Expertise
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Sahil Thapa
Suman Khadayat

BIM Orientation and Implementation

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Bachelor of Engineering

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The aim of this bachelor's thesis was to understand the use of BIM tools in the construction process, create a model of an already built residential building using different Building Information Modelling (BIM) software, compare the cost output from two different methods and provide a manual for designing concrete structures using ArchiCAD and Tekla Structures.

To achieve the target, a practical case implementation of BIM in residential building was carried out. It focused on using two key BIM tools, ArchiCAD and Tekla Structures, which were used to create architectural and structural model respectively. The main objective of creating models was to compare the material take-off and compare the cost of materials with actual expenses and carry out structural documentation, 3D visualization and collaboration. The results showed that, there could be significant amount of cost reduction while using these tools.

Comprehensively, this thesis could be beneficial to the architectural and structural enthusiasts. It could be apportioned as a guide to the beginner students of ArchiCAD and Tekla Structures, especially in Nepal.

Keywords	BIM, ArchiCAD, Tekla, structural design, architectural design, building, cost, materials

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List of Abbreviations

AEC	Architecture, Engineering and Construction.
API	Application Programming Interface
BIM	Building Information Modelling
CAD	Computer Aided Design
GDL	Geometric Description Language
IFC	Industry Foundation Class
MEP	Mechanical, Electrical and Plumbing

1 Introduction

The architecture, engineering and construction (AEC) industry is evolving throughout the time. In the past few years, the AEC industry because of various seen and unseen reasons faces challenges related to cost, quality and project delivery time. AEC projects are normally spread across a wide array of small and medium sized enterprises (SMEs) and stakeholders. The difficulties in coordination and information exchange from one stakeholder to another commonly results in mistakes or misinterpretation resulting in cost overruns, delay and low-quality work. However, building information modelling (BIM) has been introduced, which has the ability to solve these problems. The BIM has changed AEC work methodology into digital-based from paper-based communication. The main problem of paper-based communication is cost, and time required to achieve critical assessment information of the projected design which includes cost estimation, energy analysis, and structural details. The use of digital communication, i.e. BIM is expanding in the construction business in order to increase the project efficiency, save cost, minimize time, perform various analyses and generate automated documentations like energy analysis and structural details. [1.]

BIM today is seen as a promising factor that is considered very important for built environment projects. However, BIM is also considered as introduction of a new application or a software. BIM and its implementation require an equal focus on people, process and technology. BIM promotes communication and collaboration between engineers, facility managers, architects and others to improve the delivery of projects. [BIM supports real time communication with the use of different application programming interfaces (APIs). It provides possibilities for the designers to utilize this function and simplify their design environment or interface. These types of design authoring and communication possibilities not only support design and construction but also help in design tracking and change management. Final output during the construction phase is an as-built BIM. The information content from an as-built BIM is largely used as a base for the operational phase of a project, or a building, to support the operation and maintenance of the building. The information supports the clients or owners in decision making and help them to make informed decisions in the early stages of designing. [2.]

The main goal of the thesis is to understand about the current changes and possibilities brought about by BIM. At the same time, it aims to introduce the content of BIM software tools and their emergence. It focuses on providing information on the basic uses of ArchiCAD and Tekla Structures while designing a residential building. The building that is designed is an existing residential building in Nepal that is redesigned in the thesis with the aid of the BIM programmes ArchiCAD and Tekla Structures. Hence, the thesis also offers a perspective of the current building construction scenario in Nepal. The existing building was originally designed and constructed in a traditional way, the thesis when redesigning the building using BIM tools and also compares the design to the one made with the traditional method. In this process of redesigning a building with BIM tools, the amount of materials used to construct the different sections of the building is evaluated and compared with the amount of materials actually used in the existing building. Additionally, the cost of the building is calculated, and the obtained result is compared to the actual cost. A step by step process of designing and quantity take-off is explained. Hence, thesis can be used to develop techniques to use Tekla Structures and ArchiCAD. Apart from the small-scale building, the thesis also introduces a BIM based project Casa Magayon as a case study. In Casa Magayon, ArchiCAD and GRAPHISOFT BIMx tools were used. The Casa Magayon demonstrates the benefit of using an excellent visual representation tool like BIMx.

This thesis is a collaborative work. Construction projects are normally done with the involvement of different design disciplines. The authors wanted to see the possibilities that BIM provides in the design and coordination between an architect and a structural engineer. Therefore, the architectural perspectives are carried out by Suman Khadayat and structural aspects’ by Sahil Thapa. At the end, a collective conclusion is derived.

2 Building Information Modelling

Building information modelling is a process through which a construction project is delivered. It is a method that connects architects, engineers and construction professionals in order to build, construct and operate efficient buildings and infrastructures. Moreover, it handles the whole process and enables digital technology in a more advanced way which benefits timesaving, cost-saving and provides better results in the construction. [3.]

BIM is not just a 3D modelling or software, it is a process or a stage to exchange reliable information, visualization and data throughout the project's life cycle. Moreover, it collects all the information about the project and enables the platform for the planning as well as increase the project performance during and after the construction. BIM has been in the construction industry for around 40 years with different names like virtual building, product model and intelligent object. The failure of accurate information keeping, data processing, timesaving and cost-saving lead to BIM in a construction Industry. BIM is an innovative technology in the AEC industry that transforms the way of how engineering projects are designed, constructed and operated. It also provides all the project stakeholders with easy information by providing better visualization and coordinated information. [2.]

BIM is a process of creating and maintaining buildings through digital technology. Since it is a digital platform, it helps to assemble the database in the planning phase and data can be adjusted and added through the following design, construction, renovation, and demolition phases. The building and systems created by designers and engineers through different programs can be overlaid to create a virtual building via the internet. The Information on building such as scheduling of doors and windows, quantity take-offs, construction labour, and materials schedules can be extracted easily and automatically that helps in minimizing errors and manual works, saving time and reducing cost. [4.]

2.1 BIM in Construction Project

BIM has been changing the AEC industry over the years, not only with design and process but also with the ability to reduce the error throughout the life cycle of the building. Moreover, it has set an example that, collaboration between different BIM tools can change the clarity of the overall project.

BIM is more than 3D modelling and has different subsets that are described in terms of dimensions such as 3D which refers to design arrangement, 4D includes a time dimension in scheduling, 5D modelling means that the cost estimation is included, 6D takes sustainability and 7D not only sustainability but also facility management into account.

Whereas 3D enables graphical and non-graphical information in a common data environment and scheduling dimension (4D) helps to construct time schedules which allow the evaluation of buildability and workflow planning of the project. 5D feature provides the possibilities of various cost analysis and optimization including the cost of purchasing and installation of the materials while 6D and 7D focus on real time information integration with BIM information to support different aspects during the facility management phase like sustainability, comparison between predicted and actual energy consumption, usage of the facility, spaces and the components. [5.]

Figure 1. BIM throughout the project lifecycle

BIM is a collaborative way of working that offers open, reliable data for anyone working on the project. Its goal is to centralize all project information in a digital knowledge platform generated by all its users. However, BIM technology is capable of reducing construction complexities by addressing it simultaneously from 7 different fronts: design -

specifications - coordination (3D), process (4D), cost estimation (5D), sustainability (6D) and life cycle (7D) as shown in figure 1.

2.2 Benefits of BIM

BIM not only strengthens the technology itself but also improves the design and build process. However, BIM provides better and more efficient decision-making and eliminates design and documentation complexities. Furthermore, BIM combines plans, sections, details, graphics and data in ways that are not possible in 2D. [6.] Additionally, some of the benefits of BIM throughout the project lifecycle are mentioned in table 1 below.

Table 1. Benefits of BIM. [7.]

Benefits	Description
Improved Scheduling	BIM saves time by minimizing project cycle times and preventing delays in the construction schedule.
Improved Site Safety	BIM offers construction safety by identifying dangers before they end up becoming the physical risk by visualizing and arranging coordination ahead of time.
Better Builds	Good coordination increases the performance of the model to a higher level. By exchanging common BIM resources, more experienced team members work together with builders in all phases of the project to have greater control over technical design decisions.
Strong facility management	BIM provides an accurate digital record of the project and helps during facility management and renovation for the entire lifecycle of the building.
Cost-saving	utilizing BIM for efficient design and manufacturing helps to reduce costs.
Better collaboration and communication	permits the team to share project models and coordinate planning, and also guarantee all design stakeholders have knowledge of the project.

BIM has become an indispensable tool for the construction industry with a number of advantages. BIM projects are more likely to succeed and maximize effectiveness for every stage of the project lifecycle and beyond.

2.3 BIM on Project Life Cycle Phase

There are different uses of BIM for each project. A project can widely be categorized into three phases Design (includes the planning phase), construction and Operation as shown in figure 1. Figure 2 shows different primary and secondary BIM uses that are possible in different project phases. Figure 2 phases have plan as a separate phase to show more onto details on BIM use whereas Figure 1 generalizes both plan and design phase into a single design phase.

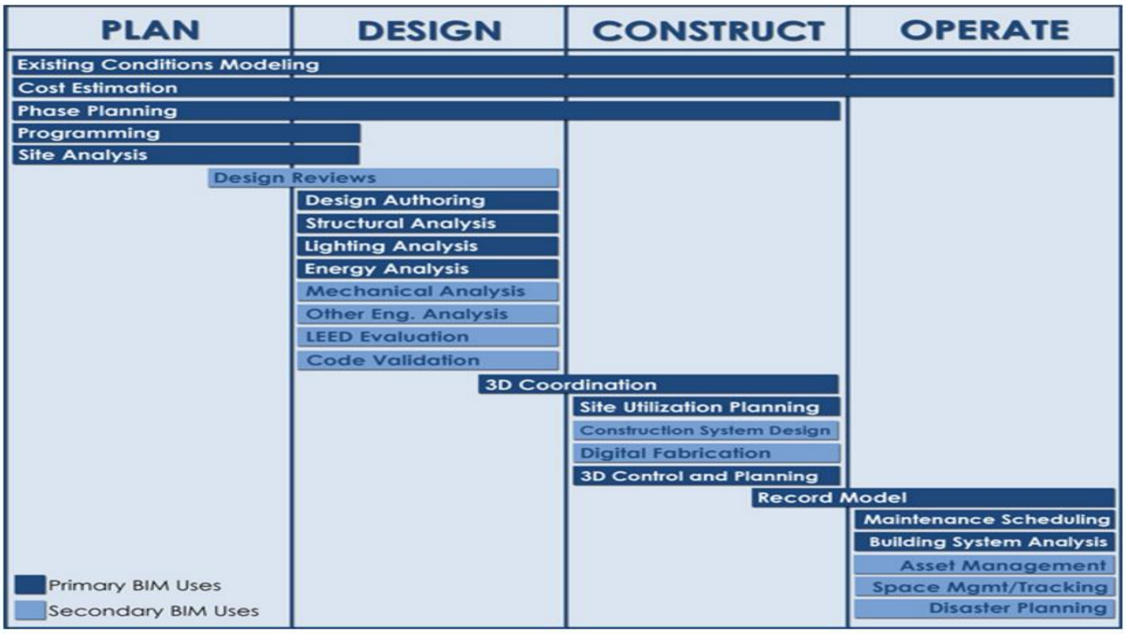

Figure 2. Project lifecycle phases

Figure 2 shows the influence of BIM in four phases of the project life cycle. It includes planning, design in a pre-construction phase, construction and operation in a post-construction phase. Currently, there are over 50 different uses of BIM have been identified for the projects at different phases. [9.] Some of the BIM uses capitalised in practical project are design authoring, design review, 3D coordination, cost estimation, documentation, 3D visualization.

In design authoring process 3D software is used to create a design of the project. Approved tools create models while audit and analysis tools study or add wealth of information in the model. Design authoring tools are the first step towards BIM and the aim is to link the 3D model to a powerful database of properties, quantities, means and methods, costs and schedules. In this study ArchiCAD and Tekla Structures were used as a design authoring tool to create a 3D model of the project. The potential value of Design authoring is used to make design transparent for all stakeholders and to create powerful design visualization. Moreover, design authoring also creates better quality control of design, cost and schedule and also builds better collaboration between stakeholder and BIM users. [8.]

Design Review is a process where stakeholders view a 3D model and provide their input to verify various aspects of the design. These aspects include assessing software compliance, analysing space design and layout in a virtual world, and setting parameters such as layout, sightlines, lighting, security, textures and colours. This use of BIM can only be performed by computer software or with special virtual mock-up facilities. Such as ArchiCAD was utilized in this study to create highly detailed model and solve design and constructability issues. [8.]

The 3D coordination software is used to detect 3D geometric conflicts by comparing 3D building system models. The aim of 3D coordination is to eradicate field clashes and project complexity. The 3D coordination has the capacity to coordinate building projects through a model and reduce field conflicts. 3D coordination also allows users to visualize the construction which helps to increase productivity and reduce time and cost. [8.]

BIM can be used during a project's lifecycle to produce reliable quantity take-offs and cost estimation. This process helps the management team, during all stages of the project, to see the cost consequences of their improvements, which can help to reduce unnecessary budget overruns due to project modifications. BIM allows to quantify modelled materials precisely and also generates more cost estimates in minimum time. Moreover, it also saves estimator’s time by reducing quantity take-off time. The resources required to perform the cost estimation are model estimating software, design authoring software, accurately built design model and cost data. [8.]

Documentation is the most popular form of using BIM technology. The information-enhanced 3D model is used to generate 2D drawings directly and eliminates the rework in CAD software. 2D documentation usually includes plans, sections, 2D elevations as well as drawings of construction details, workshop drawings, schedules and architectural visualizations. Changes made to the 3D model will be automatically applied to every extracted 2D drawing and ensure continuity across the entire project. [8.]

3D Visualization feature in BIM produces accurate and detailed building models in a real-time. Before its actual construction, clients can experience and take a virtual view of the structure meanwhile, architects and developers can get a better understanding of every floor, areas, textures, and elevations. 3D visualizations also identify errors in design from the initial phase of design, which are fixed immediately, or a suitable alternative is provided. The smallest of details like adding landscaping or choosing the colour and texture of the floor, modifying lighting in a specified room or making furniture can be visualize with the help of BIM. Moreover, it also provides actual visual measurement of the objects and their distance with other objects, which helps clients to modify arrangement of objects based on their size and available space. [8.]

2.4 BIM Program Tools

BIM contains various design product information's. These information supports various activities and trades of the construction project in different phases. It helps in proper coordination and collaboration among the AEC industry. BIM based working requires upgrade of existing tools as well as skills of people involved in a project. BIM application or software upgrade affects the workflow among the team members and the consultants of the project. Choosing the right software might be difficult and time-consuming in case the users are not familiar with BIM software. Thus, proper software investigation is needed before implementing it to any projects. [9.]

There are plenty of software available in the market but choosing the best ones which are less time consuming, cheaper and easy to use, especially in a low budget project is important. While selecting the software there are some important that should be taken into consideration. The software should be capable of converting the model into the ifc format. The capability of the software with the operating system should be checked. BIM tools should be able to get required updates from its developers with respect to the time. Furthermore, the price, flexibility, low learning curve, and availability are also regarded. [9.]

Table 2. Software tools and their basic uses

Uses	Software tool
Planning/Preliminary cost estimates	Onuma planning system (OPS), Dprofiler, Tokmo, Code-Book
Architectural/Structural Design phase	REVIT, ArchiCAD, TEKLA, Bentley BIM, Vectorworks
Building Service system	ArchiCAD MEP, REVIT MEP, Bentley BIM, MagiCAD, Pipe designer 3D
Clash Detection	Solibri model checker, Bentley Navigator, trimble connect, bimspot
4D Scheduling	Vico office, Naviswork simulate, Bentely navigator
5D cost estimation	Vico office, Innovaya, costx

Above mentioned software are some commonly used BIM tools in the Projects. There are other tools as well in the market that are not listed. A brief introduction of BIM tools used in this thesis for the architectural and structural modelling are described below with their background and features.

2.4.1 ArchiCAD

History

ArchiCAD is the first and most popular software of the Graphisoft company. The origin of the Graphisoft company was in the early 1980s and it was founded by Gábor Bojár. After Hungary's communist history, a group of three-dimensional mathematical modelling experts decided to open a company, but they had no access to up to date and powerful computers. This limitation led the company to develop 3D modelling software that could be compatible in inexpensive computers. In 1983, Graphisoft participated in CeBIT trade show at Hannover, Germany and demonstrated their software in a Macintosh. Graphisoft was appreciated by Steve Jobs and later it was supported by Apple. This support from apple was a major amplification and a successful factor for the Graphisoft company. [10.]

ArchiCAD was first introduced in 1987 as a virtual building concept and it was the first software to depend on the full capacity of new Apple product Macintosh II. Graphisoft sold almost 2000 software packages worldwide by 1989. In 1993, Graphisoft released ArchiCAD for MS Windows. Later, in 2003 ArchiCAD was regarded as BIM tool and enabled architects to draw walls, windows, slab, doors and roofs. Earlier, it was only used to create 2D and 3D geometry. [10.]

Features of ArchiCAD

ArchiCAD is a BIM tool that allows users to design virtual buildings with virtual components like walls, windows, slabs, doors, furniture and roofs. Moreover, it allows users to work in 2D or 3D models on the screen. The three-dimensional model can be exported in two-dimensional drawing at any time beside that plans, elevations and sections can also be constantly renewed in case users rebuild the view. ArchiCAD also has Geometric Description Language (GDL) which allows to create new components and also Application Programming Interface (API) to support 4D and 5D software like Vico office suite or Tocoman iLink for cost estimation and scheduling. ArchiCAD also allows users to exchange data among other software by importing and exporting DWG, DXF, ifc and BCF files. ArchiCAD also includes immediate 2D navigations and improves the workflow and the productivity. [11.]

2.4.2 Tekla Structures

History

In 1966 Teknillinen laskenta oy (‘technical computing’) was founded. The man behind the idea was Reino Heinonen, who was appointed as managing director in 1966. The first company premises were built-in Simonkatu, Helsinki. The main concept of forming a company was to set up a unified computer programming office for various engineering offices. In 1968, Tekla started focusing on structural engineering, road building and earth moving and started updating software. As computers started growing Tekla started developing along with them. The computerized calculation made engineering work easier, faster and more efficient than before. In 1975, the economic crisis and recession slowed down the Tekla business. Despite the economic crisis, Tekla did not stop developing software. Software like plotter software and graphic printing were developed during the time of recession. In the beginning of 1990, the x-product family was founded. Xsteel which was completed in 1993 was a major success in the export product business and sold over 300 customers in 38 different countries. In 1996, Tekla started its first subsidiary in Sweden and started investing in the international market. By 2008, Different subsidiaries were founded around the globe and 80% of net sales came from international operations. By 2009, around 16000 licences were sold over the world. Today Tekla is an international firm with over 550 employees around the globe and considered as a successful company in the construction business. [12.]

Features of Tekla

Tekla is a BIM modelling program which supports concrete and steel detailing and fabrications in a 3D environment. TEKLA supports both API and ifc data format. It can be linked with different structural analysis programs like STAAD, SAP2000, Robot Millennium and Microsoft excel. API software can link with architectural programs like AutoCAD and ArchiCAD. Tekla also supports open formats like dxf, ascii, fem, cimsteel, fabtrol xml, ifc, ifczip, ifcxml, 3dd, dgn, igs, and iges. Tekla has BIMsight which allows programs to view ifc files in 3D. BIMsight is a viewer program and it has many features. The main feature of BIMsight program is the clash detection and checks conflicts. Tekla also has construction management such as scheduling, quantity take-off and 4D visualization. Tekla also allows multiple users working on one central file and visualizes the project without any complex interpretation. [13.]

3 Building History of Nepal

Geographically, Nepal is located between India and China. Therefore, the construction and architecture of buildings are influenced by all three cultures, symbolizing their heritage. There is no legitimate evidence of early construction styles of residential buildings. However, from the inscriptions of old temples and palaces, the tentative idea of construction can be derived. [14.]

Nepal is a geographically diverse country; there are high altitude Himalayan regions, hilly strip mountains, and low land terai regions. The constructions of shelter have been highly depended on the conditions and the cultures practiced in those regions. The temples and palaces mostly built-in the Kathmandu valley can provide an elusive concept of architectural and construction history in that region. The arrangement of houses, temples, stupas and urban spaces was shaped by the various Hindu and Buddhist practices. It gave the city a distinctive physical and oriental nativity.

Early Nepali Home, Pre-medieval period (300 AD- 879 AD)

- Stones and decorative motifs were used influenced from architecture in India.

Newari home, Medieval era (1200 AD- 1769 AD)

- Use of bricks and wood as the main structural material started. Tiles and carved woodwork were dominant influenced from Tibeto-Burmese.

Shah home (1769 AD- 1846 AD)

- The Mughal architecture from India introduced in Nepal.

Rana home (1846 AD- 1951 AD)

- Neo classical or European style design adapted.

Modern Nepali home (1951 AD onwards)

- Use of concrete and bricks started as a result of globalization and westernization.

Figure 3. Residential architectural style through Nepalese history [16.]

The chart presents the brief history of residential architecture in Nepal. The Indian and Chinese influence is evident throughout the years. Since wood was abundant in Nepal in comparison to present scenario, timber was mostly used in structural parts such as columns, beams, roof frames, doors and windows. Later in late medieval era the use of brick and clay mortar were combined to construct superstructures and plinths. After the introduction of reinforced concrete in the 1950s the traditional brick-walled residential houses were changed into bungalow structures. [15.]

4 Initial Steps in Building a New House in Nepal

There are a lot of procedures required to commence the construction of a building in Nepal. A landowner is obliged to follow all the legal responsibilities before starting to build a house. The first criteria are to design the desired layout of a house by an architect. There are various architect and engineering firms that can design and conceptualize the layout. However, it is mandatory to hire a professional who is registered in Nepal Engineering Council. The design should follow the criteria of the National Building Code. [16.]

When designing a building, the site, the area available and the client's convenience is taken into consideration. According to the new urban planning and building construction laws of 2015; it is forbidden to construct a new housing taller than three stories near another house which is less than one and a half meter apart. The law instructs buildings up to 10 meters high should leave setback of 1.5 meters from the border of the land plot. In addition, there should be a minimum of 3 metres distance between the house and the centre of the road connecting the house. [16.]

After sketching a design by implementing all the mandatory laws, the process of acquiring building permits is carried out. The process might differ according to the regions. However, in municipal areas the registration is done through the Electronic Building Permit System (E-BPS). Nonetheless, the designers are also obliged to submit hard copies of the design to the concerned municipality. This process takes 25-30 days which can be divided as follows. [17.]

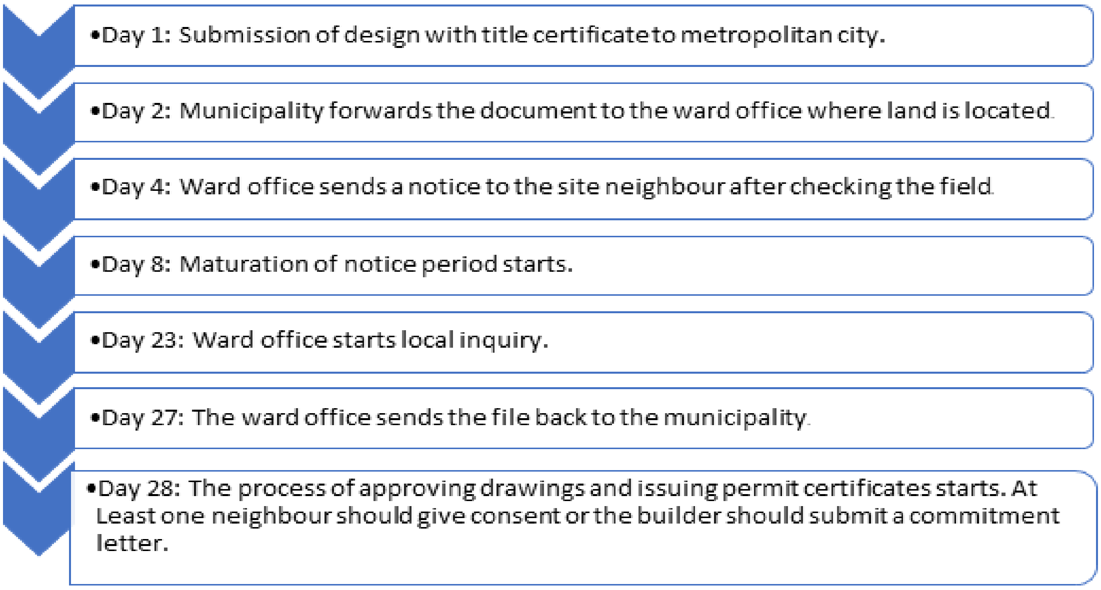

Figure 4. Acquiring building permit process [17.]

As the chart in figure 4 suggests, the building permit acquiring process is a long and exhausting task. The process lengthens due to the consumption of time in transferring files in different office departments. A smooth link between different departments is lacking.

The currency used in Nepal is Nepalese rupee which can be abbreviated as Rs or NRs. The official measurement system used in Nepal is metric system, however, customary units and imperial units are also used. [18.] one euro is equivalent to 130 NRs. [19.] Table 3 shows required documents and charges to acquire permit in order to construct new house in Nepal.

Table 3. Required documents and charges for house construction permit

Documents Required	
• Owners identity card or registration certificate of company • Certificate of registered architect or engineer • Cadastral extract • Land ownership or lease proof • Building plan • Tax payment paper • Structural plan	
The original documents along with the copies should be submitted to the Metropolitan city office.	
Charges	
Residential building	NRs 269 per m^2
Ownership transfer (multiple)	NRs 75 per m^2
Ownership transfer (once)	NRs 54 per m^2
Usage charge	NRs 54 per m^2
Building completion certificate	NRs 22 per m^2
The Department of Urban Development also charges a NRs 2,000.00 designer fee. The Department authorizes the project designer. The license is called the Certificate of Designer, and it should be renewed every year. The fee is NRs 1,0000.00 per annum. For each building design the Municipality charges an additional NR 2,000.00.	

It is obliged to design a house only from registered architect or engineer and submit all the required documents to acquire a permit. The service charges for the residential building is low.

5 Case Study: Casa Magayon

The International property award (2016-2017) winner project Casa Magayon was started in 2014 and completed in 2015 by the SARCO Architects Costa Rica. This residential building has a total area of 1290 m^2 located in Guanacaste, Costa Rica. The total budget of this project was 3 million euros and it was a completely BIM-based project. The

SARCO used Graphisoft's ArchiCAD and BIMx software tools in this project. The use of Building Information Modelling allowed the combination of both 3D and 2D, resulting in the best visual displays of the award-winning project in figure 5. [20.]

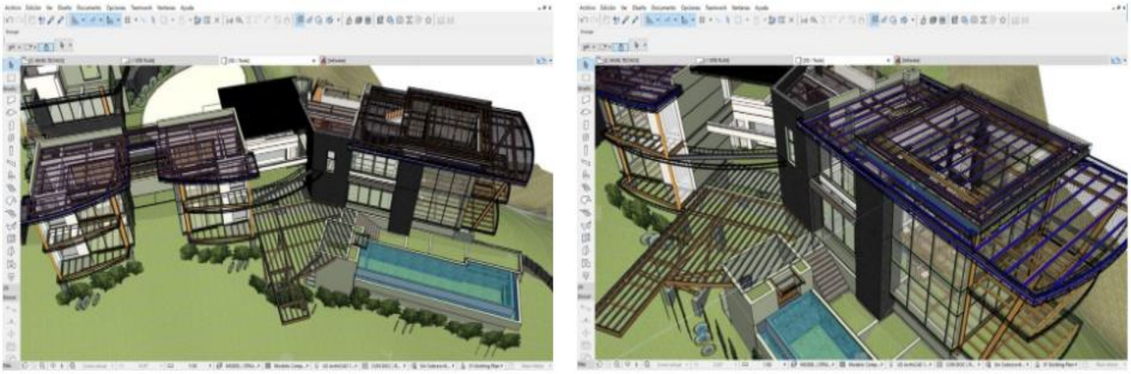

Figure 5. Casa Magayon model modelled with ArchiCAD [20.]

SARCO Architects used BIMx as a central communication and visualization element throughout the whole work process. BIMx allows 3D and 2D documentation of complex ArchiCAD models into simpler and understandable form. SARCO Architects used BIMx to present the precise model to clients and used colour in final documentation. Moreover, BIMx was also used in this project to picture the detailed design and to interact with suppliers. [20.]

The key aim of the case study is to learn the concept of BIM tools in real-life projects and to understand the use of BIM tools collaboration in the different phases of the BIM project. In the Casa Magayon project SARCO Architects implements the BIM process through the whole project in order to show the exact layout to clients. The above building project indicates that the proper use of the BIM method has led to better outcomes. In their project, SARCO Architects used ArchiCAD For Design Authoring and structural Analysis and further collaborated with BIMx for Design review. ArchiCAD allows them to enhance the design and layout of the project, while BIMx makes the project look more comprehensive and easier to communicate with clients and suppliers. [20.]

6 Practical Project: Existing Single-Family House in Nepal

To study the benefits of BIM, the thesis studies an existing single-family house in Nepal by redesigning it. The redesign is carried out as a practical project following the BIM procedure. For the process, an existing building designed and constructed with the traditional method is chosen. The selected building is a two and half storey single family house located in Budhanilkantha 5, Kathmandu, Nepal. The owner of the building is Mrs. Devaki Adhikari. The valuation and registration are done by the Department of Land Revenue under the Ministry of Land Reform and Management. See appendix (1) for more details. Table 4 shows the parameters of the existing residential building which is redesigned using BIM tools as practical project for the thesis.

Table 4. Information of residential building

Building Information: Residential building	
Land area	158.98 m^2
Ground floor area (Plinth)	85.36 m^2
First floor area	87.09 m^2
Frame structure	Reinforced concrete
Cost	9,283,531.25 NRs

The building was built in 2004, and the life expectancy of the building is evaluated to be 60 years. The design of the building was done in the traditional hand and paper method. This design was later drawn in 2D designing software. A floor plan map is available in appendix (1).

7 Modelling the Single-Family House in ArchiCAD

The architectural modelling of the single-family house redesigned in the thesis was done in ArchiCAD version 23. The project was simple since the building is already existing and the project plan was already available. The architectural drafting was started with a regular student version of ArchiCAD 23. Initially, a template was chosen where there is also an option to browse another different template. For now, there is no such template for a building built in Nepalese environment. Therefore, the standard ArchiCAD template was chosen for simplicity. However, if the project were to be repeated, a new template could be prepared manually, saving the time for further arranging the project.

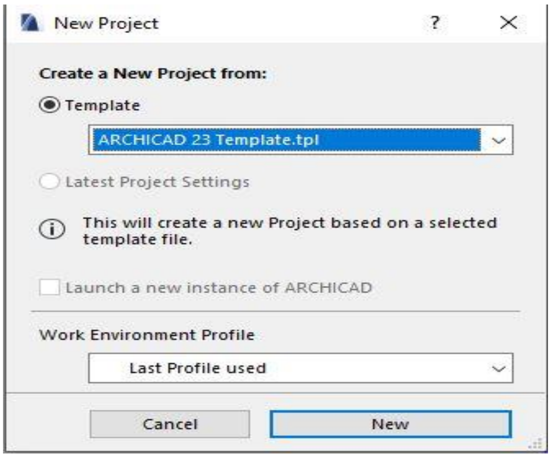

Figure 6. Dialog box for New Project

After selecting the template for the new project, a project preference was set. Project preference is a versatile toolbox that allows designers to choose a preferable working environment. For instance, different countries use different system of measurement to regulate and define different purposes of science and business. Hence, different project parameters such as working units, rules and standards, project location can be redefined by clicking the ‘Options’ from the toolbar and ‘Project Preference’ leading to different sets of dialog boxes as shown in figure 7.

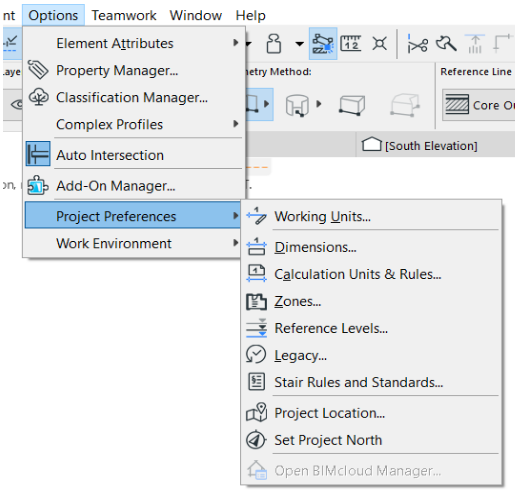

Figure 7. Project preference settings

The ArchiCAD interface is the most adaptable and efficient since it allows a learning environment to the users. The interfaces like drawing area, info box, menu bar, and navigator tool bars are perfectly aligned and flexible. These interfaces can be changed and arranged upon the necessity of the user. Thus, due to this flexibility a bigger drawing area can be achieved as well.

7.1 Grids and Stories

The ArchiCAD allows simplified installation of grids. The user can pre-choose the installation of a grid and put a column at the same time. So, when redesigning the sample single-family house, the grids were placed among the centre of columns, assisting the plan to be more visible and logical. The horizontal and vertical gridlines were placed at a distance of different intervals as shown in figure 8.

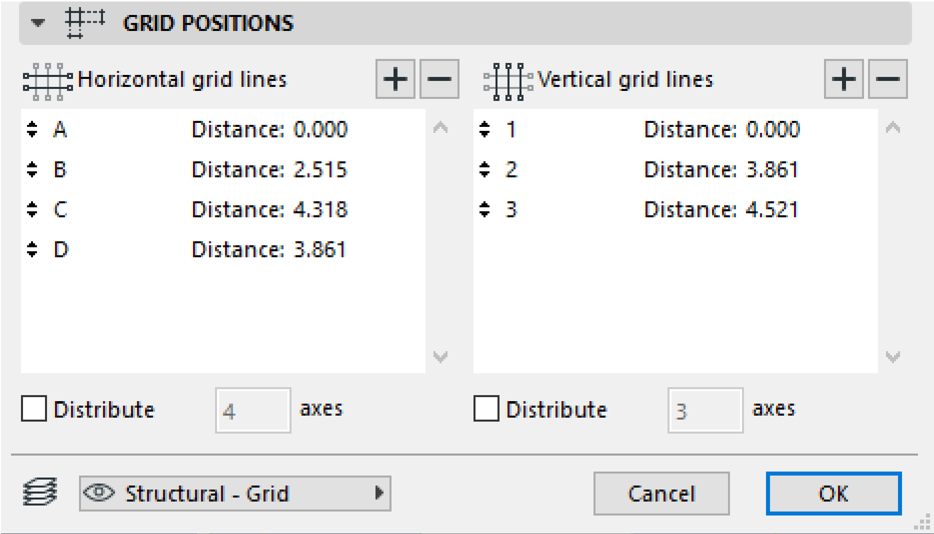

Figure 8. Grid position in ArchiCAD

Similarly, assigning stories was also an important part in the redesign of the single-family house. The stories were assigned by opening the dialogue box from the 'Stories Navigator' toolbox on the left and 'Settings' allowed for the creation of the three stories of the building.

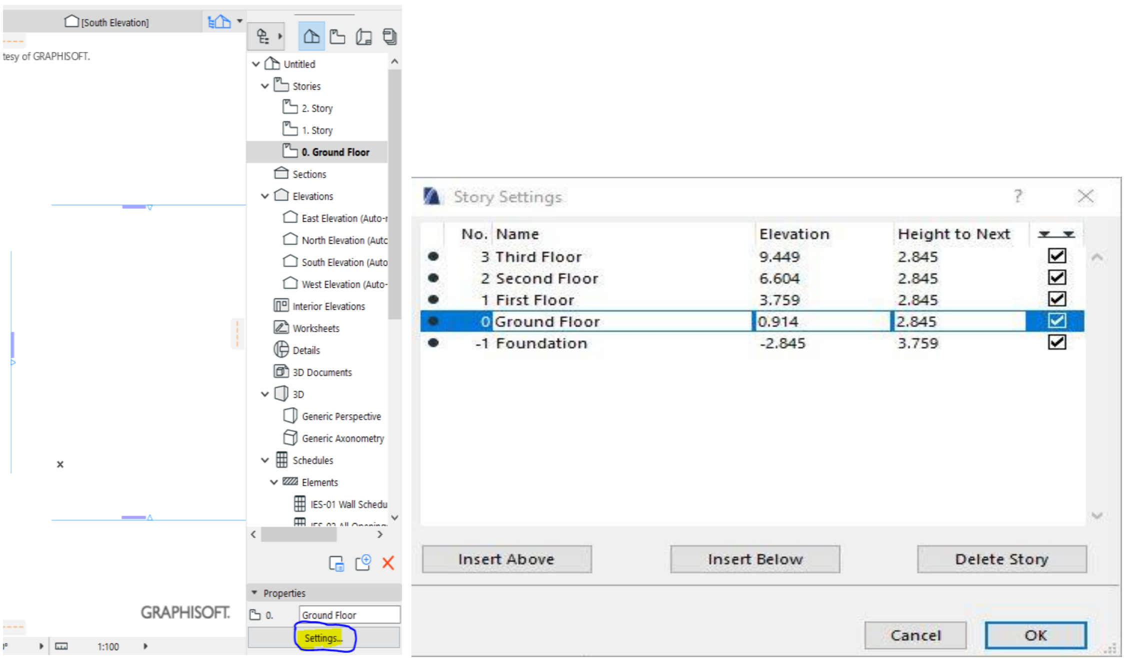

Figure 9. Story Settings in ArchiCAD

The three stories were defined above the ground floor, and a foundation was defined below the ground floor. The height of each floor was set 2.845 meters.

7.2 Placement of Building Structure

ArchiCAD allows the designer to import drawings from various other software applications like AutoCAD, Revit, Sketchup and other designing tools from where a reference can be imported. However, in this redesign case, the dwg files from AutoCAD could not be retrieved. Therefore, the drawing was made from the blueprint of the building. After the placement of grids and correct stories, the columns were visible, and a floor plan was created by using different design tools like walls, columns, slabs, doors, windows and other components.

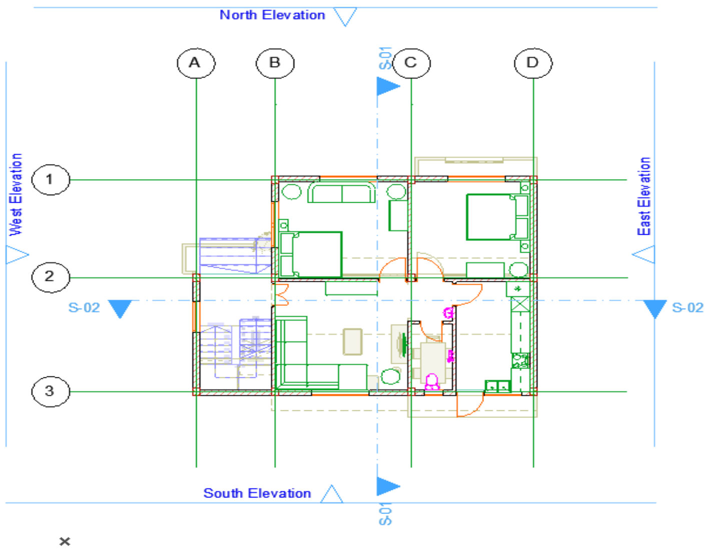

Figure 10. Plan drawing in ArchiCAD

The initial ground floor plan layout indicated the installation of grids and the proper automated elevations. The elevations can be also changed depending on the orientation of the building, but the practical case project in this study was simply facing north. The Elevations, Sections and 3D places helped further throughout the designing of the building where different elevation can be seen and sections can be traced for accuracy.

7.3 Settings of the Building Materials

The ArchiCAD Library offers different sets of building materials of different characters and properties. In addition, it also allows the user to modify the properties of a building and the materials. It lets users create a new material where elements of choice and design can be installed, and an existing design can be modified as well. The dialogue box of building material can be opened from ‘Options> Element attributes> Building materials’ from the menu bar. In the redesign project of the single-family house, the external and internal walls were of brick of different sizes. Hence, in the composite structure toolbar the name of building materials and their properties were defined. The wall profile is double plastered with one layer of brick in interior walls and two layers of brick in exterior walls.

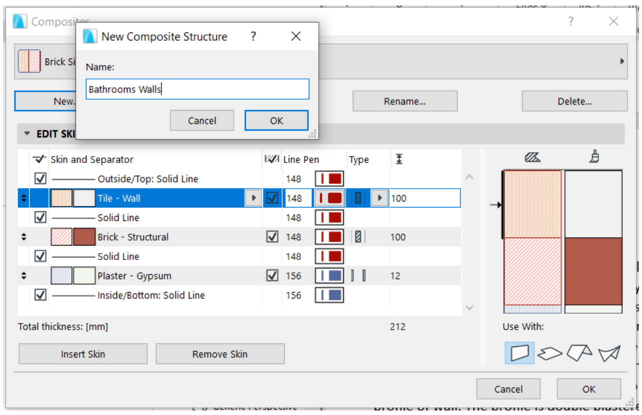

Figure 11. New composite wall structure dialog box for bathroom wall

As shown in figure 11, complex profiles of walls were defined in the wall of the bathroom. The composite structure of ArchiCAD allowed for the creation of a wall and tiled slabs in the toilet and bathroom. Hence, this process of creating walls demonstrates that the availability of wall profiles in ArchiCAD makes it easier to work.

7.4 Creating Architectural Model in ArchiCAD

There are different properties of the tools that create or design a building. Some are structural and some are architectural, whereas some are of plumbing and some are of HVAC. For the model created in this thesis for the existing single-family building, an architectural profile unit was used where only limited foundation, walls, slabs, columns, roofs, doors and windows were created. The process of designing these units is explained below.

As shown in figure 9, the foundation story was created at first where the ground floor is rising 0.914 meters from the ground. The pad footings were created as referenced to the 2D drawing available from the blueprint. So, in ArchiCAD drawing a pad footing is complex since it is not available directly from the library or profile. Hence, the structure was later created in Tekla Structures.

The wall is created from choosing the wall icon from the toolbox or also can be inserted from Design tools button from toolbar. After clicking the icon, a wall dialogue box appears. In this study, two different walls were created one with a double layer brick wall and another a single layered brick wall. From the dialogue box, different parameters such as the width and height of the wall, override surfaces and the classifications were chosen for two different wall types. The first option of wall, ‘basic wall’ was chosen consisting of only one layer of material. The next option of composite was chosen for a bathroom walls as mentioned in the composite building tool in figure 12.

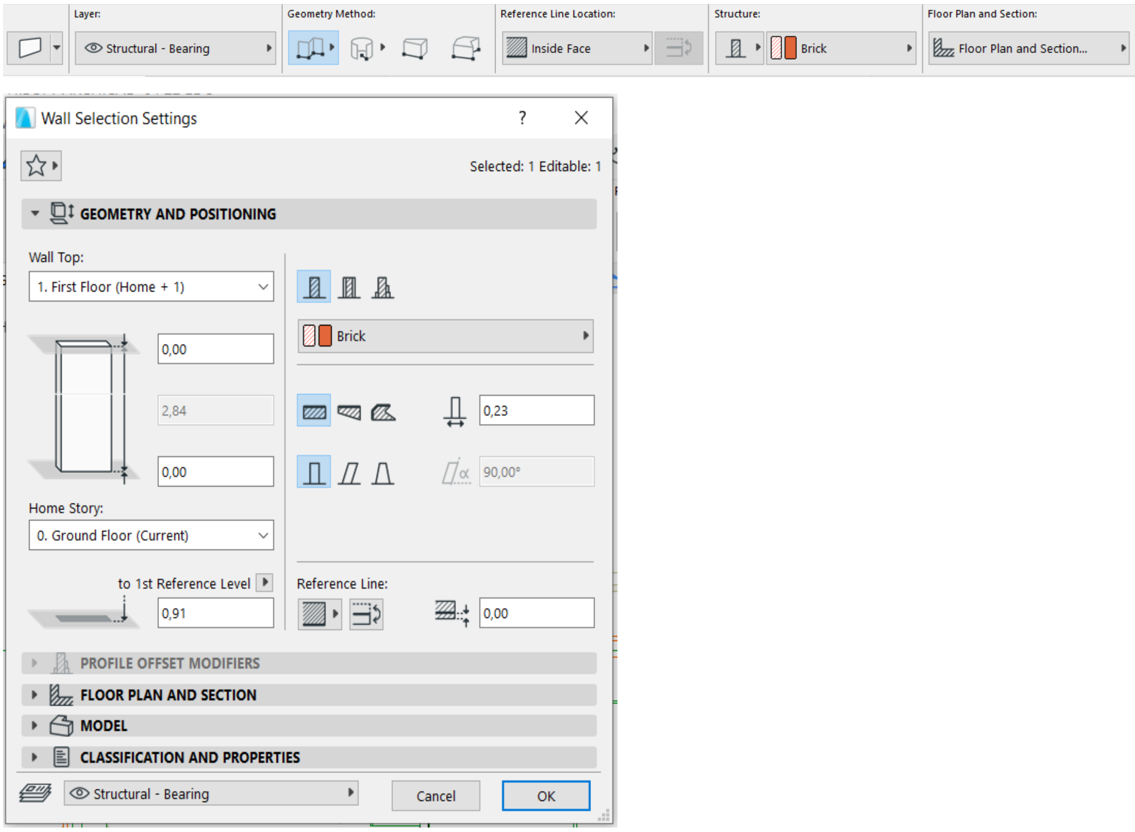

Figure 12. Wall default settings

There are a total six types of reference lines for building a wall in ArchiCAD. They are inside face, outside face, core inside and core outside. There is also the possibility to select different settings directly from the toolbox appearing at the top of the drawing page.

Slabs for the redesign of the existing single-family building were created by opening the dialogue box by clicking ‘Slab ‘icon from the toolbox. The dialogue box has different parameters where one can moderate and define the thickness of the slab, and material choosing. ArchiCAD has a versatile tool that runs by turning on the ‘Suspend groups’ from the toolbar. At the same time, the dialogue box of slab allows to define the story. Similarly, to walls, there are different options to define the slab like a basic slab option and a composite slab option. When installing a slab like wall, there is a toolbox appearing above the drawing page which is a basic editing tool for addition of slab. It is a small version of the dialogue box itself allowing to change the orientation, story, references other preferences as shown in figure 13.

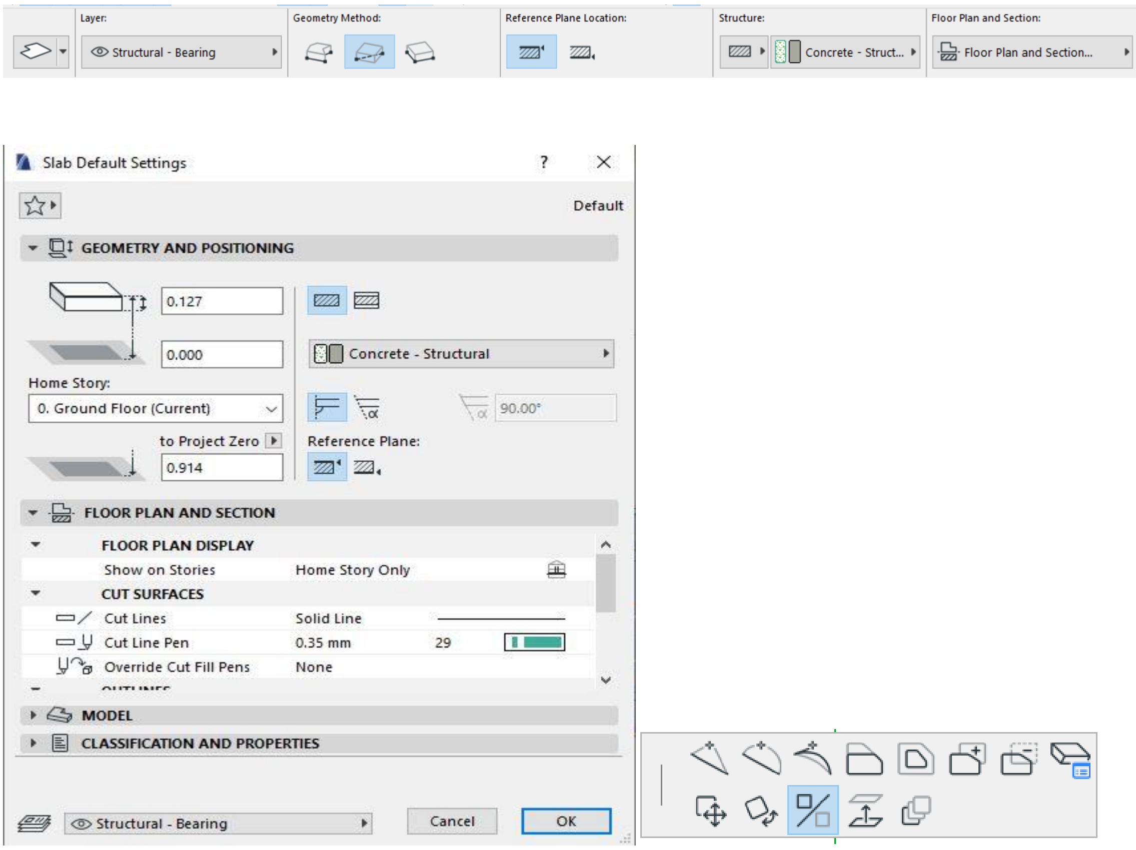

Figure 13. Slab default settings

The roof is projected in the third floor of the building. The design tool of the roof has a similar dialogue box as other building component. From the dialogue box, one can change the parameters, define the angle of pitch, choose whether single plane or double plane and other geometries as shown in figure 14. The dialogue box also allows the stories placement and choose its height. Similarly, basic material, unique material or composite material for the roof can be selected. Likewise, the dialogue box also allows to assign an angle for the roof edge. The roof created was a multi-plane with the 15-degree plinth angle and a thickness of 0.076 meters.

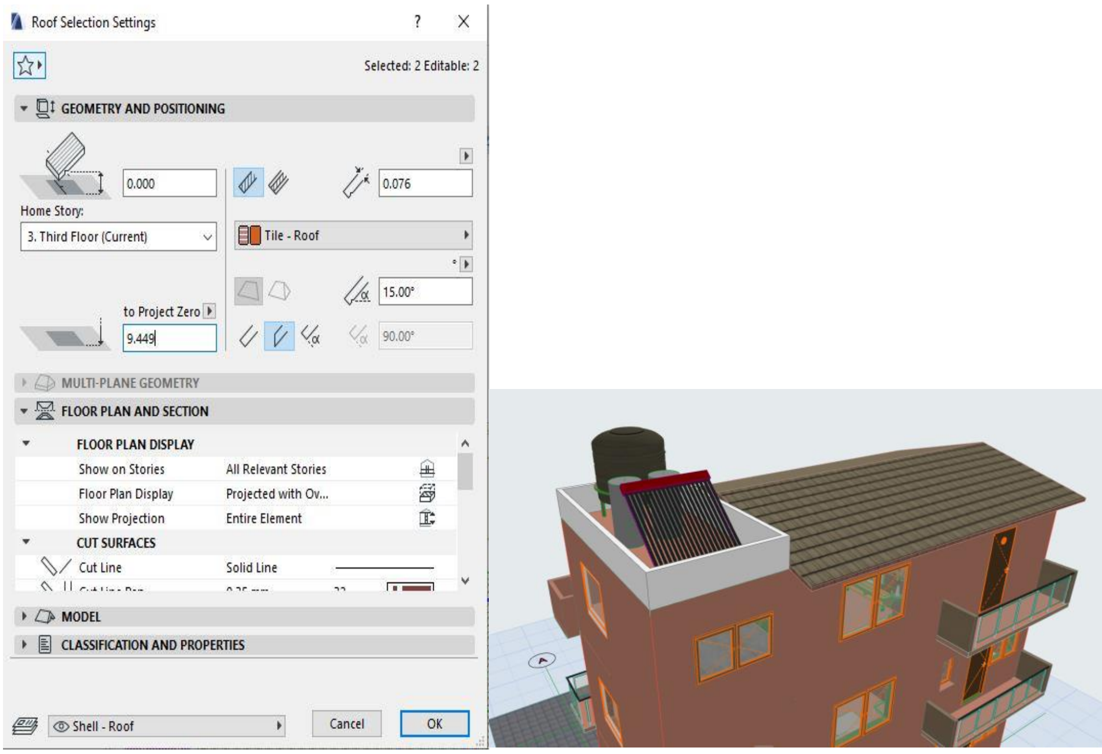

Figure 14. Roof selection settings and 3D roof model

There are various forms of stairs placement in ArchiCAD, some are formed from default stairs settings and some are downloaded as an object. However, staircase is also available in ArchiCAD library. Generally, there is a staircase design toolbox that opens up a separate dialogue box. Staircase has different list of suggested height and width for Treads and Risers following the rules and standards. From the dialogue box, one can edit the different parameters of length, breadth and height of stair, define landing options, edit the riser height and angle and also identify the baseline of placement. The flight type or the landing type stairs could be selected from the staircase selection setting dialogue box based on structure. Figure 15 represents the function of dialogue box of staircase in ArchiCAD. Meanwhile, in this created model of single-family house there are 2 automated landing U- shaped staircases connecting ground floor to third floor. One circular staircase in the third floor to connect to the water tank and solar panels.

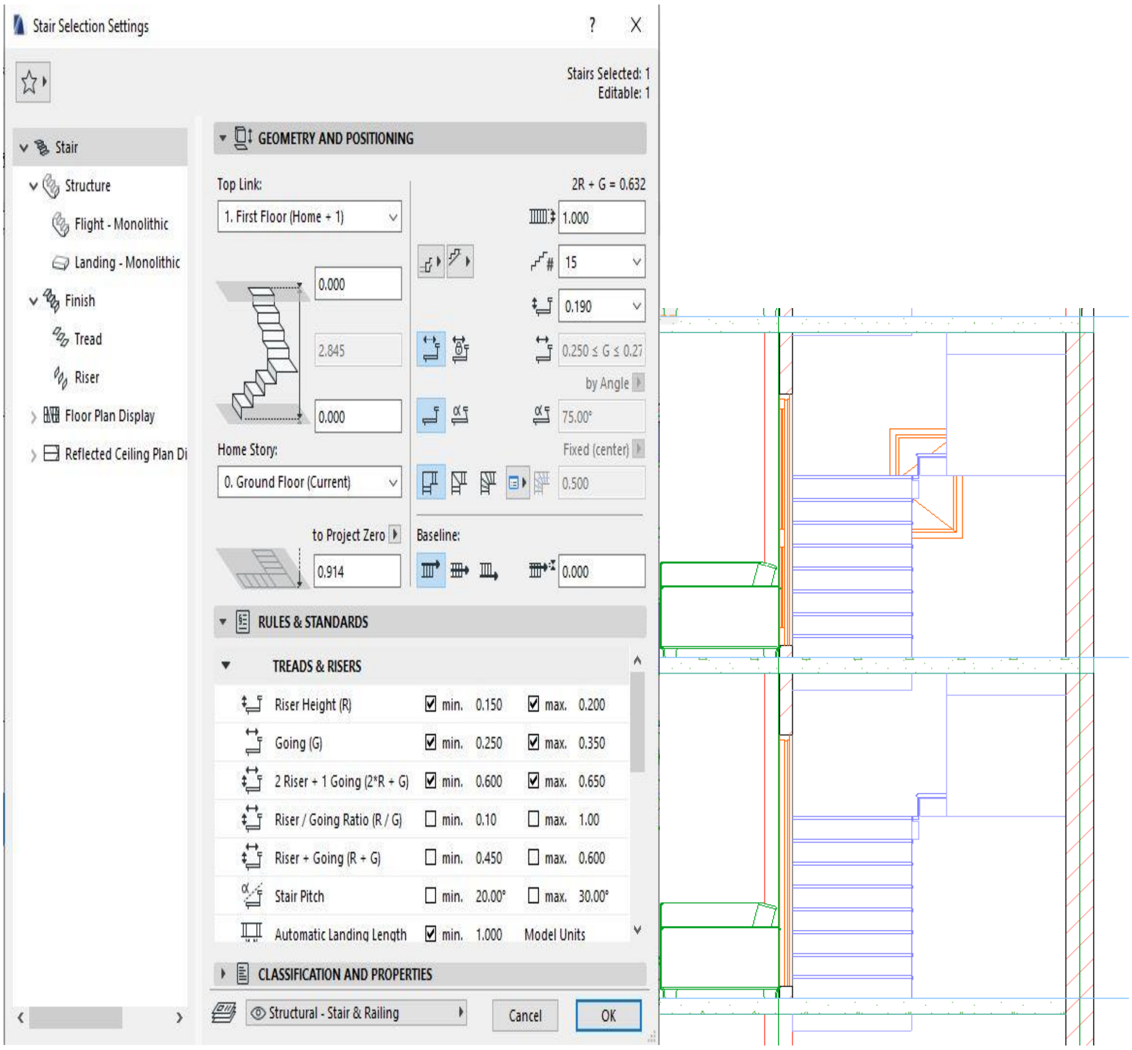

Figure 15. Stair default settings and staircase section model

In ArchiCAD, doors are added in a plan from selecting a door icon from the design toolbox. There are various types of doors available in libraries where one can modify and edit the parameters and adjust whether facing inside or outside while placing them in drawing. The reference point for the door can be added with respect to the bottom of the floor and edited from the dialogue box. The storefront door setting allows the user to define the opening, distinguish the nominal sizes, add natural ventilation, door leaf type or put the right type of handle. The precise settings help users to distinguish the material property economically and aesthetically. Meanwhile, there are different door types in the building depending on the room type and entrance. The door in entrance as shown in figure 16 is a storefront double door opening with double leaf and other doors in every room is a single leaf opening.

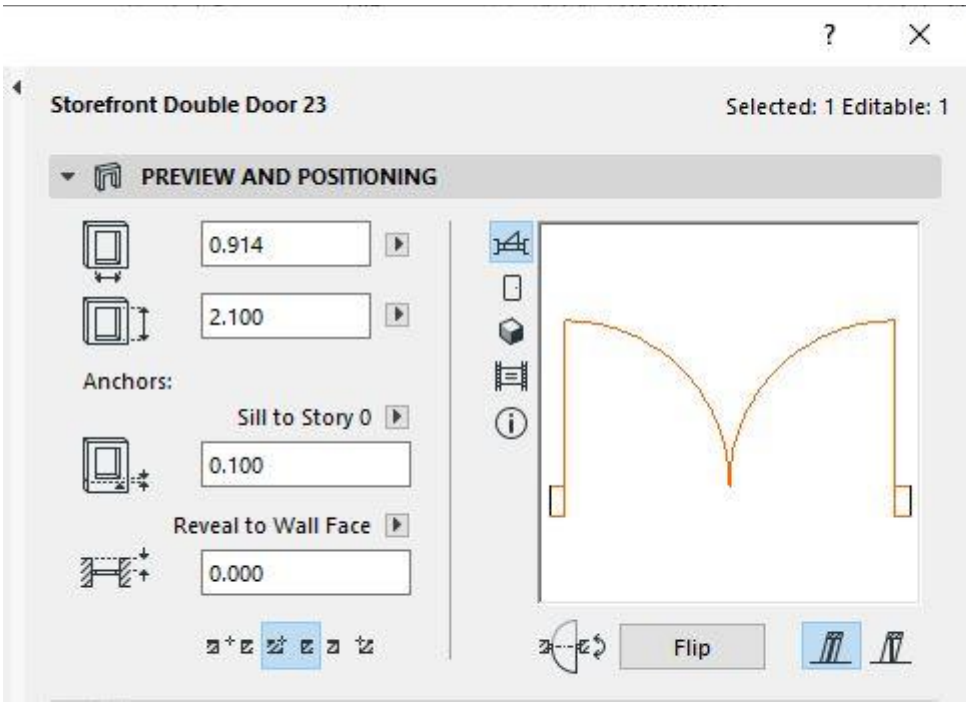

Figure 16. Door default settings

Windows are placed in walls by choosing the window tool from the design toolbar. The dialogue box of window toolbar helps to modify the perimeter of length, breadth and anchors with respect to the sill, story and wall chore facade. As similar to the door setting, the storefront setting of windows also allows user to modify shape of panel, reveals, addition of natural ventilation, model attributes, and wall opening. However, there are various windows placed in the building of this case project. Some are double slash windows, and some are regular one plane windows which are positioned depending upon the type of room and living space as shown in figure 17.

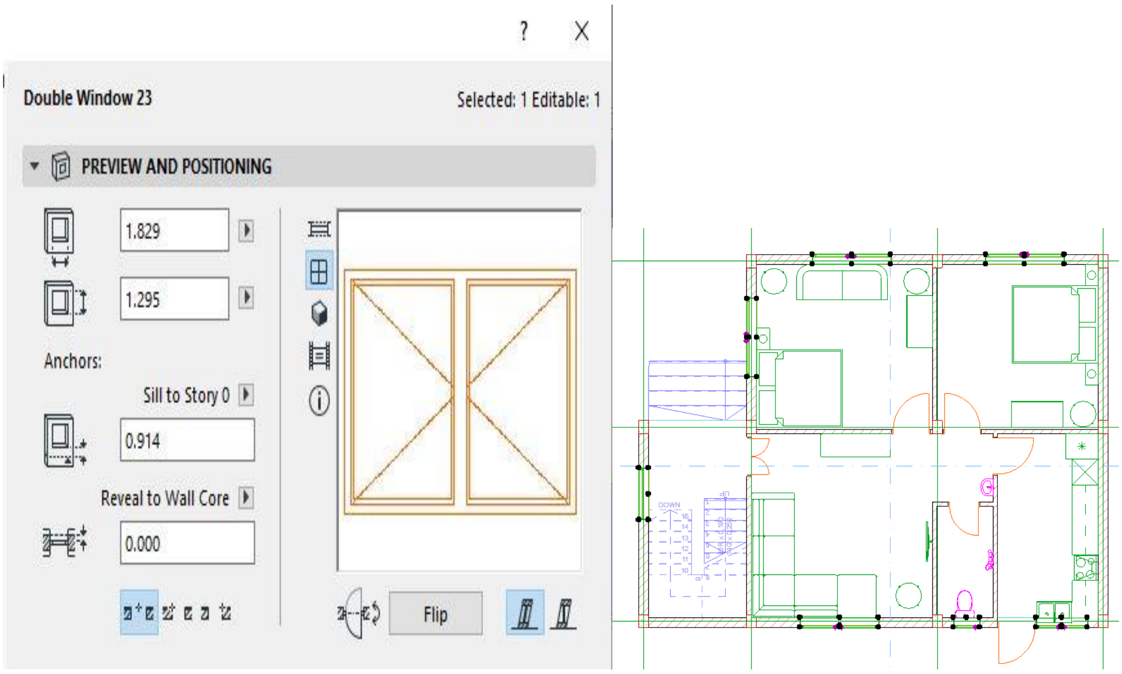

Figure 17. Window default settings and positioning of windows

ArchiCAD has a set of objects available by default in the library. It includes a set of kitchen accessories, utilities for toilet, tap, sink, and trash bins. The platform of ArchiCAD lets users to retrieve the list of data's and details of selected objects and use them for further quantity and quality assurance. Besides, it has an online platform where the users can download the necessary objects and skip the whole 3D modelling of the object itself allowing users to save time and carry out task efficient. In the model created for the thesis, different objects with different properties are placed. For instance, the showers and WC are placed directly from the library in toilets. The living room is completely furnished which allows the user to analyse the living space and investigate the property of material. ArchiCAD can also edit the property of material from the object selection dialogue box as shown in figure 18.

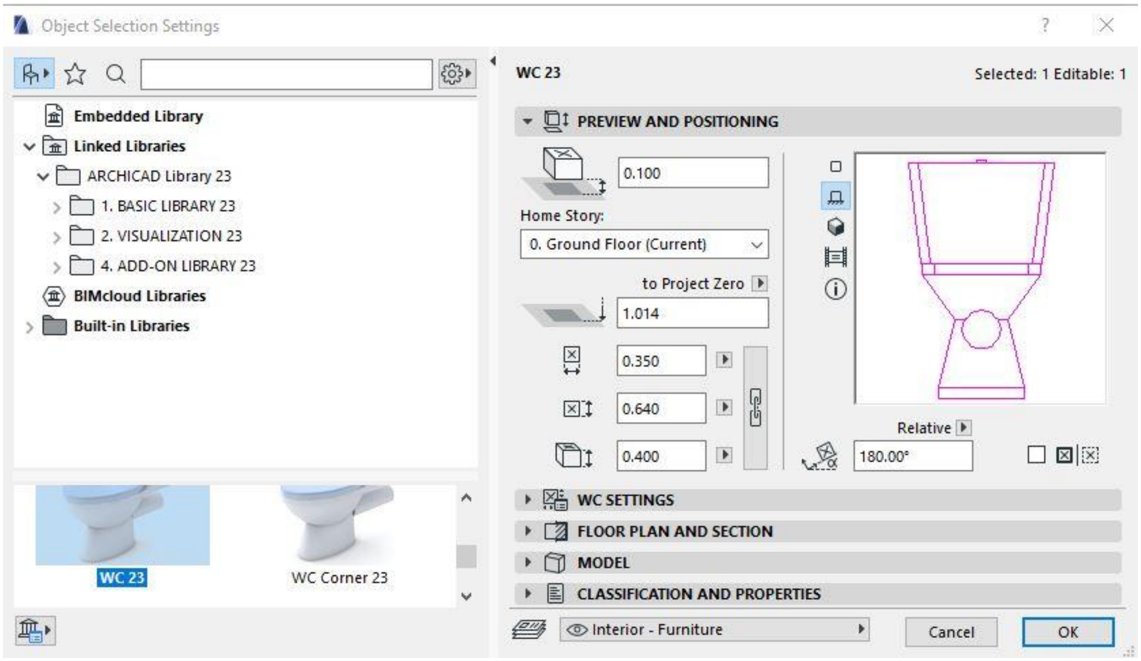

Figure 18. Object default settings box

ArchiCAD includes different sets of drawings that can be created mostly based on floor plan, elevation, sections and 3D perspectives. The navigator tool contains" view" section which is normally used to create different views with various combinations and settings. The model designed in ArchiCAD acts as a single source of information and thus allows users to create different types of vies from the model elements – for example floor plans in different presentation modes and scales. Information exchange between these views have a versatility to save or export them in different formats like dwg, pdf, bimx, ifc as required in the project. To create a drawing, in the single-family house model a new layout was created by selecting 'Documents' then 'Layout' and then 'New layout book', which was later assigned with different names based on the drawing type. The printing paper size is defined whether A2, A3 or A4. After that each element was placed inside the layout book and the drawings were created. When the layout book is ready, the drawings are available in the 'Publisher set' to be published. For instance, users can publish it as a pdf file or a BIMx- Hyper model. Moreover, there are various settings to define the paper size, setting properties for publishing and a path to save the files.

8 Structural Modelling of the Single-Family House in Tekla Structures

The structural modelling of the building was done in Tekla Structures 2019. The ifc model exported from ArchiCAD was used as a reference file to create a model in Tekla. The software was used primarily to design reinforced concrete beams, columns and foundations.

The working environment was set up before starting to work on it. Since there is no database for the working environment of Nepal, this project was done under Finnish environment. The licence configuration of the software is an educational version as shown in figure 19.

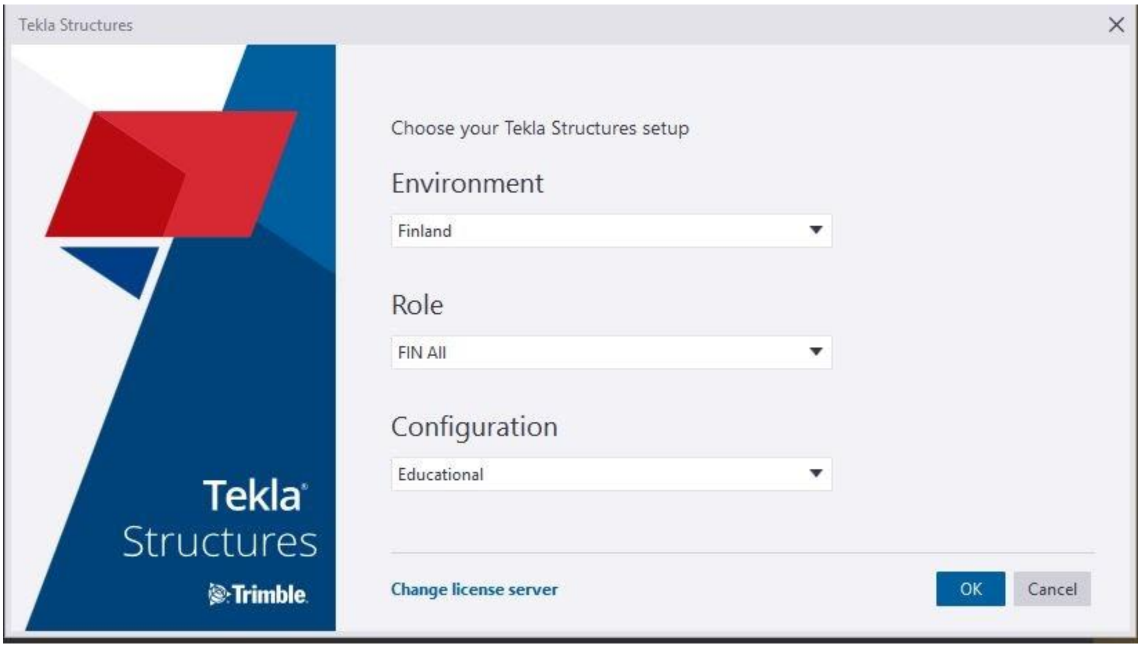

Figure 19. Tekla Structures setup

The commands and views are easily accessible in Tekla Structures interface. Figure 20 shows all the essential working areas and labels.

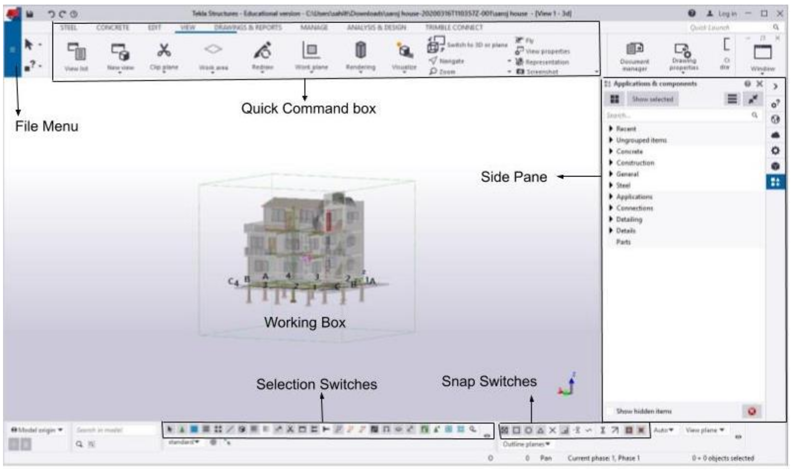

Figure 20. Tekla interface with reference ifc model of building

While creating a new model in Tekla Structures, it automatically creates a rectangular grid and a view. The radical grid was not necessary to create; therefore, the existing rectangular grid was modified using the grid properties in the side pane. The grid properties were opened by double clicking the grid. The X grid lines vertical to work plane, Y grid lines horizontal to work plane and Z elevations in the structure coordinates were adjusted as shown in figure 21. The numbers represented the vertical label whereas alphabets represented the horizontal label.

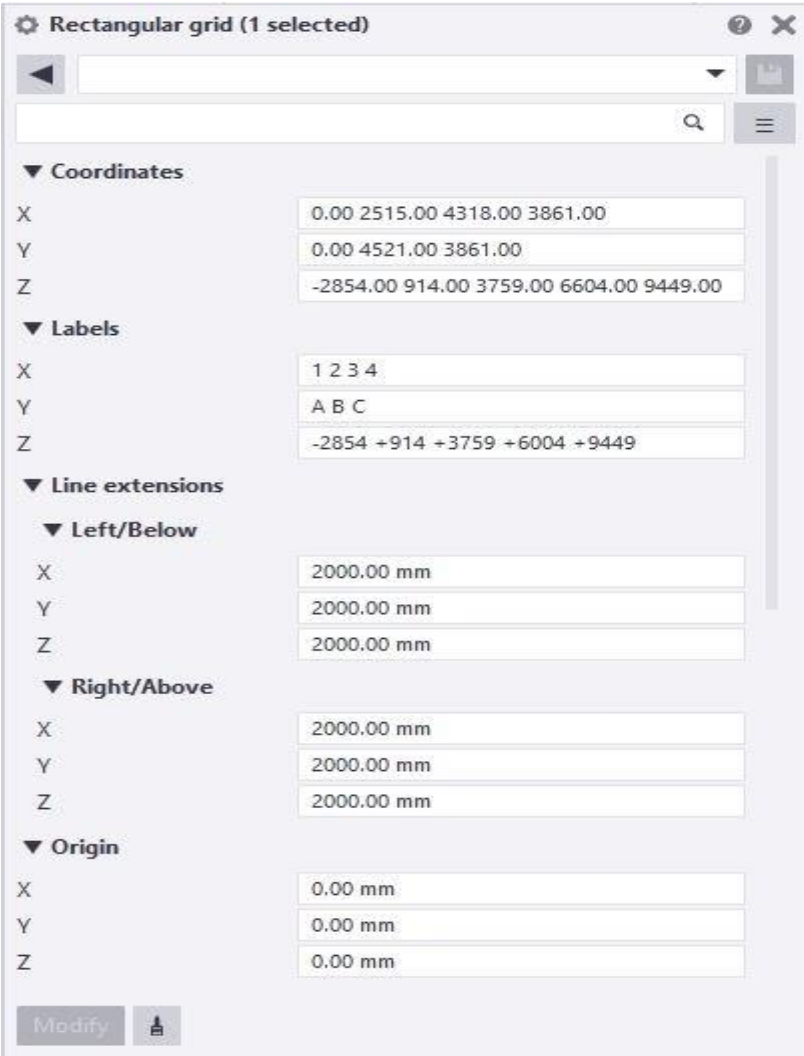

Figure 21. Tekla grid setting

The ifc model of the building exported from the ArchiCAD was imported in Tekla Structures by clicking the reference model button in the side pane. The Tekla Structures support ifc and ifcXML format, therefore ifc format was saved from ArchiCAD. The original location of the single-family house model in ArchiCAD was in origin X (0,0), Y (0,0), Z (0,0), hence the ifc model was imported in the same origin as shown in figure 22. The reference model can also be located in a different coordinate system.

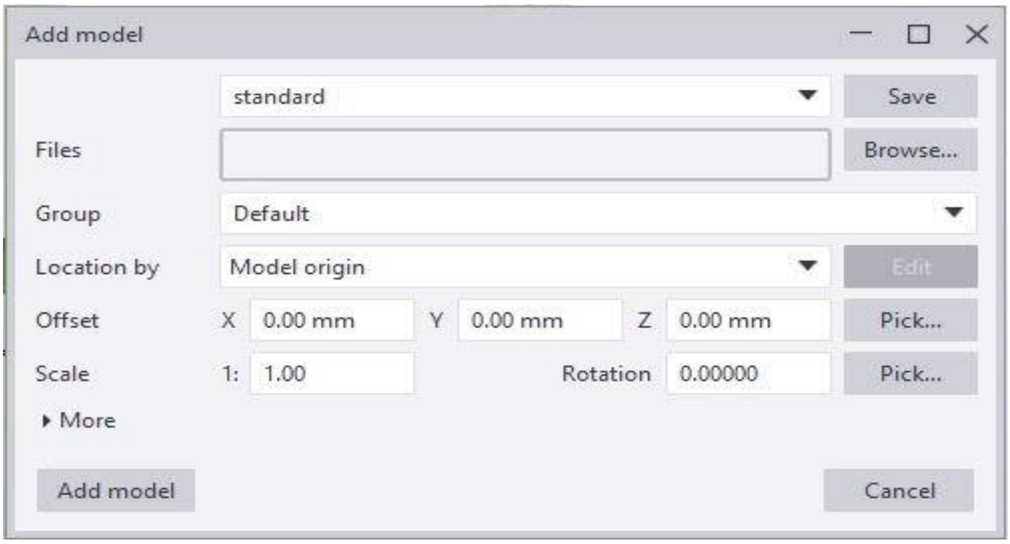

Figure 22. Reference model importing dialogue box

The foundation in the single-family house was created by clicking the footing in the concrete tab of the quick command box. In this model pad footing was created and modified according to the measurements. The dimension of the pad was made 500 mm * 500 mm and the concrete material M25 was used.

Figure 23. Footing property dialogue box

The columns for the model created in this thesis were done on the concrete command tab by selecting the concrete column icon. The different attributes such as material, profile, class and other parameters were defined in the property dialogue box as shown in figure 24.

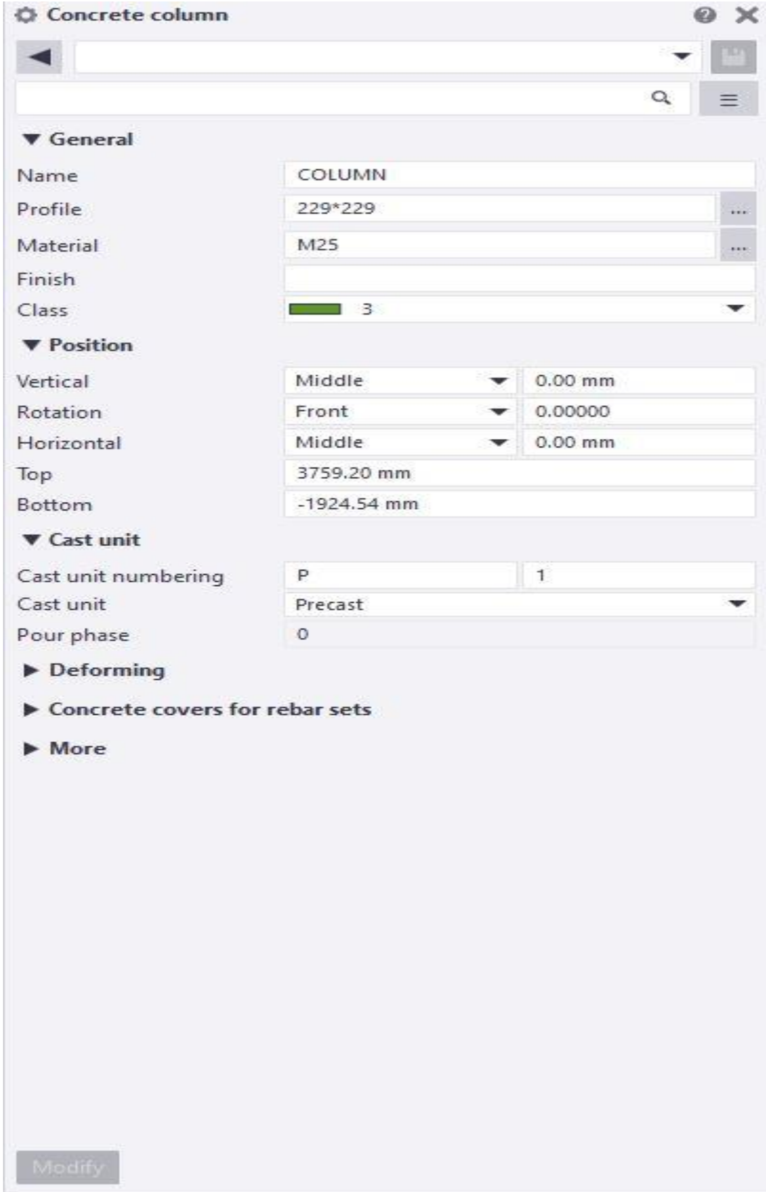

Figure 24. Column properties dialogue box

The beams for the model created in this thesis were done on the concrete command tab by selecting the concrete column icon. The beam was drawn by picking two points and different attributes such as material, profile, class and other parameters were defined in the property dialogue box as shown in figure 25. The dimension of the beam was defined 229*229 mm.

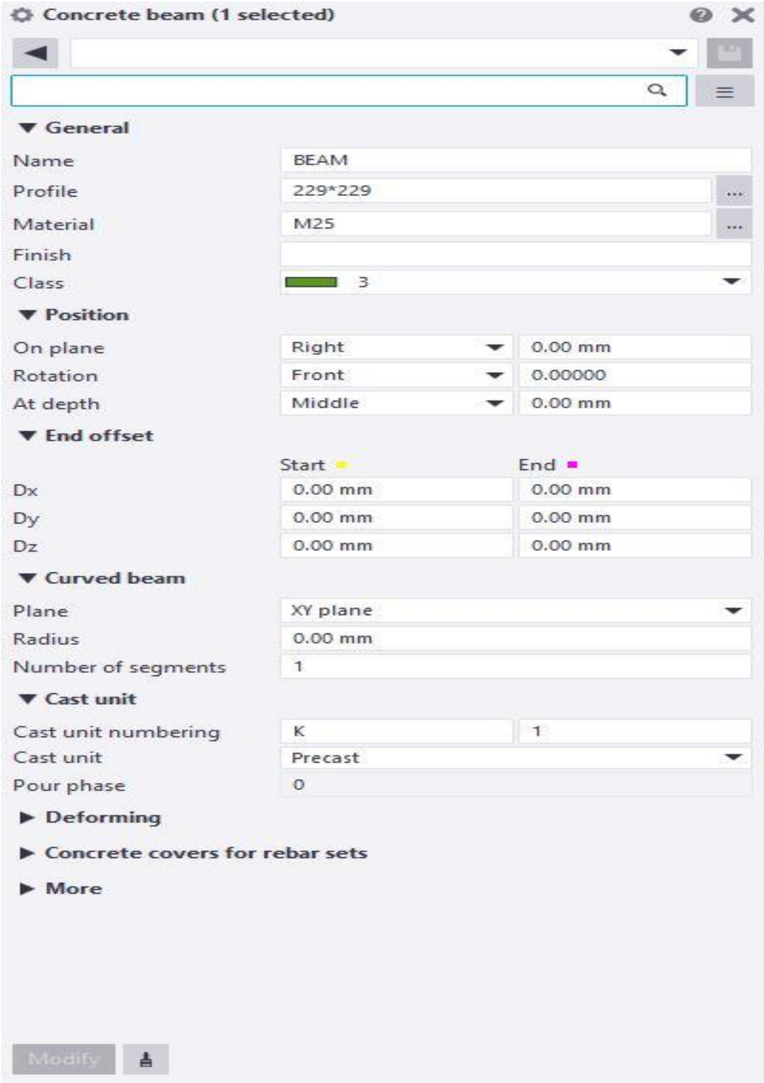

Figure 25. Properties of beam dialogue box

To create the reinforcement for the model in this thesis, the 'beam reinforcement 63' was selected for the beam and the parameters for concrete covering, stirrups and tension bars were adjusted in the beam reinforcement dialogue box. Similarly, 'column reinforcement 83' was used for the columns adjusting all the parameters required. Bottom bar and rebar combination was made for the reinforcement of pad footings.

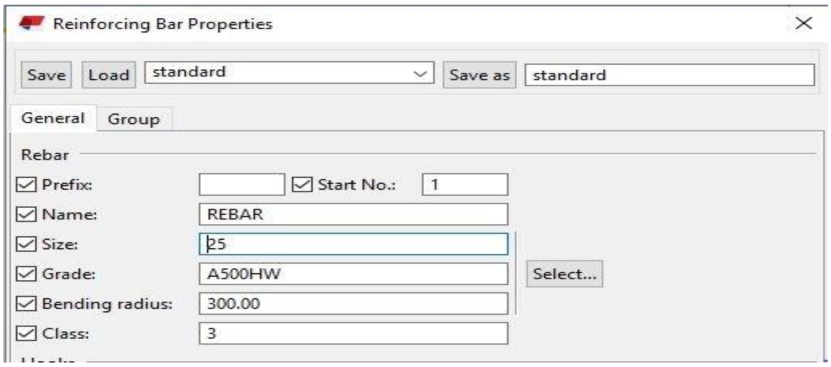

Figure 26. Reinforcement property dialogue box

The reinforcement rebar used is of grade A500HW. This is the commonly used material. It has a bending radius of 300 mm as shown in figure 26.

9 BIM data exchange/ collaboration

Above process of creating the single-family house model shows the use of different BIM tools for a single project. In the process ArchiCAD was used to create a design and further collaborated with Tekla Structures for the structural design with the help of ifc format. An ifc file format allows the exchange of model and non-graphical data between us. This standard file format results in better designs and an increased efficiency and productivity of the project. While designing a model in ArchiCAD it is kept in mind that, it is going to be shared with structural designer. Hence, all column and beam were defined initially in the created model. ArchiCAD has a built-in translator named 'Data Exchange with Tekla Structures' which is optimized to export models to Tekla Structures. This option was used to save the file.

In Tekla Structures, the model was inserted as a protected reference model via 'Insert reference model' tool. The entire model or only the elements on the model can be imported. In this study, google drive was used to share the file and project related communication. BIM tools aided to solve the design issues by offering to communicate the design in different ways, such as virtual model interactive format. Hence, the collaboration between architect engineer and structural engineer can be done seamlessly in their own independent space and time.

10 Interior Design

The 3D viewing tool is beneficial in changing the pre-conceived ideas of design while working on preliminary construction phase. Since the traditional methods used by the owners to construct the existing single-family house redesigned in this thesis did not offer a visualization option, the owner of the house did not realise they would disagree with their initial plan after the construction. Therefore, when redesigning the model on ArchiCAD, the owners were given an opportunity to view the 3D model and make the design changes which they wished they could do for the existing building.

The interiors of the house were not designed in the early 2D plot of the single-family house. However, while redesigning the same single-family house for this thesis, the objects placement was done in detail with the help of an ArchiCAD function. This helps the parties of a project to anticipate the required products and the space to place them more conveniently. Additionally, ArchiCAD can sort out and hold the steadiness of 3D models which helped to update the progressions rapidly according to the changes demanded by the owner. Figure 27 is rendered from ArchiCAD and shows the placement of interior furniture defined by the owner. This is the top floor of the redesigned single-family house with a limited space in comparison to other floors. Designing in ArchiCAD helped to pre-assume the required space for the kitchen and create the remaining space as a living area with just a small brick wall partition. Furthermore, all the furniture was placed after calculating the living space area and the material amounts required. This helped to limit the time, quantities and cost in the design phase itself.

Figure 27. Interior design rendering

Similarly, as shown in figure 28, a hand basin outside the bathroom was designed in the ground floor of the building. Due to 3D visualization features in ArchiCAD, the empty space was recognized. Utilizing the space, a basin of perfect dimensions was chosen and fitted in the space in the model. The owner had not been able to recognise the need of a basin when the house was first designed using traditional method. Hence, the use of ArchiCAD to re-create the design for this thesis helped to visualise the idea and make the decision to progress in the early stage of design.

Figure 28. Rendered image of basin placement

Therefore, these small changes at design phase help to reduce the efforts and costs required in later phase. While rendering these images in ArchiCAD, the designer is able to set the desired climate, lighting and environment.

11 Quantity Take-off

Quantity take-off is used to measure the building elements, which is later, used to estimate their cost and workload. In the process of QTO, the project is broken down into smaller units, which are easy to measure and estimate. It is taken as one of the most important tasks in the process of construction.

In a BIM based approach, the QTO can be directly automated. Mostly, a BIM tool utilizes the geometric properties of elements and provides quantities like area, volume in documented form. BIM based QTO offers easier and more detailed project cost estimation, minimizing time and expenses. ArchiCAD is one of the most used design tools and it includes routines to extract quantities from the model automatically. The designing of model created in this thesis is done in ArchiCAD, hence the QTO is extracted using the same tool. In ArchiCAD, the elements to be measured are selected and the measurement parameters are defined. ArchiCAD serves a wide range of pre-defined parameters. It also allows users to define new measurement parameters using the GDL programming feature. The interactive user interface of ArchiCAD offers more options for arranging and presenting the data. It allows users to edit some of the fields directly on the starting sheet by creating new configurations, and these changes are later processed automatically in the building model. Furthermore, ArchiCAD can save output tables in different formats, including excel, pdf and dwf. Therefore, the further processing of data is minimized. [21.] The thesis also looks at how QTO is done with Tekla Structures. In Tekla Structures, material quantification can be quickly generated by using the organizer tool.

11.1 Quantity Take-off and Cost Estimation from ArchiCAD

After performing the quantity take-off using ArchiCAD, the procedure to benchmark the prices of bricks, windows and doors of the created model is attempted. The goal of benchmarking the price is to adjust and understand the price estimation of the model created in this thesis. The price from the analysis list of Nepal government was inputted in the result obtained from quantity take-off in order to get the cost estimation of data. The estimation procedure is less time consuming than collecting the data. Since most of the data's while constructing the single-family house using traditional method was not recorded, the comparison of costs is only done between use of bricks, doors and windows, and amount of concrete and steel used in footings, beams and columns in traditional process and BIM process.

The Interactive schedule tool in ArchiCAD is automated method to evaluate and quantify the contents of geometric data and information of building elements which is presented in a systematic form of tables and chart.

The default scheme contains predefined schedules available that is linked to every element type and are in ‘Schedules’ under the ‘Project Map’ tab of ‘Navigator’ toolbox. The schedules are based on elements, components and surfaces.

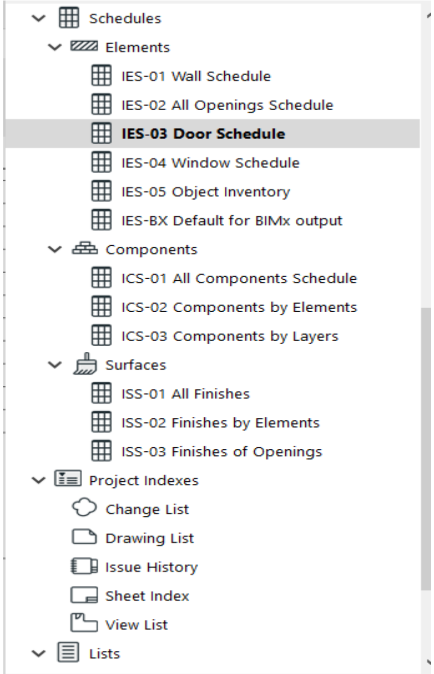

Figure 29. Schedule navigation tab

Elements lists contain basically any kind of elements and includes all the related properties like area and volume, character properties like thermal resistance, and strength. Likewise, component lists are enhanced and objected to make list of information about sub element of composite, profile or basic elements. The enhanced list could include the volumes of certain skin of composite wall or certain characterstics of floor slabs. Surface lists provide information about exposed areas and finishes among the surfaces. The schedules helps to evaluate and visualiize the final finishes of the building. Here are some of the examples that have been gathered in this theis model based on doors, windows, objects.

In the ArchiCAD model, double clicking the ‘IES 03 All Openings Schedule’, the information chart opens up with different categories of opening functions. There is a ‘Scheme Settings’ button on the top right of the information chart. The scheme chart has various list of existing schedules. The ‘All Openings Schedule’ is selected and there are various criterias for selection of the classification like doors or windows. Below the criteria field there is ‘Field’ box where one can add the needed property for instance addition of element ID, quanity, zone, Nominal W*H size and other different properties according to the requirements of designer as shown in figure 30.

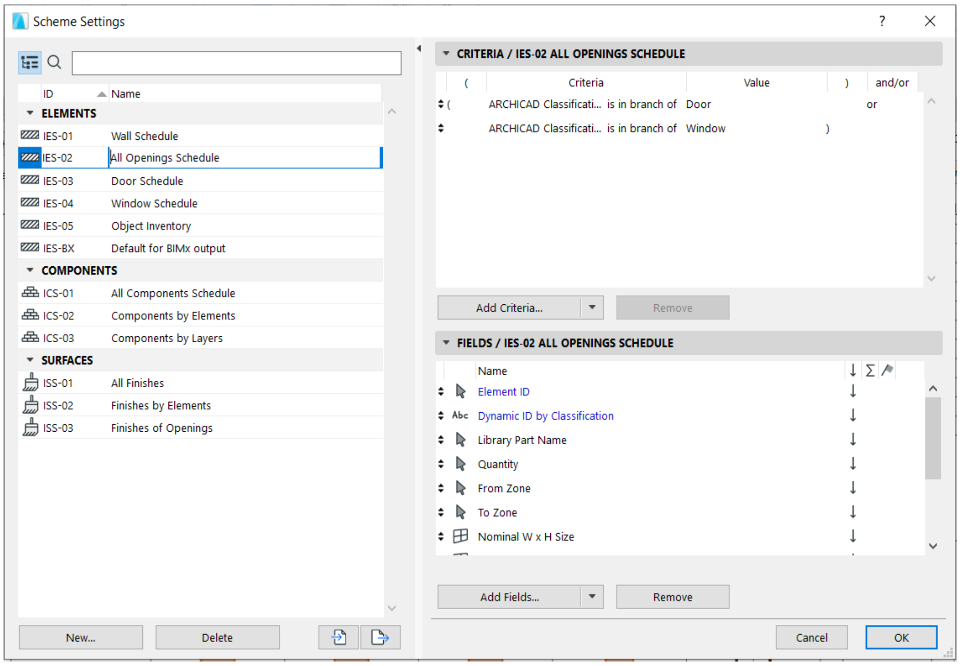

Figure 30. Scheme setting window for created model

In the model created in ArchiCAD, the information charts are verified and are evaluated easily, and one can modify the height, text style and other font styles. This also allowed to have access to the settings and make changes directly in the schedule.

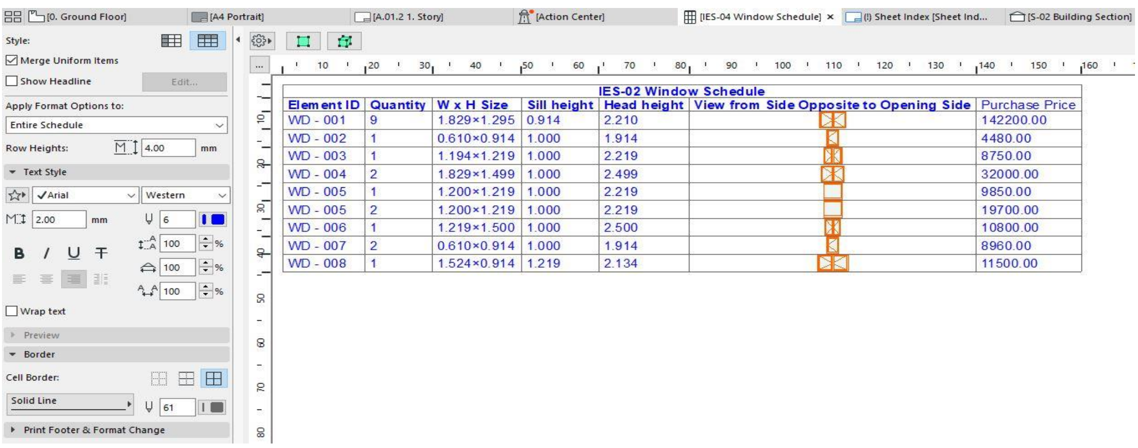

Figure 31. Schedule formatting window for created model

In order to estimate cost of the single-family house designed in ArchiCAD, the severel steps are follwed using interactive schedules. First step is to set cost values for elements in the created model. For instance, the cost calculation of door was done by using the feature of interactive scheduling. For this at first the object is selected and the purchase price is added to the ‘Classififcation and Properties’ of door as shown in figure 32.

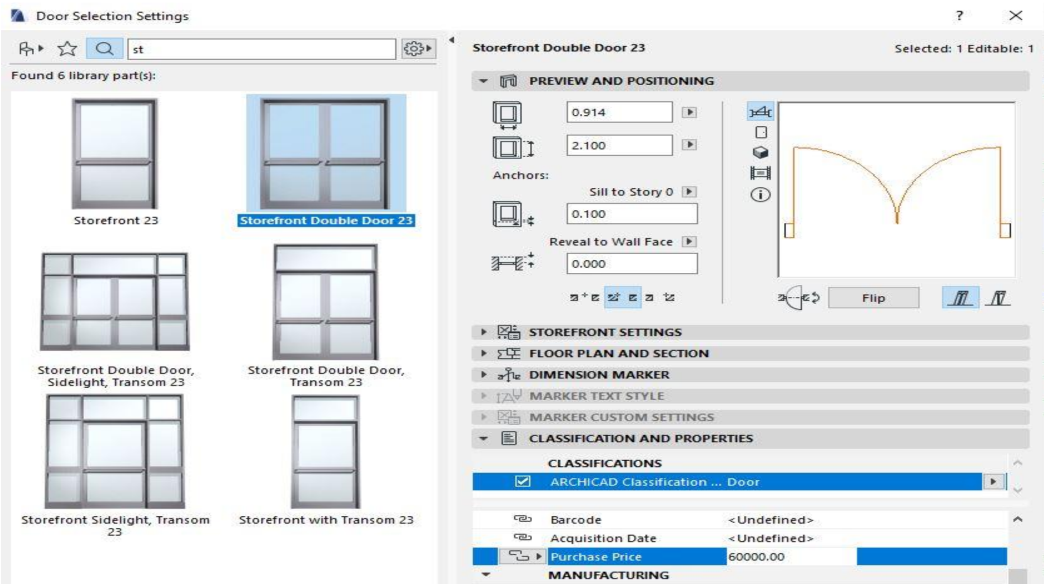

Figure 32. Door setting classification window

After the addition of price in the object properties, a new schedule element is added for only three front floors of the design for the cost estimation of door.

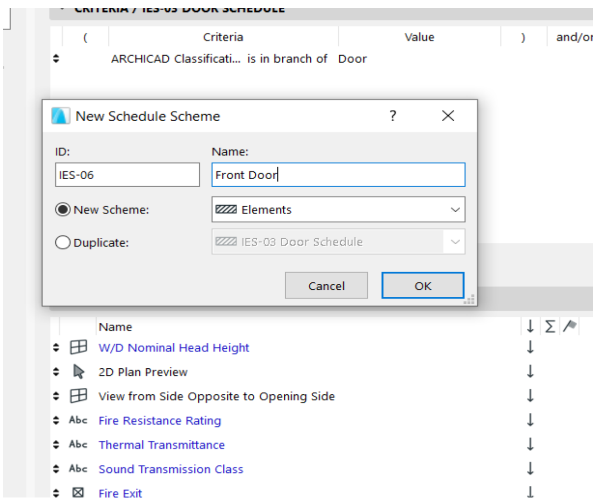

Figure 33. Schedule scheme window

After the addition of correct parameters in the scheme settings, the schedule for front three doors were traced from interactive scheduling. Also, by enabling the summation feature, the individual cost of each door as well as the total cost of the door can be found in schedule. However, the scheme settings can allow to add or remove any fields of parameters of properties from the schedule narrowing the content of the field.

ArchiCAD also allows to save interactive schedule to Microsoft Excel, DWF, PDF or Tabbed text for further documentation. The CTRL shift and save button redirects the straight save whereas in ‘save as’ option the designer can save the schedule in any of the above-mentioned format.

Table 5. Cost estimation of bricks. [24.]

Number of bricks to purchase	31,648
Brick size	115mm × 57mm × 240mm
Cost per brick	16.39 NRs
Total	**518,711**

Table above indicates the number of estimated bricks and cost per brick needed to build the walls of recreated single-family house in ArchiCAD. The size of the brick is commonly used standard Nepali brick dimension. Total number of bricks estimated to build the single-family house were multiplied by the current price of the brick to obtain the result. The quantity take-off result is available in appendix (3).

The following two tables show the price estimation for the doors and windows of the single-family house project. Data collected from the quantity take-off is inputted along with the price taken from the rate analysis of Nepal government to obtain the result. The following estimation is based on the current price of timber, glass, transportation and carpentry taken from rate analysis of Nepal government.

Table 6. Cost estimation of doors.

s. n	Dimension (m ²)	Quantity	Price/per (NRs)	Total price (NRs)
1.	0.9*2.1	12	7,600	91,200
2.	0.914*2.1	3	60,000	180,000
3.	0.737*2.1	1	6,900	6,900
To-tal		**16**		**278,100**

The table above indicates the size of the doors at their price. The total number of doors used in the building is 16. Dimensions and numbers have been taken from the quantity take-off and their prices are different depending on their dimension as seen in table above. However, there are 3 doors of dimension 0.914*2.1 m ² which are particularly expensive than other doors. These are the front doors which are specially carved and designed only using timber wood. The other doors are made of plywood which is comparatively cheaper.

Table 7. Cost estimation of windows.

s. n	Type	Dimension (m ²)	Quan-tity	Price/per (NRs)	Total price (NRs)
1.	Double window	1.829*1.295	9	15,800	142,200
2.	Storefront win-dow	1.2*1.219	3	9,850	29,550
3.	Single window	0.610*0.914	3	4,480	13,440
4.	Double window	1.194*1.219	1	8,750	8,750
5.	Double window	1.829*1.499	2	16,000	32,000
7.	Double window	1.219*1.5	1	10,800	10,800
8.	Double window	1.524*0.914	1	11,500	11,500
	Total		**20**		**248,240**

The table above shows the cost estimate for the windows of the recreated single-family house for this thesis. The total number of windows in the building is 20, while there are

12 double windows, 3 single windows and 3 Storefront windows. The price of the windows depends on the size of the windows. The total cost calculated for windows is 248,240 rupees, as shown in the table above.

11.2 Quantity Take-off and Cost Estimation from Tekla

In Tekla Structures, the quantity of concrete and steel rebar was calculated to estimate the total cost of constructing beams, columns and footings of the recreated single-family house model. The concrete material used in the structure is M25, which has the crushing strength of 25nm/mm² at 28 days. The minimum requirement of crushing strength of concrete set in Nepal National Building Code, NBC 205:1994 is 15nm/mm² at 28 days for a 150 mm cube [22.]

The total volume of concrete output result of recreated model from Tekla Structures is 30.6 m³. The result is available in table of appendix (5). The concrete yield result from Tekla Structures is the wet volume of concrete.

In order to calculate amounts of cement, sand and aggregate, the following calculation is performed:

The ratio of cement, sand and aggregate in M25 type concrete is $1{:}1{:}2$

Dry volume of concrete $= 52\%$ more of wet volume [23]

For $1\ \mathrm{m}^3$ of concrete,

$$Dry\ volume\ of\ concrete\ =\ 1+\ (52/100)*1=\ 1.52\ m^3$$

Therefore, for 30.6 m³ of wet concrete,

$$Dry\ volume\ =\ 30.6*1.52\ =\ 46.5\ m^3$$

Now, Sum of ratio of M25 concrete is

$$1 + 1 + 2 = 4$$

Hence,

$$Volume\ of\ cement = (1/4) * 46.5 = 11.6\ m^3$$

$$Volume\ of\ sand = (1/4) * 46.5 = 11.6\ m^3$$

$$Volume\ of\ aggregate = (2/4) * 46.5 = 23.3\ m^3$$

Again,

The amount of cement in kg is

$$11.6 * 1440 = 16740\ kg$$

Where, density of cement is 1440 kg/m^3

A bag contains 50 kgs of cement, the number of bags needed for the recreated single-family house model is

$$11.6 * 1440 = 16740\ kg$$

The prices of building materials in Nepal, with the cost of transportation and labour included are given in table 8 below.

Table 8. Rates of different materials in Nepal [24]

Materials	**Unit**	**Cost (Rs)**
Cement	bag (50kg)	920
Sand	m^3	3,998
Aggregate	m^3	3,998

Next, the total estimated cost of concrete used in constructing beams, columns and footings are calculated based on table 8. The results are shown in table 9.

Table 9. Total cost of materials used

Material	**Amount**	**Cost (Rs)**
Cement	335 bags	308,200
Sand	11.6 m^3	46,378
Aggregate	23.3 m^3	93,153
	Total Cost: 447,731	

Therefore, the total cost of concrete estimated using Tekla Structures is 447,731 NRs. Similarly, the total amount of the steel used in the created model is exported from Tekla Structures which is mentioned in appendix (5).

According to the output exported from Tekla organizer the total weight of steel used is 2097 kg. The cost of TMT bars in Nepal is 77 Rs per kg, and including the transportation cost it costs 79 Rs per kg. [24.]

Therefore, the total cost of steel used in beams, columns and footings of recreated model for this thesis is

$$2097 * 79Rs = \mathbf{165,663\ NRs}$$

Hence, the total cost of steel used in structural parts of recreated single-family house is 165,663 Nrs.

12 Comparisons and Results

The aim of the practical project of redesigning an existing single-family house in this thesis was to estimate the quantity and costs of the house with the BIM tools and compare the costs, element by element, to the actual costs of the house when it was built using the traditional method. All the costs from the current redesign have been calculated and these costs are compared to the actual expenditure when constructing the building.

Table 10. Actual cost expenditure on components

Components	**Amount**	**Unit cost (NRs)**	**Total cost (NRs)**	**Inflation cost (2020) (NRs)**
Cement	355 bags	330	117,150	354,608
Sand	13.4 m³	1,340	17,956	54,352
Aggregate	26 m³	1,400	36,400	110,181
Steel	2109 kgs	30	63,270	191,516
Bricks	37840	5.5	208,120	629,970
Doors and Windows	-	-	176,387	533,916
Total			**619,283**	**1,874,543**

Table 10 above shows the cost expenditure in different components of the constructed house. The mentioned quantities of cement, sand, aggregate and steel are only for the construction of beams, columns and footings. In order to compare the cost estimated using BIM and the actual cost spend on purchasing the materials, all the costs are converted to the current cost using the inflation calculating website. [25.] The prices include labour and transportation cost as well. The conversion showed that the inflation-adjusted total costs of the actual construction would be 1,874,543 NRs. The inflation-adjusted total costs of material use are compared with the results from the QTOs done with ArchiCAD and Tekla Structures.

Table 11. Cost estimated from BIM tools

Components	**Amount**	**Unit Cost (Rs)**	**Total Cost (Rs)**
Cement	335 bags	920	308,200
Sand	11.6 m³	3,998	46,377
Aggregate	23.3 m³	3,998	93,153
Steel	2097 kgs	79	165,663
Bricks	31,648	16.39	518,711
Doors and Windows			527,303
Total			**1,659,407**

Table 11 shows the amount and cost calculated using the BIM based tools. In table 12 the inflation-adjusted total costs of material use are compared with the results from the QTOs done with ArchiCAD and Tekla Structures.

Table 12. Comparison between two different methods

Components	**Actual Amount**	**BIM Based Amount**	**Inflation-ad-justed cost**	**BIM based cost (NRs)**
Cement	355 bags	335 bags	354,608	308,200
Sand	13.4 m³	11.6 m³	54,352	46,377
Aggregate	26 m³	23.3 m³	110,181	93,153
Steel	2,109 kgs	2,097 kgs	191,516	165,663
Bricks	37,840	31,648	629,970	518,711
Doors and Windows	-	-	533,916	527,303
Total	**-**	**-**	**1,874,543**	**1,659,407**

The table above shows a significant difference in cost when the single-family house is redesigned using BIM technology. The amount of material use has been deduced while using the BIM model. However, there has been only a slight change in cost of doors and windows. Due to the same frame sizes and material use in door and window, the cost could not be reduced. The considerable saving in the cost is witnessed in bricks. The resulting number of bricks to be purchased calculated from ArchiCAD were substantially less than the actual bricks used. Similarly, Tekla Structures helped to reduce the amount of concrete and steels.

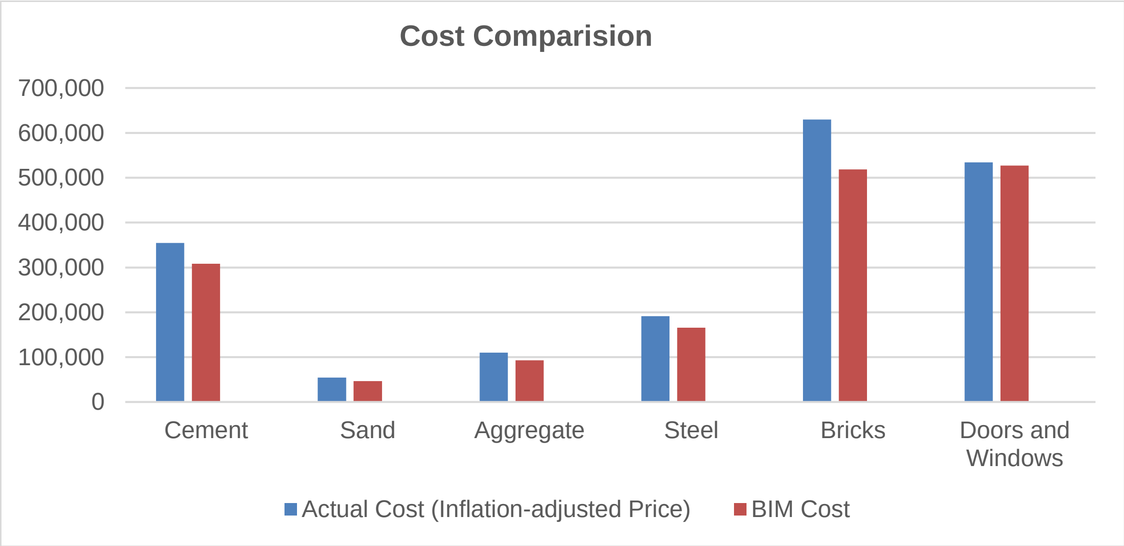

Figure 34. Bar graph showing cost comparison

In figure 34, the bar chart shows side to side comparisons of two different methods. The difference in values in a small-scale single-family house is remarkable which suggest there is a possibility of achieving vast contrast in values when traditional method is replaced by the BIM technology in large constructions. In terms of percentage BIM tools managed to reduce 11.5% cost in materials. There is a significant difference in amount of cement and bricks used in two different methods. The bar below shows the comparison between these two materials in terms of amount used.

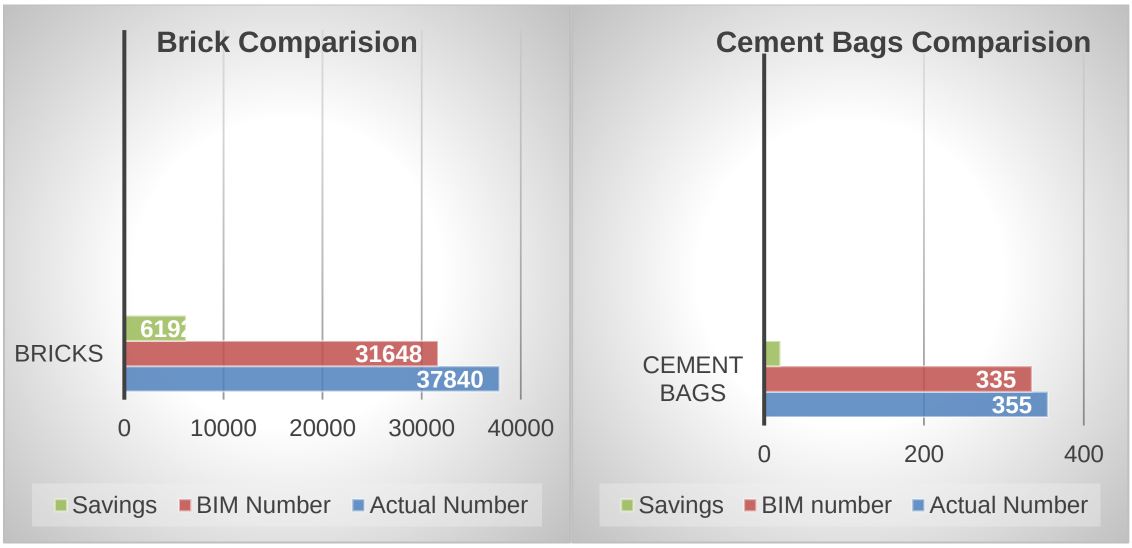

Figure 35. Charts comparing number of bricks and volume of cement

The charts in figure 35 shows the comparison between most affected components while constructing a house. The number of bricks and volume of cement to be purchased is not rightly estimated most of the time while using traditional method of construction. In this single-family house built using traditional method both the materials were overused. There can be seen 16 % of drop in the number of bricks to be purchased or used after using BIM tools. Similarly, the consumption of cement is dropped by 5.6 %. Hence, with the use of BIM tools, the estimation and purchase of these materials can be done precisely.

13 Conclusion

The thesis has outlined the relevance of BIM tools in the construction process. The possibility to complete a project in a designated short period of time is remarkably increased using BIM tools. As in the case study of Casa Magayon discussed in chapter 5, the stunning 3D visuals in the pre-construction phase help to conceptualize the end project, minimize the errors, fulfil the owner's prerequisites and win the trust of financers in big projects. The Casa Magayon project shows that the possibility to complete the project in a designated short period of time is remarkably increased using BIM tools. Additionally, Tekla Structure is also one of the most popular modelling tools used all over. The software provides a variety of options to smoothly design structural models. The key feature of BIM modelling is seamless linking between different design tools. The architectural model for the existing single-family house discussed in chapter 6 was created in ArchiCAD and linked with Tekla Structures by an ifc file in this thesis.

In order to validate the importance of BIM technology, the single-family house was redesigned with ArchiCAD and Tekla Structures. The residential building is located in Kathmandu, Nepal. Hence, the traditional methods practiced when building a house in Nepal were specified. The country being geographically diverse, the construction process and cost varies according to the location. However, the process of acquiring the building permit is still extremely inconvenient and long. The thesis primarily focused on interacting with the user interface of two key BIM tools; Tekla Structures and ArchiCAD. It showed the features of these tools and provided the guidelines on how to use them. The final goal was to estimate the amount of materials used to construct the different parts of the redesigned single-family house using BIM tools and comparing them to the amount of materials used in the actual, traditional construction. Eventually, the costs evaluated by BIM technology yielded a smaller cost expenditure than the traditional method of construction. Therefore, the material use can be reduced by precisely making early estimations, controlling the wastage, and making necessary design changes. The use of ArchiCAD and Tekla structures in this project yielded a16% and 5.6% drop in the amount of bricks and cement required in the construction, respectively. The cost saving turned out to be 11.5%. Even though the comparison was done for some specific parts of the house, it is enough to conclude that the material use saving can be done, resulting in savings in constructing costs. Furthermore, 3D design visualization helped the owner of the house to visualise the possible changes needed in the house which was not possible in the first traditional construction. Thus, the satisfaction of a customer is ensured by the BIM tool features.

In conclusion, ArchiCAD and Tekla Structures can be said to be major tools to ratify the demand of BIM in the construction industry. BIM could be a considerable solution for the construction industry in a country like Nepal, where the construction process is chaotic, disorganized and not documented. However, it is also necessary to make the legal process smooth and adapt the BIM technology in guidelines.

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Appendix 1. Old Floor Plan

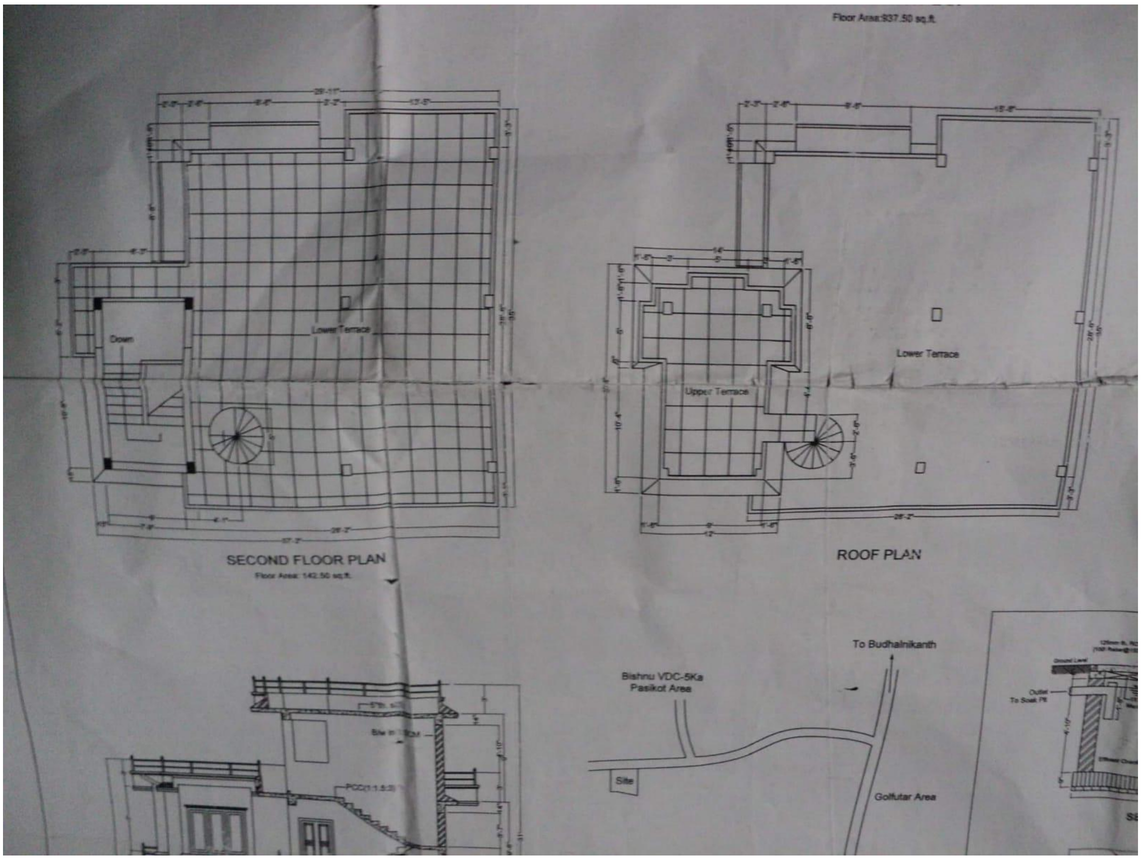

Figure 1. Floor plan plotted in 2D

Appendix 2. ArchiCAD Publications

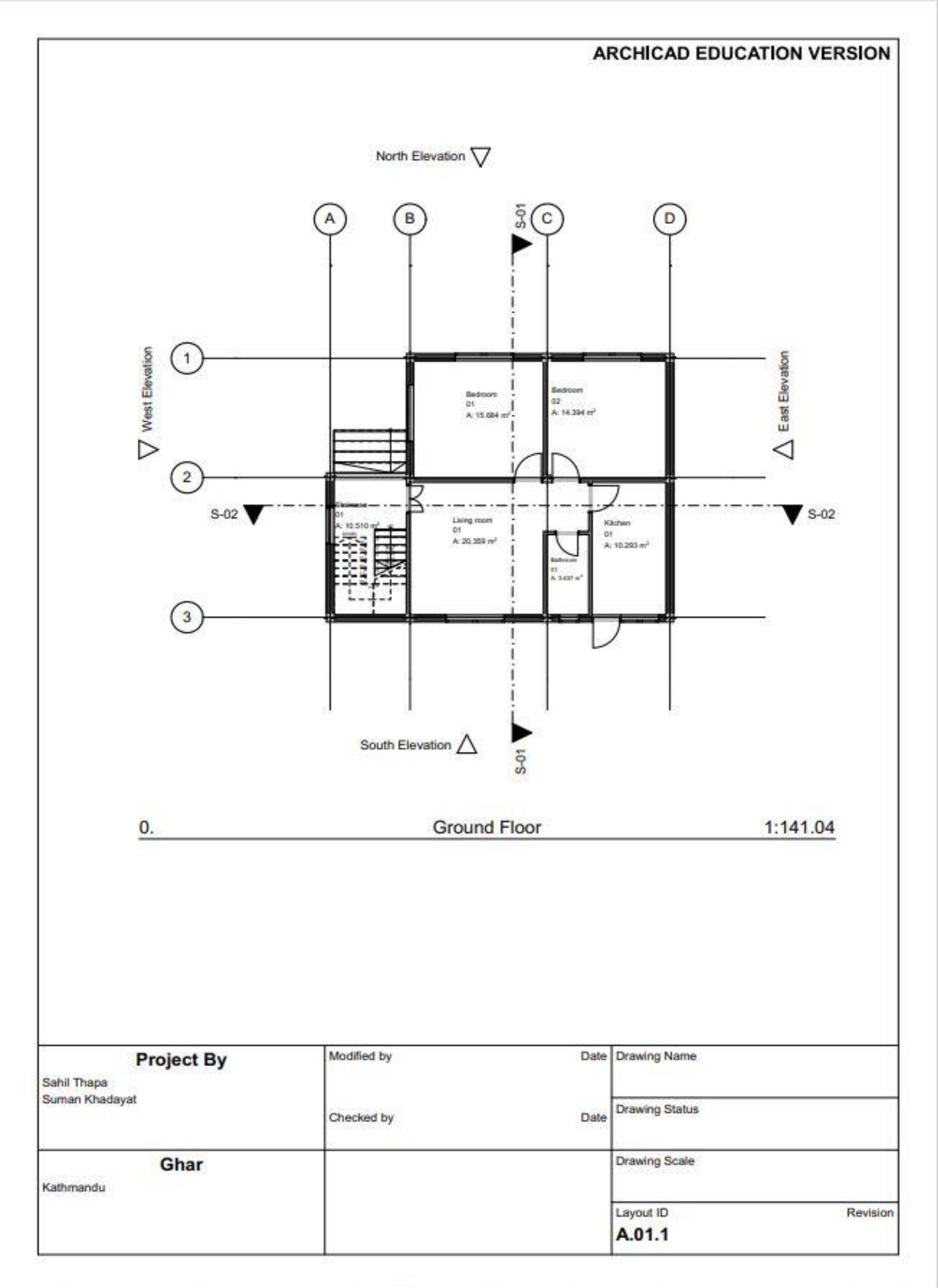

Figure 1. Ground floor plan

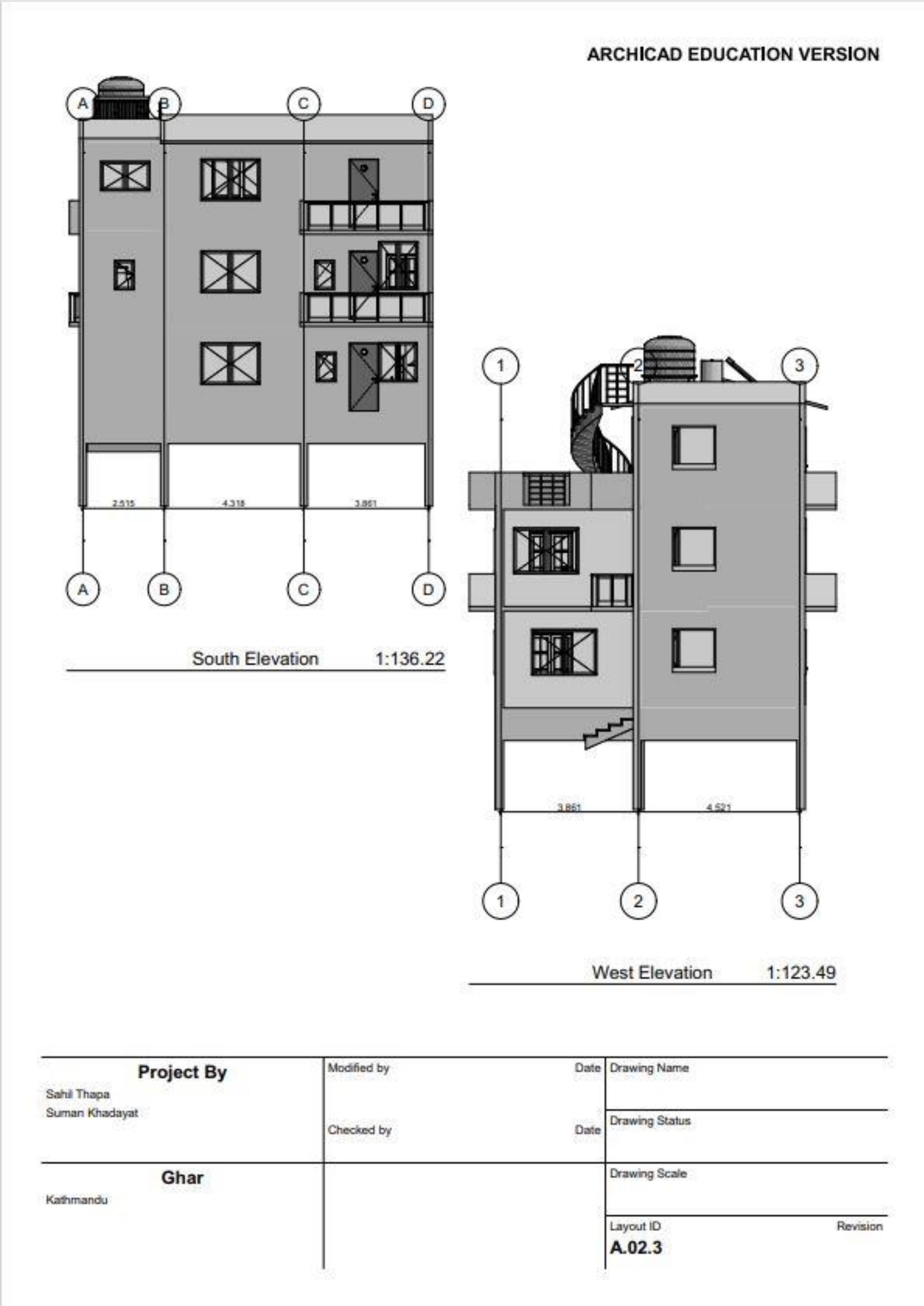

Figure 2. South and West elevations

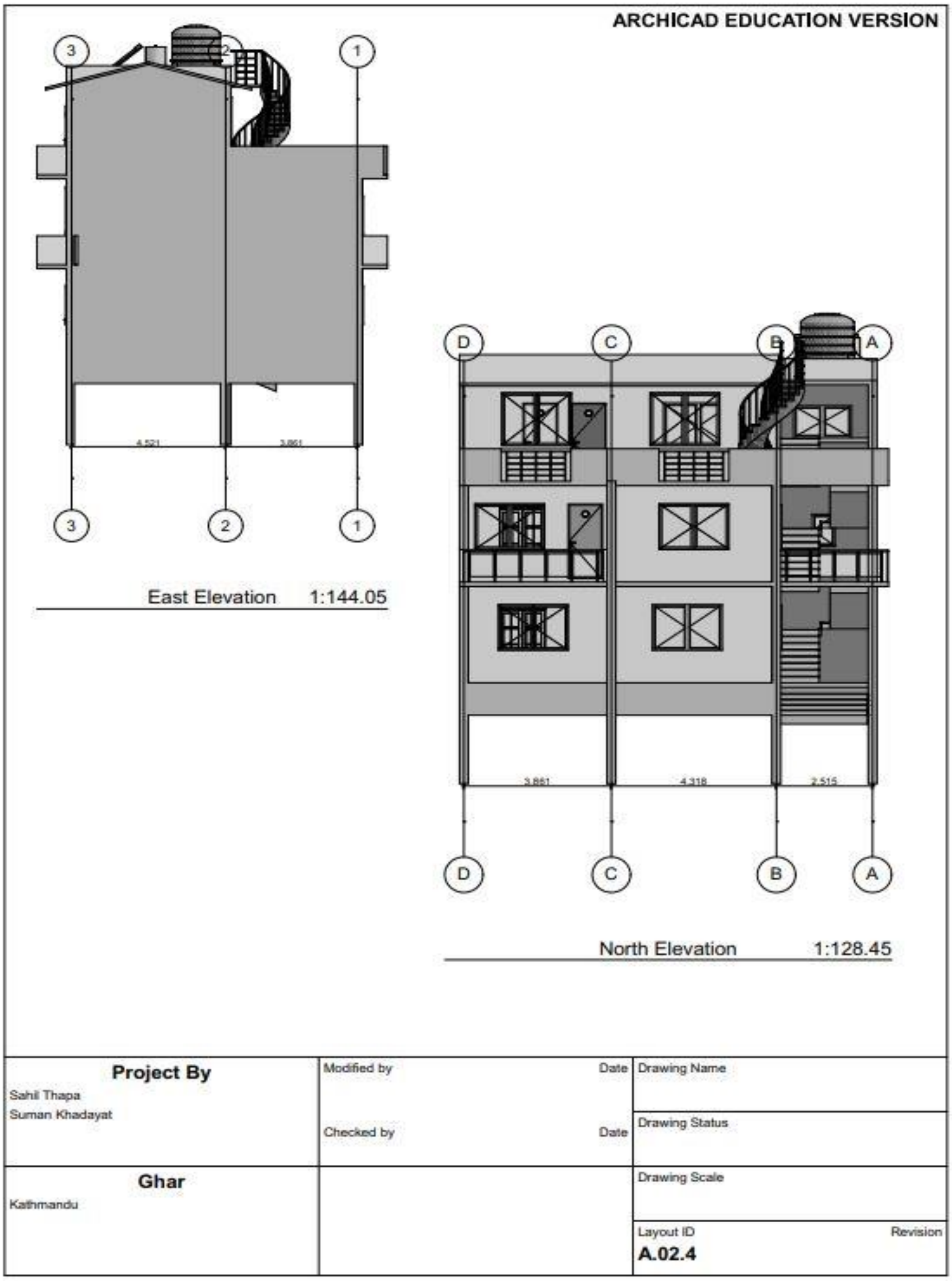

Figure 2. East and North elevations

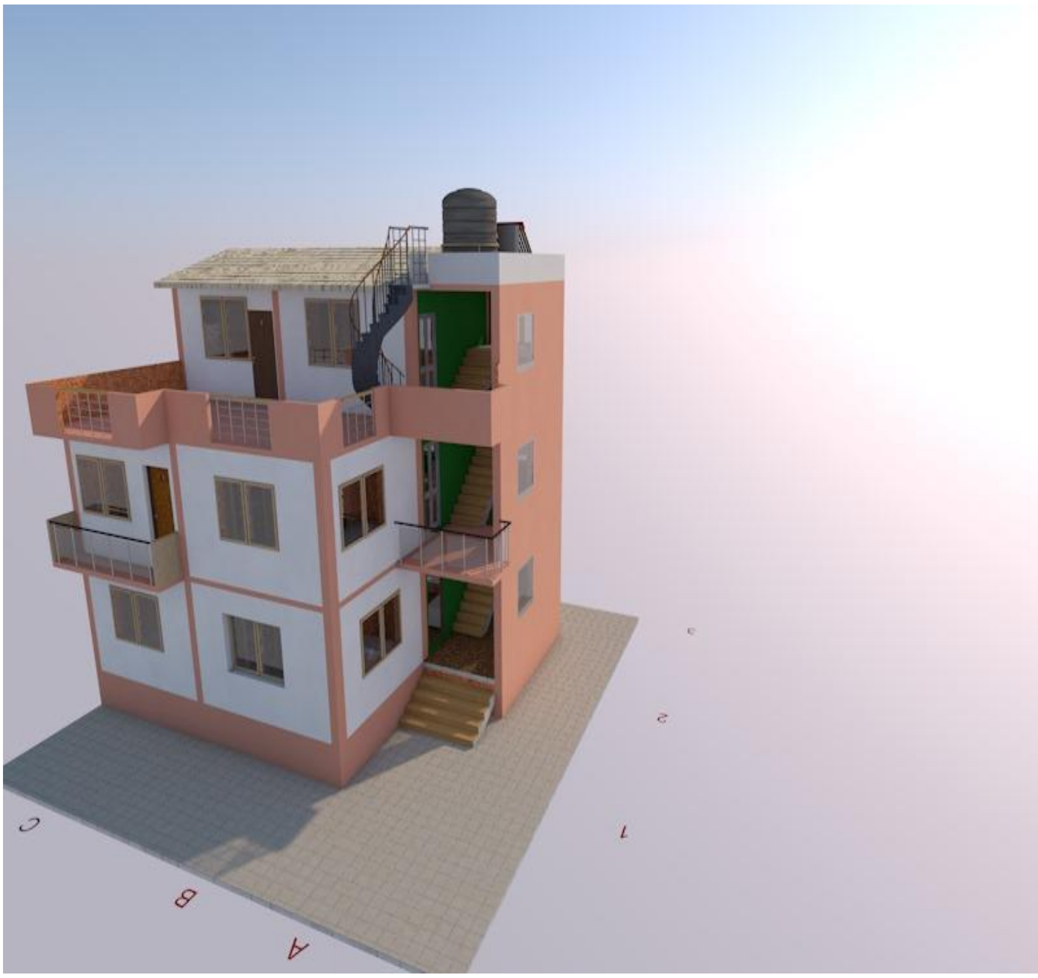

Figure 3. 3D rendered front view

Appendix 3. Quantity Take-offs from ArchiCAD

Element ID	Height [m]	Brick type and measures	No. of bricks to purchase	Cost Per Bricks	Total Cost
SW - 001, Brick, Exterior					
	2.845	Nepal Standard - 115 mm × 57 mm × 240	509	16.39	8342.51
	2.845	Nepal Standard - 115 mm × 57 mm × 240	652	16.39	10686.28
	2.845	Nepal Standard - 115 mm × 57 mm × 240	711	16.39	11653.29
	2.845	Nepal Standard - 115 mm × 57 mm × 240	758	16.39	12423.62
	2.845	Nepal Standard - 115 mm × 57 mm × 240	820	16.39	13439.8
	2.845	Nepal Standard - 115 mm × 57 mm × 240	842	16.39	13800.38
	2.845	Nepal Standard - 115 mm × 57 mm × 240	862	16.39	14128.18
	2.845	Nepal Standard - 115 mm × 57 mm × 240	955	16.39	15652.45
	2.845	Nepal Standard - 115 mm × 57 mm × 240	955	16.39	15652.45
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1101	16.39	18045.39
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1138	16.39	18651.82
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1172	16.39	19209.08
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1172	16.39	19209.08
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1274	16.39	20880.86
	2.845	Nepal Standard - 115 mm × 57 mm × 240	1568	16.39	25699.52
	2.845	Nepal Standard - 115 mm × 57 mm × 240	2215	16.39	36303.85
	2.845	Nepal Standard - 115 mm × 57 mm × 240	2370	16.39	38844.3
	4.572	Nepal Standard - 115 mm × 57 mm × 240	681	16.39	11161.59
SW - 002, Brick, Interior					
	0.914	Nepal Standard - 115 mm × 57 mm × 240	126	16.39	2065.14
	2.845	Nepal Standard - 115 mm × 57 mm × 240	96	16.39	1573.44
	2.845	Nepal Standard - 115 mm × 57 mm × 240	100	16.39	1639
	2.845	Nepal Standard - 115 mm × 57 mm × 240	100	16.39	1639
	2.845	Nepal Standard - 115 mm × 57 mm × 240	113	16.39	1852.07
	2.845	Nepal Standard - 115 mm × 57 mm × 240	357	16.39	5851.23
	2.845	Nepal Standard - 115 mm × 57 mm × 240	362	16.39	5933.18
	2.845	Nepal Standard - 115 mm × 57 mm × 240	376	16.39	6162.64
	2.845	Nepal Standard - 115 mm × 57 mm × 240	388	16.39	6359.32
	2.845	Nepal Standard - 115 mm × 57 mm × 240	448	16.39	7342.72
	2.845	Nepal Standard - 115 mm × 57 mm × 240	473	16.39	7752.47
	2.845	Nepal Standard - 115 mm × 57 mm × 240	490	16.39	8031.1
	2.845	Nepal Standard - 115 mm × 57 mm × 240	835	16.39	13685.65
	4.572	Nepal Standard - 115 mm × 57 mm × 240	559	16.39	9162.01
SW - 003, Brick, Exterior					
	0.61	Nepal Standard - 115 mm × 57 mm × 240	59	16.39	967.01
	0.61	Nepal Standard - 115 mm × 57 mm × 240	72	16.39	1180.08
	0.61	Nepal Standard - 115 mm × 57 mm × 240	137	16.39	2245.43
	0.61	Nepal Standard - 115 mm × 57 mm × 240	143	16.39	2343.77
	0.914	Nepal Standard - 115 mm × 57 mm × 240	10	16.39	163.9
	0.914	Nepal Standard - 115 mm × 57 mm × 240	27	16.39	442.53
	0.914	Nepal Standard - 115 mm × 57 mm × 240	31	16.39	508.09
	0.914	Nepal Standard - 115 mm × 57 mm × 240	33	16.39	540.87
	0.914	Nepal Standard - 115 mm × 57 mm × 240	38	16.39	622.82
	0.914	Nepal Standard - 115 mm × 57 mm × 240	39	16.39	639.21
	0.914	Nepal Standard - 115 mm × 57 mm × 240	43	16.39	704.77
	0.914	Nepal Standard - 115 mm × 57 mm × 240	48	16.39	786.72
	0.914	Nepal Standard - 115 mm × 57 mm × 240	49	16.39	803.11
	0.914	Nepal Standard - 115 mm × 57 mm × 240	61	16.39	999.79
	0.914	Nepal Standard - 115 mm × 57 mm × 240	65	16.39	1065.35
	0.914	Nepal Standard - 115 mm × 57 mm × 240	130	16.39	2130.7
	0.914	Nepal Standard - 115 mm × 57 mm × 240	200	16.39	3278
	0.914	Nepal Standard - 115 mm × 57 mm × 240	204	16.39	3343.56
	0.914	Nepal Standard - 115 mm × 57 mm × 240	363	16.39	5949.57
	0.914	Nepal Standard - 115 mm × 57 mm × 240	437	16.39	7162.43
	0.914	Nepal Standard - 115 mm × 57 mm × 240	771	16.39	12636.69
	0.914	Nepal Standard - 115 mm × 57 mm × 240	799	16.39	13095.61
	0.914	Nepal Standard - 115 mm × 57 mm × 240	1000	16.39	16390
			31648		518710.72

Figure 1. Quantity take-off of walls

IES-02 Door Schedule				
Element ID	**Quantity**	**W x H Size**	**Purchase Price**	**View from Opening Side**
DOO - 001	1	0.900×2.100	7600	
DOO - 002	1	0.900×2.100	7600	
DOO - 003	1	0.900×2.100	7600	
DOO - 004	1	0.737×2.100	6900	
DOO - 007	1	0.900×2.100	7600	
DOO - 008	1	0.900×2.100	7600	
DOO - 009	1	0.900×2.100	7600	
DOO - 010	1	0.900×2.100	7600	
DOO - 012	1	0.900×2.100	7600	
DOO - 013	1	0.900×2.100	7600	
DOO - 014	1	0.900×2.100	7600	
DOO - 016	1	0.900×2.100	7600	
DOO - 017	1	0.900×2.100	7600	
ENTDOO - 00	3	0.914×2.100	180000	
			278100	

Figure 2. Quantity take-off of doors

IES-02 Window Schedule				
Element ID	**Quantity**	**W x H Size**	**View from Side Opposite to Opening Side**	**Purchase Price**
WD - 001	9	1.829×1.295		142200
WD - 002	1	0.610×0.914		4480
WD - 003	1	1.194×1.219		8750
WD - 004	2	1.829×1.499		32000
WD - 005	1	1.200×1.219		9850
WD - 005	2	1.200×1.219		19700
WD - 006	1	1.219×1.500		10800
WD - 007	2	0.610×0.914		8960
WD - 008	1	1.524×0.914		11500
				248240

Figure 3. Quantity take-off of windows

Appendix 4. Publications from Tekla Structures

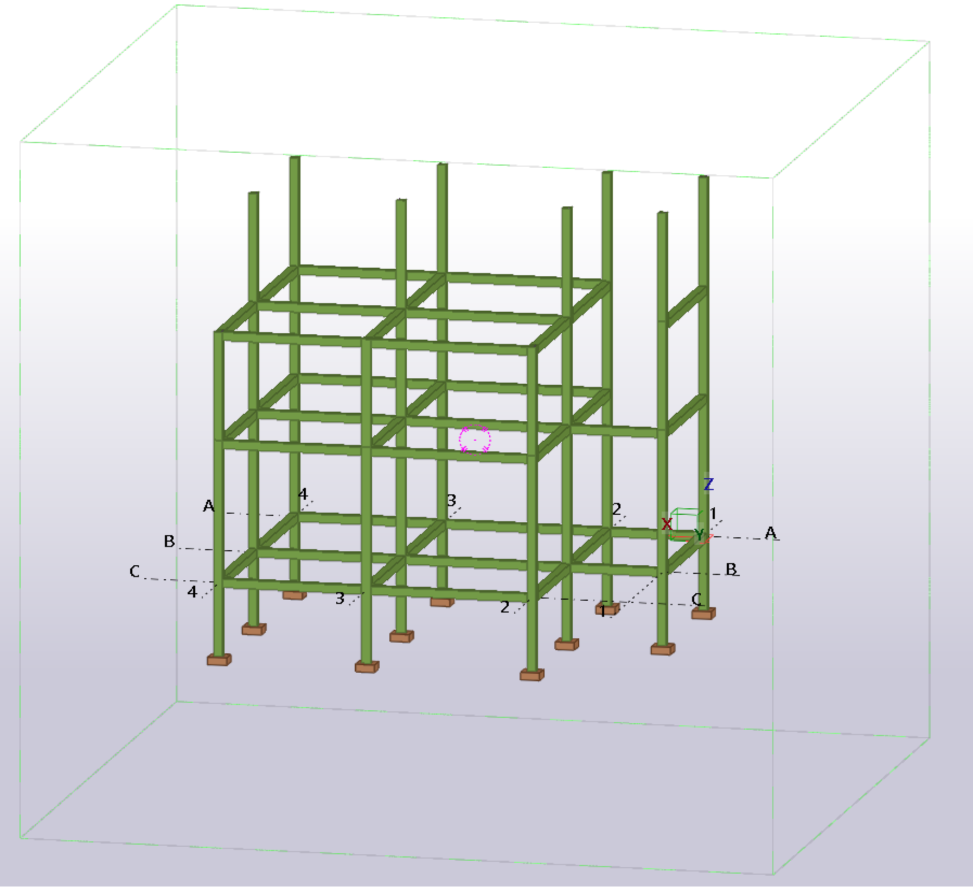

Figure 1. 3D view of structural model

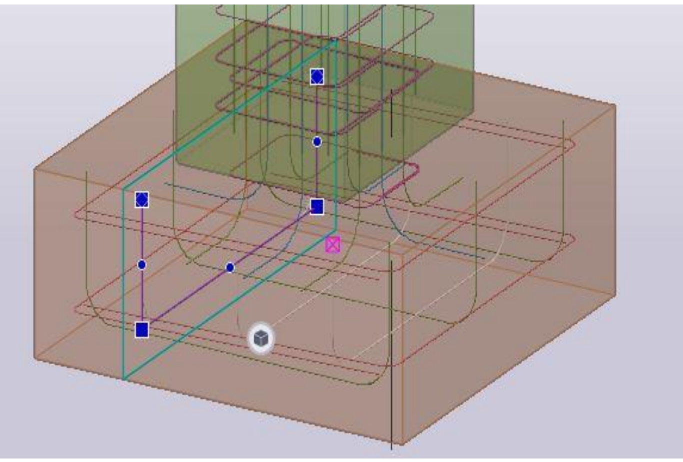

Figure 2. Pad footing and rebar

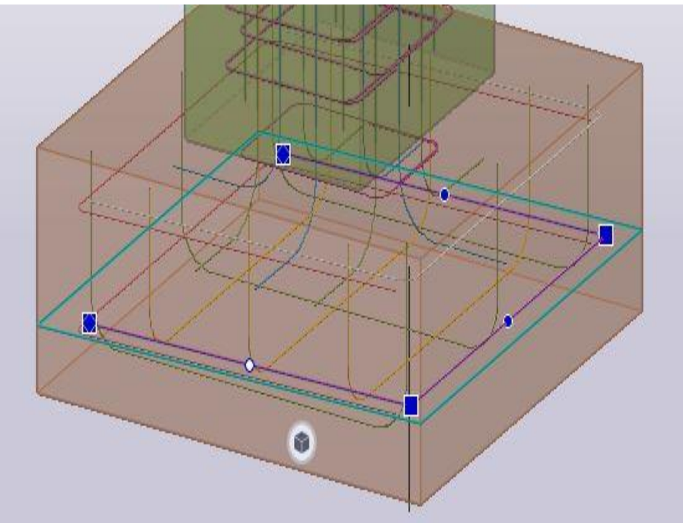

Figure 3. Rebars in footing

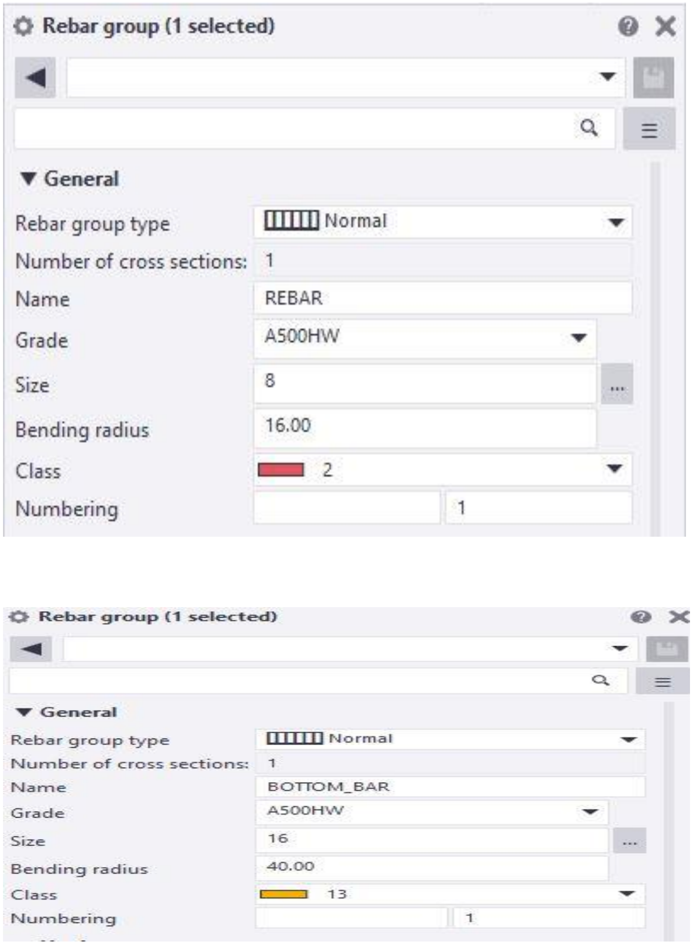

Figure 4. Rebar setting window

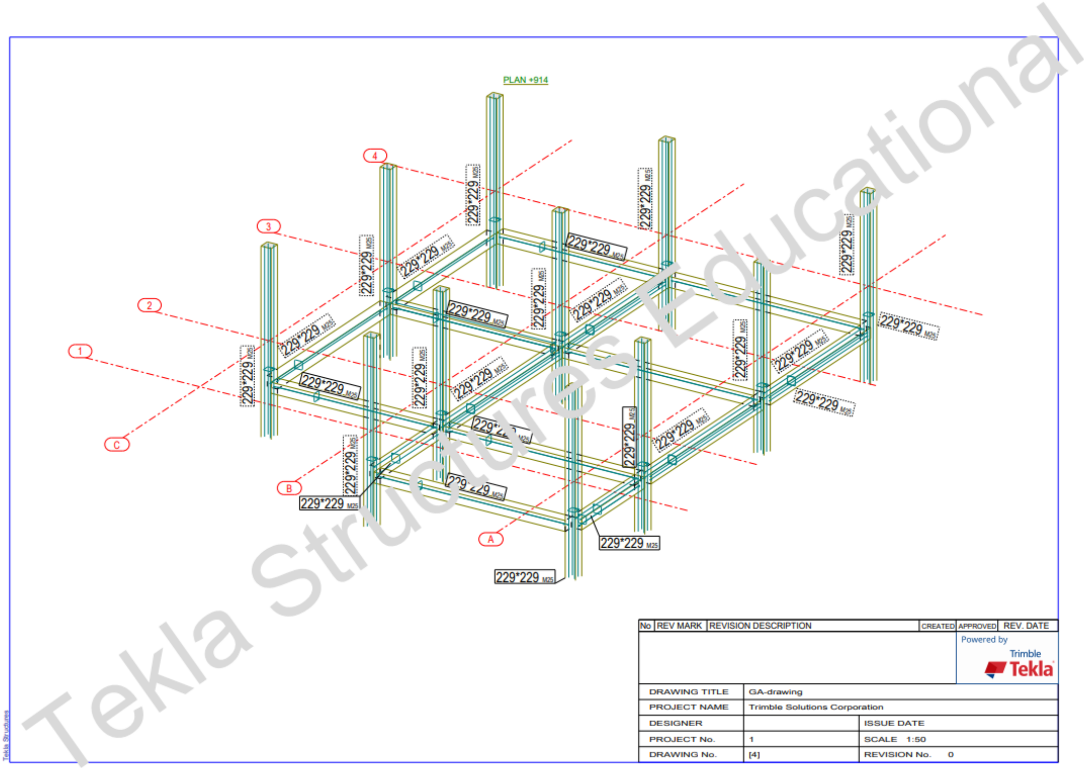

Figure 5. Bars and columns dimensions

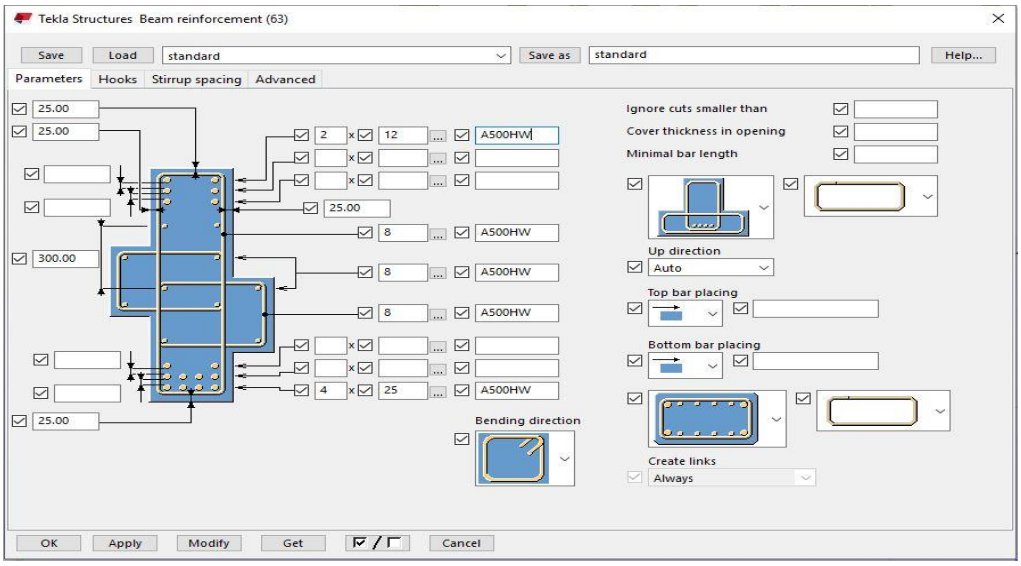

Figure 6. Reinforcement property window

Appendix 5. Quantity Take-offs from Tekla Structures

Count	Name	Material	Profile	Volume / m3	Weight / kg
2	BEAM	M25	229*229	0.1	288
1	BEAM	M25	229*229	0.1	288
11	COLUMN	M25	229*229	0.1	358
8	COLUMN	M25	229*229	0.1	358
3	BEAM	M25	229*229	0.2	457
2	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
1	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	540
1	BEAM	M25	229*229	0.2	540
4	BEAM	M25	229*229	0.2	540
3	BEAM	M25	229*229	0.2	540
1	BEAM	M25	229*229	0.2	540
2	Pilari	M25	229*229	0.3	715
9	Pilari	M25	229*229	0.3	835
11	FOOTING	M25	500*500	0.1	120
1	BEAM	M25	229*229	0.1	288
2	BEAM	M25	229*229	0.1	288
3	BEAM	M25	229*229	0.2	457
2	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
1	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	457
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	515
3	BEAM	M25	229*229	0.2	540
3	BEAM	M25	229*229	0.2	540
1	BEAM	M25	229*229	0.2	540
4	BEAM	M25	229*229	0.2	540
1	BEAM	M25	229*229	0.2	540
11	COLUMN	M25	229*229	0.1	358
8	COLUMN	M25	229*229	0.1	358
11	COLUMN	M25	229*229	0.3	715
11		M25		0.1	120
Total					
				30.6	73,478

Figure 1. Concrete volume take-off

Count	Name	Content type	Length / m	Weight / kg
88	REBAR	REBAR	1	1
11	STIRRUP	REBAR	0.81	1
11	BOTTOM_BAR	REBAR	0.64	1
11	BOTTOM_BAR	REBAR	0.68	1
22	REBAR	REBAR	1.26	2
22	STIRRUP	REBAR	0.84	3
4	TOP_BAR	REBAR	2.23	3
25	TOP_BAR	REBAR	3.58	4
13	TOP_BAR	REBAR	4.03	5
13	TOP_BAR	REBAR	4.24	5
4	BOTTOM_BAR	REBAR	2.23	6
17	STIRRUP	REBAR	0.72	7
2	STIRRUP	REBAR	0.76	8
11	STIRRUP	REBAR	0.84	9
25	BOTTOM_BAR	REBAR	3.58	9
4	STIRRUP	REBAR	0.68	9
13	BOTTOM_BAR	REBAR	4.03	10
13	BOTTOM_BAR	REBAR	4.24	10
25	STIRRUP	REBAR	0.68	11
26	STIRRUP	REBAR	0.68	12
44	REBAR	REBAR	5.63	3
76	STRAND	STRAND	2.845	2
Total				
			1,093.83	2,097

Figure 2. Steel weight take-off