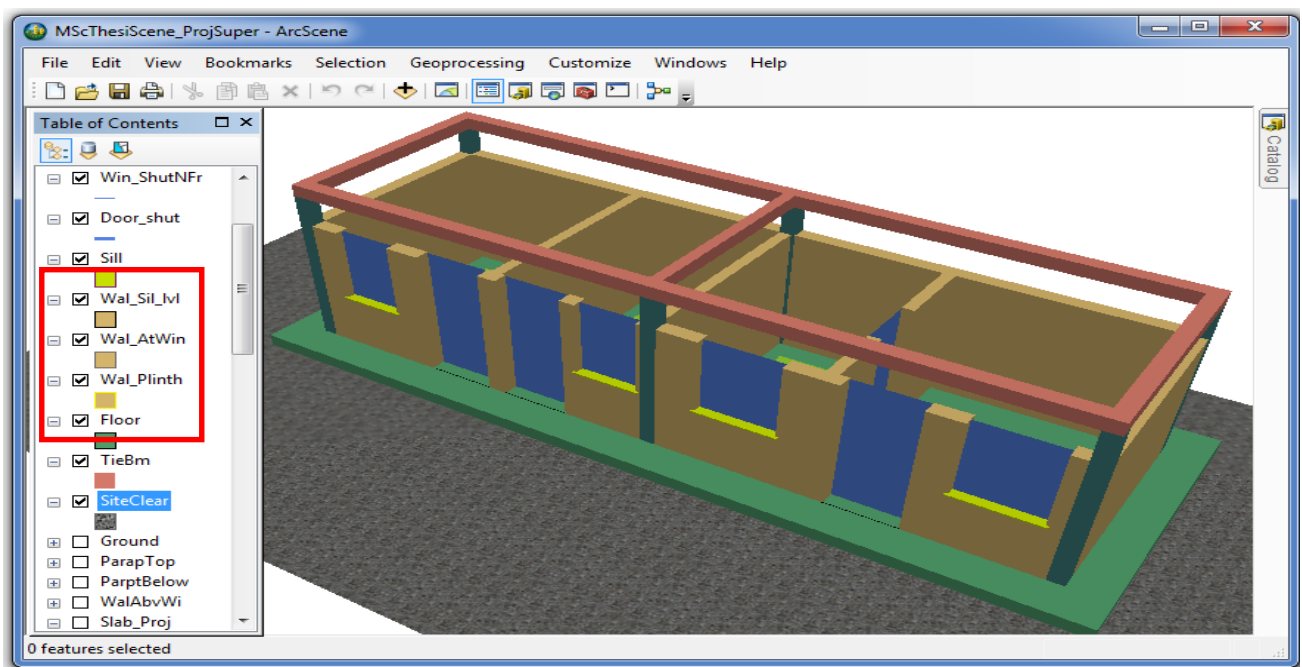


Figure 4. 7: 3D view of superstructure detail

Figure 4.5 shows that 3D model of the building using Arcsene. Compared to the 3D model of Revit GIS-based 3D model of the building has a more visual aspect and also aesthetical. The 3D model is generated from imported architectural drawing to ArcMap and by creating the feature class of each activity for work break down structure (WBS). Figure 4.6 shows that the

superstructure of the case study without the roof to visualize the internal part of the building. The table of content on the left shows in detail the feature class of each activity.

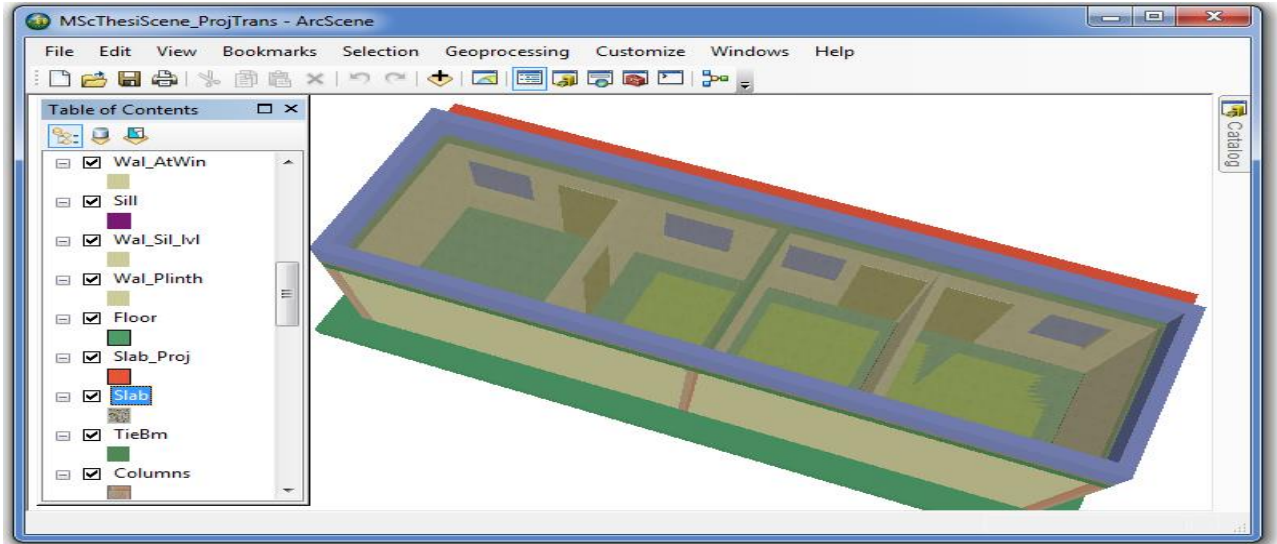


Figure 4. 8: 3D roof slab set transparent to display internal detail more clearly

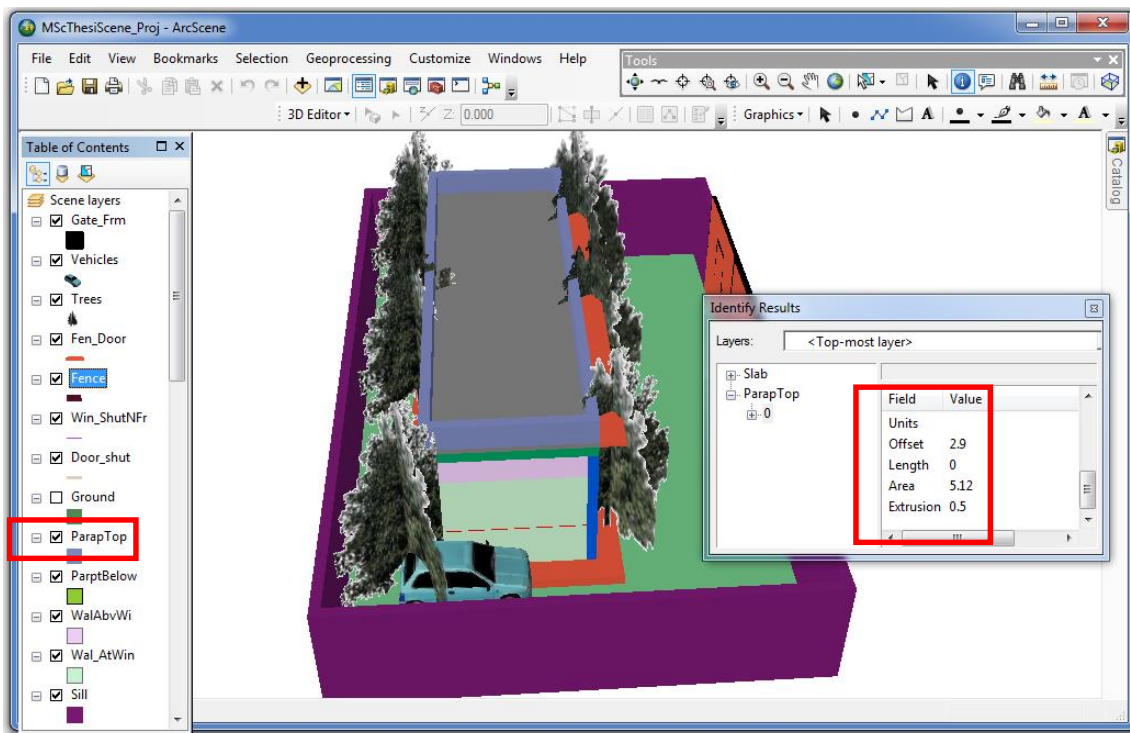


Figure 4. 9: Retrieved detail of 3D building components using identify tool

Figure 4.8 shows that Identify tool is used to check details of as-built components in the 3D by retrieving attributes such as dimensions, material type used, etc. In figure 11 the details of the parapet are made displayed by clicking on with identify tool.

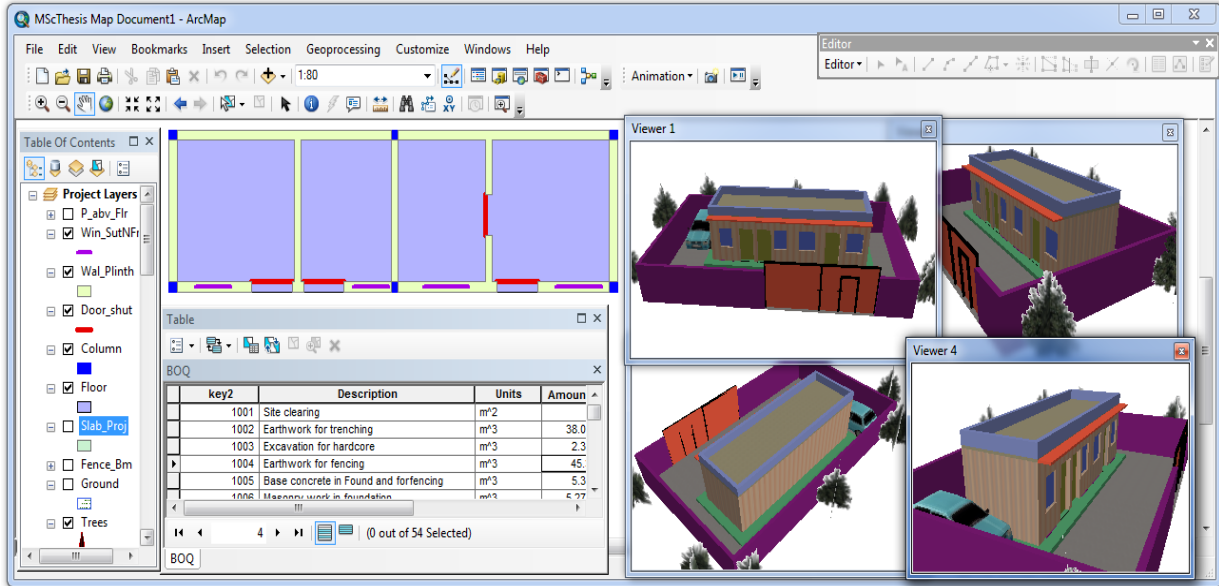


Figure 4. 10: Different 3D perspective from ArcSene

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 the BOQ of the building and shown in the lower-left corner.

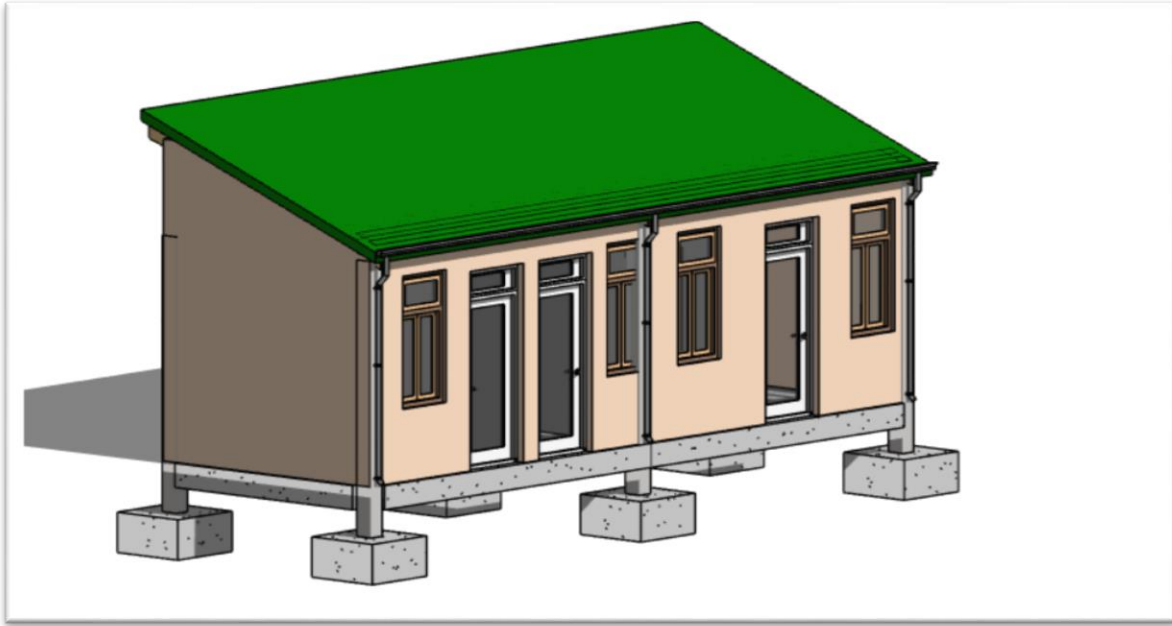


Figure 4. 11: 3D model of building using BIM software

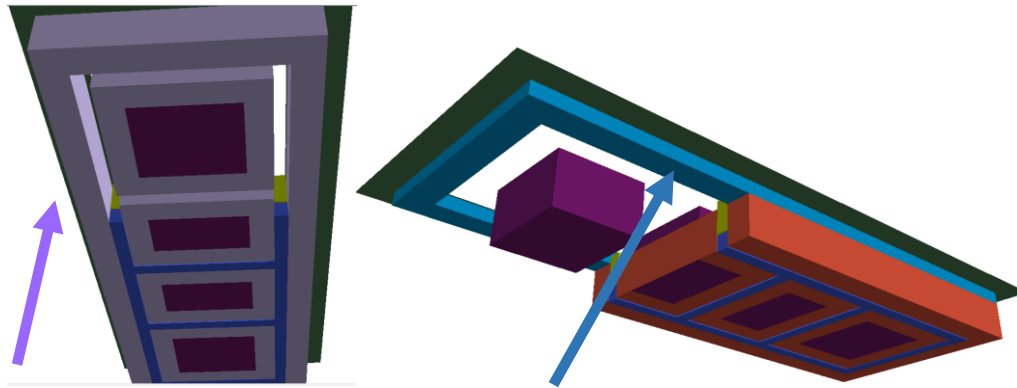


Figure 4. 12: the different 3D perspective of building using BIM software

Figure 4.10 and figure 4.11 show a different 3D perspective of the case study using BIM technology. To develop the 3D model of the building architectural drawing of the case study is imported to BIM-based 3D software. After inputting important information, a 3D model of the

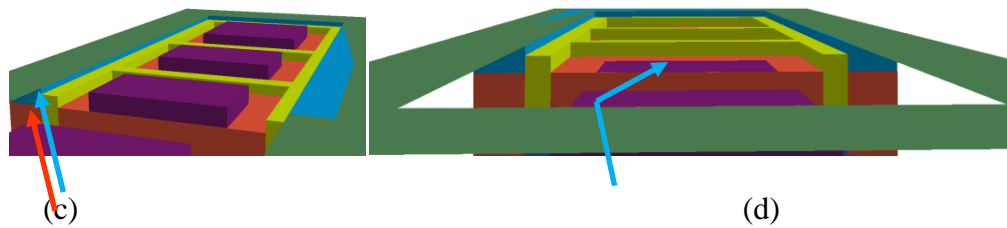
building is generated by using Revit. Despite the technological advancement of BIM software, it is not good in visual aspect compared to 3D model GIS-based. However, it is yet used as a model in the construction industry.

✓ **Ease of 3D Viewing of Components:**



First stage backfills 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 4. 13: 3D view of the substructure of a building

✓ **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 superstructure 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.

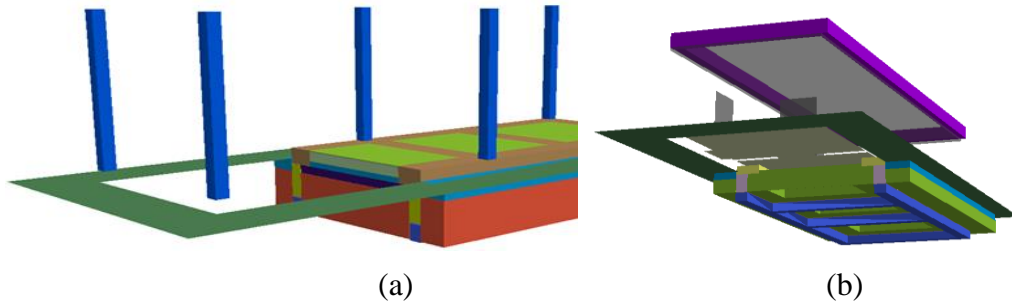


Figure 4. 14: Layers ON/OFF applied on superstructure to display the substructure

✓ **Transparence to View Obstructed Objects**

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

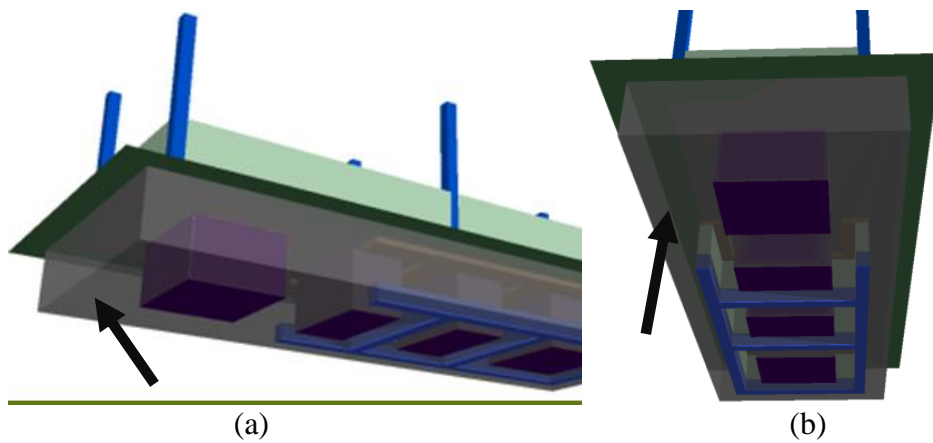


Figure 4. 15: Object made transparently

✓ **Error Identification:**

By implementing the proposed methodology, the 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.

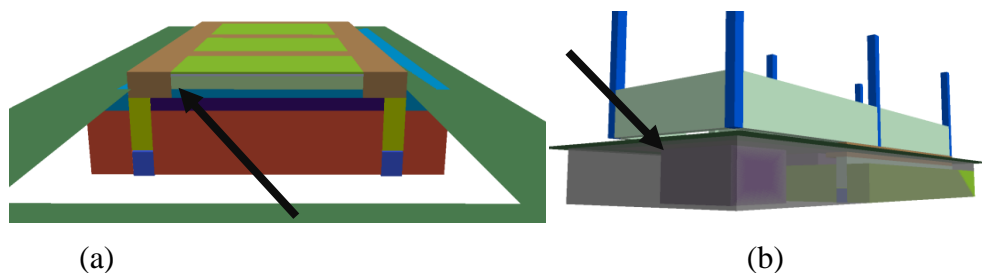


Figure 4. 16: Detail display to alleviate errors

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 with the help of the zooming functionality, This seemingly small error will have a 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 mistakes by incorporating the space occupied by columns (blue space) while calculating the area of the wall. It is committing a double count error. GIS avoids such intruding mistakes in calculation.

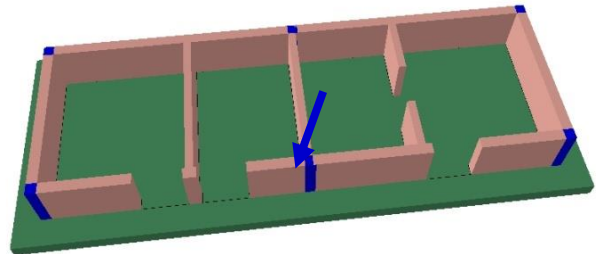


Figure 4.17: Most commonly committed double error

Better Accuracy and Imagination

Note that the grade beam 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 mistakes 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 upthrust.

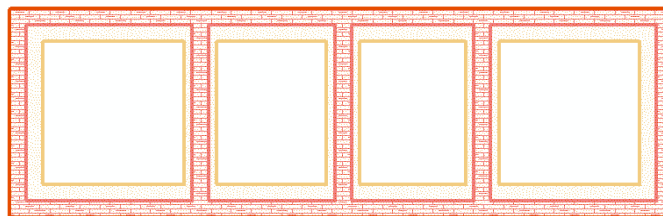


Figure 4. 18: Visualization to calculate the net surface area of a formwork

In Figure 4. 19: Centerline used to calculate the exact volume of RCC, 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 the double-counting error of overlapping portions because space (shown by a red circle) is already occupied by the horizontal beam.

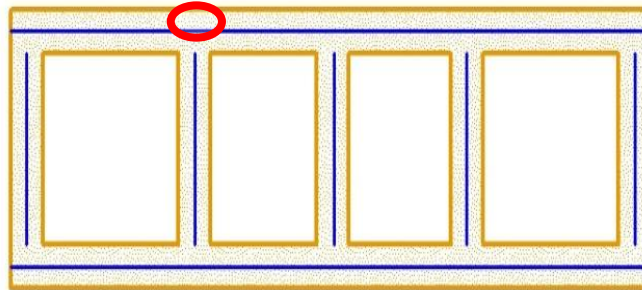


Figure 4. 19: Centerline used to calculate the exact volume of RCC

✓ **Efficient Color Selection**

The esthetically beautiful color combination can be made with trial and error by combining the fundamental RGB (Red, Green, and Blue) colors. By using the color selector option and viewing their real effect or contrast on the building components. For example, the color selected for the gate is the combination of RGB: 230, 85, and 58. An 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>).

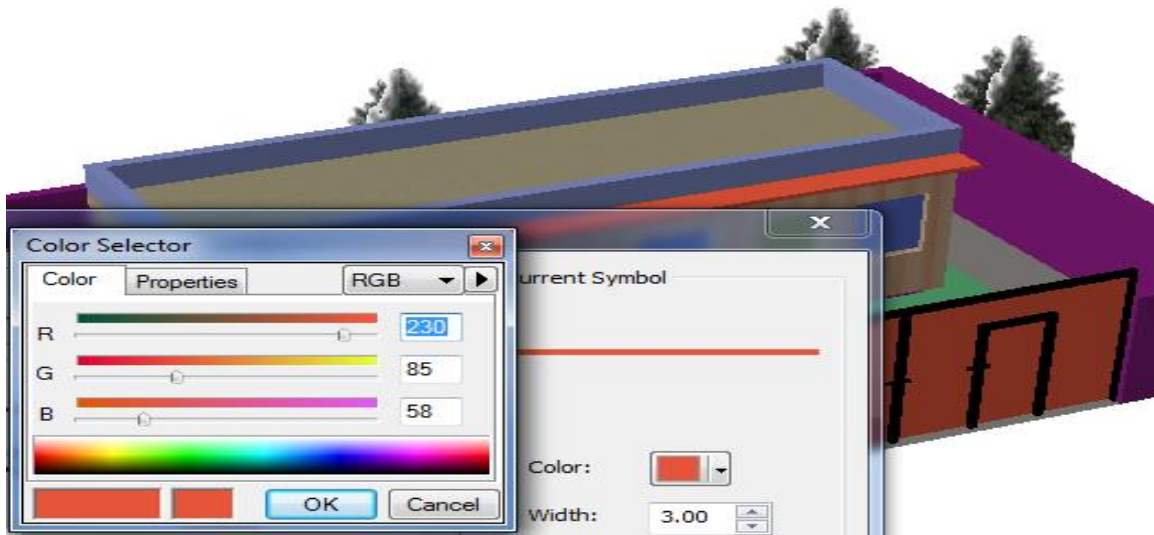


Figure 4. 20: Effective and efficient way of color selection

Specific objective 3: To prepare cost estimation and schedule of construction building using GIS.

✓ **ArcGIS Interface:**

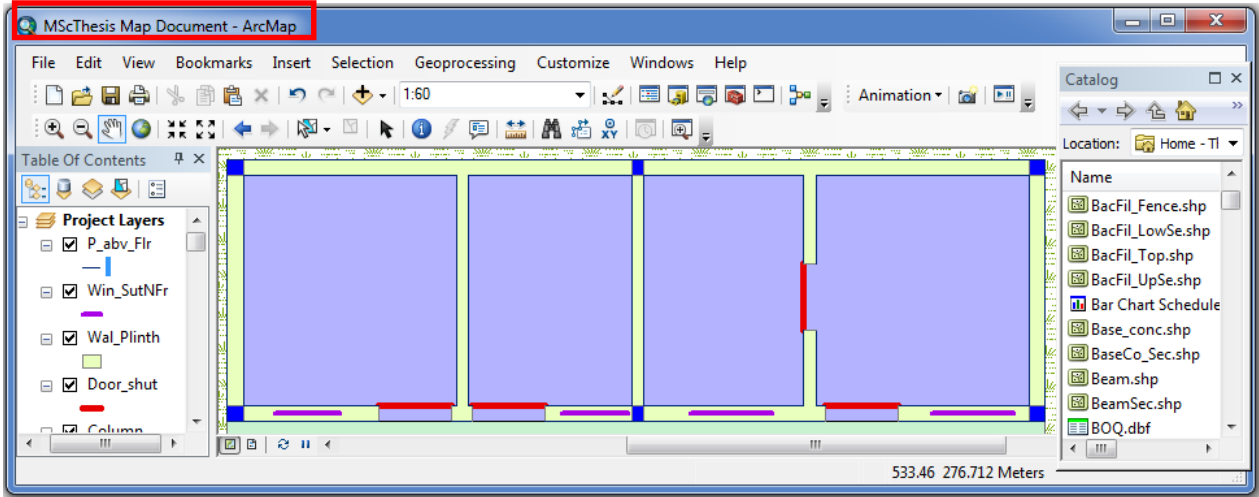


Figure 4. 21: Selected 2D data layer in ArcGIS interface

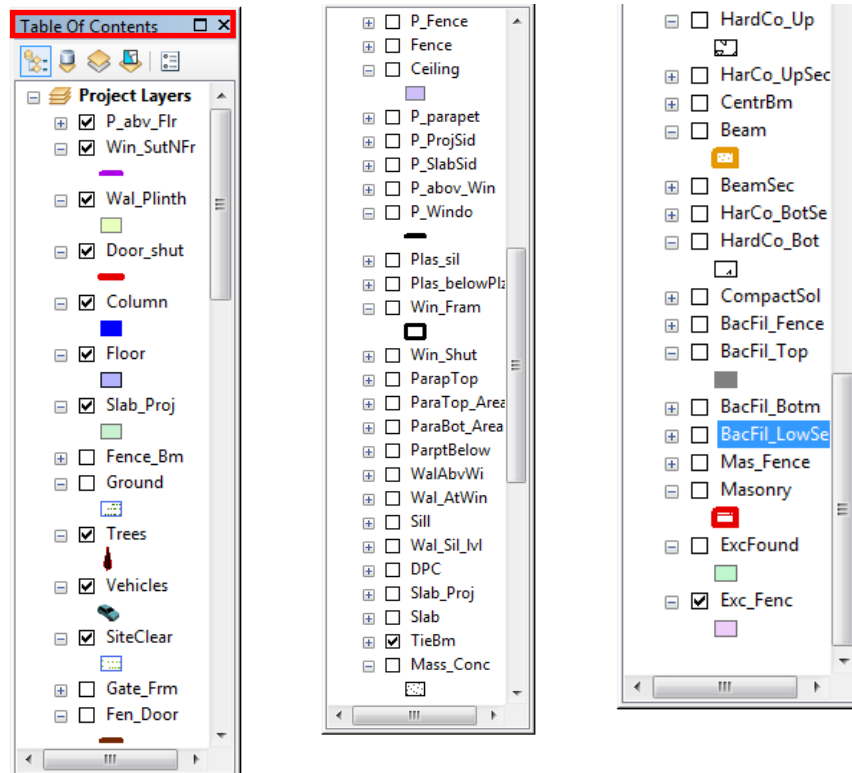
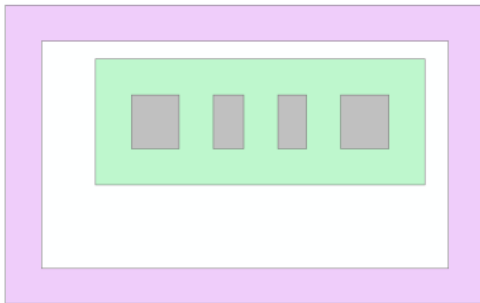


Figure 4. 22: Data layer in ArcMap

The file names in the figure are abbreviated to comply with the 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 a shapefile or feature class and their base height and/or feature height has been written in respective attribute tables.

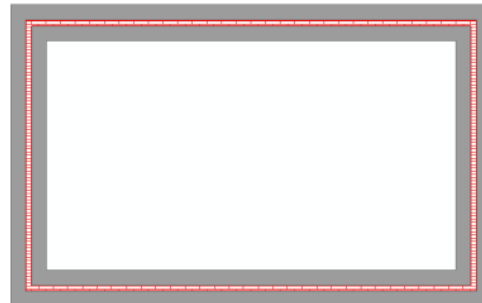
✓ **Sample Data Layers from ArcMap Window**

The screenshots in (a - p) provide details of layers used to estimate earthwork, backfill, masonry work, plastering, and other work items.



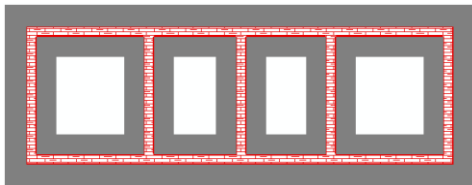
Excavation: Fencing [80cm depth, violet], foundation [103cm, green], hardcore [25cm, gray]

(a)



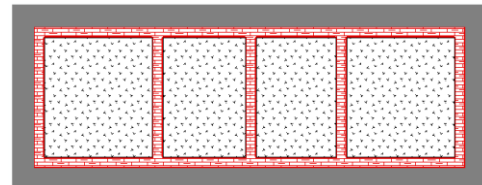
Backfill [80cm, gray] around the base concrete & foundation masonry of the fence [80cm, red]

(b)



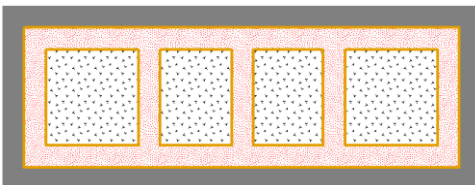
Backfill around foundation masonry (gray) [¹@ 45cm - 125cm depth]

(c)

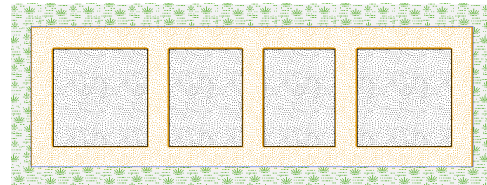


Backfill and hardcore around masonry (red)[¹@ 30cm - 45cm]

(d)



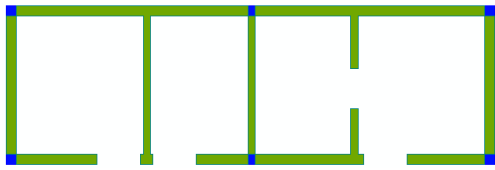
Backfill, grade beam (orange) and hardcore [¹@20cm - 30cm]



NGL (green), grade beam (yellow), and mass concrete [¹@0-20cm]

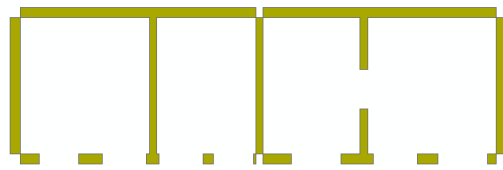
¹ Depths hereafter in this figure are measured from plinth level

(e)



Floor plan (white) above the plinth, Column

(f)



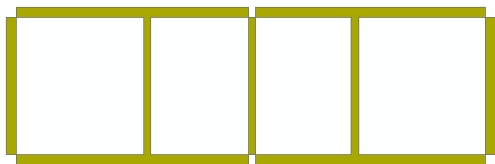
Wall @ window level

(h)



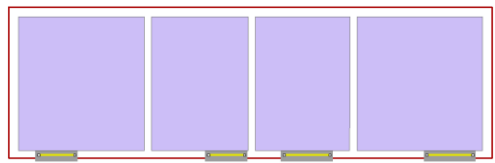
Door shuttering

(g)



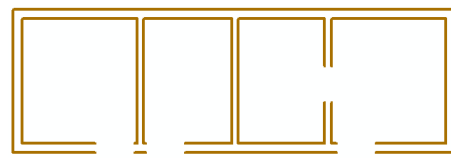
Wall above the window level

(i)



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

(j)



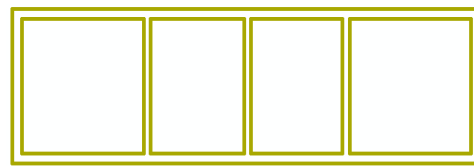
Plastering in/out-side wall from plinth to sill level (90 cm height)

(k)



Plastering in/out-side wall @ window level (120 cm height)

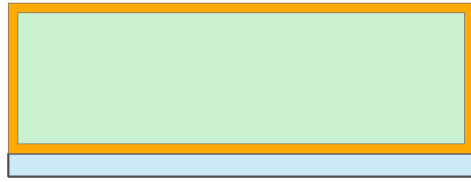
(l)



Plastering in/out-side wall above the window level

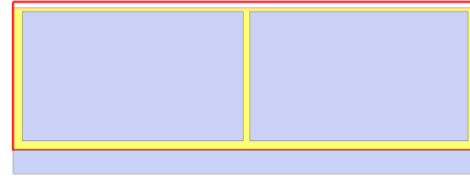
(m)

(n)



Parapet wall (orange), roof slab, slab projection.

(o)



Formwork (violet) below the slab and its projection

(p)

Figure 4. 23: Sample data layers of activity

✓ **Constructed Layers Vs. Work Items**

In the sample building, more than fifty-five different data layers are generated for quantity takeoff and 3D visualization. Except for five layers (i.e., doors, windows, 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, hardcore, beam, column, walls, slab, doors shutter, windows shutter, door/window frame section, parapet, and fencing

Table 4. 1: Table of a bill of quantity

OID	OBJECTID	Units	Height	Area	Length	Perim
0	3	m^2	0	135	0	0
1	0	m^3	1.03	36.93	0	0
2	0	m^3	0.63	8.375	0	0
3	0	m^3	0.3	17.815	0	0
4	0	m^3	0.78	28.555	0	0
5	0	m^3	0.25	14.2	0	0
6	0	m^3	0.25	9.27	0	0
7	0	m^3	0.15	23.625	0	0
8	0	m^3	0.3	15.5	0	0
9	0	m^3	0.1	16.5	0	0
10	0	m^3	0.15	16.5	0	0
11	0	m^2	0	29.3963	0	0
12	0	m^2	0	26.278	0	0
13	0	m^2	0	26.278	0	0
14	0	m^3	2.6	0.24	0	0
15	0	m^3	0.9	5.50467	0	0
16	0	m^3	0.02	4.72299	0	0
17	0	m^2	0	0.937884	0	0
18	0	m^3	1.2	4.78457	0	0
19	0	m^3	0.584	6.16075	0	0
20	0	m^3	0.2	5.54018	0	0
21	0	m^3	0.1	30.75	0	0
22	0	m^3	0.08	5	0	0
23	0	m^2	0	35.75	0	0
24	0	m^3	0.1	1.24974	0	0

Table 4. 2: Activity cost and percentage of the cost estimated

OID	Activity	Cost	Cost_prec
0	A	1854	0.39
1	B	3757.219203	0.79
2	C	26700.803777	2.41
3	D	6815.513808	1.43
4	E	703.079861	0.15
5	F	1527.1875	0.32
6	G	37660.370262	7.89
7	H	17744.825623	3.72
8	I	18176.95785	3.81
9	J	1734.744898	0.37
10	K	4743.234375	1
11	L	4936.5916	1.04
12	M	2691.900077	0.57
13	N	6666.688018	1.4
14	O	234069.498506	49.04
15	P	46525.30927	9.75
16	Q	52204.171844	10.94
17	R	433.091527	0.1
18	S	6521.684989	1.37
19	T	11502.472126	2.41

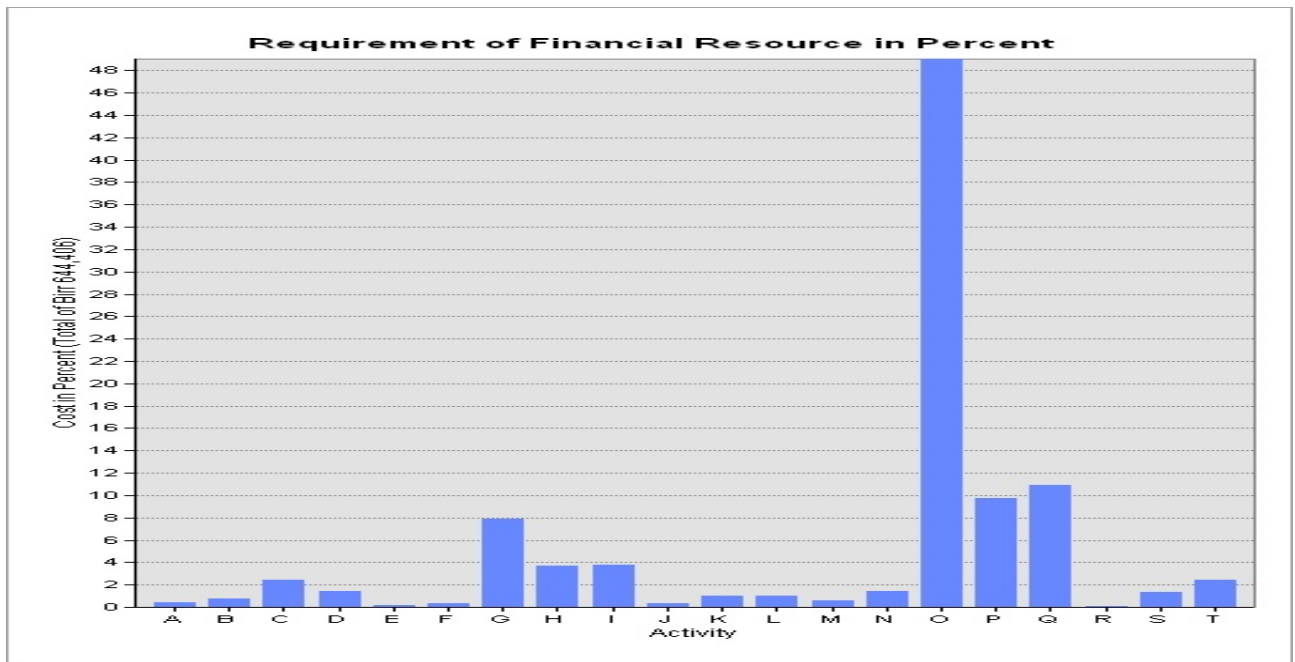


Figure 4. 24: Percentage of cost for each activity prepared using ArcGIS

Table 4.3 shows that the input information for the bill of quantity used to prepare cost estimation of the building construction. Having all eight fields the researcher joins with the attribute of feature

Table 4. 4: Schedule table imported to ArcGIS to integrate database

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

Table 4. 5: Total slack and Critical of activity

	OID	Activity	Duration	EST	EFT	LST	LFT	Tot_Slack	Remark
	0	A	11	0	11	0	11	0	Critical
	1	B	15	11	26	75	90	64	--
	2	C	7	26	33	90	97	64	--
	3	D	1	33	34	97	98	64	--
	4	E	1	11	12	29	30	18	--
	5	F	6	12	18	30	36	18	--
	6	G	14	11	25	22	36	11	--
	7	H	25	11	36	11	36	0	Critical
	8	I	2	36	38	36	38	0	Critical
	9	J	3	38	41	38	41	0	Critical
	10	K	1	41	42	41	42	0	Critical
	11	L	1	42	43	42	43	0	Critical
	12	M	1	43	44	43	44	0	Critical
	13	N	1	44	45	44	45	0	Critical
	14	O	15	45	60	45	60	0	Critical
	15	P	4	60	64	60	64	0	Critical
	16	Q	11	64	75	64	75	0	Critical
	17	R	1	75	76	75	76	0	Critical
	18	S	4	76	80	76	80	0	Critical
	19	T	18	80	98	80	98	0	Critical

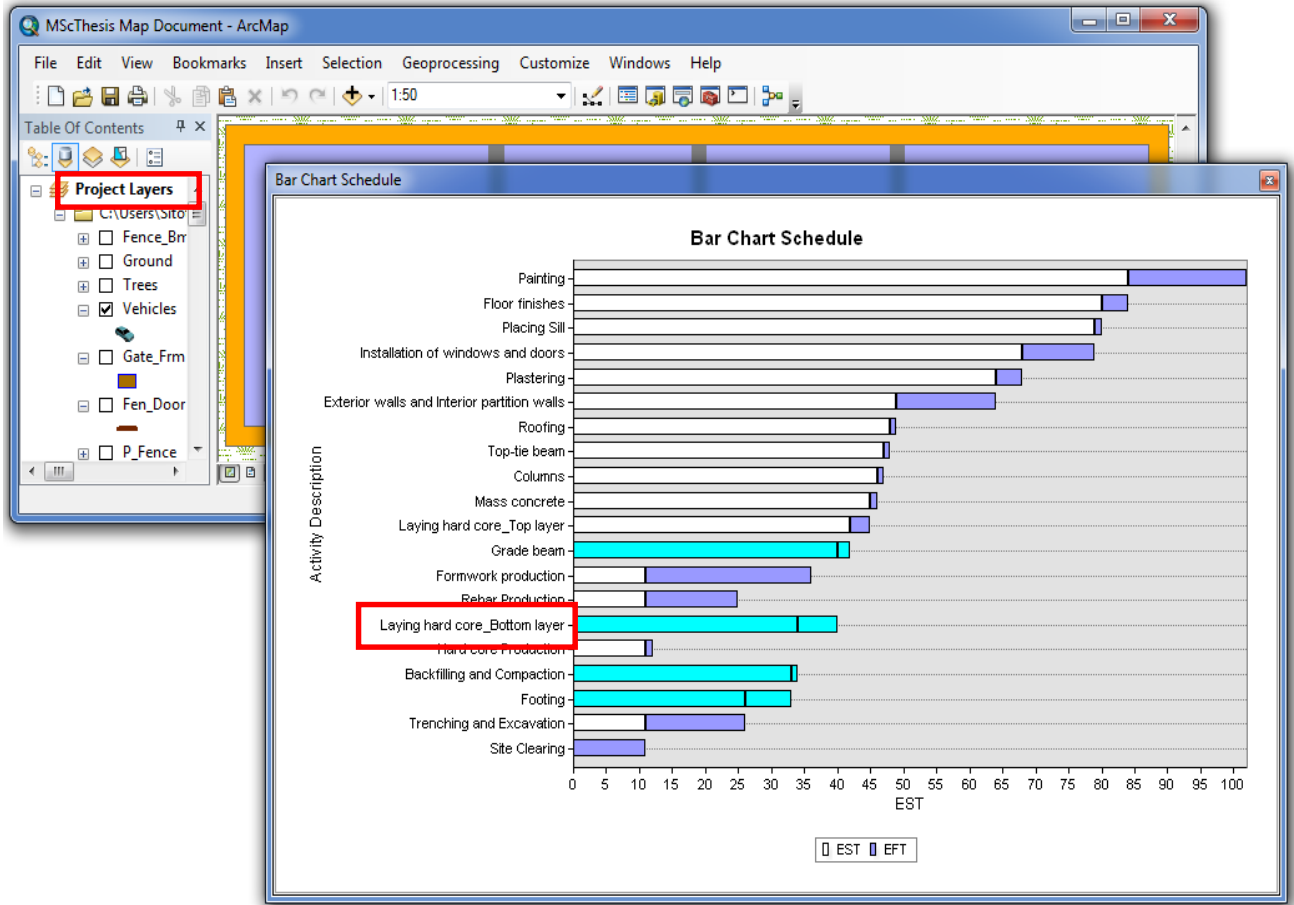


Figure 4. 25: Bar chart in Arc GIS showing the project schedule

ArcGIS reads the schedule prepared in an Excel spreadsheet and converts the schedule to “.dbf” data format that is ArcGIS’s standard table format. Then, the in-built *chart document* functionality in ArcGIS is used to generate a bar chart from the CPM schedule. A 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 4. 6: Structured query language using ArcGIS

The screenshot displays the ArcGIS interface with a 'Select by Attributes' dialog box open. The dialog box is titled 'Bekalu_MSc project.mxd - ArcMap' and 'Select by Attributes'. It prompts the user to 'Enter a WHERE clause to select records in the table window.' The 'Method' is set to 'Create a new selection'. A list of attributes is shown, including 'OID', 'OBJECTID', 'Key_', 'Unit', and 'EST'. The 'EST' attribute is selected. The WHERE clause is entered as: `'EST' >= '09-June-20' AND 'EST' <= '16-May-20'`. The 'Apply' button is visible. To the right, a table window titled 'Table' shows the 'Project_TableFinl' table. The table has columns: OID, OBJECTID, Key_, Unit, EST, EFT, Planned, and Exe. The rows are numbered 0 to 19. Rows 3 through 16 are highlighted in cyan, indicating they are selected. The status bar at the bottom of the table window shows '(5 out of 20 Selected)'. The table data is as follows:

OID	OBJECTID	Key_	Unit	EST	EFT	Planned	Exe
0	1	10001	m²	07-April-20	18-April-20		
1	2	10002	m³	18-April-20	02-May-20		
2	3	10003	m³	02-June-20	09-May-20		
3	4	10004	m³	09-June-20	10-May-20		
4	5	10005	m³	18-April-20	19-April-20		
5	6	10006	m³	10-May-20	16-May-20		
6	7	10007	kg	18-April-20	01-May-20		
7	8	10008	m³	18-April-20	12-May-20		
8	9	10009	m³	16-May-20	18-May-20		
9	10	10010	m³	18-May-20	21-May-20		
10	11	10011	m³	21-May-20	22-May-20		
11	12	10012	m³	22-May-20	23-May-20		
12	13	10013	m³	23-May-20	24-May-20		
13	14	10014	m³	24-May-20	25-May-20		
14	15	10015	m³	25-May-20	10-June-20		
15	16	10016	m²	10-June-20	14-June-20		
16	17	10017	m²	14-June-20	25-June-20		
17	18	10018	m²	25-June-20	26-June-20		
18	19	10019	m²	26-June-20	30-June-20		
19	20	10020	m²	30-June-20	17-July-20		

Table 4.8 shows that the ability of GIS in using query language to retrieve different information from the GIS database. This helps the user in accessing construction progress information through the database which most BIM technology lack.

✓ Sample cost data from BIM window

<Structural Column Schedule>			
A	B	C	D
Family and Type	Length	Count	Cost
AS_EXT_COLUMN_H: Default	4.43	1	3200.00
AS_EXT_COLUMN_H: Default	3.43	1	3200.00
AS_EXT_COLUMN_H: Default	4.43	1	3200.00
AS_EXT_COLUMN_H: Default	3.43	1	3200.00
AS_EXT_COLUMN_H: Default	4.43	1	3200.00
AS_EXT_COLUMN_H: Default	3.43	1	3200.00
Grand total: 6		6	19200.00

Figure 4. 26: Cost estimation of the column using Revit (5D BIM)

<Wall Schedule>					
A	B	C	D	E	F
Family and Type	Area	Length	Width	Cost	Total Wall Cost
Basic Wall: Generic - 200mm	40 m ²	9.80	0.20	500.00	19979.28
Basic Wall: Generic - 200mm	11 m ²	3.20	0.20	500.00	5640.29
Basic Wall: Generic - 200mm	16 m ²	9.80	0.20	500.00	7818.22
Basic Wall: Generic - 200mm	11 m ²	3.20	0.20	500.00	5339.42
Basic Wall: Generic -150mm 2	8 m ²	3.20	0.15	400.00	3360.00
Basic Wall: Generic -150mm 2	8 m ²	3.20	0.15	400.00	3360.00
Basic Wall: Generic -150mm 2	7 m ²	3.20	0.15	400.00	2628.48
Basic Wall: Generic -150mm 3	33 m ²	13.03	0.15	400.00	13178.17
Basic Wall: Generic -150mm 3	32 m ²	15.24	0.15	400.00	12676.76
Basic Wall: Generic -150mm 3	33 m ²	13.03	0.15	400.00	13028.17
Basic Wall: Generic -150mm 3	38 m ²	15.24	0.15	400.00	15094.42
Grand total: 11				4800.00	102103.21

Figure 4. 27: Cost estimation of the wall using Revit (5D BIM)

Figures 4.25 and 4.26 show the cost estimation of column and wall respectively which are attained by Revit that is advanced 5D building information modeling. After inputting important information of cost and schedule the Revit is produced cost estimation and schedule of each work break down structure activities.

<Window Schedule>		
A	B	C
Family and Type	Count	Cost
Window- Double Shutter with Openable Glass: 1500x1500 mm	1	4000.00
Window- Double Shutter with Openable Glass: 1500x1500 mm	1	4000.00
Window- Double Shutter with Openable Glass: 1500x1500 mm	1	4000.00
Window- Double Shutter with Openable Glass: 1500x1500 mm	1	4000.00
Grand total: 4		16000.00

Figure 4. 28: Cost estimation of the window using Revit (5D BIM)

<Door Schedule>				
A	B	C	D	E
Family and Type	Type	Count	Door Material	Cost
Door_Swing_CGI_Single_Transom: As Specified in the Contract Documents	As Specified in the Contract Documents	1	Metal - Aluminu	6000.00
Door_Swing_CGI_Single_Transom: As Specified in the Contract Documents	As Specified in the Contract Documents	1	Metal - Aluminu	6000.00
Door_Swing_CGI_Single_Transom: As Specified in the Contract Documents	As Specified in the Contract Documents	1	Metal - Aluminu	6000.00
Door_Single-Flush: 0915 x 2032mm	0915 x 2032mm	1		4000.00
Grand total: 4				22000.00

Figure 4. 29: Cost estimation of the door using Revit

4.2. Results from interview and focus group discussion

The purpose of this focus group and interview was to provide insights to build upon the quantitative survey results and gain an in-depth view. The focus group interviews had three specific objectives:

- To gain insight into the similarity and difference between BIM and GIS
- To understand construction stakeholder benefit using the integration of GIS and BIM technology.
- To gain further insight into how GIS and BIM integration enhance cost estimation and schedule

A focus group was conducted on August 3rd, 2020 G.C using a zoom meeting and lasted approximately 75 minutes. A discussion guide was created for the members of a focus group. The discussion guide served as the blueprint for the focus group session, although the direction was allowed to stray from the guide

Feedback from the interview and Focus Group Meeting indicated as the case study shows, the integration of GIS and BIM technology can be useful for testing the feasibility and validation of finding of the platform alternatives. The integration provides the functions to 1) speed up the cost estimation of the building using the construction database; 2) generate the duration of the construction work; 3) help construction stakeholders benefit in visualizing the construction building.

Table 4. 7: Summary of feedback from interview and focus group

Aspect evaluated	Feedback and its Analysis
Relevance of research	All respondents agreed that the research is quite relevant and timely. Almost all respondents mentioned that they are currently implementing both GIS and BIM. The representatives of the two companies mentioned that they are trying to use both GIS and BIM simultaneously but are facing issues of an integrated system. Most respondents answered this question as part of answers to other questions. All respondent answer the question that the integration of GIS and BIM technology is useful and practical in construction industries such as in private and governmental housing
Usefulness (practicality)	
Should the research be advanced to further stages (asked at the early stage of research)	This question was asked during early demonstrations/discussions about the solutions to identify whether the solution is worthwhile and feasible to carry forward. All participants unanimously agreed that the solution and the concept are relevant and should be developed further.
Implementation test and readiness for a pilot	All respondents agreed that if such a system were available, they would like to implement it on their projects. All respondents agreed to carry out a pilot project if a suitable project and resources were found.

From table 4.9 the researcher concludes that the integration of BIM and GIS software are very important in the aspect of minimizing construction error misinterpretation and misunderstanding. The feedback from the focus group shows that integration is also very crucial for enhancing the visualization and decrease the delay of the construction schedule.

The comparison of the proposed method and existing methods

Table 4. 8: Comparison of proposed and existing methods

Function	Integration of GIS and BIM	BIM	Remark
Layer	✓	✓	
Database	✓		
Spatial data	✓		
Non-spatial	✓	✓	
A spatial operation such as query and clip etc.	✓		

Table 4.8 explain that there is the difference between geographic information system and building information modeling. Their difference is in the aspects of database spatial analysis and using a query. The software is best when they integrate.

Validation of finding

Table 4. 9: Evaluating validation of research

Criteria	Goal	Tactics
Credibility	Establishing the match between the constructed realities of respondents (or stakeholders)	<ul style="list-style-type: none"> ✓ Multiple data sources (interviews, focus groups, and documents) ✓ Discussion of the findings of a case study of a residential building with both GIS and BIM subject-matter experts. ✓ Presenting and discussing the progress of the research at various stages, and eventually, the outputs of the study were also discussed with core stakeholders such as some residential construction project managers, experts, etc.
Transferability	Presenting a sufficiently detailed account of the findings allow a reader to judge how the findings can be transferred to other settings	<ul style="list-style-type: none"> ✓ Through the description of the research context, the construction projects, technology, people, and their interaction ✓ Purposeful case-sampling strategy with representative cases for projects executed in the integration of BIM and GIS
Dependability	Ensuring that methodological and the	<ul style="list-style-type: none"> ✓ Documentation of all data collected ✓ Case study database in GIS (Geodatabase)

interpretations process are documented so that a reader can follow the choices made by the researcher

- ✓ Intensive use of direct quotations in the textual accounts of findings
- ✓ Through the description of the research process (research design methodology, clarification of assumptions, etc.)

Conformability

Ensuring that the data and interpretations of the researcher are grounded in the context and are not just a result of the researcher's imagination

- ✓ The role of an outside observer helped to interpret the findings in a less biased manner
 - ✓ Making the research process explicit to colleagues
-

4.3. Discussions

The building of the case study would have taken 102 consecutive days for the completion if the productivity rate of the construction work is practical as per the set standard. However, the building took more than 120 days for its completion when the schedule was developed using BIM software. Similarly, the estimated construction cost was 644,406 birr inclusive of the 35 percent profit margin however, the cost was 657,294 birr when quantified using BIM technology. This shows that the integration of GIS and BIM technology enhanced by 2% of the cost estimated and 0.009% duration was observed.

A similar study by Amirebrahimi (2015) on the data model in integrating GIS and BIM for cost estimation and schedule of a two-story building, and showed that the cost estimation and schedule of the building was enhanced. This result was consistent with the current study. Another study by Bansal and Pal (2010) showed that the cost estimation of a five-floor building with a basement was enhanced by 7% of the cost estimated by BIM technology and 0.2% of duration when GIS software was applied.

Another study was conducted on GIS-Based 4D Model Development for Planning and Scheduling of a Construction Project and showed that GIS-based scheduling is vital in minimizing the redundancy and enhance visualization of construction progress(Naik et al., 2011). Thus, this finding was consistent with the finding of the current study.

CHAPTER FIVE: CONCLUSIONS & RECOMMENDATIONS

5.1. Conclusions

This research aimed to enhance the 5D BIM of the residential building using GIS software. The study demonstrated the significance of an integrated GIS-BIM system for better visualization, storing, and utilizing spatial information that is used for the planning process, quantity takeoffs, cost estimation, and so forth.

From generated 3D model of the building, it was concluded that consistent interpretations of the construction building, quick and clear understanding of information for different construction stakeholders were developed. A clear procedure was developed for preparing the cost and schedule of construction buildings by exploiting the capabilities of ArcGIS to maintain data in different themes. The result showed that the time and cost required to complete the construction building was reduced when GIS-based cost estimation and scheduling was applied

Thus, the study concludes that the integration of GIS and BIM technology enhanced the BIM software in the aspect of databases issue, a spatial aspect, and improved the visualization of the building. As result, the construction members can easily understand the construction progress, minimize the error and decrease the construction delay.

5.2. Recommendations

Based on the findings and conclusions presented, the following recommendation was suggested.

- Since the enhancement of BIM technology using GIS is verified the construction stakeholders (such as site supervisors, managers, real estate developers, etc.) may incorporate the integration of GIS and BIM technology into their work to maintain the quality of construction which helps in reducing data redundancy, access the database through a query, understand the locational information of the construction site, and enhance visualization of construction building.
- This study may be utilized as a springboard for further researches in related topics, and with a new angle of investigation for complex construction projects.
- 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.

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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 the foundation	m ³	0.63	8.38		5.28
1007	Masonry work for the 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 the 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 the 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 rooftop	m ²		37.00		37.00
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	Terrazzo	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 the topsoil to a depth of 20cm.
B	Trenching and Excavation	Earthwork for trenching in the foundation, for hardcore placement, and 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 the 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	Hardcore Production	Hardcore Production
F	Laying hardcore Bottom layer	Hard Core in the foundation (bottom layer) (15cm)
G	Rebar Production	Ø8mm and Ø12mm reinforcement bar production (superstructure)
H	Formwork production	Formwork for all work items
I	Grade beam	C-25 concrete (Sub-structure) Grade beam footing (including fence)
J	Laying hardcore Top layer	Hard Core in the 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

OID	key *	Activity	Activity Description	Duration	EST	EFT	LST	LFT	Tot_Slac	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

Annex D: reinforcement of bar

✓ **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) * 0.7m

= 207.2m $\phi 8$ stirrup

✓ **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) * 0.7m = 168.7m $\phi 8$ stirrup

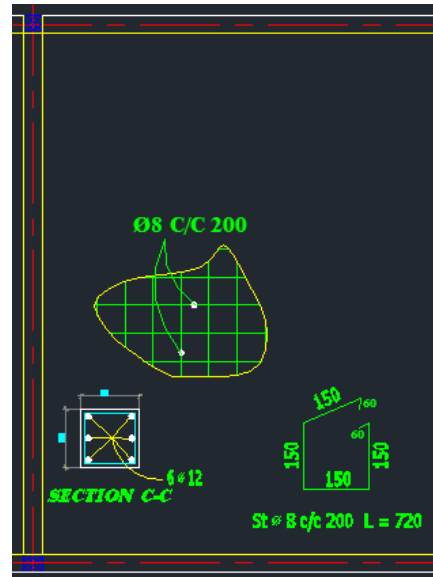
✓ **Column (for the building):**

- No. of columns = 6

- Column's total height = 6 no. x 2.6m = 15.6m

- Length of $\phi 12$ rebar = $6 * 15.6$ m = 93.6m $\phi 12$ rebar

Rebar arrangement in section of the beam and slab



– No. of stirrup places (rounds):

$$= \text{Length}/\text{spacing} + 1 = 15.6\text{m}/200\text{mm} + 1 = 78 + 1 = 79 \text{ places}$$

$$\text{Length of } \phi 8 \text{ stirrup: } 79 \text{ places} * 0.7\text{m} = 55.3\text{m } \phi 8 \text{ stirrup}$$

✓ **Column (for the Fence):**

– No. of columns = 16 No. [i.e., 1@ 3m spacing].

– Length of a column: 2.2m

$$\text{Total length: } 16 \times 2.2\text{m} = 35.2\text{m}$$

– Length of $\phi 12$ rebar = $4 * 35.2 \text{ m} = 140.8\text{m } \phi 12$ rebar

– No. of stirrup places (rounds):

$$= \text{Length}/\text{spacing} + 1 = 35.2\text{m}/200\text{mm} + 1 = 176 + 1 = 177 \text{ places}$$

$$\text{Length of } \phi 8 \text{ stirrup: } 177 \text{ places} * 0.7\text{m} = 123.9\text{m } \phi 8 \text{ stirrup}$$

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:

$$= \text{Shorter side}/\text{spacing} + 1 = 3.58\text{m}/200\text{mm} + 1 = 17.9 + 1 = 18.9 \sim 19 \text{ places}$$

– 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 1: Quantity of rebar and stirrup in meter

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 a 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

Annex E: Early start time and early finish time (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. 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 within the column and j within the row, the cell (i, j) within the matrix contains the EFT of activity i if i is a quick forerunner 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. 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. Subsequently, the EST for action A in cell B4 is given by the equation 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 the expected completion time of the activity from the input data in the range A3:D203 (named as Inputs). r locating 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.

♣ **“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 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 sets for activity, as it were in turn around. Two additional columns are embedded in this sheet to store the values of the LST-LFT sets for each activity. Besides, a cell (A2 in the EST-EFT sheet) is used that stores the value of the maximum of the EFTs of all the activities.

For an activity pair i and j , i within the column and j within the row, the cell (i, j) within the matrix are that the LST of j if j is an instantaneous successor of i , maximum of all the EFTs (the content of cell A2 within the EST-EFT sheet) otherwise. Note: The LST_LFT table here refers to cell range C2:GV4 within the LST-LFT sheet. The subsequent 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 employed here rather than the vertical lookup. The formula is copied to the opposite cells of the matrix within the LST-LFT sheet. Conditional formatting has been used again to shade/hatch out the cells with the LST adequate to the utmost of all EFTs (i.e., 102 days during this case) to enhance the presentation of the results. The cells are shaded with colors to hide formulas/figures that aren't so important to be displayed for the reader. Once all the cells of the matrix are calculated the ultimate 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 instance, is given by Cell C4: =MIN (C6:C205)

The LST is computed by deducting the activity completion time from the LFT. The procedure used for activity A is Cell C3: = C4-VLOOKUP (C2, input_, 4, FALSE) which is then copied to other cells within the range C3:V3 of the LST-LFT sheet. The VLOOKUP function is employed to extract the activity completion time from the Input sheet. Once the LST_LFT table is completed, the minimum expected project completion time is obtained by taking the utmost of all the LFTs. Cell A2 within the LST-LFT sheet contains that value and therefore the formula for that cell is Cell A2: =MAX (C4:GV4).

“Critical Path” Sheet: The (EST, EFT) and therefore the (LST, LFT) pairs for the activities are extracted from sheets EST-EFT (Table 10) and LST-LFT and therefore, the total floats are calculated by subtracting the EST from LST. If the result's zero, then the activity may be a critical activity. Among the network of activities, the set of critical activities form-critical path of the project dictating project construction.

Annex F: Key questions asked in the interview and focus group

- ✓ How the research is relevant?
- ✓ How can we describe the Usefulness of research?
- ✓ Should the research be advanced to further stages?
- ✓ Would you consider implementing it in the project area?
- ✓ How Readiness for a pilot?
- ✓ What is the similarities and difference between GIS and BIM?
- ✓ What is the drawback of BIM technology when implementing the 5D model?

Annex G: 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-Aprl-20	18-Aug-20	135.0	1,854	80
10002	B	Trenching and Excavation	m ³	15	18-Aprl-20	02-Sep-20	68.68	3,757	95
10003	C	Footing	m ³	7	02-May-20	09-Sep-20	15.3	26,701	75
10004	D	Backfilling and Compaction	m ³	1	09-May-20	10-Sep-20	49.4	6,816	
10005	E	Hard core Production	m ³	1	18-Aprl-20	19-Aug-20	5.2	703	
10006	F	Laying hard core Bottom layer	m ³	6	10-May-20	16-Sep-20	3.5	1,527	
10007	G	Rebar Production	kg	14	18-May-20	01-Sep-20	1,610.3	37,660	
10008	H	Formwork production	m ³	25	18-Aprl-20	12-Sep-20	98.0	17,745	
10009	I	Grade beam	m ³	2	16-May-20	18-Sep-20	7.5	18,177	
10010	J	Laying hard core Top layer	m ³	3	18-May-20	21-Sep-20	1.7	1,735	
10011	K	Mass concrete	m ³	1	21-May-20	22-Sep-20	2.5	4,743	
10012	L	Columns	m ³	1	22-May-20	23-Sep-20	2.0	4,937	
10013	M	Top-tie beam	m ³	1	23-May-20	24-Sep-20	1.1	2,692	
10014	N	Roofing	m ³	1	24-May-20	25-Sep-20	3.5	6,667	
10015	O	Exterior walls and Interior partition walls	m ³	15	25-May-20	10-Oct-20	35.2	234,070	
10016	P	Plastering	m ²	4	10-June-20	14-Oct-20	442.0	46,525	
10017	Q	Installation of windows and doors	m ²	11	14-June-20	25-Oct-20	27.6	52,204	
10018	R	Placing Sill	m ²	1	25-Junet-20	26-Oct-20	0.9	433	
10019	S	Floor finishes	m ²	4	26-June-20	30-Oct-20	26.3	6,522	
10020	T	Painting	m ²	18	30-June-20	17-Nov-20	442.0	11,503	

Annex H List of work item

<i>Sr. No.</i>	<i>Components Represented by Layers</i>	<i>Different Data layers Constructed (Payment items)</i>	<i>GIS Element Used</i>	<i>Height/ Thickness</i>	<i>Base-height (cm)</i>
1	2	3	4	5	6
1	Site clearing (sqm)	<ul style="list-style-type: none"> ▪ Representing clearing of topsoil and trees 20cm depth, a total area of 11m x 4.2m 	Polygon	---	-20 [†]
2	Earthwork for foundation (cum)	<ul style="list-style-type: none"> ▪ 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 the foundation of the fence (cum)	<ul style="list-style-type: none"> ▪ Representing excavation work for trenching (20+50x2 cm width). 50cm working space on both sides. 	Polygon	80	-20
4	Masonry work of the foundation in cement mortar (cum)	<ol style="list-style-type: none"> 1. Representing one step masonry work (25cm width) 2. Representing lean concrete (C-7) in a base foundation (cum) 	Polygon	63 30	-30 -79

[†]Negative numbers represent depth below floor level and are measures in centimeter.

5	Backfill around foundation and Stonemasonry. Backfill up to the lower surface level of the hardcore from the bottom level (cum)	<ul style="list-style-type: none"> ▪ 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)	<ul style="list-style-type: none"> ▪ Representing backfill from 20cm (i.e., GSL) to 45cm level from the floor level 	Polygon	25	-20
7	Compacted soil surface	1. Representing excavation above the compacted soil surface excluding excavation for foundation base	Polygon	25	-20
		2. Representing surface area of the compacted soil		---	-45
8	Hard Core in the foundation (Bottom layer)	<ul style="list-style-type: none"> ▪ Representing Hard Core in the foundation at the level of masonry (bottom layer) 	Polygon	15	-45
9	Grade beam (C-25)	<ul style="list-style-type: none"> ▪ 30cm depth x 50cm x-section 	Polygon	30	0
10	Hard Core in the foundation (upper layer)	1. Representing (upper layer) Hard Core in the foundation at the level of the grade beam	Polygon	10	-30
		2. Representing C-25 cyclopean concrete for the floor		15	-5

11	Site work	<ul style="list-style-type: none"> ▪ Representing site work/Leveling the site 	Polygon	--	-20
12	Floor: Net floor area	<ol style="list-style-type: none"> 1. Representing cement screed (sqm) 2. Representing Terrazzo tile (sqm) 	Polygon	3 2	-2 0
13	Columns (C-25)	<ul style="list-style-type: none"> ▪ Columns (cum) 	Polygon	260	0
14	Top-tie beam (C-25)	<ul style="list-style-type: none"> ▪ Top-tie beam 	Polygon	20	260
15	Roof Slab (C-20)	<ul style="list-style-type: none"> ▪ Representing 10 cm thick R.C.C slab 	Polygon	10	280
16	Projection of the slab (C-20)	<ul style="list-style-type: none"> ▪ Representing 8 cm thick projection of R.C.C slab. 	Polygon	8	280
17	D.P.C (sqm)	<ul style="list-style-type: none"> ▪ Representing Damp proofing course (2cm) 	Polygon	---	---
18	Wall below sill	<ul style="list-style-type: none"> ▪ Representing wall from floor level to sill 	Polygon	90	0
19	Wall @ sill level	<ul style="list-style-type: none"> ▪ Representing wall for sill thickness (2cm) 	Polygon	2	90
20	Sill (sqm)	<ul style="list-style-type: none"> ▪ Representing Sill 	Polygon	2	90
21	Wall @ Window level	<ul style="list-style-type: none"> ▪ The wall at the Window level 	Polygon	120	92
22	Wall above windows	<ul style="list-style-type: none"> ▪ Representing HCB wall above the door 	Polygon	48	212
23	Parapet @ the bottom	<ul style="list-style-type: none"> ▪ Representing HCB parapet at the bottom 	Polygon	10	280

24	Parapet @ the top	<ul style="list-style-type: none"> Representing HCB parapet at the top 	Polygon	50	290
25	Door shutter	<ul style="list-style-type: none"> Representing Door shutter including frame 	Line	210	0
26	Windows shutter	<ul style="list-style-type: none"> Representing windows shutter 	Line	120	92
27	Plastering below plinth	<ul style="list-style-type: none"> Plastering outside the wall and between the ground and floor level for a height of 20cm. 	Line	20	
28	Plastering above plinth up to sill level	<ul style="list-style-type: none"> Plastering inside/outside the wall and between floor and sill level for a height of 90 cm. 	Line	90	
29	Plastering @ sill level	<ul style="list-style-type: none"> Plastering inside/outside the wall at sill level for a height of 2 cm. 	Line	2	
30	Plastering @ window level	<ul style="list-style-type: none"> Plastering inside/outside the wall between sill and lintel level for a height of 120cm. 	Line	120	
31	Plastering above the window level	<ul style="list-style-type: none"> Plastering inside/outside the wall and above the lintel level for a height of 68cm. 	Line	68	
32	Roof Ceiling	<ul style="list-style-type: none"> Net area of roof Ceiling 	Polygon	---	
33	Excavation for trenching, fencing	<ul style="list-style-type: none"> Excavation for trenching, to a depth of 50cm and 50cm working space on both sides 	Polygon	50	-20

34	Masonry for the foundation of fencing	<ul style="list-style-type: none"> 50cm 	Polygon	50	-20
35	Grade beam for fencing	<ul style="list-style-type: none"> The same cross-section as that of the building. 	Polygon		
36	Fencing	<ul style="list-style-type: none"> Fencing with 20cm HCB, excluding the main gate 	Polygon	270	-70
37	Plastering the fence	<ul style="list-style-type: none"> Plastering inside/outside the fence for a height of 220 cm. 	Line	220	-20
38	Main gate	<ul style="list-style-type: none"> Main gate, a height of 270cm 	Line	270	-20
39	Formwork @ the sides of the grade beam	<ul style="list-style-type: none"> Representing formwork @ two sides of the grade beam 	Line	0.3	
40	Formwork @ the bottom of the grade beam	<ul style="list-style-type: none"> Representing formwork @ the bottom of the grade beam 	Polygon		
41	Formwork for Column	<ul style="list-style-type: none"> Representing formwork for elevation column 	Line	260	
42	Formwork for Top-tie beam	<ul style="list-style-type: none"> Representing formwork for the sides of the top-tie beam 	Line		
43	Formwork for Slab and Projection	<ul style="list-style-type: none"> Representing formwork below the slab 	Polygon		
44	Formwork @ the sides of the slab	<ul style="list-style-type: none"> Representing formwork @ the side of the slab 	Line	10	
45	Formwork @ the sides of the projection	<ul style="list-style-type: none"> Representing formwork @ the side of the slab projection 	Line	8	

