PROJECT COORDINATION STUDY OF SHAREBIM ON STRUCTURAL SKELETAL OF A REINFORCED CONCRETE BUILDING

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PROJECT COORDINATION STUDY OF SHAREBIM ON STRUCTURAL SKELETAL OF A REINFORCED CONCRETE BUILDING

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"PROJECT COORDINATION STUDY OF SHAREBIM ON STRUCTURAL SKELETAL OF A REINFORCED CONCRETE BUILDING"** was prepared by **CHONG WENG KHUEN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Building Information Modelling (BIM) is implemented to improve coordination, planning, and management processes. The coordination and planning of BIM have been proven to reduce the communication and material procurement issues faced in the construction industry. This study aims to model and quantify a project building's structural model and to describe how important ShareBIM functions as a communication platform during the design phase to complete the study. The objectives of this study are to model the structural framing in the Autodesk Revit model; quantify the beam, column, and slab elements; and perform a statistical analysis of concrete, rebar, and shear link costs and quantities. A set of high-rise reinforced concrete building drawings has been used as a reference to achieve the aim and objectives in this study. A 3D skeleton model is built in Autodesk Revit and exported to ShareBIM to conduct a collaboration check of clash issues between MEP and the architectural model. The finalized model has been conducted structural analysis in Esteem 9, then compute quantity take-off and perform statistical analysis for the cost and quantities of concrete, rebar, and shear links. In short, structural material procurement was computed at a value of RM3.314 million for this building. This study helps to reduce any uncertainties and arguments during actual construction.

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LIST OF SYMBOLS / ABBREVIATIONS

Δc_{dev}	Deviation of concrete cover, mm
λ	Slenderness ratio
λ_{lim}	Limiting slenderness ratio
$A_{sw/s}$	Area of shear reinforcement per spacing
$A_{sw,min/s}$	Area of shear reinforcement per spacing
$A_{s,prov}$	Area of reinforcement steel provided, mm^2
$A_{s,req}$	Area of reinforcement steel required, mm^2
C_{min}	Minimum concrete cover, mm
C_{nom}	Nominal concrete cover, mm
f_{ck}	Characteristic of compressive strength, N/mm^2
G_k	Characteristics permanent load
M_{sx}	Bending moments at short span, kNm
M_{sy}	Bending moments at long span, kNm
Q_k	Characteristics variable load
S_{max}	Maximum shear link spacing, mm
V_{Ed}	Shear force, kN
V_{min}	Minimum shear resistance, kN
$V_{Rd,c}$	Design shear resistance, kN
%	Percentage
1D	One-Dimensional
1F	First Floor
2D	Two-Dimensional
3D	Three-Dimensional
4D	Four-Dimensional
5D	Five-Dimensional
6D	Six-Dimensional
7D	Seven-Dimensional
8D	Eight-Dimensional
A	Square mesh
AEC	Architecture, Engineering, and Construction
B	Rectangular mesh
BIM	Building Information Modelling

BOM	Bill of Material
BQ	Bill of Quantities
BRC	Reinforcing Fabric of Steel
BS	British Standard
C	Class
CAD	Computer-Aided Design
CDE	Common Data Environment
CIDB	Construction Industry Development Board
COBie	Construction Operations Building Information Exchange
DA	Small square mesh
EC	Eurocode
EC0	Eurocode 0
EC1	Eurocode 1
EC2	Eurocode 2
GF	Ground Floor
GIS-BIM	Geographic Information System
GSA	General Services Administration
HVAC	Heating, Ventilation, and Air Conditioning
IFC	Industry Foundation Classes
MEP	Mechanical, Electrical, and Piping
mm	Millimeter
MPa	Megapascal, N/mm^2
NCI	National Cancer Institute (NCI)
PWD	Public Works Department
QTO	Quantity Take-Off
R	250MPa yield strength rebar
RM	Ringgit Malaysia
T	460MPa yield strength rebar

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The workflow of the Architectural Engineering and Construction industry (AEC) has been altered by the inventive and revolutionary deployment of Building Information Modelling (BIM) technologies (Lee et al., 2015). BIM technologies enabled consideration of the rushed schedule, operating safety, and information accuracy during the design and construction stages. In fact, accumulated complex information has caused an issue during any stage of construction (Julide, 2016). Hence, BIM technologies may assist construction professionals, such as architects, civil, structural, mechanical engineers, etc., to coordinate design information among construction professionals in the BIM model at initial stages. A massive amount of data was integrated to enhance efficiency and lower issues during construction. Referring to the coordination of BIM increases the design quality and reduces the interference of clashes in the BIM model in the AEC industry (Lee et al., 2015). This is because the BIM model provides better visualisation based on a three-dimensional (3D) model that increases problem-solving efficiency.

According to Lee et al. (2015), all the data and information are integrated by the designed 3D model in the initial stages of the construction stage. The model enhances the work productivity of construction progress among different construction sectors. Therefore, the application of BIM coordination technologies lowers the transferring of information issues and increases the construction quality to prevent any delays in the project.

According to Harun (2017), the construction sector is one of the most essential industries in Malaysia's economy. The development of the construction industry is crucial since it is a crucial sector in assisting Malaysia in reaching its goal of becoming a developed nation. The first government project to employ BIM was launched in 2010, called the National Cancer Institute (NCI). However, the Malaysian government agreed in 2016 that BIM would be used in government projects. This is because of the many challenges faced during the implementation of BIM after the NCI project.

1.2   Importance of the Study

The outcome of this research demonstrates the behaviour of construction professionals in adopting BIM for coordinating their construction projects. This study also shows the importance of utilising BIM to overcome the problems faced in the construction design stage. Moreover, the study increases the knowledge of fresh construction professionals to continuously adopt BIM in their future construction projects due to the beauty of BIM technology.

1.3   Problem Statement

Rapid development has always existed in Malaysia since the 1990s until now. However, a study shows that the adoption of BIM is still lagging. This is because of the building industry's difficulties, which have slowed the adoption of BIM in Malaysia. Certain construction organisations and property developers have yet to implement BIM for the construction sector (Kong et al., 2020). Acceptance and knowledge of BIM among Malaysian contractors were investigated by CIDB (Kong et al., 2020). The proportion of BIM usage and awareness in Malaysia is displayed in Figure 1.1 (Kong et al., 2020). The chart shows that the percentage of BIM adoption can be considered high, but the awareness of BIM is low. In other words, lack of awareness might lead to improper use of BIM technology. Hence, from a summary of the chart, it can be concluded that most of the BIM adopted construction organisations might not fully use the benefits of BIM. Thus, it might cause waste during the construction and design stages.
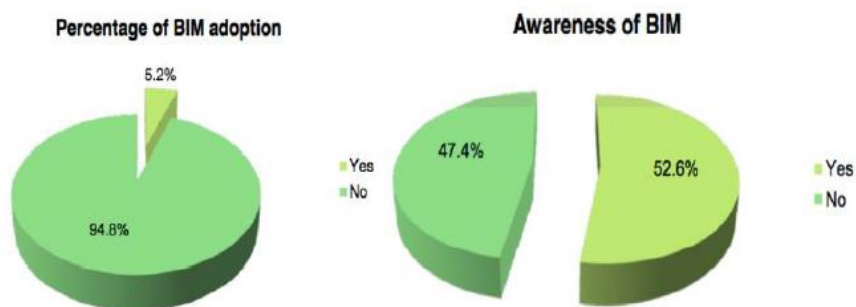
Figure 1.1: BIM adoption and awareness among construction organisations in Malaysia (Kong et al., 2020).

The rapid development of the construction industry has negative impacts, especially on communication issues and construction waste (Mah et al., 2016). There are two types of construction waste: physical and non-physical waste. Non-physical construction wastes are activities mainly in time. According to Alexis (2018), the traditional construction method requires a long time and more experienced, highly skilled designers and builders (Alexis 2018). Alexis also stated that the longer the time spent, the larger the budget costs in the construction industry. This is because the traditional method requires more human resources to coordinate the project. Thus, more of the budget was spent on labour costs.

Physical waste can be defined as construction material waste. Construction material waste is generated from solid waste such as wood, concrete, rebar, shear link, etc. In 2016, a significant amount of construction debris contributed to approximately 41% of the solid waste generation in Malaysia (Mah et al., 2016). Mah (2016) stated that one of the problems occurs due to mistakes and errors in design. According to Paul (2016), design error can be defined as the possibility of replacing or correcting a construction material. The plan clearly states the instructions during the construction and design phases. However, this will happen in several types of situations, such as having multiple opinions from the construction professionals, insufficient construction technology, etc., during the design stage of construction (Mah, 2016). Design errors contribute to a change in the volume of orders in the construction element. In addition, rising material costs have had a direct influence on the price of doing business. From the year 2020, a rise of 13 % to 20% in construction expenses, which includes mild steel prices rising by 41% and sand prices rising by 20% (Moh, 2022). Hence, physical waste has brought a big loss of profit to the project.

Poor communication in the construction industry is defined as poor communication between construction agencies. Lack of communication will lead to the exchange of incorrect information between construction agencies. Many researchers have conducted the issue of poor communication in the construction industry (Gamil and Abdul Rahman, 2018). It attracted the concern of the studies due to its importance in the construction industry. Gamil (2018) found some factors that cause poor communication, such as lack of

effective communication platforms, improper communication channels, poor progress measurement, delayed notification of the change, etc. This issue might lead to project failures subjected to project cost and time overruns in the form of rework during any construction stage. However, rework brings physical and non-physical waste to the construction industry. Gamil (2018) also mentioned that there had been gradual increments over 26 years from 2011 to 2017 in communication studies in the construction industry. This indicates the issue has gotten more serious and more concerning in the construction industry.

1.4   Aim and Objectives

The main aim of the research is to model and quantify a project building's structural model and to describe the importance of ShareBIM, used as a communication platform to complete the 3D BIM model. The specific objectives of this research were to:

   i.   To model the structural framing in Autodesk Revit.

  ii.   To quantify the beam, column, and slab elements.

 iii.   To perform statistical analysis for concrete, rebar and shear links cost and quantities.

1.5   Scope and Limitation of the Study

The scope of this research is to model the 3D structural BIM model based on an ongoing project of reinforced concrete buildings in Autodesk Revit. Depending on the anticipated development level of BIM knowledge, BIM knowledge can be covered in detailed design, analysis, modelling, and cost estimation of construction materials. In contrast, ShareBIM covers clear communication between project teams. Therefore, the following outlines the five scopes of work in the entire modelling chain:

   i.   A 3D structural model of the reinforced concrete building is prepared using Autodesk Revit.

  ii.   Clash detection between elements from the architect and MEP model in ShareBIM.

 iii.   Coordination works between project teams in ShareBIM.

 iv.   Structural analysis of the structural model in Esteem 9.

v.   The finalized 3D structure model is undergoing statistical analysis for concrete, rebar, and shear link cost and quantities.

There are several limitations to this study. This project is a high-rise reinforced concrete building, still in the planning stages. The architectural and structural plans given by the supervisor are unfinished. The drawings contain a lot of missing or incorrect information, such as no detailing of the structure plan and inconsistency of the structure layout plan, resulting in a partially created BIM model. In the case of no way, the project must undergo structural analysis to proceed due to a lack of detailing in the structure. Therefore, several situations are not considered, including lateral load, earthquake load, wind load, and shear wall during structural analysis. Besides that, the building under study is a high-rise reinforced concrete building with 26th floors. Thus, my limitations existed; therefore, the 26th to 9th floors were chosen instead of the entire building. This is because the entire building consists of 4 floorplans: roof, 25th to 9th floor, 8th to 1st floor, and ground floor. Aside from that, it was my first time implementing ShareBIM in this study.

1.6   Contribution of the Study

The findings of this study will benefit the construction industry, particularly in Malaysia, in terms of deriving information from the BIM model. Besides that, it will improve the quality of structural framing modelling by BIM. This study assists all construction agencies in enhancing communication by using ShareBIM. This will reduce time and human errors by having an effective communication platform because modifications in building drawings often occur in the construction sector. In addition, this research also accurately quantifies the structural elements and materials of a reinforced concrete building in Autodesk Revit. As a result, the beauty of BIM coordination of a building increases the problem-solving and interest of organisations that plan to adopt BIM in future projects.

1.7   Outline of the Report

There are five chapters included in this paper:

i. Chapter 1 is a study of the application of BIM coordination technology. The outline of the study is illustrated. It is included the importance of the study; problem statement; aims of the study; research objectives; scope; limitations of the study; and contribution to the construction industry, especially in Malaysia.

ii. Chapter 2 is the literature review. A brief introduction to Building Information Modelling (BIM), dimensions of BIM, the lifecycle of BIM, application of BIM coordination technologies, closed and open BIM, the importance of open BIM, BIM tools, challenges and advantages of BIM are described in this chapter. Besides that, clash detection, design standard of Eurocode (EC), concrete framing structure elements, and construction materials are also described in this chapter. Lastly, quantity take-off (QTO) by BIM and cost estimation of material by BIM of the project are studied, as is how information from different parties is exchanged with each other during the lifecycle of the project.

iii. Chapter 3 is the methodology and the flow of work throughout the research. The flows cover modelling of a high-rise reinforced concrete structural framing, structural analysis; quantity take-off, the collaboration between the project team to examine issues of the entire building; and cost estimation of quantities used.

iv. Chapter 4 is the results and discussions. This chapter presents the discussion during collaboration obtained from ShareBIM and the modification of the structural BIM model due to the clash detected after ShareBIM. The result of the structural analysis generated from Esteem 9 is used to perform manual verification by following the design standard of EC2 in depth. The computation of quantity and material take-off was obtained from Autodesk Revit. Lastly, statistical analysis of concrete, rebar, shear link cost, and quantities are presented and discussed in depth in the last section of this chapter.

v. Chapter 5 is the conclusions and recommendations. This chapter concludes with the results based on accomplishing the aim and objectives of this study. Moreover, recommendations are proposed for this study in the future.

CHAPTER 2

LITERATURE REVIEW

2.1   Introduction

This chapter covers the basic information of BIM, a process and practice of virtual three-dimensional (3D) structural model design throughout its lifecycle. A 3D structural model design by BIM coordination tools to cover clash detection between architecture and mechanical, electrical, and piping (MEP) model. It also covers the types of structure and material used by the design standard of European code, quantity take-off, and cost estimation in the bill of quantities (BQ). In addition, BIM's concept, application, coordination, benefits, and challenges have been discussed in this chapter.

One of the definitions for BIM is building an information model instead of modelling (Dmlinux, 2016). A building information model is defined as a 3D digital model. It only consists of 2D drawings, 3D visualisation, project management, fabrication details, building management, bill of quantities, and model analysis. These features are the focus of the design stage of the project. As a result of the above definitions, BIM is described as a technique for creating 3D digital information models using software applications to improve communication and interaction among stakeholders. In addition, BIM is not only just a design tool only for engineers but also can create many layers of metadata within a collaborative workflow. Figure 2.1 shows the actual digital model.

Figure 2.1: Actual digital model (Dmlinux, 2016).

Building Information Modelling (BIM) is defined as an entire process of using three-dimensional (3D) data to develop and manage building data throughout its lifecycle, as well as using appropriate BIM software to improve building design and construction productivity. (Dmlinux, 2016). There are several features of utilising BIM during the process, including spatial relationships, building component properties, building geometry, geographic information, quantitates, law and regulations, service, construction management, etc. Furthermore, BIM is used to share knowledge through a digital presentation and provide a solid platform for decision-making throughout the project's lifecycle. Succar (2009) concluded that BIM could be said as a digital format to organise the appropriate project data and building design throughout the lifecycle of the building. In addition, CIDB (2014) stated a similar definition: BIM surrounds processes to communicate, produce and analyse digital information models for the lifecycle of an entire construction in the form of modelling technology. However, BIM is to obtain more precise and detailed geometry and data, to computerise the project models rather than a manual process. This software also provides a durable base for interfacing analysis and cost application. Figure 2.2 shows the entire process of BIM.
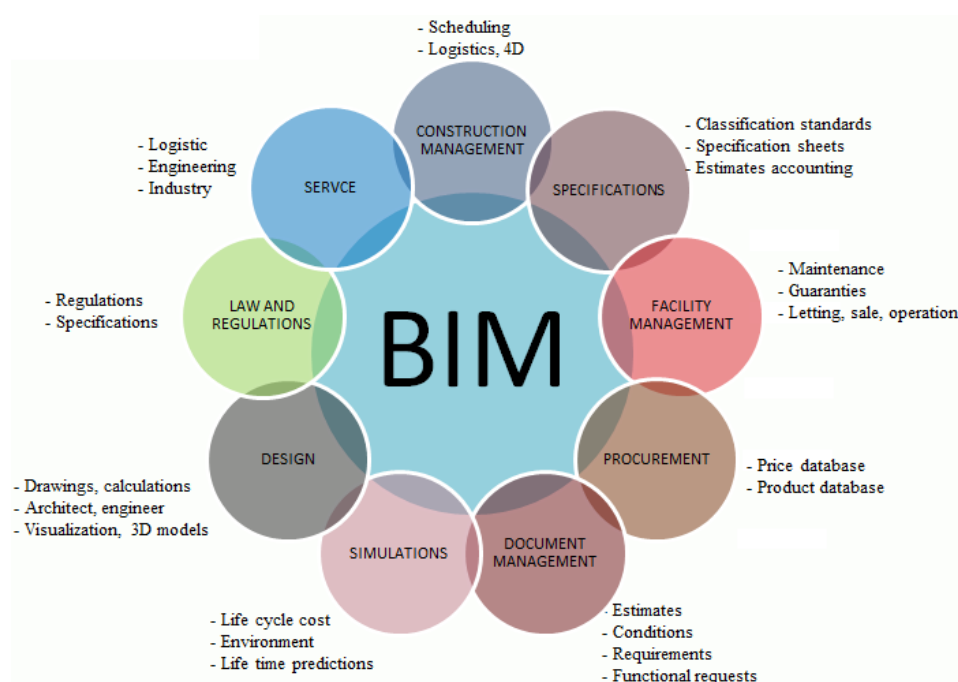
Figure 2.2: Entire process of BIM (Dmlinux, 2016).

In this research, BIM software named Autodesk Revit acts as a primary software to model the structural framing. In contrast, ShareBIM acts as a communication platform with the architects and other engineers involved in the project's design stage. ShareBIM is a BIM-enabled Project Management Collaboration Platform (mesgroup.asia, 2021). It offers a particular Common Data Environment (CDE) platform for storing, displaying, and able to share BIM models, drawings, animations, renderings, and other work-related information (mesgroup.asia, 2021). Finally, cost estimation and statistical analysis of structural element cost and quantity are prepared when there are no more issues with the architects and other engineers.

2.2 Dimensions of Building Information Modelling (BIM)

BIM has been transformed into one-dimensional (1D), two-dimensional (2D), three-dimensional (3D), four-dimensional (4D), five-dimensional (5D), six-dimensional (6D), seven-dimensional (7D), and eight-dimensional (8D) versions based on the application of product lifecycle management (PLM) to the construction industry. Building Lifecycle Management (BLM), or unified project management, is the name of this system (Reizgevičius et al., 2018). This development has been visible in the usage of huge volumes of data in 3D architectural models. Figure 2.3 shows the eight dimensions of BIM.
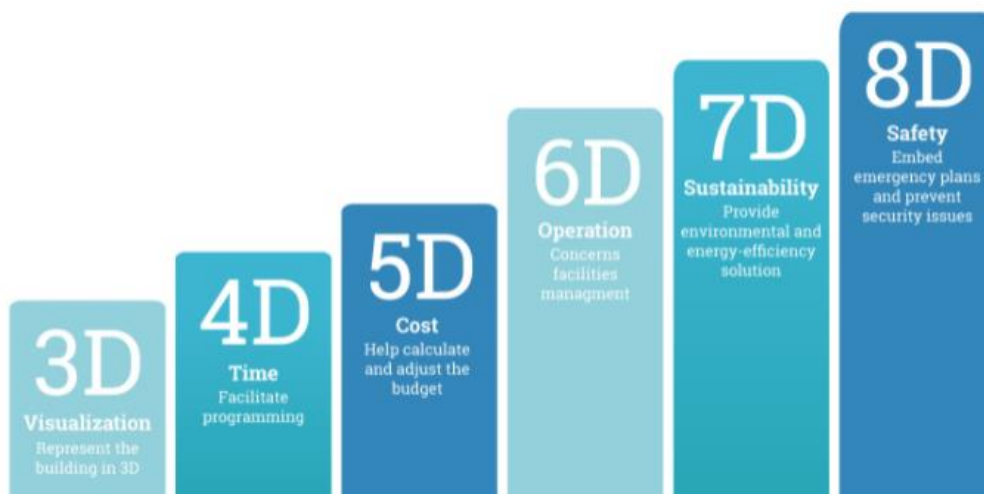
Figure 2.3: Eight dimensions of BIM (Centrelinestudio.com, 2019).

One-dimensional (1D) is the process and governance. It consists of laws and contracts regarding the use of BIM in public work (Centrelinestudio.com, 2019).

Two-dimensional (2D) refers to the drawing of 3D models. All the 2D sections and elevation plans have been dragged out of the 3D model. Thus, the appearance of BIM is to help construction professionals more efficiently and make them more confident in the data. Figure 2.4 shows the 2D drawings dragged out from a BIM 3D model. The 2D drawings will automatically be updated when there is a change in design options.
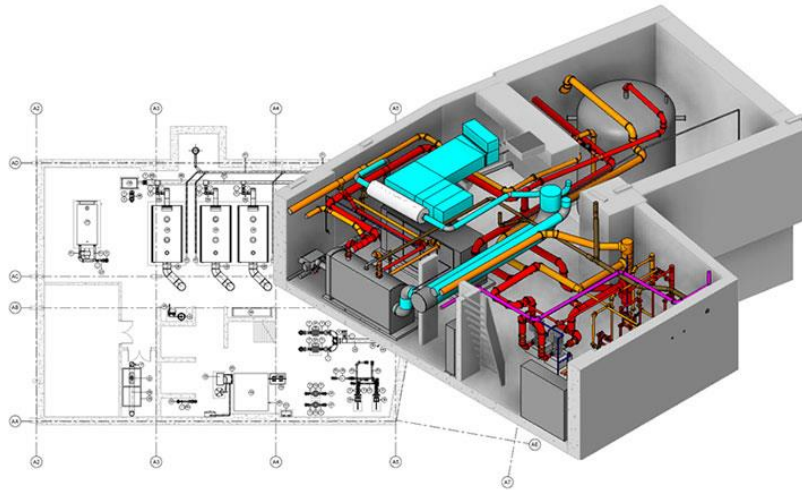
Figure 2.4: 2D of BIM dimensions (Bethany, 2017).

Three-dimensional (3D) is present of a virtual model made up of a frame model of the building. A 3D model in BIM represents major dimensions among all because it enables construction professionals to understand easily and communicate project information more smoothly. BIM enables multi-coordination and analysis, as in architectural, MEP, and structural models. Reizgevičius (2018) also stated that the construction organisations planning to apply the BIM process or life cycle in the project should have to model a 3D model by BIM. Otherwise, the project will not be able to proceed to further dimensions or life cycle. Figure 2.5 shows a completed 3D BIM model, which included structures, architecture, and MEP. In the 3D dimension, it allows to visualise better than with imagination. It also enables a virtual man to walk through the entire building to conduct a virtual inspection during the design stage.
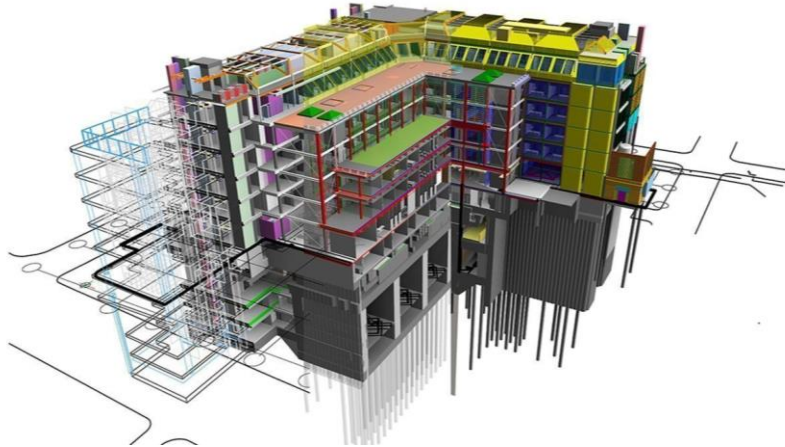
Figure 2.5: 3D of BIM dimension (Usha B., 2019).

Four-dimensional (4D) is referred to time. It refers to the advanced linking of the 3D BIM model with schedule-related information. This data may be used to generate accurate schedule information and visual displays for demonstrating how the project will be developed sequentially by schedule management software such as Microsoft Project synchronized with 4D software such as Synchro4D or Navisworks (Centrelinestudio.com, 2019). The 4D BIM model also facilitates the construction professionals and clients to visualize the total period and display the progress of overall construction activities through the lifetime of the project. Thus, the 4D of BIM can be defined as 3D plus schedule. Figure 2.6 shows the period of construction activities needed to complete the project.
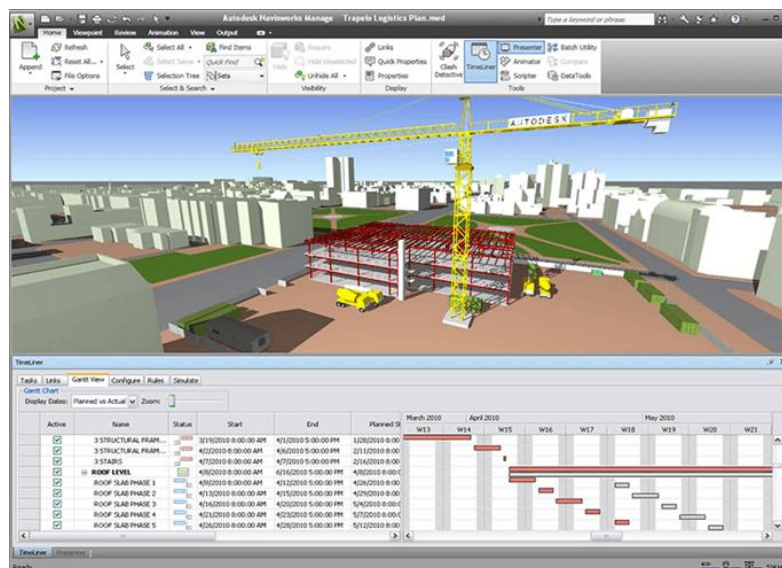
Figure 2.6: 4D of BIM dimension (Centrelinestudio.com, 2019).

Five-dimensional (5D) is determined to cost planning and estimation. It consists of all the cash flow, budget spending, and measurement in this dimension. The BIM model is also integrated with the existing budget software (Centrelinestudio.com, 2019). The participants can analyse capital, operating, renewal, and replacement costs during the project based on the facts and information connected to specific components inside the model. Participants can visualise the progress of various tasks and the related costs over time when collaborating in 3D and 4D of the lifecycle. In addition, integrating 5D models enables a more cost-effective, efficient, and long-term construction strategy. Figure 2.7 shows the cost estimation and QTO in Autodesk Revit.
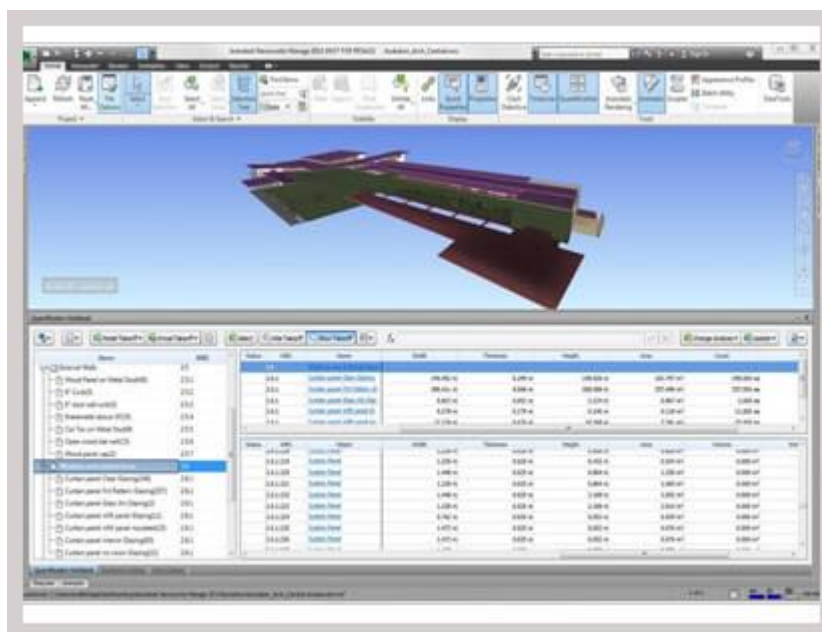
Figure 2.7: 5D of BIM dimension (Srinsoft, 2020).

Six-dimensional (6D) is mentioned for operation. It integrates infrastructure, real estate, facilities, and asset management from design to demolition (Centrelinestudio.com, 2019). Project management can use this dimension to keep the facility in good working order for the remainder of its life. However, construction professionals may identify asset information such as warranty information, maintenance, and operating manuals in 6D. 6D of the BIM dimension also gives facility managers a clearer view of planning and monitoring the maintenance cost and schedule. Moreover, software

applications for the 6D BIM dimension include Bexel Manager. This software includes asset management features, a document management system, facility maintenance planning, and 6D reporting (Bexel, 2020). The document management system in Bexel includes integrating as-built project documentation, intelligent document linking, and linking and managing documentation in a cloud-based environment. Facility maintenance planning in Bexel includes integrating facility maintenance plans into the 6D BIM model, managing FM activities and entries, scheduling maintenance tasks at regular intervals, planning and monitoring maintenance costs, and notifications on planned FM activities. Lastly, 6D reporting in Bexel includes reporting on maintenance costs, regular maintenance activities, emergency maintenance repairs and defects, templates, and FM contract execution reporting. Figure ZB shows the 6D of BIM software named Bexel. Figure 2.8 shows the 6D of BIM dimension in Bexel.
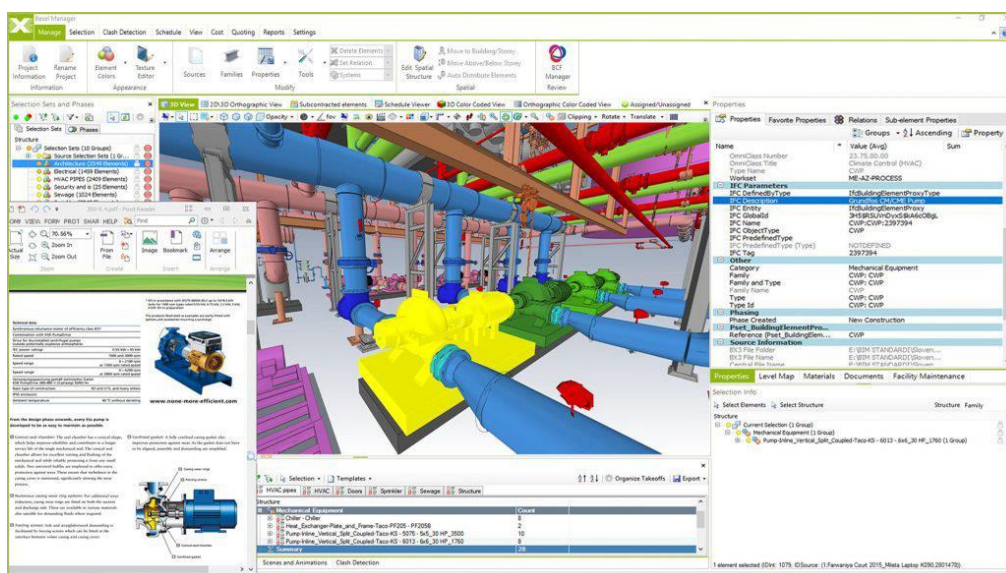
Figure 2.8: 6D of BIM dimension (Bexel, 2020).

Seven-dimensional (7D) is a sustainability process. It needs to consider the environment and assist in researching energy usage, health, efficiency, safety, and long-term sustainability (Centrelinestudio.com, 2019). This concept holds details on management and operation, such as the component manufacturer. 7D may help to determine the entire life cost of assets and make reasonable cost and sustainability-related decisions by

utilising the schedule of installation, maintenance plans, best configurations for optimised performance, lifespan, etc., in the 7D of the lifecycle. Figure 2.9 shows the heat analysis of a two-storey high building using software named Energy3D. This application creates a comfortable environment for humans to live in during pre-construction. Thus, construction professionals may increase the number of trees in the software to lower the heat contrast.
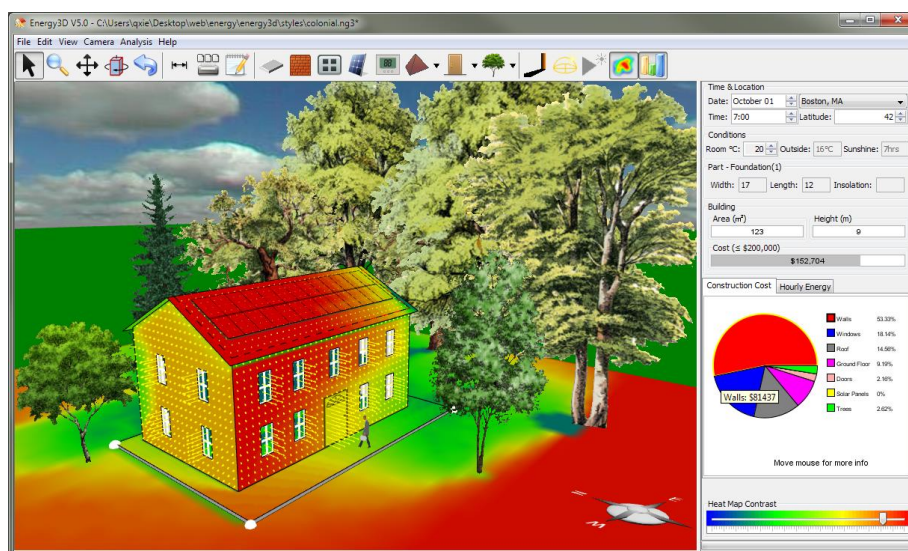
Figure 2.9: 7D of BIM dimension (Charles, 2015).

Eight-dimensional (8D) is referred to safety. It consists of a model with security and healthcare information. This dimension concentrates on three tasks: evaluating the risks caused by selected design and construction solutions, offering the highest risk options, and explaining the need to control specific hazards on the project site (Reizgevičius et al., 2018). Thus, 8D can become a valuable tool for managing construction sites effectively. The result of the 8D BIM virtual model is a realistic model that perfectly reproduces the actual construction site, complete with all the machinery, temporary work, the motion of workers, etc. As a result, this allows the construction professionals to verify the overall dimensions and simulate emergencies to assess the correctness of the design choices. However, 8D of BIM is enabled to run the risk identification analysis and overview the workflows in advance so that each role of the construction professional can be prepared well for each type of activity and prevent any hazards by examining the work time schedules.

Figure 2.10 shows the 8D BIM model with safety identification and prevention in construction planning. For example, in the figure, the 3D model is an external model with safety fencing at the perimeter of the building to prevent fall hazards for construction workers. This fall protection system may be dismantled after the project, and thus the construction professional must include the QTO of safety fencing individually to avoid a budget shortage.
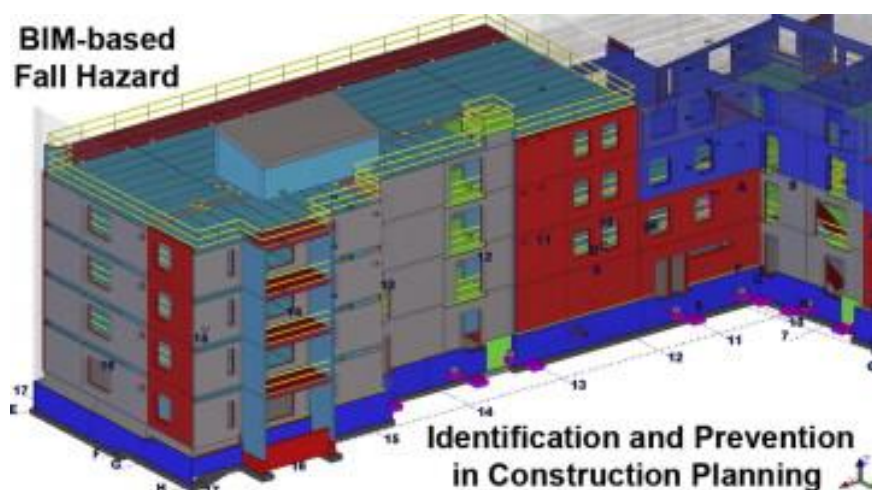
Figure 2.10: 8D of BIM dimension (Sijie.Z, 2015).

2.3   Lifecycle of Building Information Modelling (BIM)

Different project teams carry out different tasks at different stages of the project's lifecycle, and project management is always required from start to end (Charlott, 2017). The lifecycle of BIM can be defined as the process of planning, designing, operating, and maintaining a building that includes an information, object-oriented, and linear model of the facility, which is effectively a BIM model that incorporates all the building's information throughout its life cycle, (Biblus, 2020). The client, consultant, and the main contractor use the design and build contract method to work together from the beginning as one entity from the planning stage to the operation and management phase. The consultant participates in BIM's lifecycle planning and design stages, while the main contractor usually focuses on the construction, operation, and management phases. Moreover, all the activities during any construction, such as construction, operations, demolition, and waste disposal, are all factors to consider. Furthermore, all these activities are divided into three phases in the BIM process's lifecycle: the design phase, the

build phase, and the operation phase. Figure 2.11 shows the entire Building Information Modelling (BIM) life cycle of conducting all the activities relating to the building over the course.
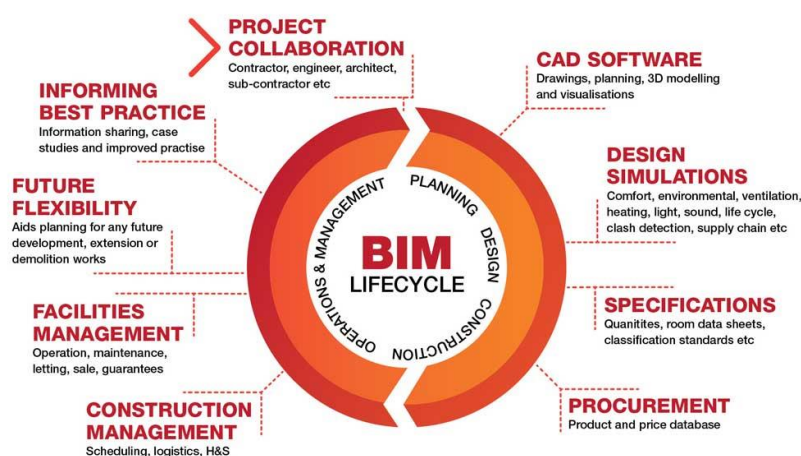
Figure 2.11: Building information modelling's (BIM) life cycle (Biblus, 2020).

2.3.1 Design Phase

The design phase is the first phase of the BIM life cycle. Activities in this phase include programming of inserting data, layout design and detailing of the design. Project teams must identify the most suitable economic structure to build in the conceptual design (Milovidova, 2014). Moreover, detailed design will be conducted by the construction professional under the requirement of the national design law. In Malaysia, the nation design law includes Uniform Building By-Laws 1984 (UBBL), Eurocode (EC), etc. Then, all the data information from project teams is required to be input in the programming stage (Milovidova, 2014). For example, project teams provide bills of quantities (BQ) based on a completed detailed design to project management and supply chain (Medium, 2017). However, there will be several arguments between the project teams and stakeholders. Thus, BIM's benefit can help minimise or resolve the argument between them. This helps the teams to produce accurate decisions and set performance targets (Bimgenia, 2012).

During the design stage, an architect must achieve a balance between the project's scope, timeline, and budget (Fadzli, 2014). All key information, such as design and modelling data, is available instantly by utilising BIM, so it

can allow project-related choices to be made more effectively and efficiently. (Fadzli, 2014). Moreover, BIM enables project teams to make further modifications to the project at any moment throughout the design stage, especially in clash detection. It can minimise the need for time-consuming, low-value consideration and manual checking. Furthermore, design ideas are captured at the moment of creation and inserted into the documentation as the project progresses. Then, all the building design and documentation work may be done concurrently rather than sequentially. Finally, BIM's automatic coordination of changes eliminates coordination errors, increases work productivity, and assist construction organisation in obtaining more projects (Fadzli, 2014). Figure 2.12 shows the features in the design and planning phase (Fadzli, 2014).
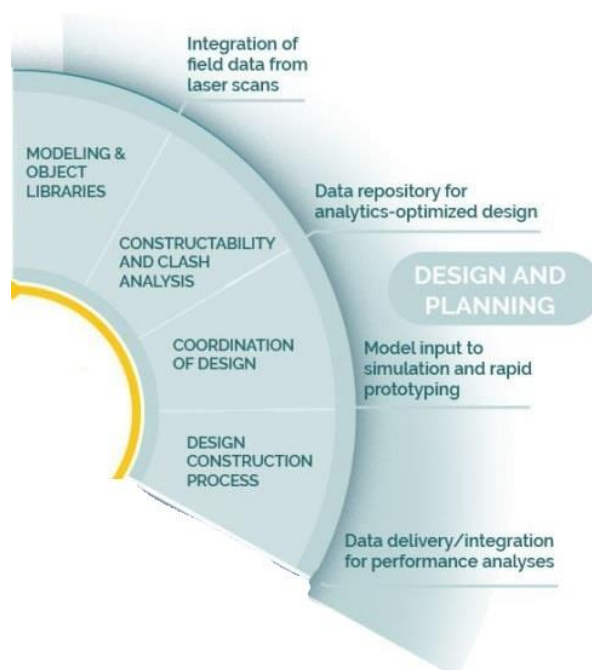
Figure 2.12: Features in design and planning phase (Fadzli, 2014).

2.3.2 Build Phase

The second phase among the three key phases is the build phase. The build phase can be defined as the construction phase, in which the structure will be built under the supervision of the project team, such as constructors, subcontractors, and suppliers. They are needed to make sure that the project has been well organized right from the beginning by using the BIM tools. Using a detailed 3D model during building can help to reduce the amount of

unnecessary paperwork and interference. (Bimgenia, 2012). For example, the materials used in the project can start with prefabricated because the object size is fixed in the design phase (Milovidova, 2014). This enables manufacturers to start making materials for projects immediately. By studying the model, the site engineer can reduce the time spent following the design of structural processes and paperwork (Bimgenia, 2012).

Figure 2.13 shows the features in the build or construction phase (Fadzli, 2014). During the construction phase, BIM leads to the continuous availability of data on the building's quality, timeline, and project budget. The builder can speed up the forecasting measurement of the material used and value engineering, as well as update measurement and construction plans. The project team can instantly generate drawings for stakeholders to indicate on-site use. Therefore, it can communicate and limit construction operations' impact on the stakeholder's project and people. As an outcome, less time and money are spent on the process and administrative challenges, leaving more money in the project budget (Fadzli, 2014).

Figure 2.13: Features in build or construction phase (Fadzli, 2014).

2.3.3   Operation Phase

The operation phase, also known as the management phase, is the last phase of the BIM life cycle. This phase can be determined as the essential phase for all (Milovidova, 2014). It is the handover and commissioning of a building after the construction phase is done. Then, BIM can also provide the stakeholders

and facility managers with the correct knowledge to operate MEP and HVAC and then deal with maintenance issues through a digital twin by installation date, material lifespan, etc. (Milovidova, 2014). In other words, BIM technology in the operation phase can help to make the process smoother and more seamless.

BIM provides continuous information about the usage or performance of the building, such as its occupants and belongings, the building's life across time, and its financial aspects, available during the management phase of the building lifecycle. Furthermore, a digital record of repairs makes it easier to adapt standard building prototypes to site conditions for businesses in identical structures in other places. Moreover, BIM makes it easier to maintain and access all the essential data about the building, such as finishes, furniture, and equipment, as well as financial data. (Fadzli, 2014). In general, it can be concluded that regular access to this type of data helps revenue and expense management in the building's operation (Fadzli, 2014). Figure 2.14 shows the features in the operations and maintenance phase (Fadzli, 2014).
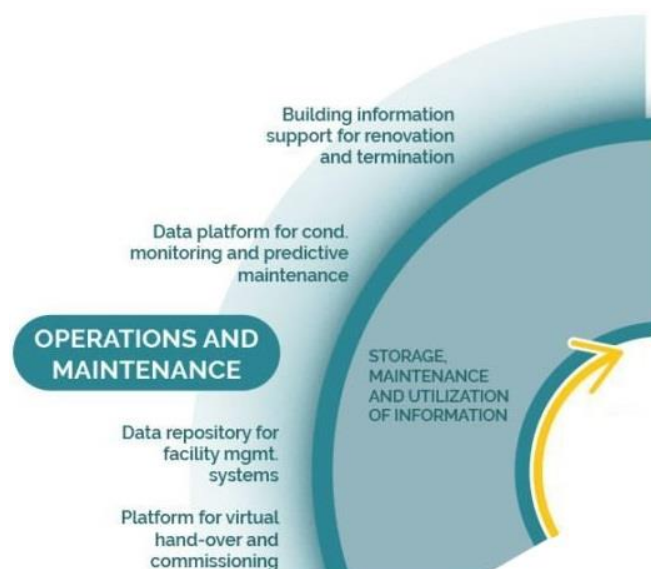
Figure 2.14: Features in operations and maintenance phase (Fadzli, 2014).

2.4 Closed and Open BIM

Closed BIM is known as lonely BIM when all the projects inside a company utilise the same BIM application software. Closed BIM refers to BIM applications within the same dealer, such as Autodesk, that several

construction organisations utilise. For example, architects may model architectural elements in Revit Architecture, structural engineers can utilise it as a reference architectural BIM model for defining the structure of a building in Revit Structure, and MEP engineers can model building services elements in Revit MEP. This solution is restricted to project participants collaborating with the same BIM application software that does not require file conversion. While this method is still not acceptable in most cases, it can aid in avoiding interoperability issues created by multiple software solutions on the same project (Acca, 2020).

Open BIM is a strategy and process allowing all project participants to communicate and share data information using a neutral file format using any BIM tools and application software (Alltosoftware.com, 2020). Open BIM model allows geometry data and data transmitted such as parametric data, quantities take-off, material measurements, and cost computation. Open BIM has resulted in the development of several agreements and open standards to service the industry (Acca, 2020). The most common open BIM standards in use include Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie) (Archilantis, 2020). Moreover, open BIM is based on worldwide access based on open standards and processes for collaborative design, construction, and operation of buildings. In addition, Industry Foundation Classes (IFC) is a neutral file format that enables data to be exchanged across software programs in the construction and facilities management industries (Acca, 2020). The IFC format significantly benefits the construction industry by allowing diverse specialists to collaborate and consistently share data during any stage of construction (Biblus, 2020). Figure 2.15 shows the difference between closed and open BIM.
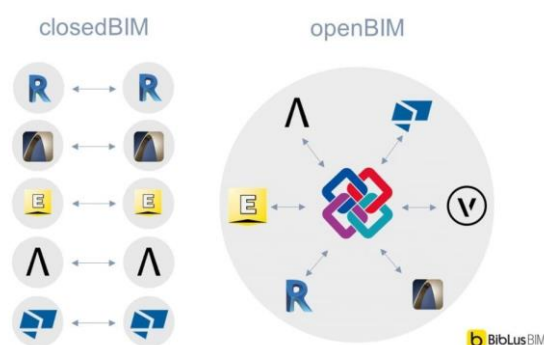
Figure 2.15: Different between closed and open BIM (Acca, 2020).

2.4.1 Importance Of Open BIM

There are a few advantages and importance of using open BIM in the construction industry. First, open BIM promotes a transparent process that allows project participants to engage independently of the BIM software tools they employ (Palumbo, 2021). Second, Open BIM creates shared concepts for commonly used procedures, allowing organisations and governments to engage in transparent commercial interaction, competitive service evaluation, and data quality assurance when procuring projects. Third, open BIM creates durable project data that can be used throughout the asset life cycle, reducing duplicate data entries and inaccuracies. Fourth, Open BIM allows small and big software companies to compete on a system-independent basis (Alltosoftware.com, 2020). Lastly, open BIM activates the online product supply side by allowing more accurate user demand searches and product data to be provided directly into the BIM.

2.5   BIM Coordination Tools and Soft Technologies

As shown in Figure 2.16, an extensive range of software tools are available on the market for modelling, analysis, and managing. Functional quality and compatibility are key issues when selecting appropriate software solutions for a specific BIM project.
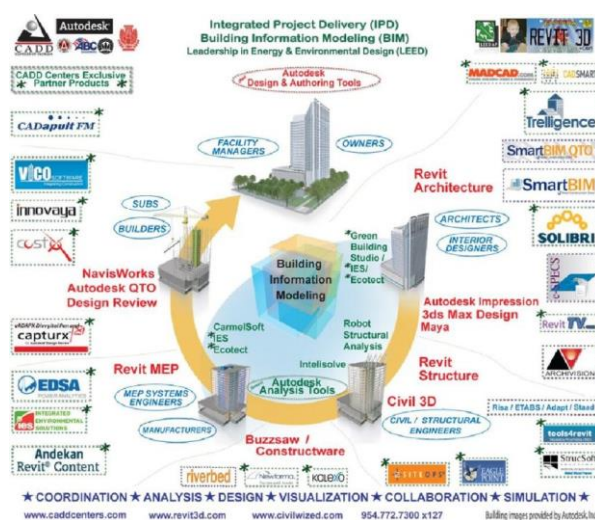
Figure 2.16: Software tools for BIM in the construction industry

(Dispenza,2019).

Some organisations have their own selected software to assist them in their project by utilising BIM software, but it is tough to gather all the valuable data (Haron, 2017). This is because some software does not provide a neutral file format to allow them to export or input the data information file. There are several types of BIM software on the market. For example, AutoCAD, Revit Architecture, Autodesk Robot Structural Analysis, Revit MEP, and NavisWorks are used in the design stage. This software contains extra data such as timelines, cost of materials, manufacturer's data, and operation information that is not available in architectural drawing software such as AutoCAD (Haron, 2017). Construction professionals from various professions can choose from a variety of BIM tools to satisfy their requirements. However, the selected tools used in this research are Autodesk Revit, Autodesk Robot Structural Analysis Professional, and ShareBIM.

2.5.1   Autodesk Revit

Autodesk Revit is one of the software and applicants in the building information modelling (BIM) platform that offers a wide range of construction professionals. (Kai, 2020). It gives users much flexibility in terms of creating and changing their work. For example, architects and design engineers may create a 3D model of a conceptual design and detailing of a building, then extract data from the 3D model, and display the model in section 2D view (Haron, 2017). Furthermore, it drastically minimizes the time spent on revisions since any changes are reflected across the project, so there is no need to make manual edits. Revit also allows users to get the quantity take-off specified in the project, thereby turning it into a construction database that aligns with the BIM principle. Figure 2.17 shows Autodesk Revit Software.

Figure 2.17: Autodesk Revit Software (Blocks, 2022).

2.5.2   Esteem Innovation

Esteem Innovation is the load-carrying analysis software that checks for design code compliance and reads the data from Autodesk Revit via BIM-integrated workflows (Johnson, 2016). File conversion from Autodesk Revit model to Esteem or Esteem to Autodesk Revit is only available in version 8 of Esteem onwards. However, procedures of file conversion between Autodesk Revit and Esteem require additional steps compared to other structural analysis software, such as Autodesk Robot Structural Analysis Professional, which is directly linked to Autodesk Revit. The additional steps are downloading the conversion program file from Esteem's official website and installing and plugging it in Autodesk Revit, as shown in Figure 2.18 (Kah Heng, 2015).
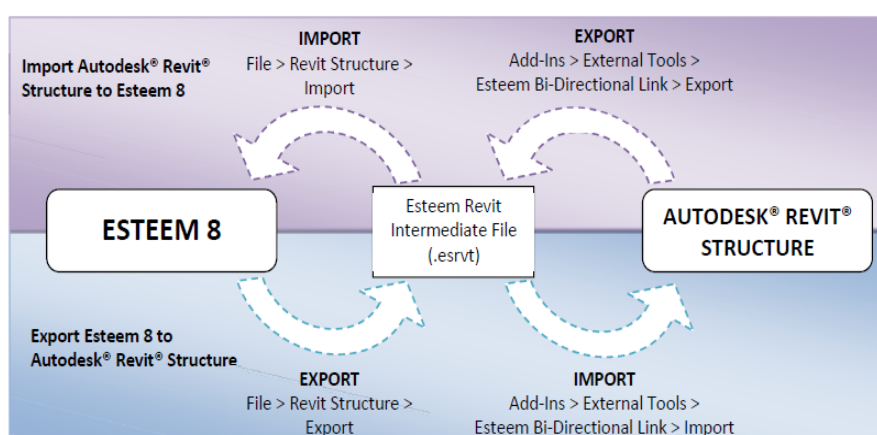
Figure 2.18: Model conversion between Autodesk Revit and Esteem software (Kah Heng, 2015).

Esteem Innovation can assist in developing more durable, constructible, collaborative designs and is linked to BIM. Although Revit

Structure cannot do actual analysis calculations, when given through to Esteem software, it may offer all the information needed for structural analysis, including QTO and cost estimation (Kah Heng, 2015). Utilising filtered views in Autodesk Revit to construct separate analytical models when needed is a side advantage of this procedure. In addition to fundamental analytical data, load combinations may be created by utilising a formula based on existing loads, which do not perform in Autodesk Revit but exist in Esteem (Johnson, 2016). Figure 2.11 shows Esteem Innovation 9.

Figure 2.19: Esteem Innovation 9 (Kah Heng, 2015).

2.5.3   ShareBIM

ShareBIM is a BIM-enabled Project Management Collaboration Platform (mesgroup.asia, 2021). It provides a communication platform for the construction professional to communicate efficiently and initiate workflows for follow-up actions throughout the project life cycle instead of using the traditional way to reduce human error. In other words, ShareBIM is a solution to wake up BIM and power up project management skills. It is fully supported on a web browser and mobile application. It contains the features of play, talk, mark-up, measure, take photos, link, and share files. Figure 2.20 shows the logo of ShareBIM (mesgroup.asia, 2021).

Figure 2.20: ShareBIM (mesgroup.asia, 2021).

## 2.6	Application of BIM Coordination Technology

Implementing BIM technology has transformed the traditional architectural building workflow (Lee et al., 2015). BIM technology was implemented throughout the detailed design phase of this project. During construction, a large amount of data was integrated to improve effectiveness and reduce corrections and errors. The application of BIM technology provides several fields for each phase of the life cycle. For example, in the design phase, it provides integration of design drawings to determine the clash between drawings. In the construction phase, it alerts immediately when there is any interruption of progress in the project.

### 2.6.1	Design Drawing Integration in Design Phase

In the way of the traditional method, two-dimensional (2D) drawings from architectural, structural, mechanical, electrical, and plumbing (MEP) were merged on the construction site (Lee et al., 2015). Hence, there are issues, and incomplete information found while merging those drawing of different revisions. As a result, it wastes resources and reduces work productivity during the late construction phase (Lee et al., 2015). BIM technology provides a cloud known as a database during the design phase to assist the design construction professionals in incorporating several types of drawings. In addition, Lee et al. (2015) also stated that BIM technology enabled combining all the 2D drawings and generating 3D BIM models with accurate parameters. Hence, work productivity has increased as progress is done automatically by BIM technology instead of utilising the workforce. The purpose of merging drawings is to determine the clashes between different models during the design phase (Lee et al., 2015). Julide (2016) stated that it is preferable to discover all the errors, including clash detection, during the design phase. This is because reworks during construction are costly compared to the design phase.

During the detailed drawing of the design phase, the 3D BIM model provided all sections cut and perspective views and was generated into drawings. For example, a project is built by using a curved steel beam. A detailed drawing of the curved steel beam may be generated from the BIM model for the manufacturer to produce the curvature (Lee et al., 2015).

2.6.2   Delivering Clash Report to AEC

Clash Detection is a significant concern in the early stage of construction projects. In the traditional method, identifying clashes is time-consuming and requires only a professional with superior design skills and experience (Kubba, 2017). It also assists in the prevention of clashes in the preconstruction stage. Clash detection can be defined as collision or conflict due to word meanings relating to overlapping elements when two things are attached (Edwards, 2018). Thus, clashes happen because of a design error, lack of accuracy in the model, and much uncertainty during the modelling that might cause the failure of the building (Chahrour, 2020). The latest version of clash detection in BIM helps construction professionals at any stage in imitating a digital space before the construction stage with an information database (Kubba, 2017). However, there are two sorts of clashes that can be detected using BIM tools which are relevant and irrelevant clashes. Relevant is defined as interferences that must be resolved. In contrast, irrelevant clashes do not require resolution because they might result from a single mistake repeated several times throughout the project (Edwards, 2018). Over a thousand relevant and irrelevant clashes might be caught during clash detection using the BIM tools. Thus, project teams play an essential role in identifying and resolving these clashes.

BIM technologies enabled inter collaboration and development and data flow between project teams. However, clash detection can improve work productivity and communication between project teams. Detected clashes during the early stage of the project will not have an immediate impact on-site and will not require rework. Rework performed by architects and engineers during construction will cause budget overruns (Raut and Swapnesh, 2017). It requires a method that enables different planning designs to be connected to spot problems in the planning design early. As a result, it can increase material efficiency while helping prevent future difficulties. For better understanding, Figure 2.21 shows a more transparent photo of clash detection.
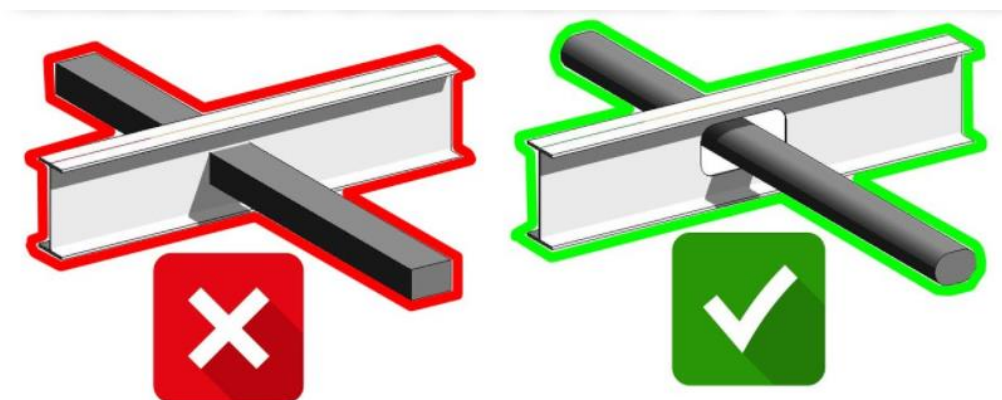
Figure 2.21: Sample of clash detection (Edwards, 2018).

2.6.3 Integrated Database in Construction Phase

According to Lee et al. (2015), BIM technology is used as a communication platform to communicate and coordinate the construction professionals' disciplines. Moreover, it is also used to share feedback from other departments; to report errors; discrepancies in the drawings, etc. Lee et al. (2015) also stated that there is a possibility of a change in the 3D model during the construction phase. With BIM technology, the finalised version of the BIM model will be uploaded to the collaboration platform up to date and inform all the construction professionals who are involved in this project immediately to increase the efficiency of discussion. Thus, every contractor and manufacturer were capable of discussing and resolving any difficulties uniformly.

2.7 Application of ShareBIM Coordination Technology

As stated above, ShareBIM is a BIM-enabled Project Management Collaboration Platform (mesgroup.asia, 2021). In other words, ShareBIM is a platform that can coordinate the project in an Artificial Intelligence (AI) way. In project coordination by ShareBIM, ShareBIM has invented four types of project coordination features in its platform. There are Common Data Environment (CDE) platforms, BIM-based cost management (CostBIM), Digital Works Supervision System (DWSS), and AI Safety Monitoring System (AI Safety) (mesgroup.asia, 2021).

2.7.1   Common Data Environment (CDE)

ShareBIM provides a dedicated Common Data Environment (CDE) platform for BIM models, drawings, animation, rendering, and other relevant work files that are stored, viewed, and shared (mesgroup.asia, 2021). A CDE suits the project to organisation-level needs, whether it is a set of BIM models for design, review for construction or documents such as Request for Information (RFI). Construction professionals can quickly check and process files online everywhere. Other than that, it enables the teams to communicate via the platform by initiating and giving feedback on the workflow. The workflow can help the project team to carry out daily quality management based on the BIM model (mesgroup.asia, 2021). Thus, the construction professional can easily submit the checklist based on the BIM model, and the dashboard of ShareBIM can also show the status to assist the site supervisor in inspecting the work.

CDE has managed to bring in a lot of benefits and advantages. There is an increased efficiency by customizing RFI forms, consolidating and tracking E-forms and workflows easily, strengthening communication, improving productivity, saving cost on purchasing additional software, compatible with Autodesk Revit and Navisworks, sharing information by a QR code, easy to trace back the object details, save time, minimize errors, check the correctness of models produced by a walkthrough, manage the task with a transparent schedule, and actual project progress with real-time updates (mesgroup.asia, 2021).

There are many modules inside ShareBIM, such as geographic information system (GIS-BIM), CDE and collaboration, tendering, contract management, cost management, procurement and supply chain, prefabrication, logistics management, site monitoring & quality management, safety management, variation, and facilities management as shown in Figure 2.22. Those features or activities are a part of the BIM life cycle and operate under ShareBIM.
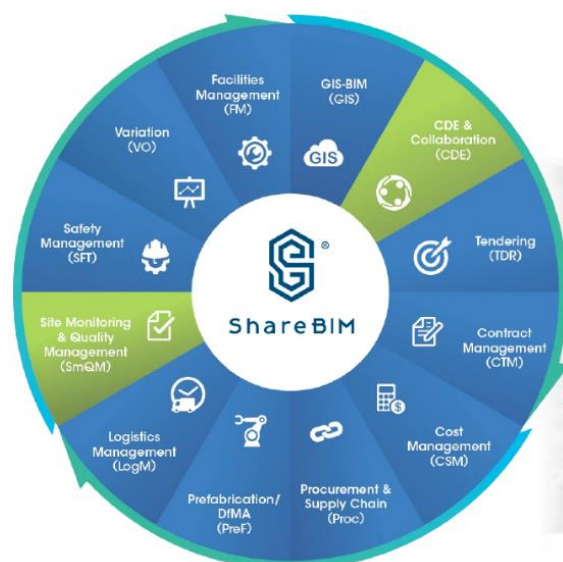
Figure 2.22: Features of ShareBIM (mesgroup.asia, 2021).

2.7.2   BIM-based cost management (CostBIM)

Quantitative data are connected with BIM models with the help of CostBIM. CostBIM is the integration of BIM technology into traditional quantity surveying procedures. It improves project cost control management, increases productivity and accuracy of estimates, and streamlines the quantity takeoff process (mesgroup.asia, 2021). CostBIM enables the creation of a cash flow simulation by integrating extracted quantities from the BIM model, construction programme and cost information. It can reveal the actual and predicted cash flow of the project to achieve a better understanding of project cash flow, as shown in Figure 2.23.

Figure 2.23: Actual and predicted cash flow chart by ShareBIM

(mesgroup.asia, 2021).

2.7.3   Digital Works Supervision System (DWSS)

The CDE from IOS 19650, which provides a collaborative environment where the entire team may exchange work and serves as the foundation for the information management process, is what DWSS is made to work with (mesgroup.asia, 2021). It improves the quality and safety of the job and the level and effectiveness of work supervision. By comparing the traditional method, the paperwork supervision process is no longer relevant to DWSS. It is a swap into an automated construction process and on-site data collection (mesgroup.asia, 2021). In other words, all the survey inspections on site are instantly recorded in multi-format types, including texts and photos, to alert all partners using a smartphone. Thus, all the partners may have an overview of the reports on the dashboard of DWSS. Figure 2.24 shows the mobile version of DWSS.
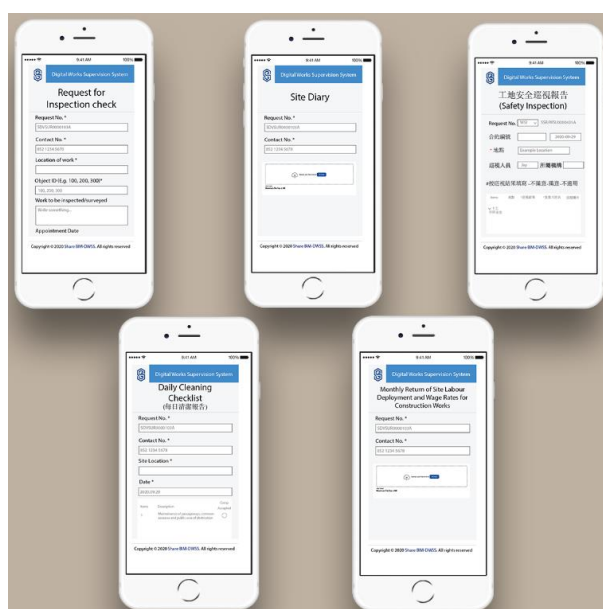
Figure 2.24: Mobile version of DWSS (mesgroup.asia, 2021).

2.7.4   AI Safety monitoring System (AI Safety)

The initial impression of a building site is usually dangerous. A study of 30% to 40% of workplace deaths occurred in the construction sector (mesgroup.asia, 2021). Therefore, AI Safety thinks that safety should be the top concern on a building site, even though it implies that much money will be spent there. Site monitoring usually involves onsite inspection by engineers or possibly the

director. Here, AI-Safety is invented to reduce the cost spent on the safety issue and the effort of security officers. Figure 2.25 shows the AI Safety and manual monitoring onsite.

Figure 2.25: AI Safety and manual monitoring on site (mesgroup.asia, 2021).

2.8 Benefits and Advantages of BIM

BIM is a centralised source that allows everybody working in the construction sector to access the same data version. As a result, project managers' communication risk can be reduced (Lu and Li, 2016). The quality and achievement of the building have increased because of the feasibility and design concept analysis. However, obtaining BIM advantages during the preconstruction phase is critical. It brings more automated low-level modifications, and precise visualisation design is required during transitions. The development of 2D drawings, cooperation among various design partners, cost estimator extraction, sustainability development, and energy efficiency are all benefits in the design phase.

Various BIM systems have been developed to solve sustainability problems throughout the building process, from design to the operation stage (Lu and Li, 2016). These BIM technologies enable the achievement of the project's objectives that are set by long-term assessment methodologies. Although the whole life should be in the foreground of BIM implementation, BIM regularly appears in the design and construction stage. There are a few benefits and advantages of utilising BIM, such as aligning construction with design, notification of changes in real-time, better project visualisation, clash detection checking, improved work productivity and communication etc. In

addition, using BIM can help reduce the problems of facility management integration (Emerald Jiju, 2015).

First, BIM enables alignment of construction with design. The traditional design process is revolutionised by information modelling, which allows the design team and contractors to collaborate (Jenny, 2018). Contractors contribute to developing more detailed and constructible designs by using BIM features such as the CDE.

Second, BIM enables alert notification of changes in real-time. It alerts project teams of any modifications during the project (Jenny, 2018). This will help the team members get the latest information faster when the stakeholders want to comment or make any changes to a file.

Third, BIM gives better project visualisation, especially in 3D models. BIM 3D models are prepared at the preconstruction stage. All the project teams, including stakeholders, can review the entire project from the beginning to help improve work productivity and communication in the construction stage (Constructiontuts, 2019). Thus, all the construction professionals and stakeholders involved in this project can experience a BIM 3D model.

Fourth, BIM identifies and coordinates clashes during the design stage. (Lu and Li, 2016). It also enables inter-project communication and development and data flow between project teams. Moreover, clash detection can help reduce time spent and prevent rework in the construction stage.

Fifth, BIM helps to improve work productivity and communication in all stages. The BIM model allows construction professionals to share and work together among other teams (Hall, 2018). In the traditional method, construction professionals used email to share the work, so it lost the work productivity, security of the project, and ineffective communication. BIM enables storing all the truth-shared data by different roles of project teams in a database (Reyes, 2022). Thus, the database allows the construction professional to access the latest project information (Reyes, 2022).

2.9   Challenges of BIM

BIM requires a revolution in work methods and technology for the construction organisation to keep up with the transition (CIDB, 2016). In Malaysia, there are still many construction organisations using traditional

methods. However, it is tough to revolutionise the culture of an organisation and construction firms will need to develop people with BIM skills and knowledge during the transformation. CIDB stated that almost 95% of construction organisations are interested in adopting BIM, but almost half lack awareness. The major factors of Malaysia's construction organisation faced are lack of time and lack of references is the major factor (CIDB, 2016). However, several difficulties have been identified that could obstruct BIM adoption in Malaysia, such as lack of time, shortage of references, etc., as shown in Figure 2.26. Figure 2.26 shows the factor and rank faced by the Malaysian construction organisation (CIDB, 2016).

Factor	Rank
Lack of time for experimentation and implementation in fast-paced projects	1
Lack of references to assist in implementing BIM	2
Lack of time to implement	3
Lack of direction of the BIM in industry	4
Our organization is inadequately unfamiliar with BIM usage	5
No BIM requirement/ mandate exists in the industry	6
Assumption that conventional methods are better than new processes	7

Figure 2.26: Factor and rank faced by the Malaysia construction organisation (CIDB, 2016).

In addition, CIDB (2016) stated that financial consideration is the biggest challenge when construction organisations try to implement BIM. Figure 2.27 shows the factor and rank of BIM adoption in Malaysia. The cost of BIM software for structural consultant firms is shown in Table 2.1, which is much higher than the traditional method.

Factor	Rank
High cost of technology	1
High training cost	2
High cost of software	3
Existing hardware incapable of running basic BIM software	4
BIM software is complicated to use	5

Figure 2.27: Factor and rank of BIM adoption in Malaysia (CIDB, 2016).

Table 2.1: Cost of Autodesk software (autodesk.com, 2022).

BIM Software	Price per year (RM)
Autodesk Revit	8,000.00
Autodesk AutoCAD	5,000.00
Autodesk AutoCAD Civil 3D	7,500.00
Autodesk InfraWorks	5,800.00
Autodesk Robot Structural	13,000.00
ShareBIM	3,960.00

2.10   Design Standard

The global construction industry widely uses Eurocode to achieve more efficient design (Nwoji, 2017). Nwoji (2017) also stated that Eurocode 2 is replacing British Standard (BS) 8110-97 regarding the economic design outcome and difficulty of usage. However, Eurocodes are the first choice among other design codes used in this research, such as Eurocode 0, Eurocode 1, and Eurocode 2. All Eurocodes must be used together with the national annex to obtain the design accurately.

Eurocode 0 (EC0) is known as the basis of structural design. It is combined with other codes, such as EC 1 to EC 2 (European Commission, 2018). It is also a keycode because it provides the basic principles of structure safety, serviceability, and durability.

Eurocode 1 (EC1) is known as action on the structure. EC 1 presents all the comprehensive loads and actions that should be taken in designing the building (European Commission, 2018). However, EC 1 has covered a few parts of action and load, such as general actions, actions induced by heavy machinery, and traffic loads on bridges.

Eurocode 2 (EC2) is known as the design of concrete structures. Eurocode 2 is covered in plain, reinforced, and prestressed concrete in the building design. It is combined with EC 1 and EC 2 to meet the requirements for serviceability, resistance, durability, and fire resistance of concrete structures. EC2 has covered a few parts: general rules for building water retaining structures, bridges, and containment structures (European

Commission, 2018). Figure 2.28 shows the correlation between Eurocode standards.
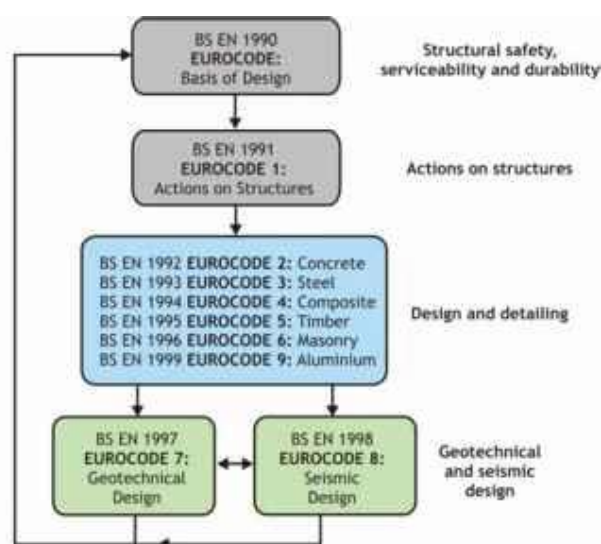
Figure 2.28: The correlation between Eurocode standards (European Commission, 2018).

2.11   Reinforced Concrete Framing Structures

A structure is made up of members that are linked to serving a beneficial purpose (Jamal, 2017). The structure is formed as a system to support all the loadings. There are a few elements that the frame of a concrete structure is formed as a system, which are columns, beams, cables, arches, footings, shear walls, plates, and slabs. In this research, the three main elements are beams, columns, and floor slabs. Figure 2.29 shows a complete concrete structural system of slabs, beams, columns, shear walls, and footings.
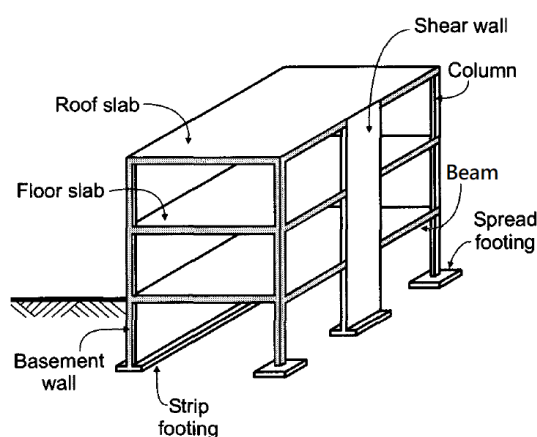
Figure 2.29: Components of a reinforced concrete building (Jamal, 2017).

2.11.1 Slabs

Slabs play an essential role in a concrete structural element constructed on the floor to create a flat surface. It is a horizontal structural component having parallel or nearly parallel top and bottom surfaces (Izat, 2018). Generally, beams support the slabs directly to the column or wall. In the design, a few types of loads must be considered, such as self-weight load, dead load, live load, floor finish load, snow load, and earthquake loads. Moreover, all the loads stated above are distributed to the beam, wall, or column either one-way or two ways depending on the ratio of its length. A 2-way slab is defined as the ratio of the long side divided by the short side being less than 2, while a 1-way slab is defined as the ratio of the longer span to the shorter span being larger than 2 (Izat, 2018). Figure 2.30 shows the load distribution system from one-way and two-way slabs to the supporting member. Figure 2.31 shows the slab's load transfer to different supporting parts.
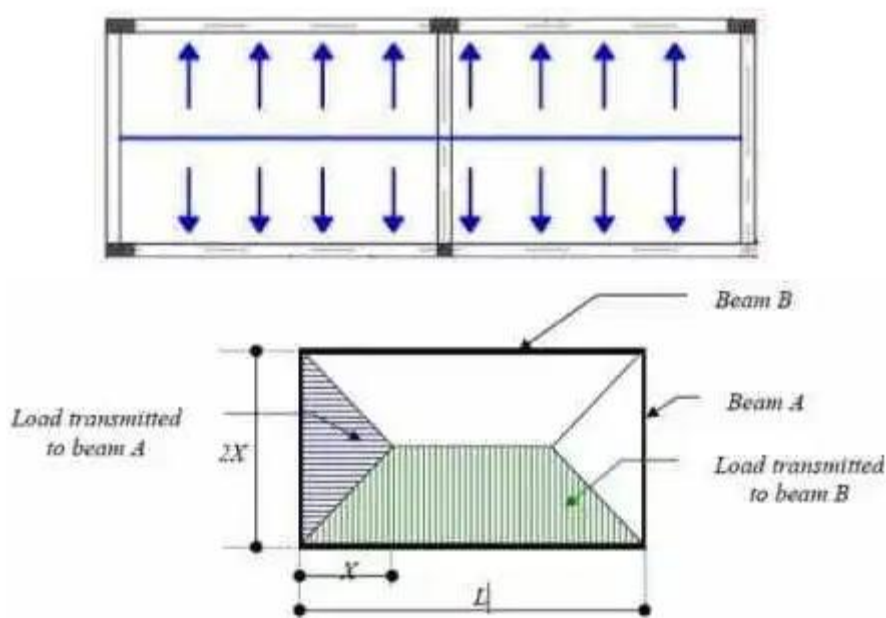
Figure 2.30: Load distribution system from one-way and two-way slabs to the supporting member (Izat,2018).
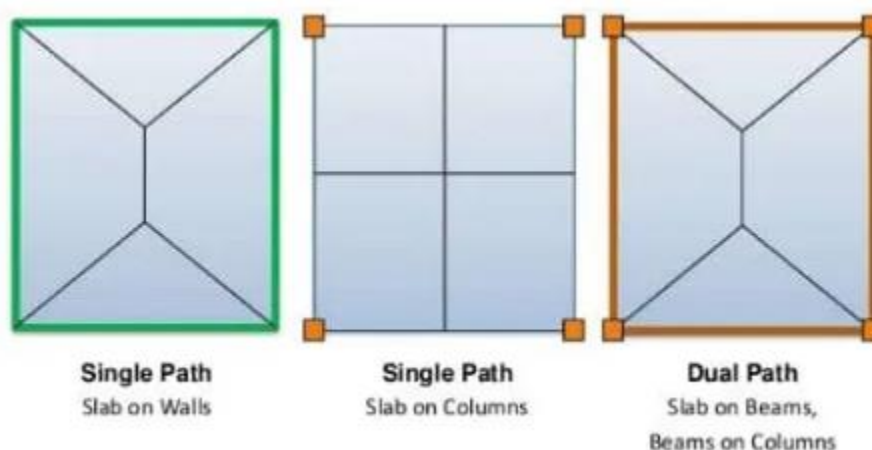
Figure 2.31: Load transfer from slab to different kinds of supporting parts (Izat,2018).

2.11.2 Concrete Beam

Concrete beams are linear structural elements that carry shear force, bending moment, and vertical load. In this research, all slab loading is transferred to the beam, resulting in reaction forces at the beam's end of the support point. Shear forces and bending moments will be generated within the beam because of all the forces applied. However, a few loads on the beam must be considered, such as self-weight load, dead load, live load, torsional load, and total loads from the slab. Figure 2.32 shows that the loads are transmitted to columns or other supporting structural components at their endpoints.
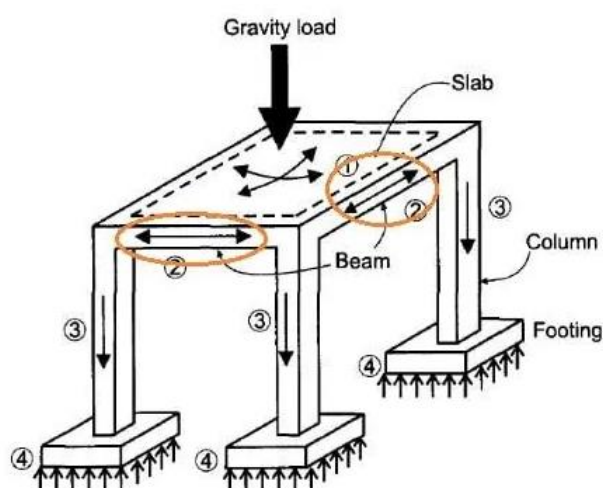
Figure 2.32: Load transfer from the beams to the column (Izat, 2018).

2.11.3   Concrete Column

Concrete columns are defined as long vertical structural elements in rectangular, square, or circle shapes that carry load mainly in compression (Izat, 2018). Columns are used to transfer all the loading to the foundation or ground. The bending action in the reinforced concrete column may produce tensile forces over a part of the cross-section axes. In the design, a few load loads on columns must be considered, such as self-weight load, total loads from slabs, and beam. Figure 2.32 above also shows that the foundation supports the columns and that the weight has been transferring from the slab and beam to the columns. The column will receive the axial force that has been transferred from the beams and then will be transferred the axial loads again to the footing. Furthermore, columns will transfer such loads to the footing when lateral loads are applied. Finally, the footing will resist all the moment and shear of the entire structure loads.

2.11.4   Footing

Structural footings are defined as structural elements that transmit the load of the superstructure to the underlying soil below the structure (Izat, 2018). Footings are intended to transfer these loads to the soil without exceeding the safe bearing capacity. As a result, it must keep the settlement of the structure to a bare minimum to avoid sliding and overturning. In the design, a few types of loads on the footing must be considered, such as dead load, live load, wind load, soil pressure, and a total load of an entire structural element of the building. The soil is the foundation of the footing, while all load forces acting on the footings will be transmitted to the soil. The soil must be capable of carrying these loads, referred to as bearing capability. Bearing capacity varies according to soil type and is a critical component in determining the dimension of footings. Figure 2.33 shows the loads transferred from structural elements to the soil through the footing.
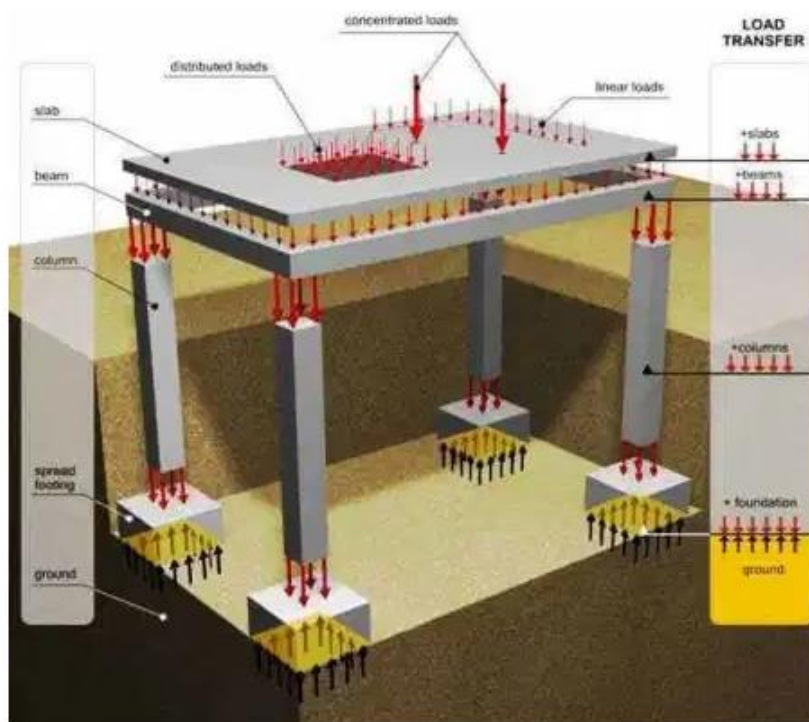
Figure 2.33: Loads transfer from structural elements to the soil through footing
(Izat, 2018).

2.12   Construction Material

Most construction materials used in the Malaysian industry are reinforced concrete (Yassin, 2012). It can be used to construct buildings, water retaining structures, retaining walls, foundations, highways, and bridges. It is a combination material made up of steel reinforcing bars and a shear link embedded with concrete. These three materials have their strengths and weaknesses in properties. However, the compressive strength of concrete is strong, while the tensile strength is low. When exposed to low compressive stresses, the steel bar can withstand large tensile stresses but buckles (Yassin, 2012). However, concrete embedded with steel bars will result in solid compression and tension. Figure 2.34 shows a skeleton view of concrete.
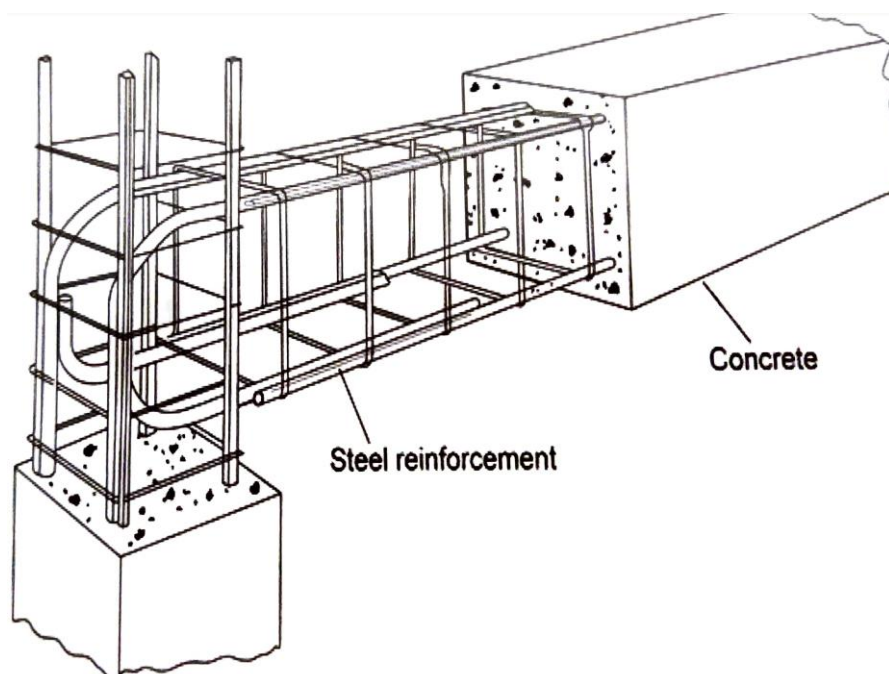
Figure 2.34: Skeleton view of concrete (Yassin, 2012).

2.12.1   Concrete

Concrete is a building material that lends itself to frame-type construction, as it can be easily shaped to resist the applied loads (Nawy, 2008). It has high compressive strength, is more fire-resistant than steel, has a long service life or minimal maintenance cost, is the most cost-effective structural material, and can be cast into any shape.

In addition, there are a few challenges to using concrete as the primary building material (Nawy, 2008). First, the tensile strength of concrete is roughly one-tenth of its compressive strength. Second, it will affect the final strength of concrete when mixing, casting, and curing concrete. Third, the cost of the forms needed to cast concrete is too expensive as the cost of concrete may be equal to the cost of concrete placed in forms. Lastly, the concrete might be cracked due to shrinkage and the application of live loads.

The crushing strength of concrete cubes or cylinders formed from the mix determines its strength (Yassin, 2012). These are tests after 28 days. For example, C25/30 is the standard concrete used in the industry; 25 means the cylinder crushing strength f_{ck} of 25 N/mm2 with a cube strength of 30 N/mm^2. Table 2.2 shows the strength classes of concrete and its use.

Table 2.2: Strength classes of concrete and its use (Yassin, 2012).

Class	f_{ck} (N/mm^2)	Usage
C16/20	16	Plain concrete
C20/25	20	Reinforced concrete
C25/30	25	Reinforced concrete
C28/35	28	Prestresses concrete / Reinforced concrete subjected to chlorides
C30/37	30	Reinforced concrete in foundation
C32/40	32	Reinforced concrete in foundation
C70/85	70	Reinforced concrete in foundation
C80/95	80	Reinforced concrete in foundation
C90/105	90	Reinforced concrete in foundation

2.12.2   Rebar and Shear Link

Rebar also known as reinforcing bar and shear link, is made up of rebars. Shear links are shaped into rectangular and circular shapes depending on their use. Reinforcing bar is classified into four types: hot rolled, cold worked, mild steel, and prestressing steel bars (The Constructor, 2018). A hot rolled reinforcing bar, known as "T", is the most common type of bar used for concrete structures. This is because the yield strength of hot-rolled rebar is up to 500 MPa, which is the highest compared to other types (The Constructor, 2018). High tensile yield strength will face difficulty during the shaping process of the shear link. However, the shear link is recommended to use mild steel plain bars as it has only 250 MPa, and mild steel plain bar is noted as "R" in the construction industry.

The rebar's characteristics are good in terms of compression, tension, and shear, but it will corrode if unprotected. Moreover, rebar is also weak in fire resistance. Table 2.3 shows the comparison of concrete and steel. From Table 2.3, steel embedded with concrete provides an excellent structural material as it is good in compression, tension, shear, durability, and fire resistance.

Table 2.3: Comparison of concrete and steel (Yassin, 2012).

Properties	Concrete	Steel
Strength in compression	Good	Good, but slender bar will buckle
Strength in tension	Poor	Good
Strength in shear	Fair	Good
Durability	Good	Corrodes, if unprotected
Fire resistance	Good	Poor

In the market, there are several rebar sizes in the construction industry. There are 6mm, 8mm, 10mm, 12mm, 16mm, 20mm, 25mm, 32mm, and 40mm. In other words, they are in T6, T8, T10, T12, T16, T20, T25, T32, T40, R6, R10, R12, R16, R20, and R25. The larger the size of the rebar, the higher the sectional area.

Reinforcing steel fabric, known as BRC, is a machine made with rebar joints at the intersections of the primary and cross wires made by the welding process (Rong Mah, 2020). Thus, BRC is formed in a square or rectangular grid pattern. This product saves the construction worker less time to bind with the rebars. It can save a lot of labour fees during construction. There are three types of BRC used in the construction industry, such as square mesh "A", rectangular mesh "B", and small square mesh "DA". Figure 2.35 shows the square mesh of BRC (Rong Mah, 2020).
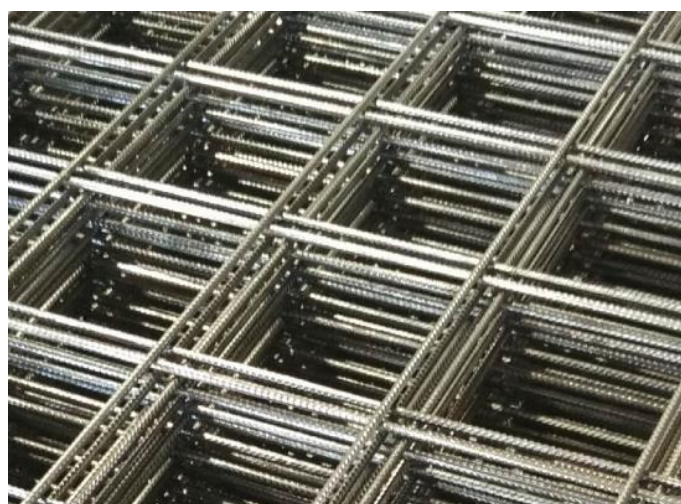
Figure 2.35: Square mesh of BRC (Rong Mah, 2020).

2.13 Quantity Take Off by BIM

The traditional quantity take-off (QTO) method involves manually choosing individual components from CAD drawings. It can calculate the measurements for take-off and enter the data into an excel spreadsheet automatically (Sharan, 2019). This technique takes a long time to generate the complete drawing's QTO list in excel. Mistakes and omissions will happen because the choosing and measuring stages rely entirely on manual tasks during the QTO process (Sharan, 2019).

QTO by BIM can reduce the time taken by the estimator to extract measurement and material quantities directly from the BIM model (Olsen and Taylor, 2017). Olsen studied that those estimators consume about 50% to 80% more time in the traditional method than in QTO by BIM. However, most BIM software includes the bill of material (BOM) functions to assist the estimator with material procurement. This function can reduce up to 80% of the time and accuracy while providing QTO (Olsen and Taylor, 2017). Figure 2.36 shows the time consumption of QTO by the traditional method and Revit.

Category	Contents	time [minutes] Manual	Revit
Table of rooms	Floor and ceiling composition	40	20
Foundations	Pads, belts, slabs	125	20
Construction phase	Walls, pillars, girders	420	10
Vertical constructions	Masonry, isolation	450	30
Wall surface	Plasters, paints	330	20
Ceiling composition	Ceiling composition	20	15
Floor composition	Floor composition	40	15
Wall composition	Wall composition	100	20
Facade	Facade	240	20
Roof composition	Roof composition	20	5
Balcony composition	Balcony composition	50	15
Groundwork	Excavations, embankments, removal	120	-
Staircases	Staircases	60	-
Other construction and work	Cleaning, shining, covering	70	20
Tables for take-offs		-	130
Total		2085	340

Figure 2.36: Time consumption of QTO by traditional method and Revit (Olsen and Taylor, 2017).

Revit and Navisworks have become the most favourable BIM software for QTO (Olsen and Taylor, 2017). This is because the software has good visualization in different views. Thus, the speed of work productivity

increases. Figure 2.37 shows the research on the most favourable BIM software in QTO.
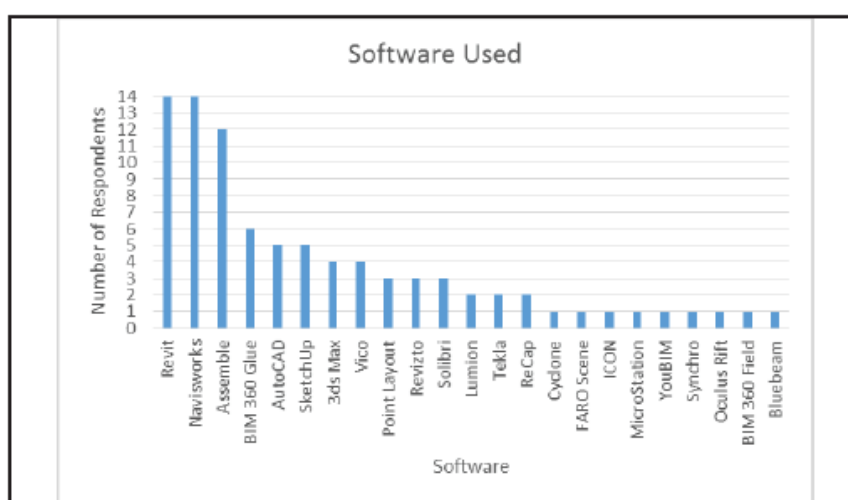
Figure 2.37: Most favourable BIM software in QTO (Olsen and Taylor, 2017).

2.14   Cost Estimation of Material by BIM

Engineers and architects are finding it challenging to keep up with the ever-increasing demands as the construction sector shifts its focus to increasingly complicated projects. Traditional procedures were discovered to be outmoded and urgently required something revolutionary (Sharan, 2019). As a result, BIM has gained traction in the AEC market (Sharan, 2019). BIM began as simple geometrical 3D modelling and has now evolved into a versatile approach that aids in various tasks. For example, Autodesk Revit enables storing product and price databases. It allows users to help stay within budget when applying materials in the design and determine the costliest materials used. The use of BIM in cost estimating has proven to be extremely helpful to all parties involved.

Cost estimation via BIM helps to evaluate design options quickly when design changes occur. The changes are automatically reflected in costs (Sharan, 2019). This allows designers to make changes to their ideas without worrying about time-consuming calculations. In addition, cost estimation via BIM helps in better forecasting as designers can leverage the power of information built up in their projects (Sharan, 2019).

There are three major ways to use BIM to help cost estimate and QTO (Sharan, 2019). To begin, export the amounts of construction components to estimate software. Second, connect the BIM tool to estimating software directly. Third, use a BIM quantity take-off tool. However, the third alternative is chosen because cost data will be provided for every single component in a project, down to a single piece of brick if cost data is added to BIM models. This is how BIM helps in better understanding component prices. Revit and other BIM software have much potential. It eliminates the stress and time spent interpreting drawings and calculating QTOs from blueprints (Sharan, 2019). As a result, the accuracy is improved, and most uncertainties are reduced to virtually zero.

This study simplifies the cost of related construction components in Tables 2.4, 2.5, and 2.6. All the costs of components are collected in the latest version based on Quantity Surveyor Online (2022) in the Malaysian construction industry.

Table 2.4: Cost of Rebar in Malaysia (Quantitysurveyonline.com.my, 2022).

Items (Rebar)	Rates (RM)	Unit	Remark
T6, T8, T10, T12	3,130.00	Tonne	RM3.13/kg
T16, T20, T25, T32	2,980.00	Tonne	RM2.98/kg
T40	3,030.00	Tonne	RM3.03/kg
R6	3,080.00	Tonne	RM3.08/kg
R10, R12	3,130.00	Tonne	RM3.13/kg
R16, R20, R25	2,980.00	Tonne	RM2.98/kg

Table 2.5: Cost of Concrete in Malaysia (Quantitysurveyonline.com.my, 2022).

Items (Concrete)	Rates (RM)	Unit	Remark
Grade 15 (Normal)	180.00	m^3	
Grade 20 (Normal)	232.00	m^3	
Grade 25 (Normal)	243.00	m^3	
Grade 30 (Normal)	255.00	m^3	
Grade 35 (Normal)	269.00	m^3	
Grade 40 (Normal)	285.00	m^3	

Table 2.5 (Continued)

Grade 45 (Normal)	245.00	m^3	
Grade 50 (Tremie 1 mix)	226.00	m^3	
Grade 55 (Tremie 2 mix)	251.00	m^3	
Grade 60 (Tremie 2 mix)	272.00	m^3	
Every grade increase	2.10	m^3	Add on
Pump mix concrete	6.00	m^3	Add on
Tremie 1 mix concrete	12.00	m^3	Add on
Tremie 2 mix concrete	18.00	m^3	Add on
Waterproofing mix	20.00	m^3	Add on
Chipping mix	40.00	m^3	Add on

Table 2.6: Cost of BRC in Malaysia (Quantitysurveyonline.com.my, 2022).

Items (BRC)	Rates (RM)	Unit	Remark
BRC A6 (2.2 x 6.0m)	106.92	Piece	$RM8.10/m^2$
BRC A7 (2.2 x 6.0m)	145.41	Piece	$RM11.02/m^2$
BRC A8 (2.2 x 6.0m)	190.32	Piece	$RM14.42/m^2$
BRC A9 (2.2 x 6.0m)	240.21	Piece	$RM18.20/m^2$
BRC A10 (2.2 x 6.0m)	296.52	Piece	$RM22.46/m^2$
BRC A12 (2.2 x 6.0m)	474.72	Piece	$RM35.96/m^2$
BRC B6 (2.2 x 6.0m)	179.63	Piece	$RM13.61/m^2$
BRC B7 (2.2 x 6.0m)	218.12	Piece	$RM16.52/m^2$

2.15 Descriptive Statistical Analysis in Construction Industry

According to Kaur (2018), descriptive statistical analysis is used to conclude all the data in an organised way by defining the relationship between variables in a sample or population. He also stated that descriptive statistics is the first step before conducting any inferential statistical comparisons during a study or research. Moreover, this statistical analysis includes a few variables such as nominal, ordinal, interval, central tendency, dispersion, position, and measure of frequency (Kaur et al., 2018).

Descriptive statistical analysis is a quantitative study that provides valuable statistical information to the construction industry. It recognised the

type of data the graph represents. However, the presence of a graph enabled the evaluation of a brief and content graph or chart from complex data. Figure 2.38 shows the types of data graphs such as pie charts, bar charts, line graphs, etc.
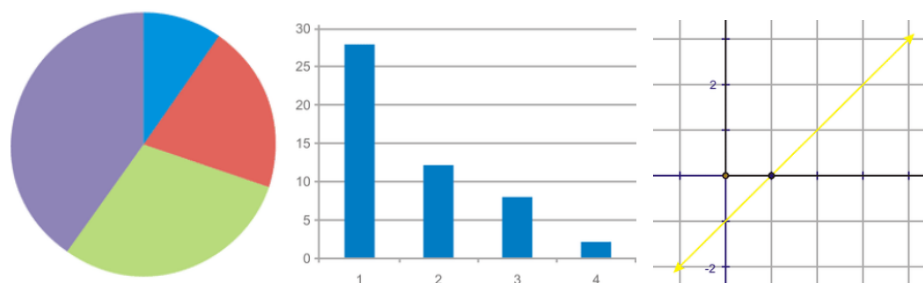
Figure 2.38: Types of data graph (Kaur et al., 2018).

Kaur (2018) stated that statistical analysis provides decision-makers with information needed to finish their tasks, such as justification of the budget, cost, and networking. Thus, the construction cost requires a large amount of cash flow. Hence, descriptive statistical analysis enabled the decision makers in construction to easily control and analyse the cost and budget control. As a result, it will improve the quality of the project and work efficiency.

Consequently, Laerd Statistics (2018) concluded that descriptive statistics represent an important part of initial data analysis and give a solid foundation for determining the variable with an inferential statistical test. It also functioned as an important way to report the most relevant descriptive statistics by using a systematic approach to prevent misleading results (Huebner et al., 2016).

2.16   Summary

In brief, the literature review introduces the general introduction of BIM regarding its history, background, and definition. Moreover, BIM has up to 8D dimensions, and its definition of each dimension is being reviewed. Besides that, the lifecycle of BIM, including three main phases, design, build, and operation is also being reviewed. Then, key features of BIM such as closed and open BIM, BIM soft technologies, application in coordination, advantages

of BIM, the challenge of BIM, and coordination of ShareBIM are also illustrated in the literature review. Besides that, the review of utilization of the European Standard code in designing the reinforced concrete elements and materials is important and specified due to the national standard rules that must be followed to develop a reliable reinforced concrete building in the study. Other than that, the comparison between the traditional method of quantity take-off and QTO by BIM is being reviewed in the literature review. Then, cost estimation of material by BIM is conducted using Autodesk Revit by using file exportation after the structural analysis by BIM software.

Rapid development in Malaysia brings construction waste. This is because of poor communication and design errors, such as poor measurement progress. Moreover, construction organizations in Malaysia still use the traditional method in their current projects and lack awareness of BIM. BIM has a lot of good tools and features that allow work productivity to be done accurately and consistently. Moreover, BIM enables the storage and exchange of extensive data among the project teams. BIM also reduces time spent on the design stage as every piece of data can be carried forward to another BIM software.

In this study, Autodesk Revit is chosen as it is the most popular appliance in the construction industry. It is used to model a structural skeletal reinforced concrete building, quantify the QTO, and cost estimation of QTO. Once the model is finalized, it undergoes clash detection with the MEP and architecture model. Then, the entire Revit file, including all the quantity and cost data inserted, is uploaded to ShareBIM for further communication among the project team. The communication includes resolving the 3D model if there are any clashes detected.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter presents the workflow and important criteria from beginning to end. Initially, planning is the beginning stage of all the processes to achieve the aim and objectives of the project on time. However, it is also applied in the current construction industry to ensure that all the procedures are well prepared during the design phase. In this project, the processes cover modelling of a high-rise reinforced concrete structural framing, structural analysis, quantity take-off, a collaboration between the project team to examine issues of the entire building, and cost estimation of quantities used. Besides, some limitations, such as earthquake load, wind load, and shear wall, are not considered during structural analysis. Furthermore, the building under study is a high-rise reinforced concrete building that consists of 26th floors. However, it has exceeded my limitations; therefore, the 26th to 9th floors were chosen instead of the entire building. This is because the entire building consists of 4 floorplans: roof, 25th to 9th floor, 8th to 1st floor and ground floor. This study requires three BIM software, Autodesk Revit, Esteem, and ShareBIM, to complete it co-ordinately.

3.2 Overview of Flowchart

In this study, Figure 3.1 shows the entire flowchart of this study. The procedures are categorised into six stages: modelling, collaboration, structural analysis, placement of rebar, quantity take-off and statistical analysis.

Initially, a 3D structural model is modelled by Autodesk Revit based on referring to 2D CAD plans prepared by the supervisor. The concrete structural framing model only includes beams, columns, slabs, and stairs. Moreover, there are a few challenges throughout the modelling process. The challenges included the improper location of the staircase and the incorrect location of the column. All these challenges are described in the following sub-chapter.

Subsequently, collaboration and communication are required between the architectural and MEP models by utilising ShareBIM. This process is important because it identifies building issues such as modelling, or clashes detected between the models. The importance of collaboration is to determine work status and lower human errors during the modelling in the design phase. At the same time, communication within the project team enabled to resolve the building issue simultaneously with other team members. In addition, all the past communication history is recorded in the database of ShareBIM to allow the teams to refer to the issue at any time until it the completely built during the construction phase. Besides that, further modification in the structural model is possible after the communication among project teams.

Once there is no further modification, the BIM model is exported to structural analysis design software Esteem 9. It required assigning loads, combinations of loads, and parametric loads manually based on the design standard of Eurocodes (EC), then performing linear analysis to design structural elements and design steel reinforcement.

Eventually, the model has exported back to Autodesk Revit for rebars and shear links placement. Therefore, quantity takes off, and materials cost estimation is generated by Autodesk Revit and exported to Microsoft Excel. Thus, a descriptive statistical analysis of reinforced concrete construction material is performed and discussed in the following chapter. In addition, all the critical data is discussed and explained in chapter four.
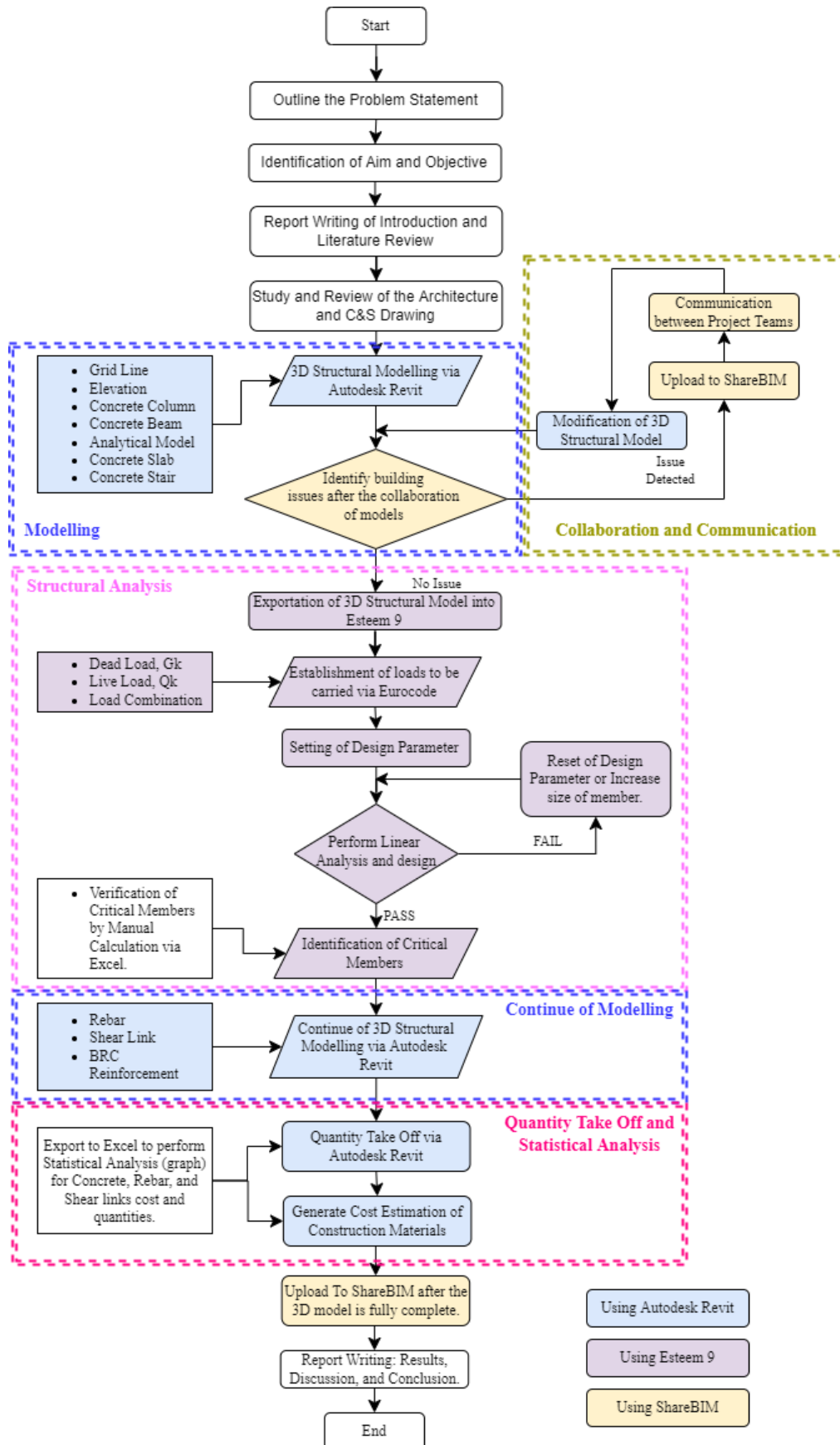
Figure 3.1: Overview of flowchart.

3.3 Building Specifications

In this study, the 9th to high roof level (HRL) is chosen to study instead of an entire building. However, the supervisor gives 2D CAD architectural and structural drawings of the reinforced concrete building, but the structure plan details are incomplete. Thus, there is limited detail in the drawing. The information in the 2D CAD drawings is summarized in Table 3.1.

Table 3.1: Summarised information of 2D CAD drawings.

Items	Size (mm)
Beams	1. 150 x 600 mm 2. 150 x 500 mm (Near drop point) 3. 150 x 540 mm (Near drop point) 4. 230 x 600 mm (Below water tank)
Column	1. 300 x 900 mm 2. 300 x 1200 mm 3. 150 x 200 mm (Roof)
Slabs	1. 125mm (In-situ concrete)
Slabs drop point	1. 100 mm (Toilet, Balcony, Residence Corridor) 2. 50 mm (Lift Waiting Area)
Staircase	1. 150 mm (Land thickness) 2. 150 mm (Riser) 3. 260 mm (Tread) 4. 1450 mm (Run width)
Elevation	1. 3265 mm (9F to 25F) 2. 4965 mm (25F to LMR) 3. 1300 mm (LMR to LRL) 4. 2500 mm (LRL to HRL)

Beams with the size of 150x600 mm are commonly utilised in the drawing, while 150x500 mm is used for 100mm drop slabs in the residence corridor. Moreover, as shown in Figure 3.2, 150x550 mm is used on 50mm drop slabs in the lift waiting area. In addition, slabs with the size of 125mm in

situ concrete are assumed since the information was not provided in the given structural drawing.
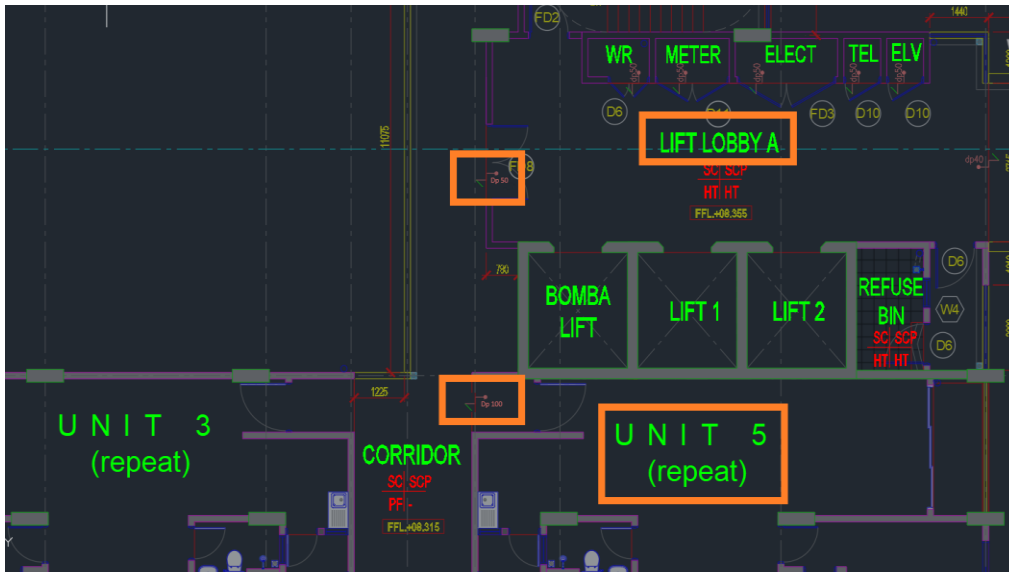
Figure 3.2: Building specifications of drop point.

Other than that, columns with size 300x900 mm are commonly used, while only two columns with size 300x1200 mm were used in the drawing, as shown in Figure 3.3.
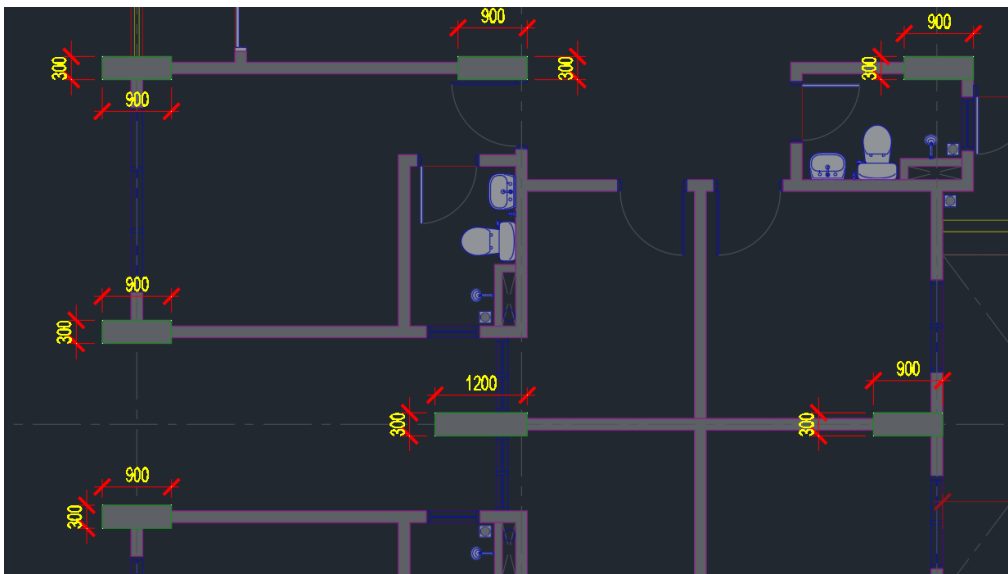
Figure 3.3: Building specifications of column.

Furthermore, the concrete building consists of three staircases; two are drawn up to the 25th floor in the side wing, and one is up to the lift motor room (LMR) floor in the middle. The information of stairs is 150 mm of landing thickness, 150 mm of the riser, 260 mm of tread, and 1450 mm of run width, as shown in Figure 3.4.

Figure 3.4: Building specifications of middle stair.

Moreover, the elevation of the building from the 9th floor to the 25th floor is measured at 3265 mm, from the 25th floor to the lift motor room floor (LMR) is measured at 4965 mm, and from LMR to the lower roof level (LRL) is measured at 1300 mm, and from LRL to the high roof level (HRL) is measured at 2500 mm, as shown in Figure 3.5.

Figure 3.5: Building specification of elevation.

3.4   3D Structural Modelling in Autodesk Revit

In this project, the skeleton of the building is focused on, such as concrete beams, slabs, columns, and stairs. Two parts of modelling are separated in the flowchart, which are internal and external modelling. External modelling refers to the appearance of the building, such as grid line, elevation, concrete column, beam, slab, stair, and analytical model. These structural components were the model's priority due to undergoing structural analysis to assess its reliability in Esteem 9. Nevertheless, internal modelling referred to rebar, shear link, or BRC reinforcement used inside the structural components after the structural analysis in Esteem 9 as shown in the flowchart.

3.4.1   Gridline and Elevation

Primarily, a structural template in Autodesk Revit is created. Then, gridlines for each floor are drawn by linking from CAD. This method prevents any human error mistakes compared to referring manually.

It is important to draw gridlines before modelling the beam, column, and slab because the gridline serves as a reference point to place structural components accurately and consistently. Figure 3.6 shows the link to the CAD button for importing a given CAD drawing to Autodesk Revit. The button for 'Link CAD' is hidden inside the insert tools box of Autodesk Revit. This study uses it as a tracing reference plan instead of manually referring side by side. This method reduces time as the reference plan and modelling plan is merged.
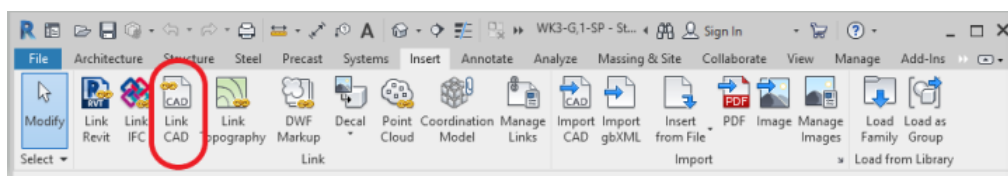
Figure 3.6: Link CAD button to Revit.

Once CAD is inserted, the CAD drawing is shown in blue, and all the gridlines are drawn on the link CAD drawing in Autodesk Revit. Then, all the names of the gridline are named according to the given plan by the supervisor to avoid dazzling off while facing any issue later. Figure 3.7 shows that the reference plan is merged in blue, and the gridlines are created.
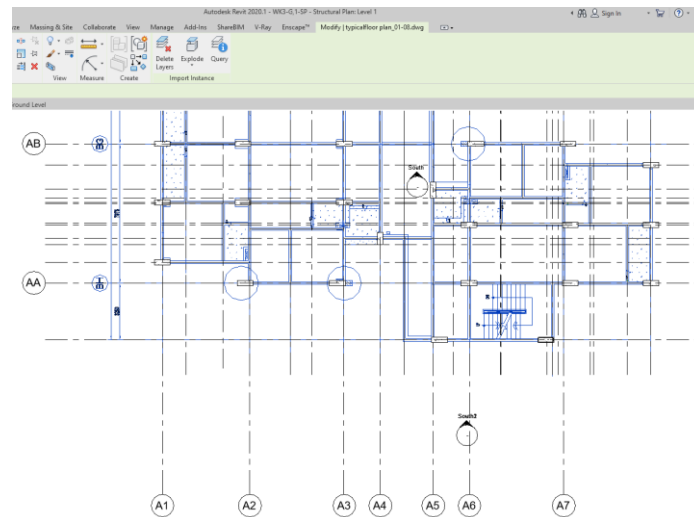
Figure 3.7: Draw grid line on Link CAD reference plan.

After all the gridlines are inserted, the elevation is placed at each level, followed by the building specification. Figure 3.8 shows an east view of the elevation in Autodesk Revit. Revit allowed inserting elevation from the elevation view of the entire model only. From Figure 3.8, Level 9 is set at 31270mm above ground level with an elevation floor-to-floor height of 3265mm.
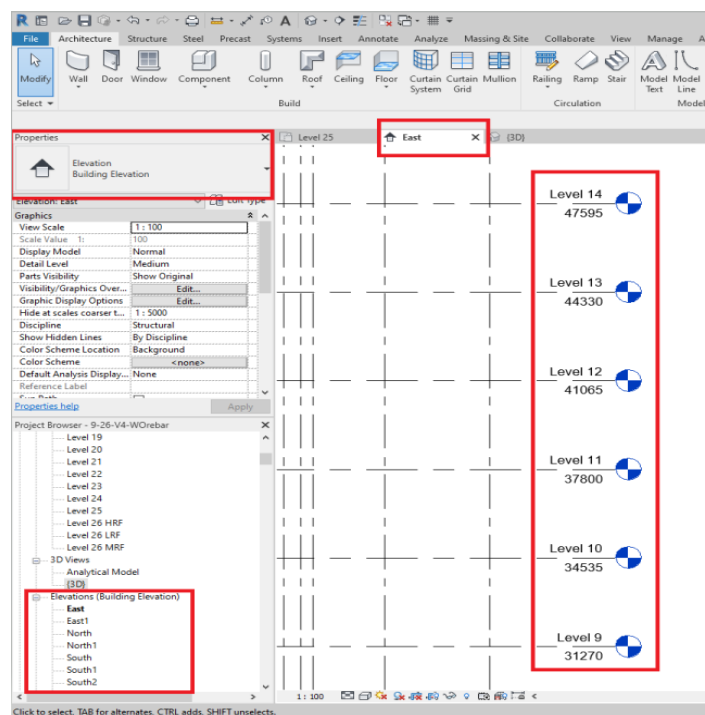
Figure 3.8: Elevation of the model is set.

Once all the grid lines and elevation are drawn, a process of rechecking is required to avoid human mistakes before placing beams, slabs, stairs, and columns in the BIM 3D model. Figure 3.9 shows the checking process between the drawing and model plans.
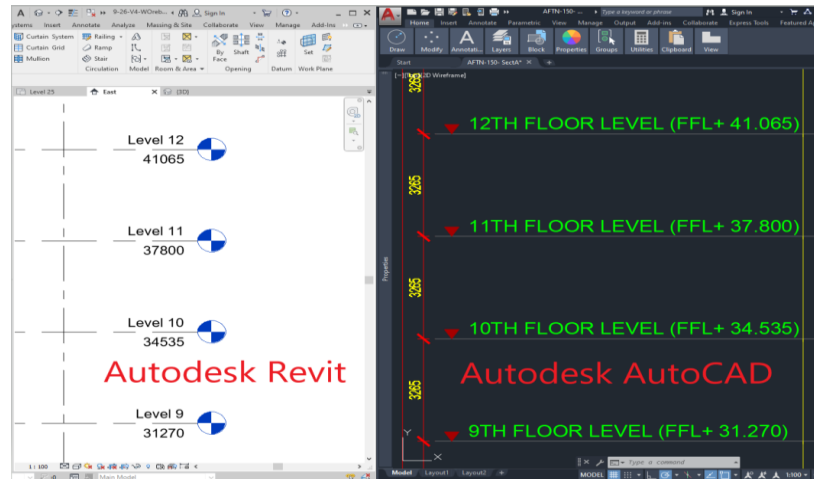
Figure 3.9: Double check process of elevation.

3.4.2 Column

The columns are placed through the button of 'column', which is hidden under the structure tab after the completion of gridlines and elevation according to each level and floor level. By referring to CAD, columns are added to the reference CAD plan. Figure 3.10 shows the column button for adding a column into the model and the edit type button to insert the type and properties of the column.
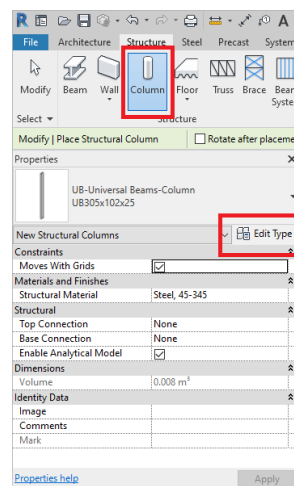
Figure 3.10: Structural column button and edit type button.

Once the button of the column in the structure tab is clicked, a default setting of the column is generated in the drawing. It is required to change the dimension of the column according to building specifications by selecting the 'Edit Type'. The type of column named concrete rectangular column in Revit families is selected as shown in Figure 3.11.
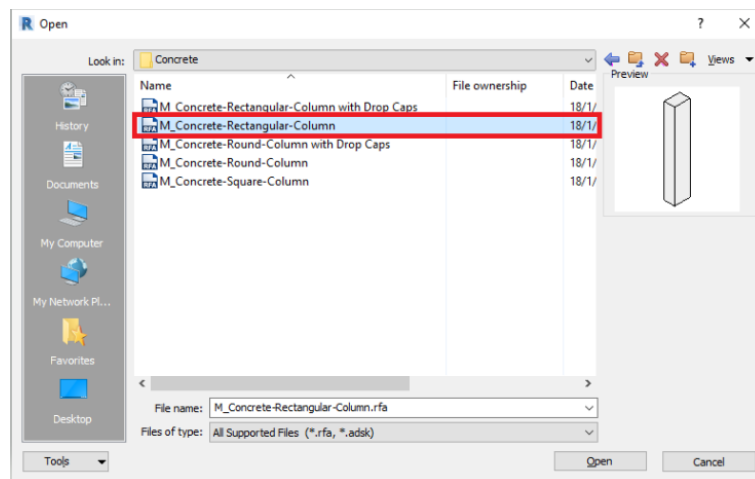
Figure 3.11: Selection of concrete type.

Afterwards, it is shown to insert the dimension of the column as shown in Figure 3.12. After that, the parameters of the column are set and proceed to the placement of the column.
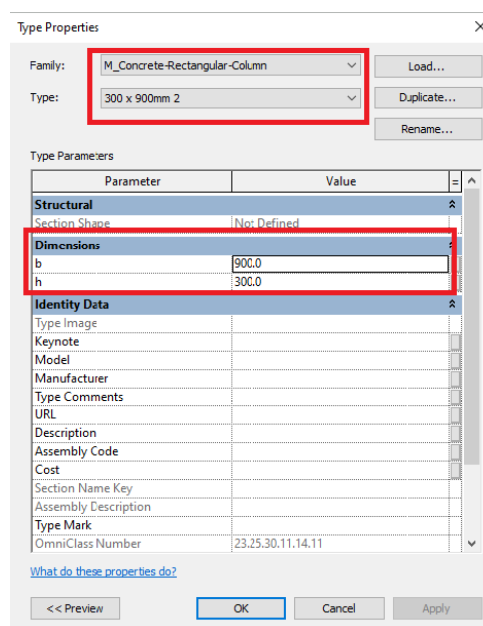
Figure 3.12: Dimension of column is inserted.

Once the column is added, the type and properties of the column are shown in the properties toolbox by selecting the column to ensure the column's parameters are set correctly, as shown in Figure 3.13.
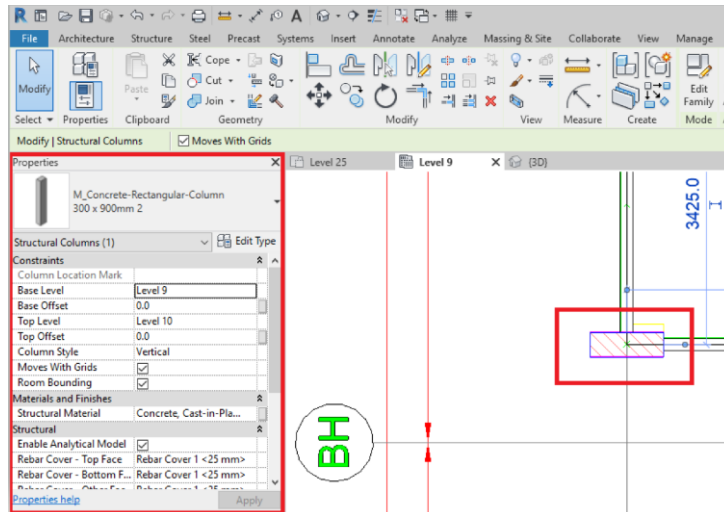
Figure 3.13: Selected column and its properties.

In addition, one challenge was faced during the modelling of the column. This is because the location of the column on the ground and first floor is not symmetrical. Figure 3.14 shows that the ground and the first-floor plans are merged, and a column in grid A3/AA is not symmetrical. The issue is solved by following the majority column of the floors. Finally, Figure 3.15 shows the 3D model after placing all the columns on each floor from the 9th to the high roof level (HRL).

Figure 3.14: Issue of placing the structural column.
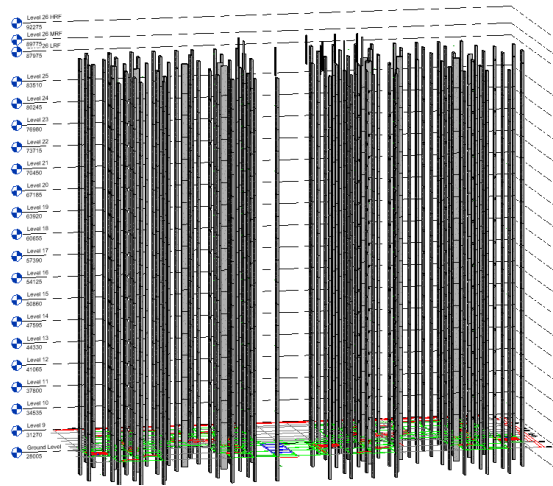
Figure 3.15: 3D model after placement of all the columns on each floor from 9th to high roof level (HRL).

3.4.3   Beam

Once the columns are added, the beam is placed by using the same procedures as the column. The steps were repeated by clicking the structural beam button and then editing the beam type. The concrete beam is loaded by the Revit families. The dimension of the concrete beam is inserted in the 'properties' toolbox. The concrete beam can be inserted once all the parameters are set correctly. Beams are added to the reference CAD plan by referring to the link to the reference CAD plan. Figure 3.16 shows the beam button for adding the beam into the model and the edit type button to insert the type and properties of the column.
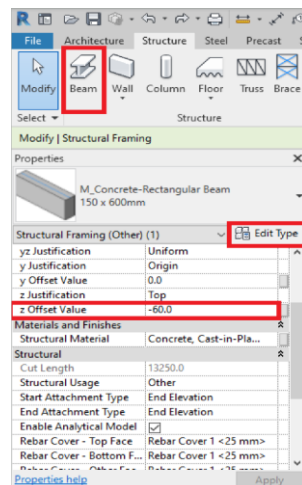
Figure 3.16: Structural beam button and edit type button.

Once the button of the beam in the structure tab is hit, a default setting of the beam is generated in the drawing. It is required to change the dimension of the column according to building specifications by selecting the "Edit Type" The selected column named "rectangular concrete beam" in the Revit families is shown in Figure 3.17.
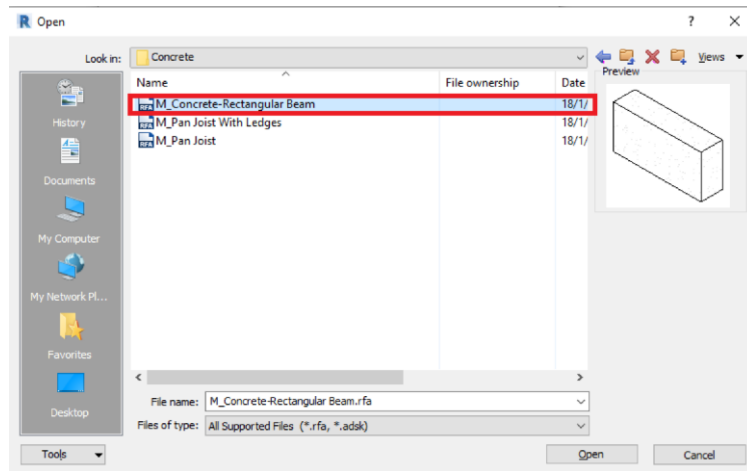
Figure 3.17: Selection of concrete type.

Then, it is shown to insert the dimension of the beam as shown in Figure 3.18. After that, the parameters of the beam are set and work proceeds to the placement of the beam.
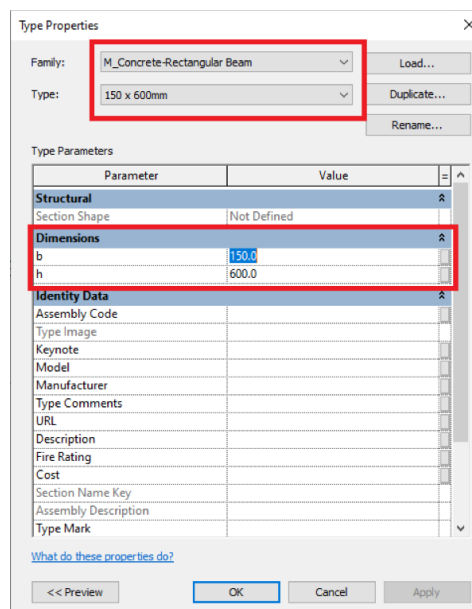
Figure 3.18: Dimension of beam is inserted.

Once the beam is added, the type and properties of the beam are shown in the 'properties' toolbox by selecting the beam. This is to ensure the parameters of the column are set accurately. In addition, an offset value of -60 mm is set according to the floor finish level given in the drawing plan, as shown in Figure 3.19.
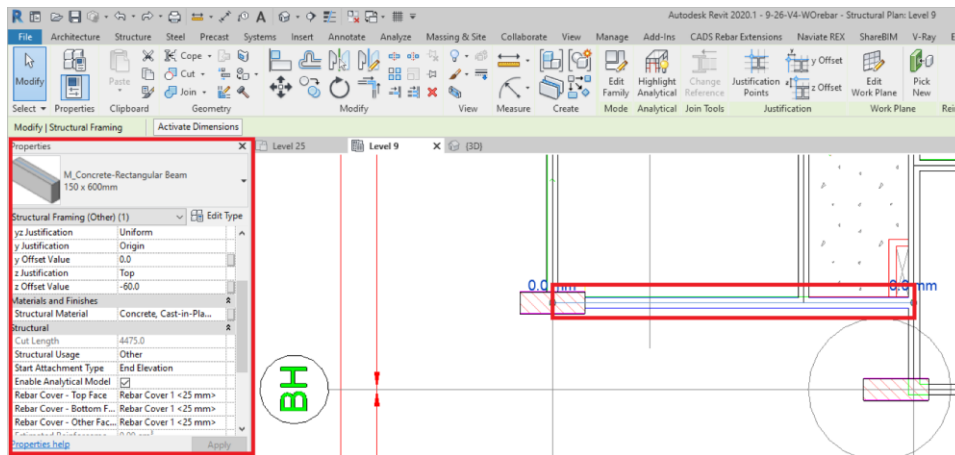
Figure 3.19: Selected beam and its properties.

In some cases, a smaller beam must be inserted below drop slabs. In the study, the corridor is designed at a drop from the residence's unit. Thus, the corridor's beam is required to be smaller, as shown in Figure 3.20. Finally, Figure 3.21 shows the 3D model after placing all the beams on each floor from the 9th to the high roof level (HRL).
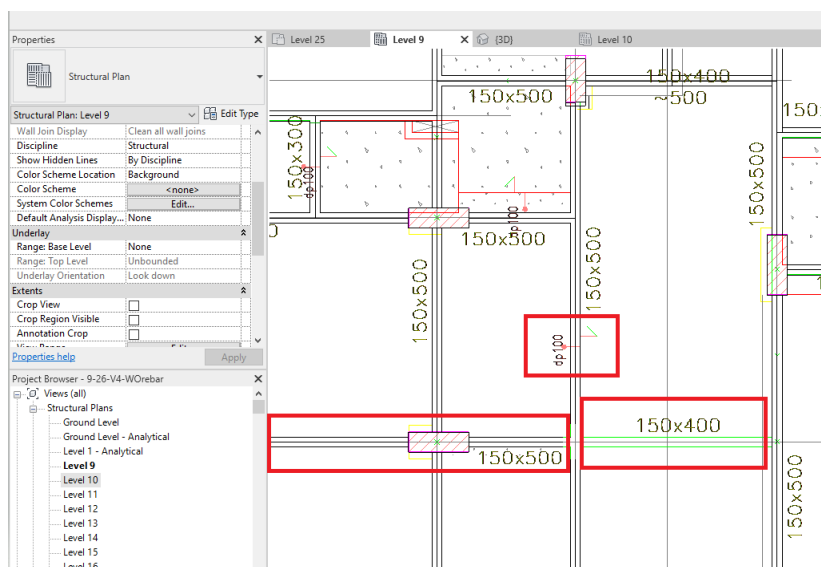
Figure 3.20: Case of using smaller beam.
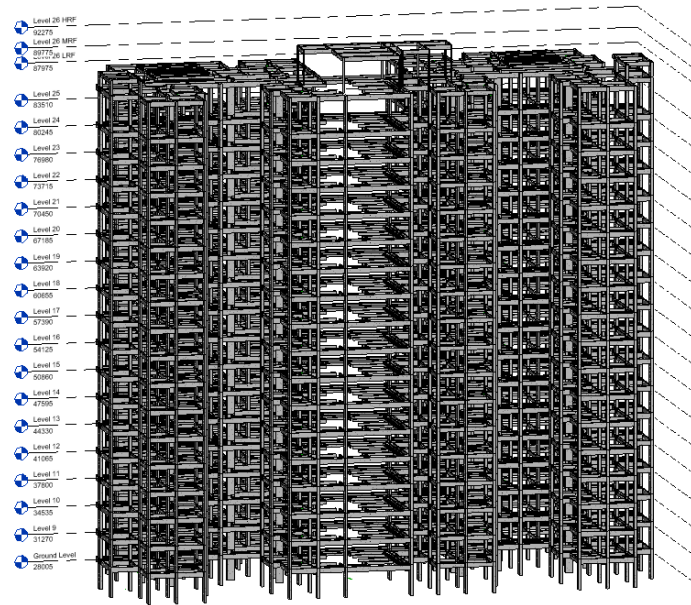
Figure 3.21: 3D model after placement of all the beams on each floor from 9th to high roof level (HRL).

3.4.4 Analytical Model

Next, the analytical of the beam must be connected to the column or beam after the beam is inserted. This is the most important part of modelling a BIM model because it carries forward structural analysis. The analytical beam informed the structural analysis software where the beam is connected, such as beam to column, beam to beam, and column to column. Figure 3.22 shows the analytical model button to show the model in the analytical view.
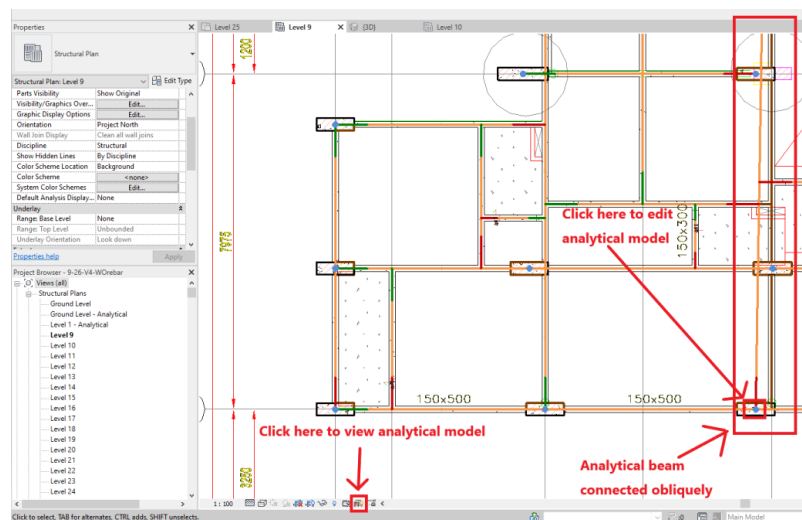
Figure 3.22: Click to view analytical model.

To modify the analytical model, click on the edit analytical model button in blue, as shown in Figure 3.22 above. Then, a pop-up screen is shown and adjusted or modified in the analytical alignment section, as shown in Figure 3.23. After modification, the analytical beam is connected neatly to the column, as shown in Figure 3.24.
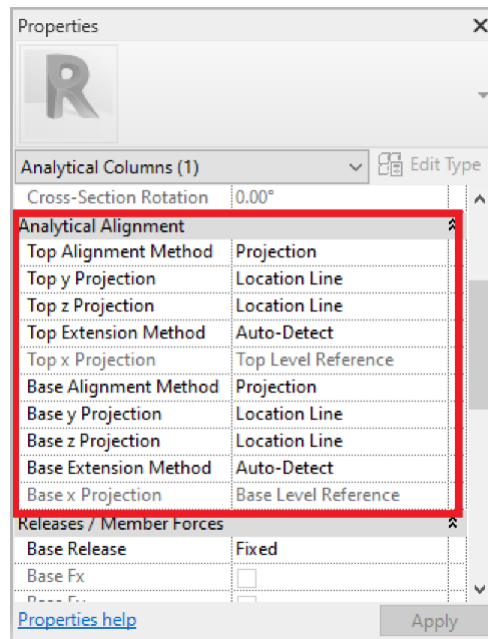
Figure 3.23: Analytical alignment of analytical model.
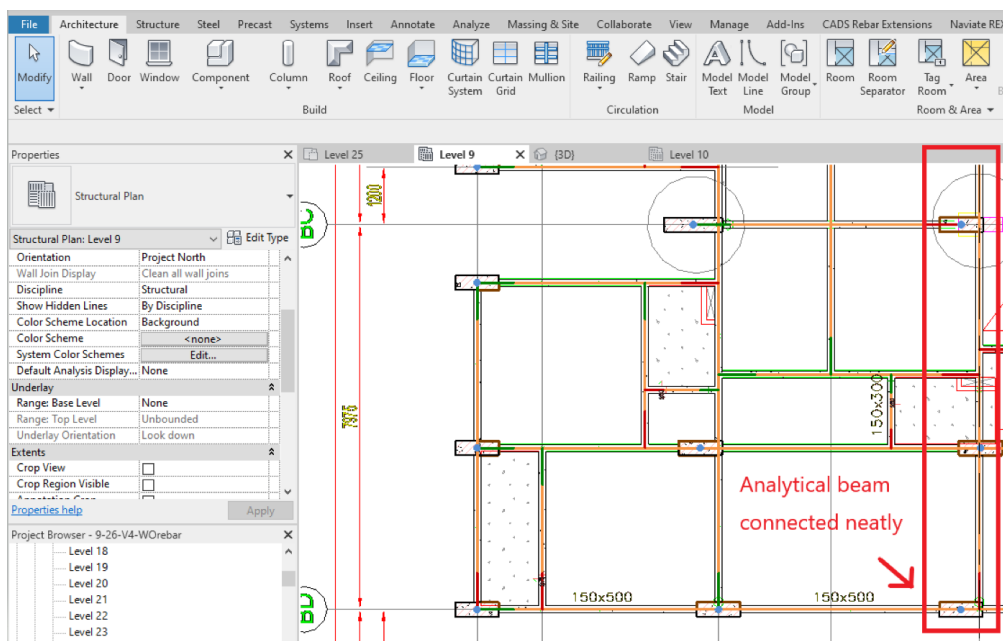
Figure 3.24: Analytical beam connected neatly to the column.

3.4.5 Slab

Subsequently, slabs are inserted into the BIM model. Slab placement procedures are almost similar to beam and column placement. Once all the parameters are set, all the slabs are drawn manually without interference with neighbour slabs and columns. This is to avoid multiple computations of material take-off. Consequently, an extra procedure named "Trim" is required to model. Figure 3.25 shows that the slab is trimmed in pink without interfering with the column and neighbour slabs.
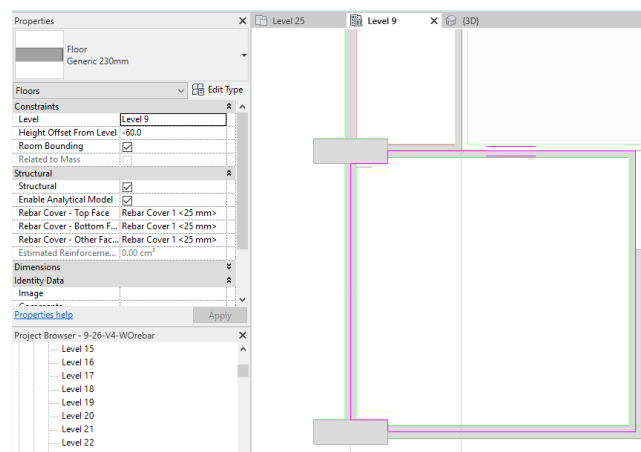
Figure 3.25: Slab is trimmed.

3.4.6 Stair

Eventually, the structural staircase is drawn using an architectural staircase and then modified into a structural staircase. This is because there was no structure stair in the Autodesk Revit. Figure 3.26 shows the button of the architectural stair, and Figure 3.27 shows the button of the model structural component. The parameters of stairs are set according to building specifications. Initially, an architectural staircase is modelled.
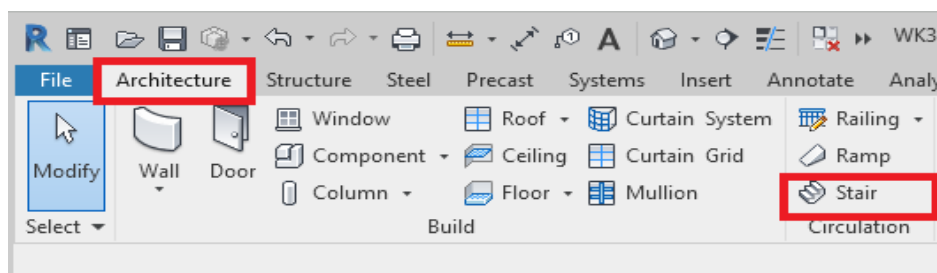
Figure 3.26: Architecture stair button.
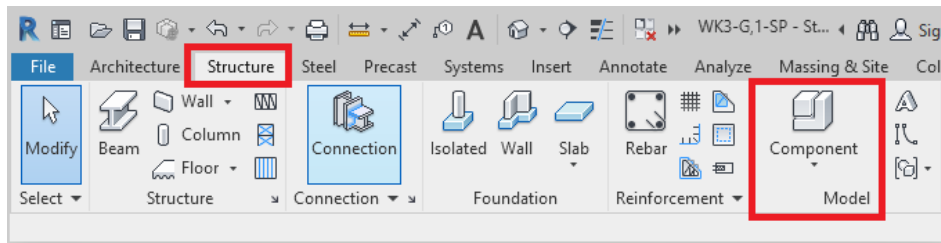
Figure 3.27: Structure component button.

Once the architectural stair is drawn, the structural stair is modelled by the feature of the structural component in Autodesk Revit. However, the architectural stair is treated as a reference stair, and the structural stair is drawn by using the placement of lines in the structure component, as shown in Figure 3.28.
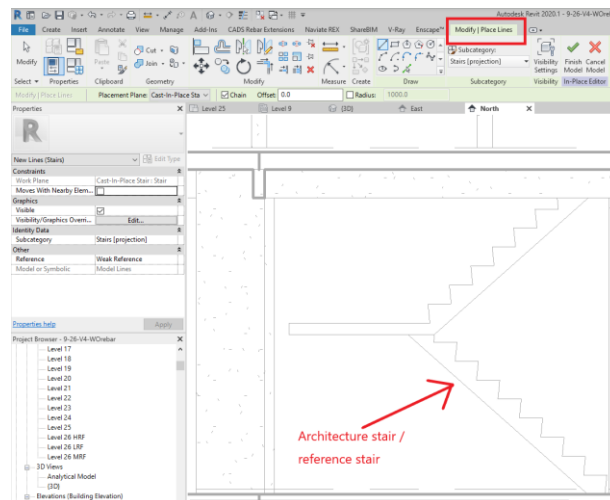
Figure 3.28: Model of Structure stair.

Therefore, the stairs are categorized as a part of the structure. This step is important because the architectural stair will not properly connect the rebar between flight and land during the rebar placement in Autodesk Revit, as shown in Figure 3.29.
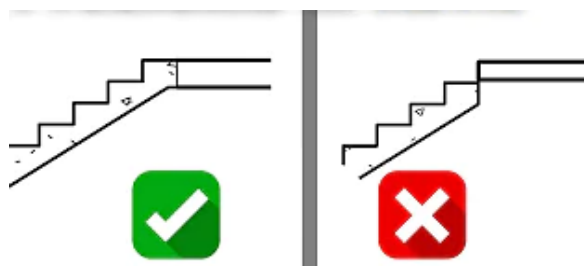
Figure 3.29: Comparison of architecture stair and structure stair in Revit.

In addition, there is one challenge faced during the modelling of stairs. The stairs on the ground and first floor are not located correctly. An up-sign of the stairs on the ground floor and the first floor has clashed. Figure 3.30 shows the stairs of the ground and first-floor plans.
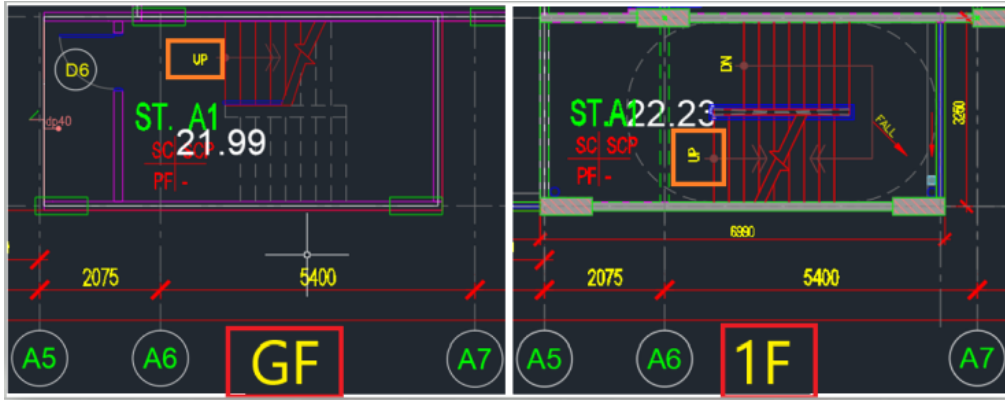
Figure 3.30: Issue of placing structural stair.

The issue is solved by following the majority of the stairs in the entire building. The stairs are the last structure to be modelled. Hence, a complete 3D skeleton structural model is created via Autodesk Revit, as shown in figure 3.31.
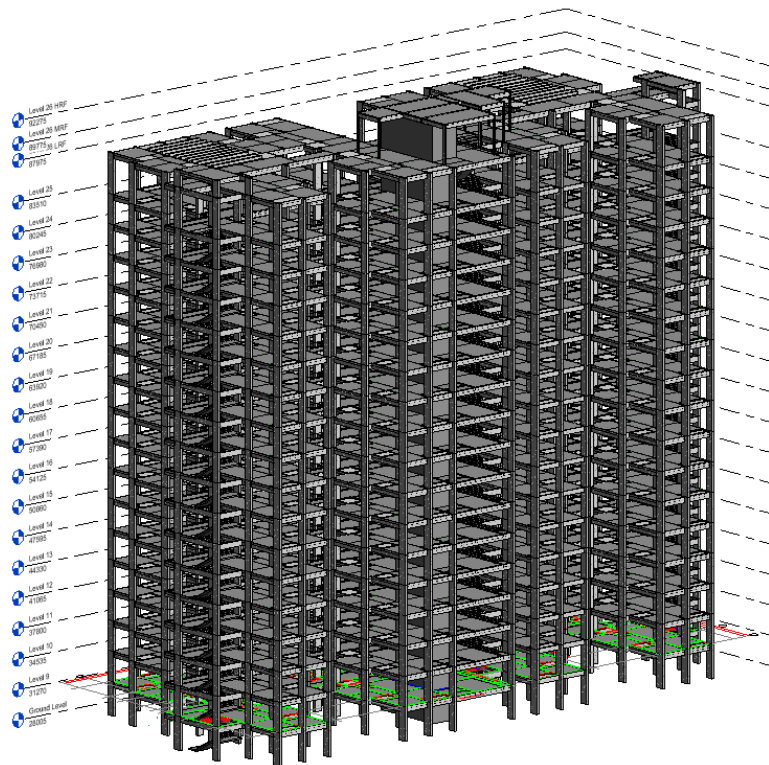
Figure 3.31: Completed 3D Skeletal model via Revit.

3.5   Collaboration and Communication in ShareBIM

The completed skeletal structure model is uploaded to ShareBIM using the ShareBIM plug-in in Autodesk Revit. This process involves collaborating with other project team members to check the building issues, such as clash detection between structural elements, elevation issues, etc. Once the completed skeleton model is uploaded, it is required to merge with architecture and MEP models to carry forward. Besides that, the sensitivity of the merged model is challenging to control the BIM 3D model's movement. However, there is a feature in ShareBIM to assist in better movement or control named "roam". Roam can be described as a movement about or travel, especially over a wide area. In other words, a virtual man acts as a control reference to walk along the BIM merged model. This is important due to the boost in better visualisation and coordination during the design phase. Thus, the model is equipped to identify errors and issues by utilising roam feature. Figure 3.32 shows the merged BIM model in ShareBIM with "roam".

Figure 3.32: Merged BIM model in ShareBIM with roam.

3.5.1   Creation of Model Issue

The virtual man is enabled to walk through the entire building to determine the errors in the BIM collaboration model. However, walking through typical floors such as roof levels and the 25th and 24th floors is required. Floors other than that are not required to check through because 9th to 23rd floors are duplicated floors from the 24th floor. For example, an error is found between the electrical trunking and the column in the study. According to Fakharifar and Chen (2017), concealing a pipe in a concrete structure will influence the structural stability and strength unless the concrete structure is designed to

embed it. This project's electrical wire box is not designed to be embedded in the structural column. Thus, this issue must be created and informed. Figure 3.33 shows a clash between the electrical wire box and the structural column.

Figure 3.33: Clash detected between electrical wire and structural column.

During the creation of the model issue, ShareBIM can note down the content and description, then set a deadline for this issue and upload media, which is much similar to authoring an email. One of the beauties of setting up a deadline for the model issue is to ensure team members take a reply within a reasonable period. Therefore, the project will not cause any postponement during the design phase. Figure 3.34 shows the issue details of the clash detected between the electrical trunking and the structural column in ShareBIM during the collaboration of BIM model.
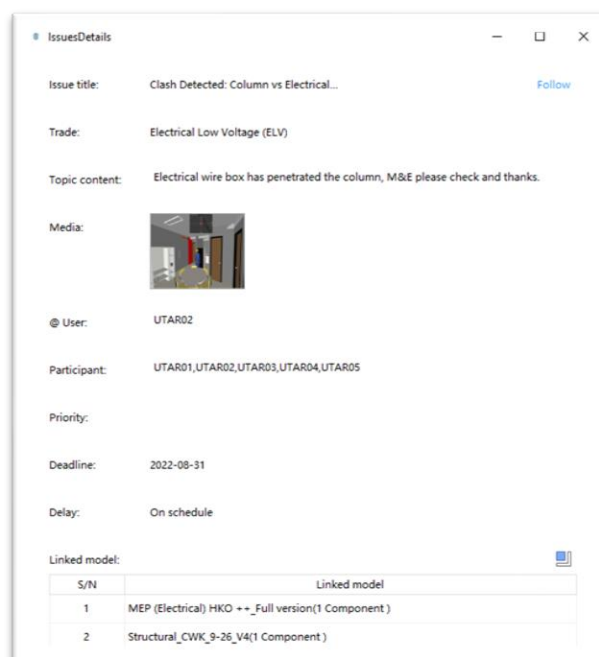
Figure 3.34: Created Issue detail of clash detected between electrical wire and column.

3.5.2   Communication

Communication in ShareBIM is referred to as feedback on the issue that another team member creates in this study. It is a type of discussion in BIM software that enables to record of all the communication history in the current project. Figure 3.35 shows a discussion of an issue between team members in ShareBIM.
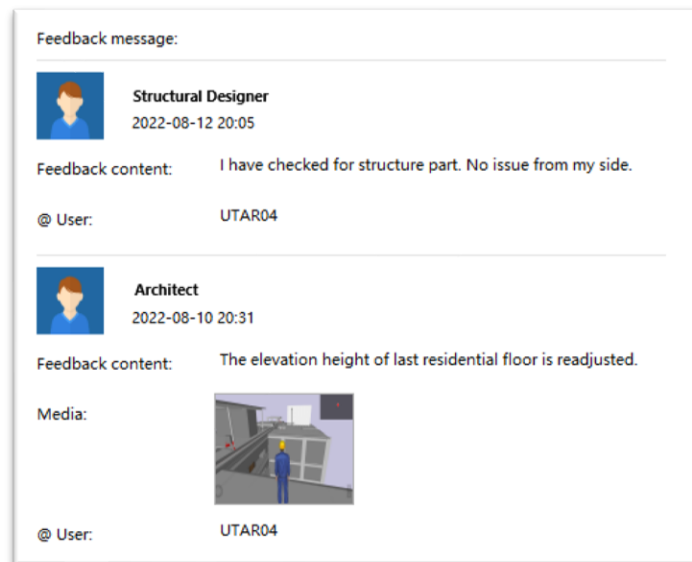
Figure 3.35: Communication of an issue between team members.

3.6   Exportation of Autodesk Revit model to Esteem 9

After all the issues are settled in ShareBIM, the 3D skeletal model in Autodesk Revit is then exported out to Esteem 9 for structural analysis and design reinforcement purposes. By exporting an Autodesk Revit model to Esteem 9, a plug-in must be installed into Revit named 'Esteem Revit Intermediate File'. Its function is to export file type from '.rvt' to '.esrvt', then Esteem 9 only able to read and load (Kah Heng, 2015). Figure 3.36 shows the procedures for exporting a model from Autodesk Revit to Esteem 9.
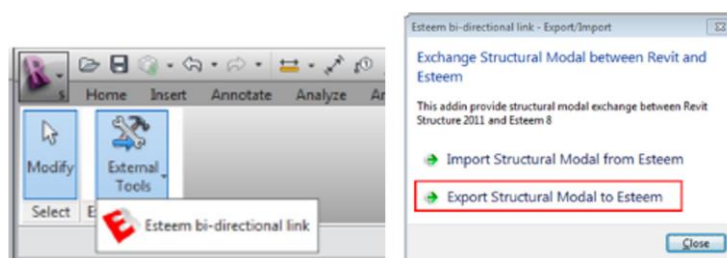
Figure 3.36: Procedures of export model from Autodesk Revit to Esteem 9.

Esteem 9 enabled to read most of the structural elements except for the stairs. Thus, stairs are not loaded in Esteem 9. This is because Esteem 9 did not provide the feature of stair analysis. Figure 3.37 shows that the 3D skeleton model was successfully exported to Esteem 9.
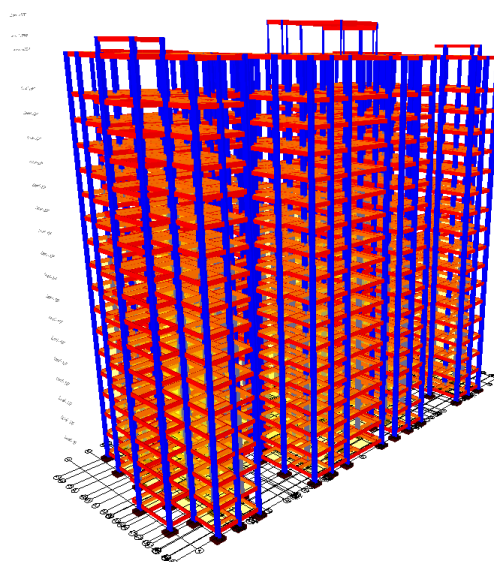
Figure 3.37: 3D skeleton model in Esteem 9.

3.7   Structural Analysis in Esteem 9

Structural analysis via Esteem 9 covered the setting of parameters, the establishment of loads from EC2, analysis, results, and identification of critical members in reinforcement design. The exported model from Autodesk Revit to Esteem 9 must be rechecked at least once to ensure all the structural members are transferred accurately. This is to avoid issues of inconsistency during the structural analysis.

3.7.1   Setting of Parameter

The setting of parameters is a process that seeks to set main factors so it can achieve a response target such as maximum, minimum, or target while, in the meantime allowing secondary factors to vary customarily. The combinations of secondary factors are used with the design of main factors to form replicates of the main factor in design. A dispersion analysis can be used to assess the resultant variance. Moreover, parameter setting in Esteem 9 is the primary step

in the model. Esteem 9 covered three important settings: floor parameter, project parameter, and project properties setting. For example, the type of code of practice, load combination, the minimum or maximum size of rebar, etc., used during analysis.

First, the project parameter setting covered the entire project setting, and the options of project parameters included practice code, material list, analysis setting, 2D analysis setting, 3D analysis setting, load combination, design of structure element setting, etc. Figure 3.38 shows the project parameters in Esteem 9.
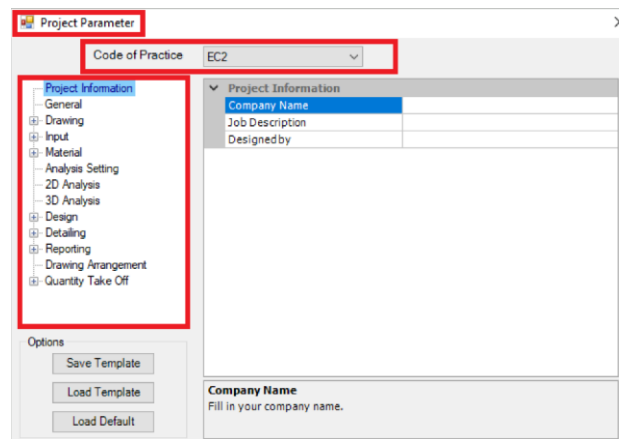
Figure 3.38: Project parameter in Esteem 9.

Second, floor parameter setting referred to parameter setting on a particular floor. The options included floor height, name, material properties, main reinforcement settings, shear reinforcement settings, design specifications, etc. Figure 3.39 shows the floor parameter in Esteem 9.
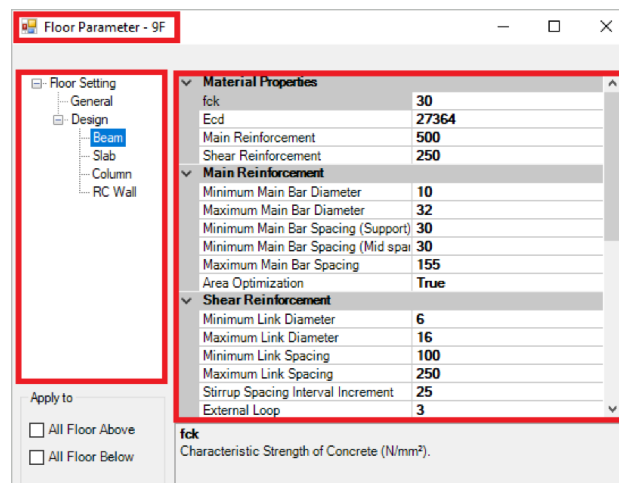
Figure 3.39: Floor parameter in Esteem 9.

Third, the project properties setting summarises all the key settings between the project and floor parameters. Users can easily modify those settings during the failure of structural analysis. Figure 3.40 shows the project properties setting in Esteem 9. Lastly, all the parameters are set according to the design standard of EC. Thus, a detailed parameter setting figure is presented in Appendix A, and Table 3.2 shows a summary of important parameter settings.

Figure 3.40: Project properties setting in Esteem 9.

Table 3.2: Summary of important parameter setting.

Parameter	Category	Setting
Code of Practice	-	EC2
3D Analysis	Lateral Load Options → Wind Load Analysis	False
3D Analysis	Lateral Load Options → Notional Load Analysis	False
3D Analysis	Lateral Load Options → Seismic Load Analysis	False
Design	Load Combination → Structure	Dead = 1.35, Live = 1.5

Table 3.2 (Continued)

Design	Floor → Beam, Slab, Column → Material Properties → f_{ck}	30 N/mm^2
Design	Floor → Beam, Slab, Column → Material Properties → E_{cd}	27364 N/mm^2
Design	Floor → Beam, Slab, Column → Material Properties → Main reinforcement	500 N/mm^2
Design	Floor → Beam, Column → Material Properties → Shear reinforcement	250 N/mm^2
Design	Floor → Beam, Slab, Column → Design → Cover, Side Cover, Spacer	25mm

3.7.2   Establishment of Loads

Loads assign is the unit weight of all the loads applied in the model to perform structural analysis based on MS EN 1991-1-1:2010. Load cases included dead loads and live loads acting on the structural components. Moreover, the structural components were designed with reinforced concrete with a density of 25 kN/m^3. All the self-weight of structural components acted as permanent load (DL) and was inputted automatically by Esteem 9.

In the study, Esteem 9 enabled inserting additional permanent and variable loads (LL). According to MS EN 1991-1-1:2010 Table NA2, most of the variable loads are under category A, which is areas for domestic and residential activities. Next, slabs experience surface loads such as DL and LL, while beams are designed to experience uniform distributed line load (UDL). Some loads need to be calculated manually, such as steel railing located on the balcony, UDL above the water tank beam, and single brick wall. Based on the given drawing, the steel railing located on the balcony consisted of Square Hollow Section (SHS) 30x30x2.0 and 50x50x2.0. Then, the water tank size is measured at 9m in length, 6m in width, and 5m in height. In addition, the permanent load of the stair is designed at 1.2 kN/m^2 while the variable load is 3 kN/m^2 based on category C32 in MS EN 1991-1-1:2010 Table NA2. However, Esteem 9 did not support the feature of stair design, so it is required to manually calculate load distribution in the spreadsheet discussed in chapter 4. The calculation of stair, railing, water tank beam, and single brick wall load

cases are shown in Appendix B. Figure 3.14 shows the sample of water tank beam calculation.

Railing at Balcony – Dead Load

- SHS 30x30x2 (26pcs in the drawing)
- Weight = 1.74 Kg/m = 0.0171 kN/m
- height = 900mm
- $UDL = \frac{Weight \times quantity \times height}{length}$

  $= \frac{0.0171 \; kN/m \times 26 \times 0.9}{3.05}$

  = 0.131 kN/m
- SHS 50x50x2 (2pcs in the drawing)
- Weight = 3.00 Kg/m = 0.03 kN/m
- Length = 3050mm
- $UDL = \frac{Weight \times quantity \times length}{length}$

  $= \frac{0.03 \; kN/m \times 2 \times 3.05}{3.05}$

  = 0.06 kN/m
- Thus, UDL of railing at balcony = 0.131 kN/m + 0.06 kN/m = **0.191 kN/m**
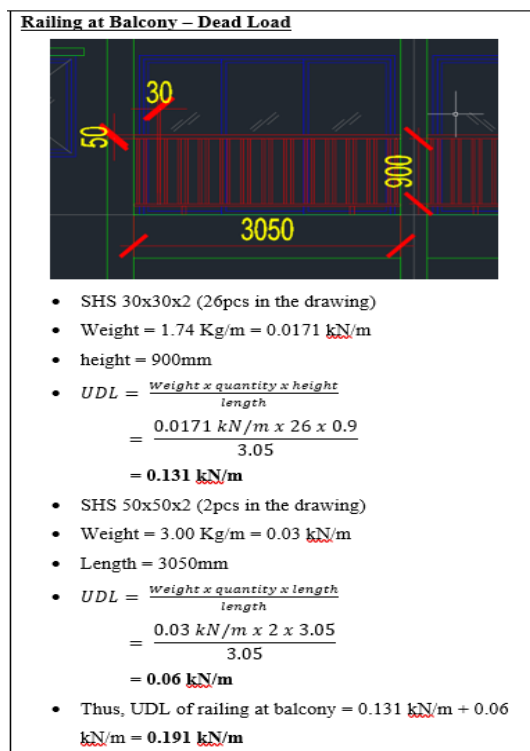
Figure 3.41: Water tank beam calculation.

In addition, the load cases of stairs are placed on neighbouring beams to carry the stair force. The detailed calculation of load cases is shown in Appendix B. Hence, all the key values of the calculated permanent load and variable load acting on the floor and beam are summarised and shown in Table 3.3. Figure 3.42 shows the load applied to one unit in Esteem 9.

Table 3.3: Summary of load cases.

Location	Load cases (kN/m^2)	EC2 Table NA2 or 6.10
Stair support by landing	A (UDL)	-
	DL – 10.5 kN/m	-
	LL – 5.1 kN/m	-
	B (Point load in column)	-
	DL – 52.8 kN	-
	LL – 25.6 kN	-

Table 3.3 (Continued)

M&E Room	DL – 7.0 (Machinery)	-
	LL – 4.0	D1
Corridor	DL – 0.5 (Floor finish)	-
	LL – 3.0	C31
Toilet	DL – 0.5 (Floor finish) + 0.5 (Water proofing) = 1.0	-
	LL – 2.0	A3
Yard	DL – 0.5 (Floor finish) + 0.5 (Water proofing) = 1.0	-
	LL – 2.5	A5
Bedroom	DL – 0.5 (Floor finish) + 0.5 (Other DL) = 1.0	-
	LL – 1.5	A2
Living Room	DL – 0.5 (Floor finish) + 0.5 (Other DL) = 1.0	-
	LL – 1.5	A1
Balcony	DL – 0.5 (Floor finish) + 0.5 (Water proofing) = 1.0	-
	LL – 2.5	A5
Railing in Balcony	DL – 0.191 kN/m	-
UDL above Water Tank Beam	1st and last beam	-
	DL – 25.02 kN/m	-
	LL – 0.25 kN/m	-
	Middle beam	-
	DL – 50.04 kN/m	-
	LL – 0.50 kN/m	-
Roof Slab	DL – 0.5 (Floor finish) + 0.5 (Other DL) = 1.0	-
	LL – 0.5 (Service load)	H
Brick Wall	DL – 10.77 kN/m	-
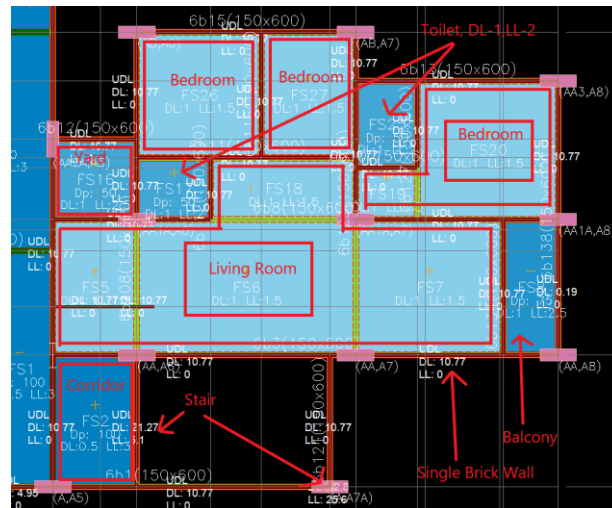
Figure 3.42: Load applied of one unit in Esteem 9.

3.7.3   Structural Analysis Results

All results of the structural analysis, including axial load, internal forces, shear forces about the x and y axis, and bending moments of the x, y, and z-axis, are produced from Esteem 9 based on the load placed on the structure and the load combinations theory from the Eurocode. In order to achieve all the valid analysis results, it is required to overview the status report to check for any failed elements in the project. Figure 3.43 shows no failed element found in the project. Figure 3.44 shows the load combinations and result of the bending moment diagram of the entire structure. The results also indicated the entire structure's critical beam, slab, and column. Other than that, Esteem 9 enabled to generate comprehensive output, which is completed details of all slabs, beams, and columns for draughting, including the column schedule. Figure 3.45 shows the comprehensive output of Esteem 9.
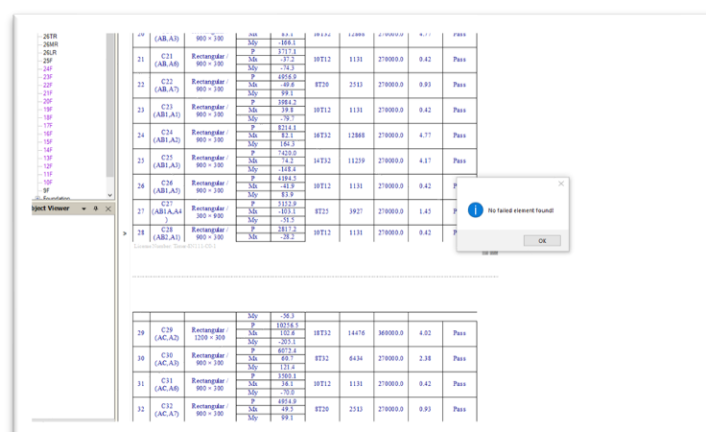
Figure 3.43: No failed element found in the project.
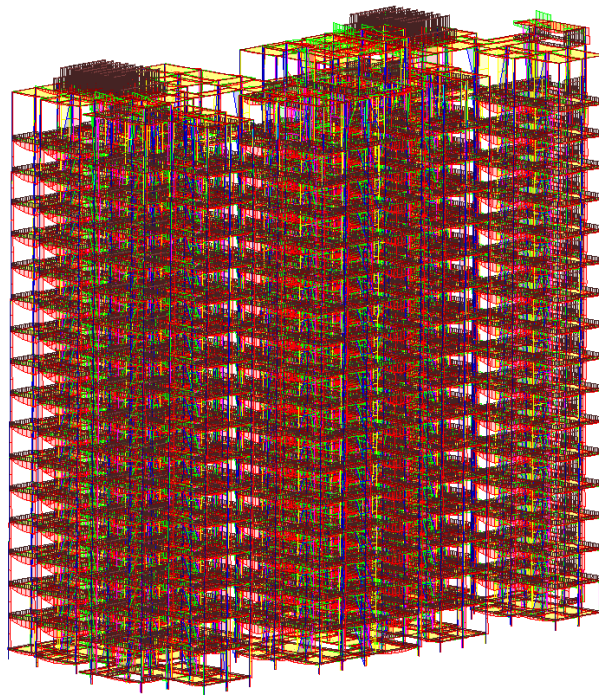
Figure 3.44: Bending moment diagram of entire structure.
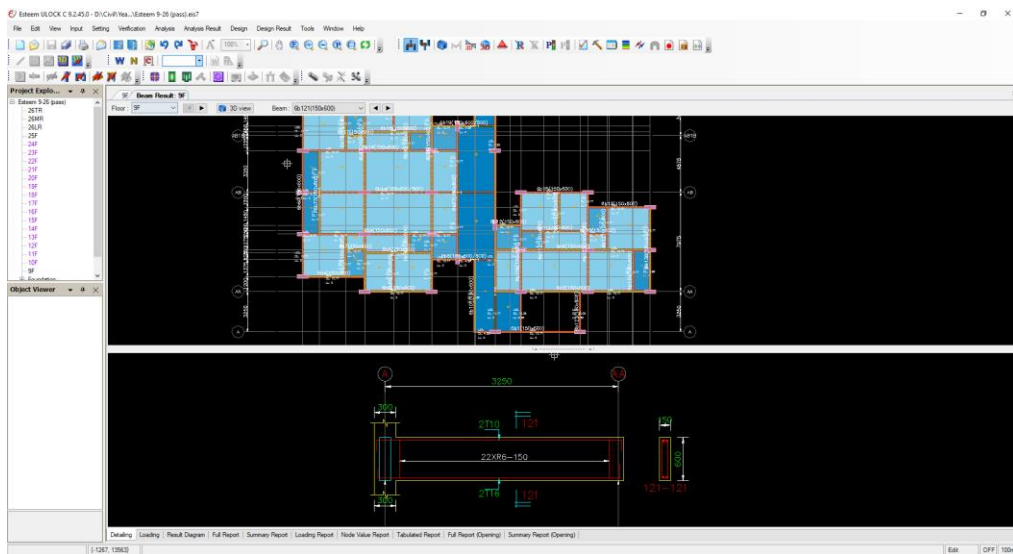
Figure 3.45: Comprehensive output of Esteem 9.

3.7.4 Verification of Critical Member Reinforcement Design

The critical bending moment of the beam, slab, and column are identified to check further the reinforcement design in the spreadsheet based on the EC 2 guidelines. The verification for beam design begins with the main reinforcement. By referring to the bending moment and shear force diagram of

the critical beam in Esteem 9, the value of z, k, and $A_{s,req}$ are calculated by using Equations 3.1, 3.2, and 3.3, respectively.

$$k = \frac{M_{Ed}}{bd^2 f_{ck}} < 0.167 \tag{3.1}$$

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{1.134}}) < 0.95d \tag{3.2}$$

$$A_{s,req} = \frac{M}{0.87 f_{yk} z} \tag{3.3}$$

Then, shear force is used to calculate the shear link and spacing between shear links. Thus, the value of A_{sw}/s, $A_{sw,min}/s$, and S_{max} are calculated by using Equation 3.4, 3.5, and 3.6 to ensure that shear reinforcement provided to the beam are supportable to resist the shear force.

$$\frac{A_{sw}}{s} = \frac{V_{Ed}}{0.78 f_{ck} d \cot\theta} \tag{3.4}$$

$$\frac{A_{sw,min}}{s} = \frac{0.08 b_w \sqrt{f_{ck}}}{f_{ck}} \tag{3.5}$$

$$Max\ spacing, S_{max} = 0.75d \tag{3.6}$$

Moreover, deflection check is required in the last stage of the calculation. The equations involved are Equation 3.7, 3.8, 3.9, 3.10, 3.11, and 3.12. The K value from Equation 3.7 and 3.8 is obtained from EC2 Table 7.4N. Then, Equation 3.9, 3.10, and 3.11 calculate the percentage of required tension reinforcement, required compression reinforcement, and reference reinforcement ratio. Lastly, Equation 3.12 shows that the value of (l/d) allowable must be larger than (l/d) actual in order to fulfil the requirements of EC2.

$$\frac{l}{d} = K[11 + 1.5\sqrt{f_{ck}}\,\frac{p_o}{p - p'} + \frac{1}{12}\sqrt{f_{ck}}\sqrt{\frac{p'}{p_o}}]\ ; p \geq p_o \tag{3.7}$$

$$\frac{l}{d} = K[11 + 1.5\sqrt{f_{ck}}\,\frac{p_o}{p} + 3.2\sqrt{f_{ck}}(\frac{p_o}{p} - 1)^{3/2}]\ ; p \leq p_o \tag{3.8}$$

$$p = \frac{100 A_{s.req}}{bd} \tag{3.9}$$

$$p_o = \frac{\sqrt{f_{ck}}}{1000} \tag{3.10}$$

$$p' = \frac{A'_{s.req}}{bd} \tag{3.11}$$

$$\left(\frac{l}{d}\right)_{allow} > \left(\frac{l}{d}\right)_{actual} \tag{3.12}$$

Next, the verification for slab design begins with the main reinforcement, same as beam as shown in Equation 3.1, 3.2, and 3.3, but the shear force is required to check instead of calculating the shear link compared to the beam. However, slabs do not provide any shear links. Equation 3.12 and 3.13 show the checking equations on slab shear design based on MS EN 1991-1-1 clause 6.2.2. Then, the equations of deflection check of the slab are similar to the beam.

$$V_{Rd.c} = 0.12k\sqrt[3]{100p_1 f_{ck}}bd > V_{Ed} \tag{3.13}$$

$$V_{min} = 0.035k^{3/2}\sqrt{f_{ck}}bd > V_{Rd,c} \tag{3.14}$$

Afterwards, the design of critical columns begins with determining the column's slenderness since it needs a distinct design method. Similar equations between short and slender columns are shown in Equations 3.15 and 3.16. These two equations are used to calculate the area of steel reinforcement. The value of x shown in Equation 3.15 is the value taken from the design chart based on the column size. Then, the maximum spacing near the lap region is 14 times the longitudinal bar diameter, whereas the maximum spacing away from the lap region is 400 mm, 20 times the longitudinal bar diameter and the size of the columns. Therefore, all these criteria have been met to guarantee that the reinforcement design is enough to support the loads placed on the structure.

$$A_s = \frac{xbhf_{ck}}{f_{yk}} \tag{3.15}$$

$$A_{s,min} = \frac{0.1N_{Ed}}{0.87f_{yk}} \tag{3.16}$$

3.8 Placement of Steel Reinforcement in Autodesk Revit

The placement of steel reinforcement is known as internal modelling, which is required in Autodesk Revit after the structural analysis is completed without any failure elements. Based on the compatibility of Autodesk Revit, it served to plug in sub-features named "Naviate REX". Naviate REX is a plug-in that can place the steel reinforcement inside the structural components easily

compared to placing it manually by using the default method. Thus, it is invented to reduce time and human error for the construction professional. Figure 3.46 shows the "Naviate REX" plug-in and the features in Autodesk Revit.
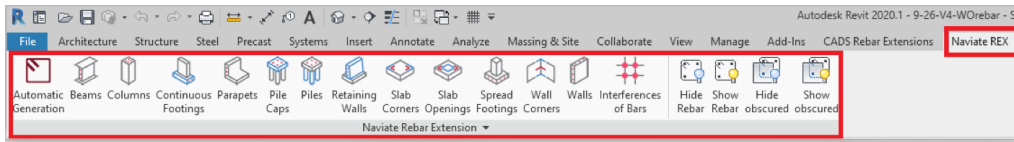
Figure 3.46: Naviate REX plug-in and features.

3.8.1 Beam Reinforcement

Beam reinforcement in "Naviate REX" enabled the production of many crooked types of reinforcement. It covered the features of edit geometry, stirrups, stirrup distribution, main bars, additional top bars, additional bottom bars, bar division, and reinforcement areas, as shown in Figure 3.47. Figure 3.47 shows the parameter setting of a beam reinforcement in the study.
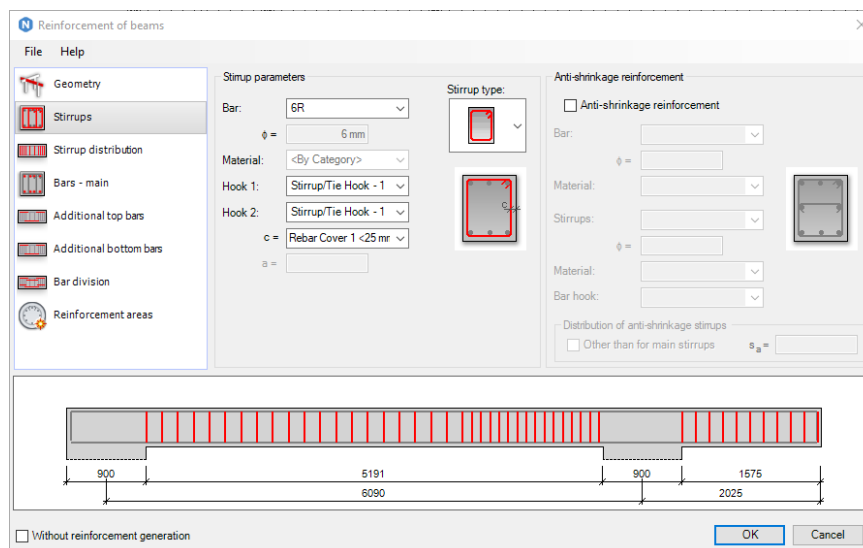
Figure 3.47: Parameter of beam reinforcement.

Once the parameters of beam reinforcement are inputted according to the structural analysis result in Esteem 9, the beam reinforcement is modelled as shown in Figure 3.48 via Autodesk Revit.
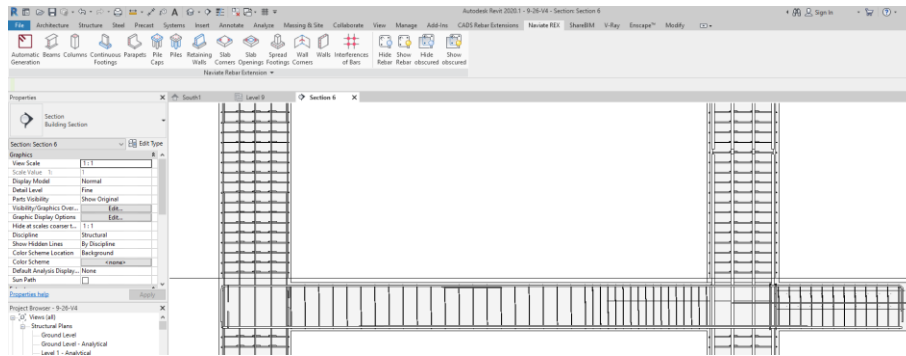
Figure 3.48: Beam reinforcement in Autodesk Revit.

3.8.2 Column Reinforcement

The procedures for modelling column reinforcement via Naviate REX in Autodesk Revit are similar to the beam. Column reinforcement in Naviate REX covered the features of edit geometry, bars, stirrups, additional stirrups, dowels, and reinforcement areas. Figure 3.49 also shows the parameter setting of a column reinforcement in the study.
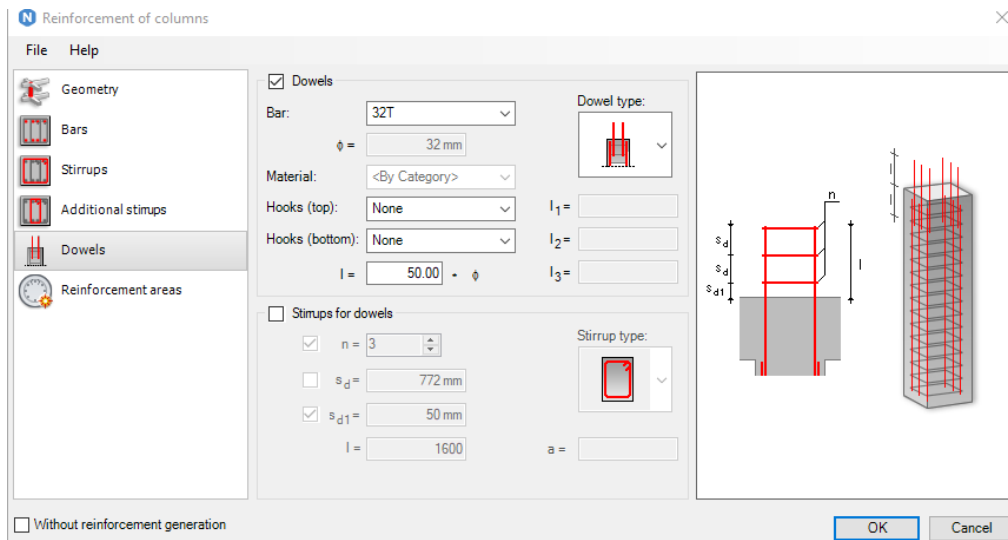
Figure 3.49: Parameter of column reinforcement.

Once the parameters of column reinforcement are inputted according to the structural analysis result of Esteem 9, the column reinforcement is modelled as shown in Figure 3.50 via Autodesk Revit.
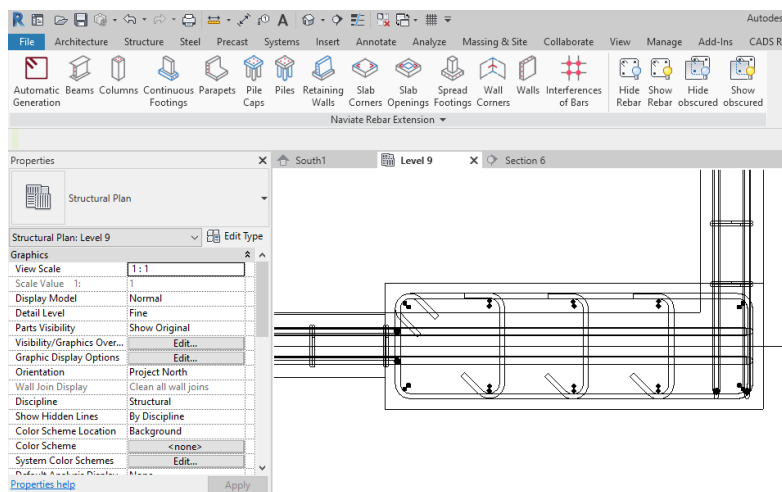
Figure 3.50: Column reinforcement in Autodesk Revit.

3.8.3 Slab Reinforcement

However, the feature of slab reinforcement in Naviate REX is used for advanced slabs such as slab openings and corners. Thus, slab reinforcement is modelled in the default features of Autodesk Revit without using any plug-in assist. Figure 3.51 shows the " Area " button hidden inside the structure tab.
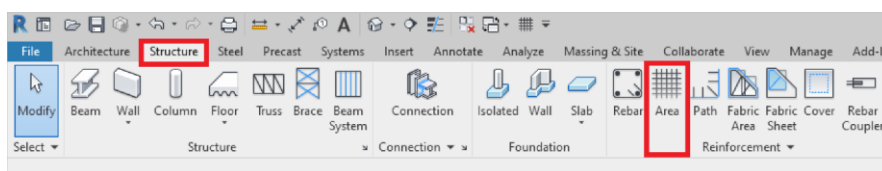
Figure 3.51: Structure Area button is shown.

After that, it is required to insert the layers of rebar needed to be modelled. The layers are inputted according to the structural analysis results generated by Esteem 9. Figure 3.52 shows the layer setting of slab reinforcement, and Figure 3.53 shows the cross-section view of slabs in Revit.
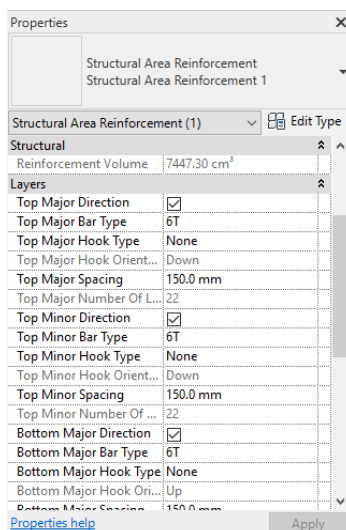
Figure 3.52: Layers setting of slabs reinforcement.
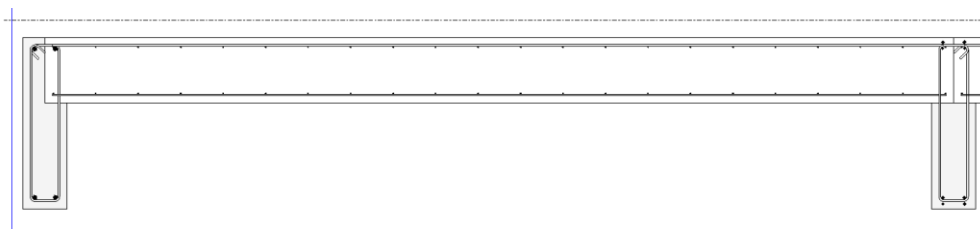
Figure 3.53: Cross-section view of slabs in Revit.

3.8.4 Stair Reinforcement

In addition, Naviate REX did not cover stair reinforcement. Thus, stair reinforcement is modelled by using the manual method. The manual referred to selecting the chosen rebar size and inserting it into the stair individually. Figure 3.54 shows the Rebar button hidden inside the structure tab.
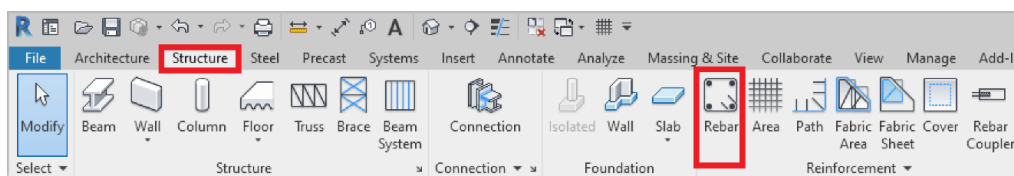
Figure 3.54: Structure rebar button is shown.

Once the chosen rebar size is selected, the rebar is plotted or drawn using the line method in the structure stairs. Therefore, modelling is done in section view. For example, in the study, structural analysis of stairs required the user to insert T10-250 rebar into the stair. Autodesk Revit is enabled to

model one rebar, then insert the rebar spacing from 'Rebar Set' as shown in Figure 3.55. The steps are repeated for all the stairs. Finally, as shown in Figure 3.56, a completed 3D skeleton model with all the reinforcement is done in Autodesk Revit.
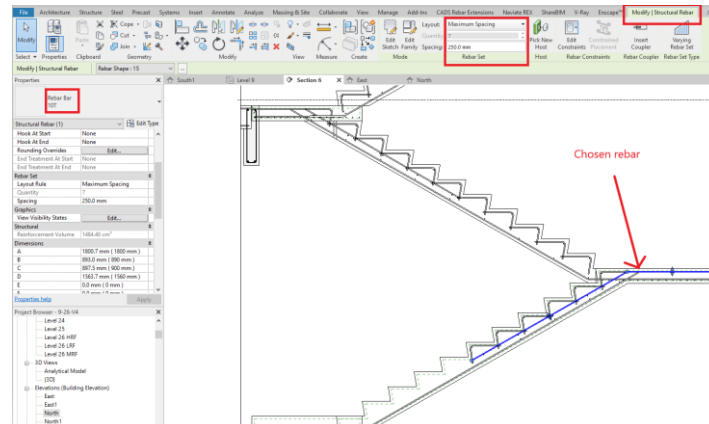
Figure 3.55: Slab reinforcement modelling.
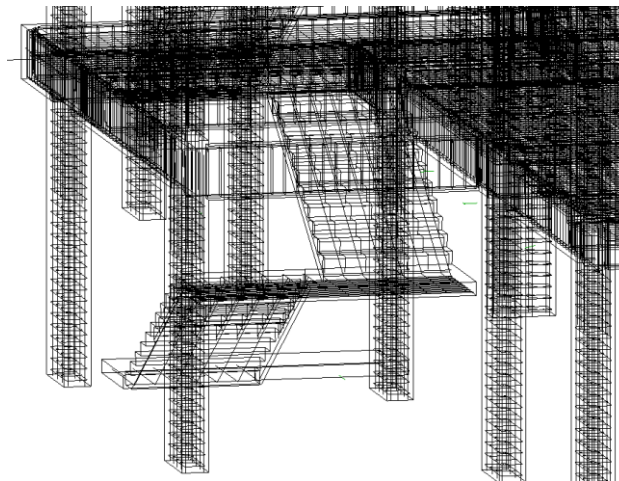
Figure 3.56: Completed 3D skeleton model with all reinforcement in Revit.

3.9 Quantity Take Off in Autodesk Revit

Quantity take-off on the structural model is conducted by utilising Autodesk Revit. The beauty of Autodesk Revit is enabled to generate material schedules or quantities by sorting, such as volume of structural elements concrete, length of structural elements rebar, and shear link on each floor from level 8 to level 26 HRF. During the generating material schedule process, a few key scheduled fields are needed to consider into the account, including family, types, structural material, count, length, volume, cost, total cost, etc. Figure 3.57

shows the key scheduled fields of the rebar schedule, while Figure 3.58 shows the major scheduled fields of the concrete schedule. This procedure is important because it shows the key details of structural elements to proceed for sorting or grouping by category, such as level.
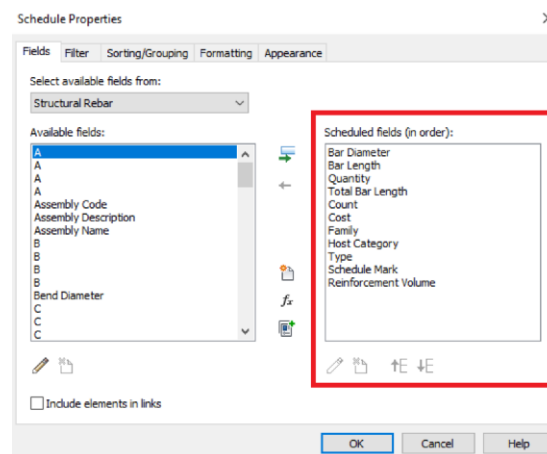
Figure 3.57: Major scheduled fields of rebar schedule.
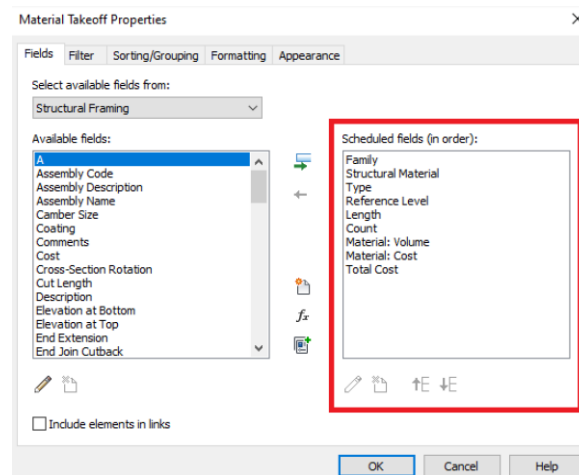
Figure 3.58: Major scheduled field of concrete schedule.

By inserting the cost of each type of rebar and concrete based on Quantity Surveyor Online (2022), the total cost of materials take-off in the model is needed to input the numerical formula manually to keep the Autodesk Revit informed. Table 3.4 shows the numerical formula of the total in each structural element.

Table 3.4: Numerical formula of total cost

Material	Quantity Unit in Revit (Q)	Material cost unit (C)	Numerical formula
Concrete	Cubic meter	RM per Cubic meter	Q*C
Rebar and Shear Link	Total length in millimetre	RM per kg	(Q/1000) *(Area of rebar in square meter) *C*7850 NOTE: Rebar density = 7850 kg per cubic meter

Accordingly, the total cost is computed immediately. Figure 3.59 shows the structural beam concrete take-off sorting schedule by floor and size. Similarly, the schedule of structural column, slab, and stair concrete take off; all the structural elements' schedules of rebar and shear link are sorted by level, and rebar type are prepared to quantify the total cost of material take off.

over: <Beam Material Takeoff (Concrete)>								
A	B	C	D	E	F	G	H	I
Family	Structural Material	Beam Size	Reference Level	Length (mm)	Count	Volume	Cost (RM per cubic)	Total Cost
Level 9								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	1057	1	0.06	243.00	13.39
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	1575	4	0.33	243.00	80.30
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	1650	5	0.42	243.00	102.52
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	3025	2	0.32	243.00	78.60
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	3725	1	0.17	243.00	40.10
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500mm	Level 9	6775	2	0.81	243.00	196.95
150 x 540mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540mm	Level 9	1057	1	0.06	243.00	14.82
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540mm	Level 9	3915	1	0.23	243.00	56.20
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540mm	Level 9	4966	2	0.59	243.00	143.90
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540mm	Level 9	8960	1	0.61	243.00	148.50
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540mm	Level 9	14575	1	0.88	243.00	213.67
150 x 600mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600mm	Level 9	1051	1	0.07	243.00	16.61
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600mm	Level 9	1525	20	1.96	243.00	476.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600mm	Level 9	2075	5	0.71	243.00	171.38
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600mm	Level 9	3060	1	0.21	243.00	50.38

Figure 3.59: Schedule of structure beam concrete take off sorting by floor and size.

3.9.1 Quantify of Structural Elements

Quantifying structural elements is a prerequisite with an additional setting of schedule material take-off in Autodesk Revit. Firstly, the additional setting is done in the sorting or grouping material take-off properties. Subsequently, it is

required to manually open the computation of the total and count from its properties, as shown in Figure 3.60.
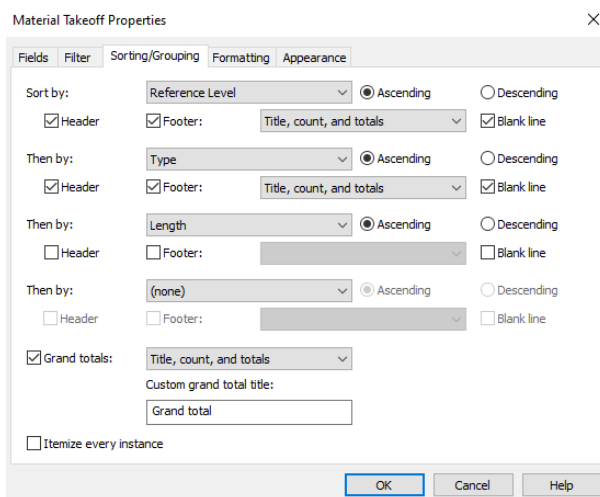
Figure 3.60: Computation setting of schedule.

Hence, the computation of the grand total and quantity of structural elements is done and shown at the bottom of every subcategory. Figure 3.61 shows the structural beam concrete take-off schedule with grand total and count.

Figure 3.61: Schedule of structural beam concrete take off with grand total and count.

3.10   Statistical Analysis

Several statistical analysis methods can be used to summarise data in an organised way by showing the relationship between cost and quantity in this

project. However, descriptive statistics is the chosen method because it includes variables such as the measure of frequency, central tendency, position, and ratio. By referring to those variables, all the complicated data computed in Autodesk Revit can be summarised into graphs, pie, or bar charts. Thus, this method is considered the most suitable method to conduct this project.

Next, the measure of frequency can be defined as the greatest number of times a particular value occurs in the data (Kaur et al., 2018). In this project, the measure of frequency is applied to compute two categories of quantity take-off. This is because it represented its brief and content data in each category. Subsequently, the first quantity take-off known as the structural elements schedule is focused on structural elements and then sorted by its size and level. It is included to quantify the structural elements and material used based on slab, beam, column, and stair. Besides that, the second quantity take-off known as the structural materials schedule is referred to the total quantity of structural materials used in the project. For example in this study, Table 3.5 shows the first frequency measurement while Table 3.6 presents the second frequency measurement. By comparing both methods, the first method is enabled to figure out the greatest number among the beams based on each floor whereby the second method figured out the total quantity of structural materials in this study.

Table 3.5: First frequency measurement.

Structural element schedule				
Level	Size	Category	Material	Total Quantity
9	150x600 mm	Beam	Concrete	0.06 m^3
			T10	30 m
			R6	25 m

Table 3.6: Second frequency measurement.

Structural material schedule		
Category	Type	Total Quantity
Shear Link	R6	149,554.00 m
Main Rebar	T10	54,146.61 m
Reinforced Concrete	C25/30	23,001.63 m

Then, the measure of central tendency can be described as the complete set of data as a single measurement (Kaur et al., 2018). There are three primary measures of central tendency: the mean, median, and mode. In this project, the mean is used to calculate the unit price of a single structural element. For instance, the total cost of the beam over its total quantity. However, the median and mode are precluded in the single measurement section during the study. This is because the calculation is illogic and meaningless. Thus, the mean is calculated by using Equation 3.17.

$$mean\ (unit\ price) = \frac{Total\ structural\ materials\ cost\ (shear\ link,etc)}{Volumn\ of\ structural\ element\ (beam,column,etc)} \quad (3.17)$$

Third, position in descriptive statistical analysis is used to determine the position of values in a dataset by using box plots (Kaur et al., 2018). Kaur also stated that box plots are frequently used for interpreting description data in graphical graphs. Thus, box plots are constructed by utilising the 25th percentile, known as the lower quartile, 50th percentile, where the median exists, and 75th percentile as the upper quartile. By referring to the meaning of position in description statistics in this study, a cumulative cost over levels line graph can be generated using all the quantity take-off data exported from Autodesk Revit. Figure 3.62 shows the sample format of position graph is used in the study.
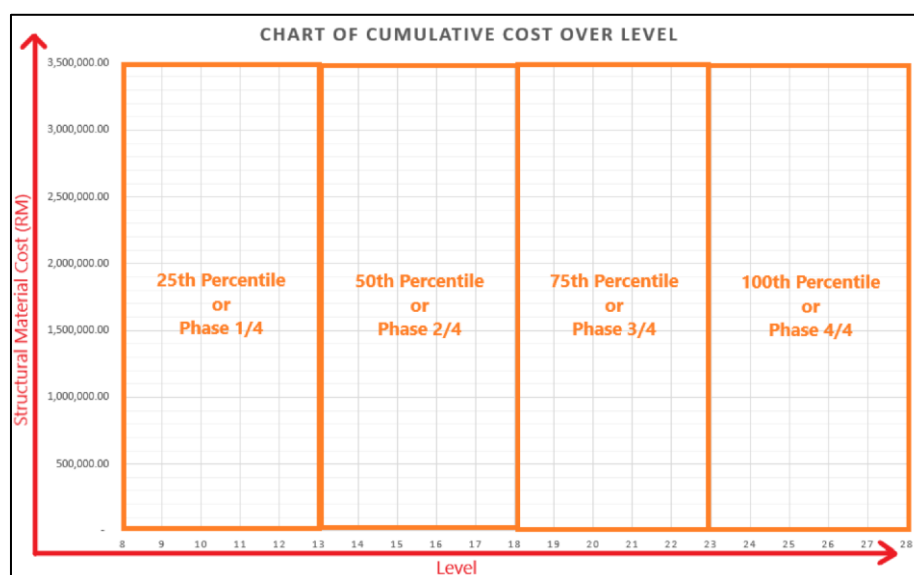
Figure 3.62: Sample format of position graph.

Finally, ratio in descriptive statistical analysis is referred to quantitative relation between values that shows the number of times one element occurs (Kaur et al., 2018). From the statement above, it can be expressed in the form of a histogram or pie chart. In the study, a pie of pie chart regarding the total cost of structural elements and materials is conducted and discussed in the following chapter. Figure 3.63 shows the sample format of ratio chart used in the study.
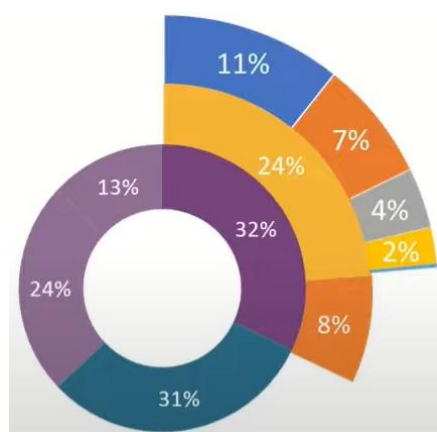
Figure 3.63: Sample format of ratio chart.

3.11   Summary

The structural framing model is done and then further developed into BIM model. The entire workflow and methodology are discussed in this chapter deeply. During the identification of issues in ShareBIM, it enabled collaboration among team members to determine the building issues in a single working platform. All the building issues including clash detection, are created in ShareBIM and then discussed in the following chapter. Then, the BIM model is imported back to Autodesk Revit and then uploaded to Esteem 9 for structural analysis. After Esteem 9, placement of steel reinforcement is modelled in Autodesk Revit then computed the number of structural elements and quantity take-off of construction materials cost and quantities. Moreover, desired data such as building issues, structural analysis, quantity take-off, and data obtained from statistical analysis are extracted from the result and discussed in the following chapter.

BIM has played a vital role in the current construction technology. By utilising BIM software such as ShareBIM, it is enabled to resolve the

communication issues faced during the design phase in the actual construction industry. This is because ShareBIM covered useful features to assist the construction professional when trouble comes. Moreover, ShareBIM also enabled to transfer of massive data or messages accurately to the person involved in the project. Next, Autodesk Revit is presented as a central piece of software as it allows for the exportation and importation of models from any type of BIM software. Therefore, it increases work efficiency and productivity. Using Naviate REX, which is a plug-in software in Autodesk Revit, was invented to reduce the time of rebar modeller. In addition, it also reduces human errors compared to the manual placement of rebar.

CHAPTER 4

RESULTS AND DISCUSSION

4.1   Introduction

This chapter presents the discussion during collaboration obtained from ShareBIM. The modification of the structural BIM model due to clash detected and model error based on the discussion after collaboration. Structural analysis is needed to perform, whereas there is no further modification of the model, and the process is presented and explained. Then, the result of the structural analysis generated from Esteem 9 is used to perform manual verification by following the design standard of EC2 in depth. Consequently, quantity and material take-off are computed and obtained from Autodesk Revit. Lastly, the statistical analysis of concrete, rebar, shear link cost and quantities are presented and discussed in depth in the last section of this chapter.

4.2   Result of Collaboration in ShareBIM

A total of 15 issues were figured out and communicated to the participants involved in this project. Nevertheless, the structural model received a total of 3 issues, consisting of 2 issues from the architect modeller and 1 issue from the MEP modeller regarding its model. Meanwhile, a total of 8 issues have been sent out, including 4 issues to the architect modeller and 4 issues to the MEP modeller regarding its model. Table 4.1 shows the relationship of the collaborated model issue among the other team members. From Table 4.1, STR stands for structural modeller; ARC represents architectural modeller, while MEP refers to mechanical, electric, and plumbing modeller.

Table 4.1: Relationship of model issue among other team members.

To / From	STR	ARC	MEP	Total Sent
STR		4	4	8
ARC	1		1	3
MEP	2	3		4
Total Received	3	7	5	15

Several hours or days later, all these issues had been replied to and feedbacked. Figure 4.1 shows the work statistics chart of issues created and completed over the days from ShareBIM. The chart shows the period of collaboration in ShareBIM among other team members from the 8th to the 22nd of August. This process took 15 days to complete the issues faced during collaboration. A total of 15 issues were created and solved on 4 different days.
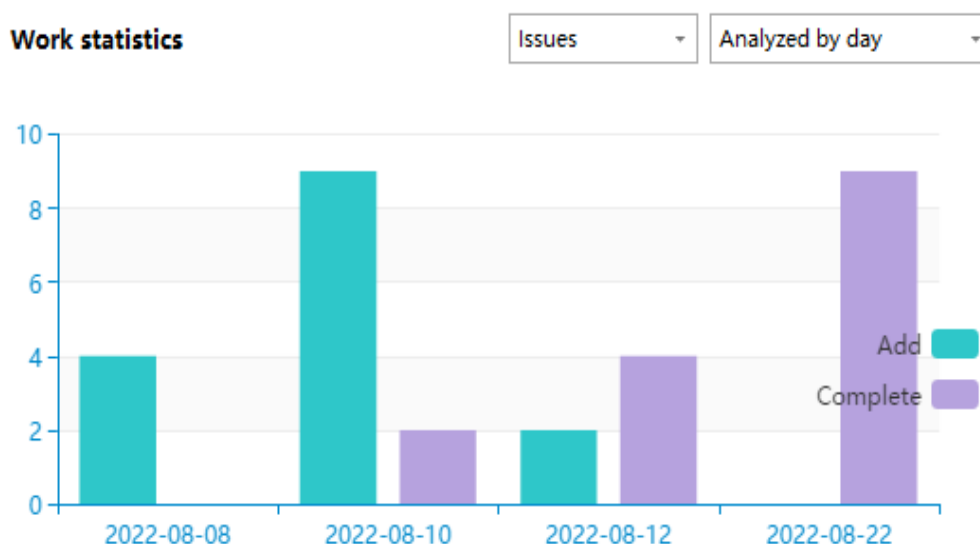
Figure 4.1: ShareBIM Work statistics chart.

4.2.1   Detail of Sent Issues

After 15 days of collaboration in ShareBIM, all the sent issues had been categorised into different trades, including Electrical Low Voltage (ELV), Architecture (ARC), Fire Protection (FP), and Cold-Water System (CW). All the issues were studied, and it can be concluded that most issues were considered a clash between two different models. However, there are least number of issues examined due to a mistake in modelling, such as failing to model the void in the corridor whereby the given drawing plan exists. Table 4.2 shows the communication of 8 detailed model issues sent and received feedback between the participants involved in the project inside ShareBIM. From Table 4.2, it consists of issue media, which is a capture of before and after modification from the BIM model, while the content is referred to communication between members.

Table 4.2: Communication of sent issues with media.
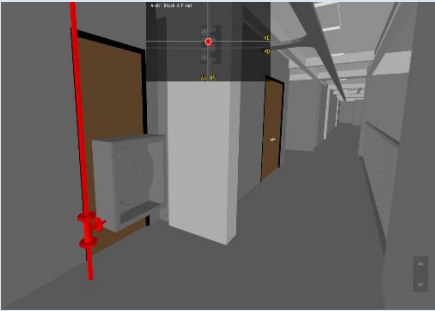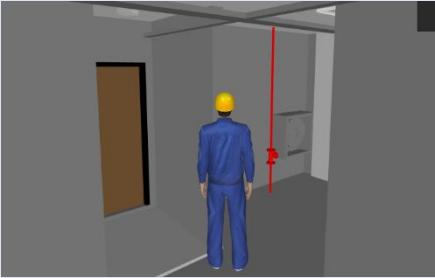
Issue Media	Communication Content
Before: After: 	Topic Content: STR: Electrical wire box has penetrated the column, M&E please check and thanks. Feedback Message: MEP: Elevation for Indoor electrical cable adjusted to avoid clashes in between.
Before: After: 	Topic Content: STR: Please recheck the location of the door. In my opinion, this location does not have any door, only a hose reel, Thanks. Feedback Message: ARC: The staircase door is re-coordinated.

Table 4.2 (Continued)
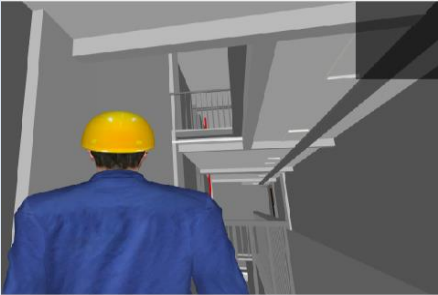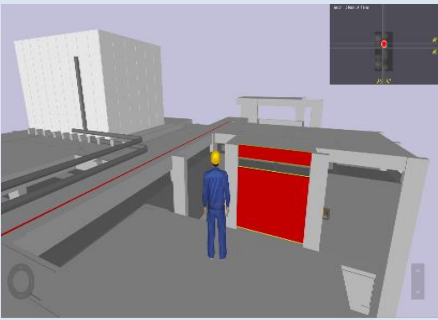
Before: After:	Topic Content: STR: Electrical cable box penetrates beam cover, please lower down it, this issue applied to every floor. Thanks. Feedback Message: MEP: Elevation of electrical cable adjusted to avoid clashes in between.
Before: After:	Topic Content: STR: There is a void in this section. Feedback Message: MEP: The void for the ceiling is structured on both sides of the model.
Before:	Topic Content: STR: Please check the elevation height of the last residential floor. There is a gap between the beam and the wall.

Table 4.2 (Continued)
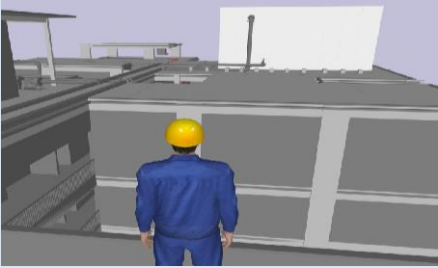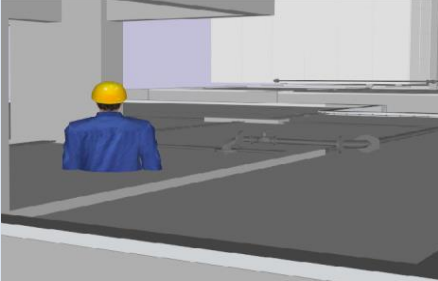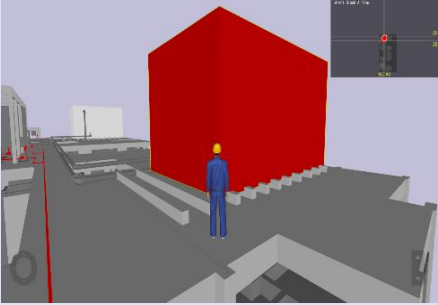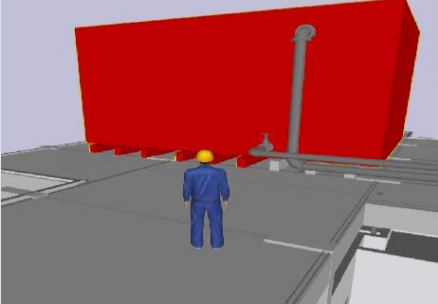
After:	Feedback Message:
	
	STR: I have checked for the structure
	      part. No issue from my side.
	ARC: The elevation height of last
	      residential floor
	      is readjusted.

Before:
 	
After:
	Topic Content:
	
	STR: Fire piping has penetrated the
	      beam and is almost hidden inside
	      the structural floor.
	
	Feedback Message:
	
	MEP: Elevation of Firefighting pipe
	      adjusted to avoid clashes in
	      between.

Before:
 	
After:
	Topic Content:
	
	STR: The water tank has clashed with
	      the beam.
	
	Feedback Message:
	
	STR: I have checked this issue with
	      MEP member, and this issue is
	      solved by adjusting the water tank
	      and beam height until fit.

Table 4.2 (Continued)

Before: After:	Topic Content: STR: In my opinion, there is a void throughout the entire building, the structure slab preserved the void, but the architecture floor no, please check and thanks. Feedback Message: ARC: The void is structured on both sides of the model.

4.2.2 Detail of Received Issues

Unfortunately, remodelling, or further modification of the 3D BIM model in Autodesk Revit needed to be carried out as there were found errors in the structural model during collaboration. As a result, a total of 3 issues were received in the notification inbox of ShareBIM regarding clash detection and modelling mistakes. From the notification inbox, there are 2 model issues received from MEP and 1 model issue from ARC. First, MEP has informed that an additional water tank beam was modelled to support the weight of the water tank. Figure 4.2 shows the issue details of 1 of the 3 received from MEP. However, the additional water tank beam existed in the given drawing plan, while the water tank size was figured out as more minor than that. Therefore, an argument from MEP was resolved by removing the additional water tank beam.
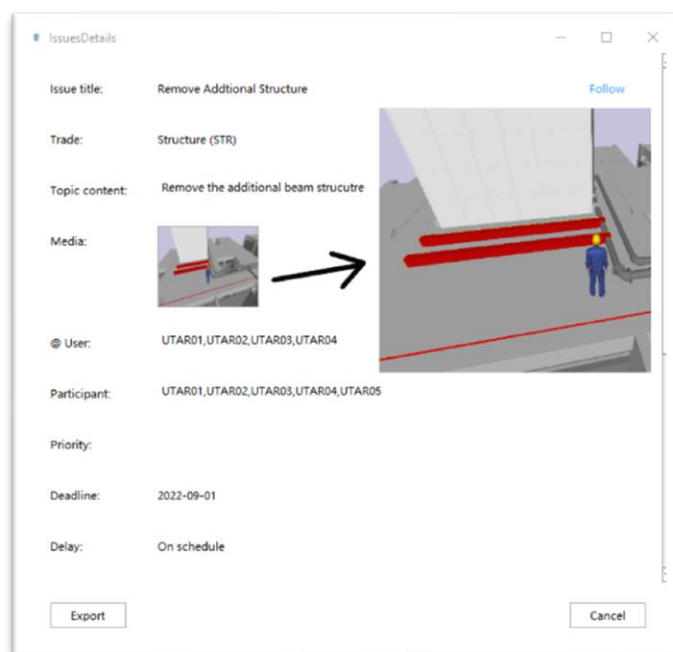
Figure 4.2: First issues from MEP.

Second, MEP also noticed a clash between the inflow of the water tank pipe and the water tank beam. According to Fakharifar and Chen (2017), the concealment of a pipe in concrete structure will influence the structural stability and strength unless the concrete structure is designed to embed it. The water tank beam is not designed to embed or penetrate any pipe in this project. Figure 4.3 shows the issue details of 2 of the 3 received from MEP. MEP had requested to shorten the water tank beam during the communication, as shown in Figure 4.4. From this issue, the water tank beam was modelled as a secondary beam, whereas both ends of the water tank beam are supported by a primary beam. Therefore, after the discussion, shortening the water tank beam is not the solution. Unfortunately, MEP must make further modifications to resolve this issue until no clash is detected.
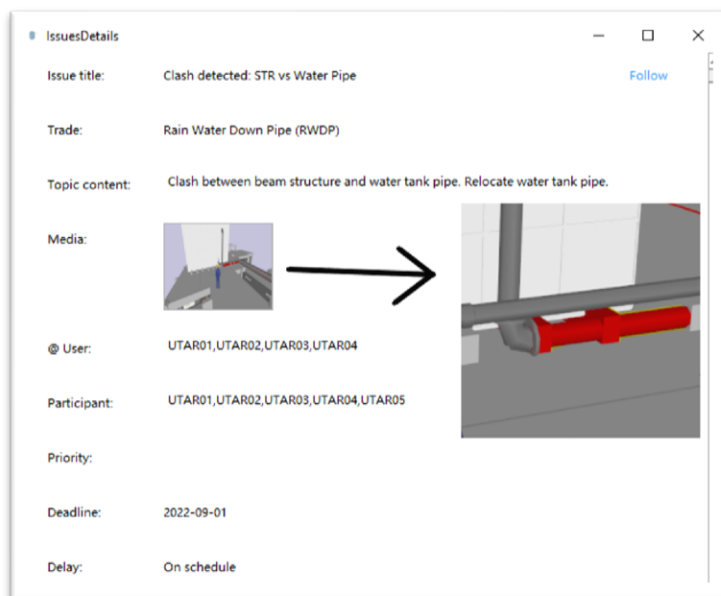
Figure 4.3: Second issues from MEP.
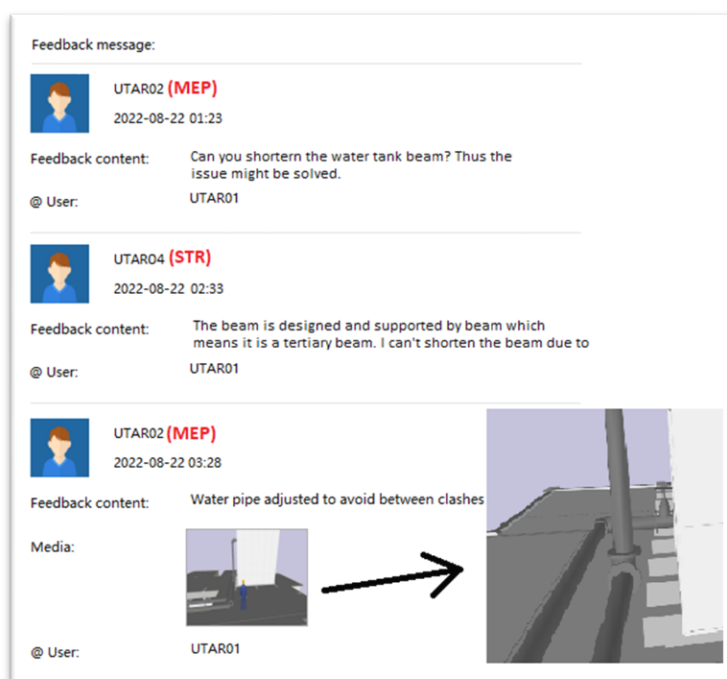
Figure 4.4: Communication of second issue with MEP.

Finally, the third issue is a modelling mistake received from ARC. Figure 4.5 shows ARC figured out that there is a gap between column to column. This issue was solved, and it was explained as a human modelling error. Thus, this issue will not significantly affect the entire structural building, either in strength or stability.
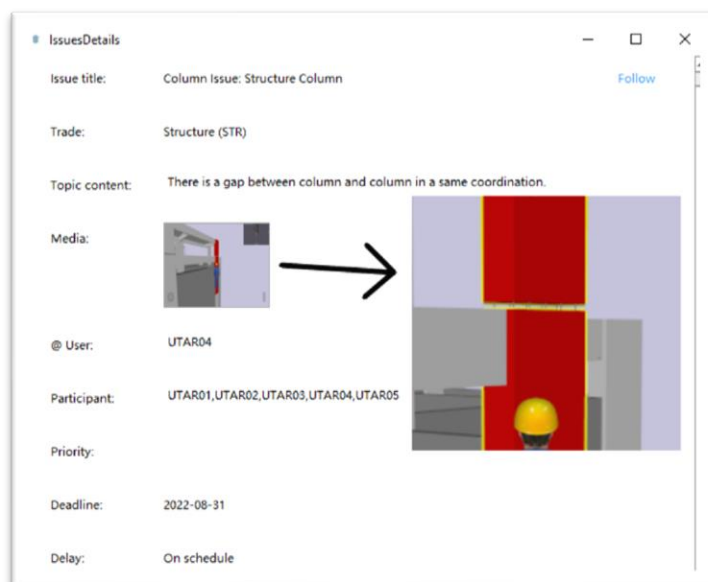
Figure 4.5: Third model issue from ARC.

4.3 Further Modification of BIM model

Based on the issues studied in the 3D BIM model, there is no clash between different models needed to solve in the structural model. In other words, all the layouts of structural elements were modelled accurately and consistently according to the given drawing. Meanwhile, an additional mistake was found in the internal 3D structural model during roaming in ShareBIM, as shown in Figure 4.6 Hence, the 3D structural model is still required to be further modified because of modelling mistakes in Autodesk Revit to improve the quality of the 3D model.
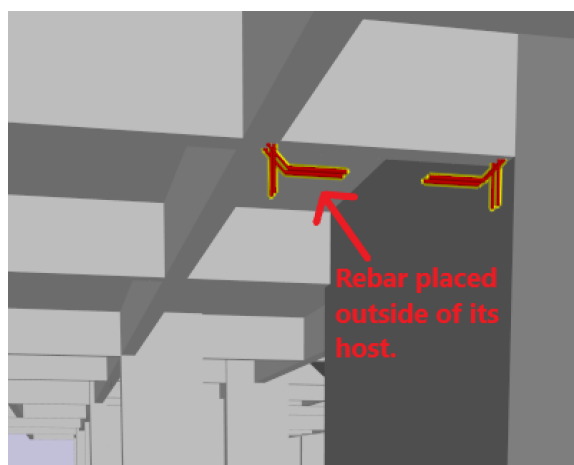
Figure 4.6: Internal additional modelling mistake.

First, the additional mistake in modelling whereby the beam rebars were placed outside of its host. As a civil engineer, rebar must be placed inside the structural elements without exceeding its cover. Hence, the following figure shows and modifies all the issues faced. Figure 4.7 shows the before and after modification of rebar in the 3D BIM model. By referring to the third received issue, the gap between the columns was resolved by lengthening the foot of the column, as shown in Figure 4.8. Therefore, these errors must be solved immediately because it will lead to computing quantity take-off inconsistently. Finally, by referring to the first received issue, there is a request from MEP to remove an additional water beam. Figure 4.9 shows the water tank beam's before and after model modification.
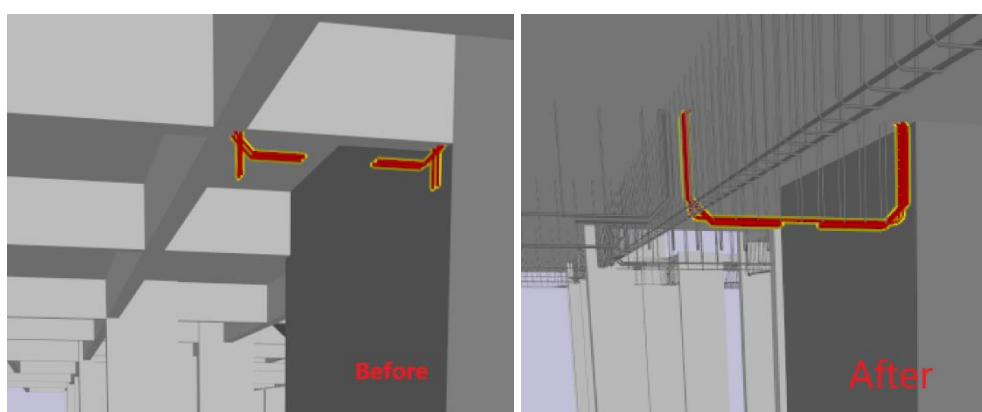
Figure 4.7: Placement of error rebar before and after.
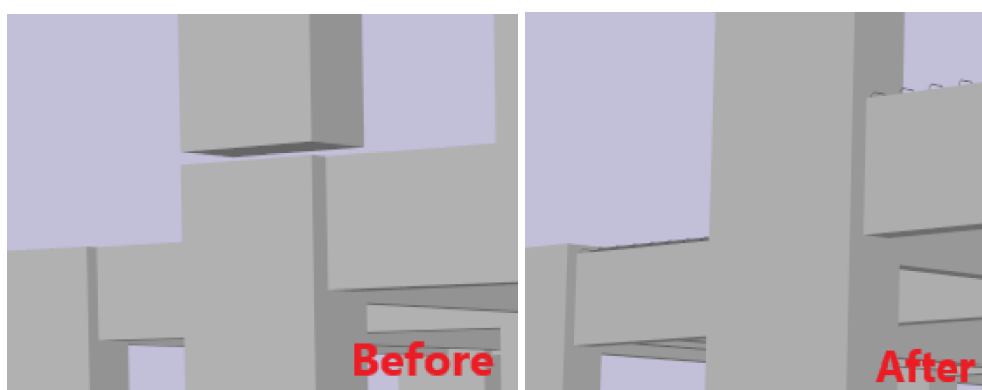
Figure 4.8: Before and after modification of gap error between columns.
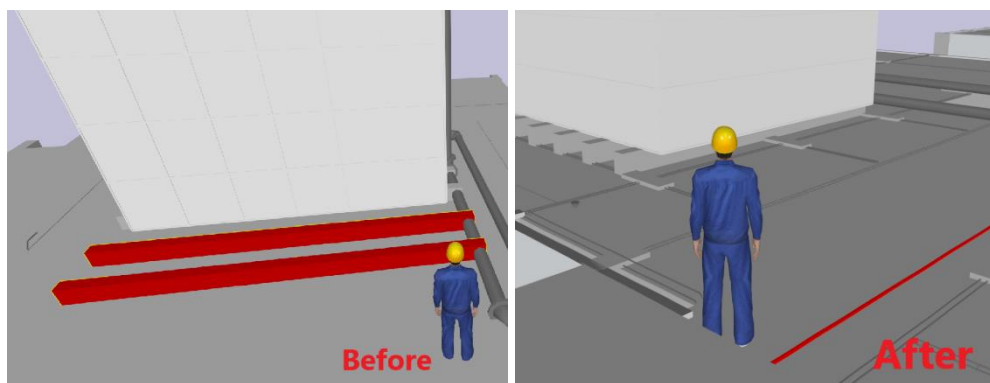
Figure 4.9: Before and after modification of additional water beam.

4.4 Manual Verification for Structural Analysis

All the critical members, such as beam, slab, and column, were obtained by Esteem 9. Then, those critical members were required to undergo a manual verification process by utilising a spreadsheet. In fact, there was a difference in the results of default design reinforcement by software compared to manual calculation design (Hiwase, 2018). Hiwase (2018) also mentioned that design reinforcement by software would have a minor over design compared to manual calculation. However, relying on software is much higher as software can reduce the time consumed and is towards the trend of BIM (Hiwase, 2018). Thus, the minor over-design by software either increases the structure's stability or prevents miscalculating parts compared to manually designed.

4.4.1 Critical Beam

By obtaining the critical beam results in Esteem 9, the critical beam with the largest moment was determined on the 10th floor named 1b21, as shown in Figure 4.10. Figure 4.11 shows the load distribution diagram that illustrates the forces that are acted on each beam, respectively.
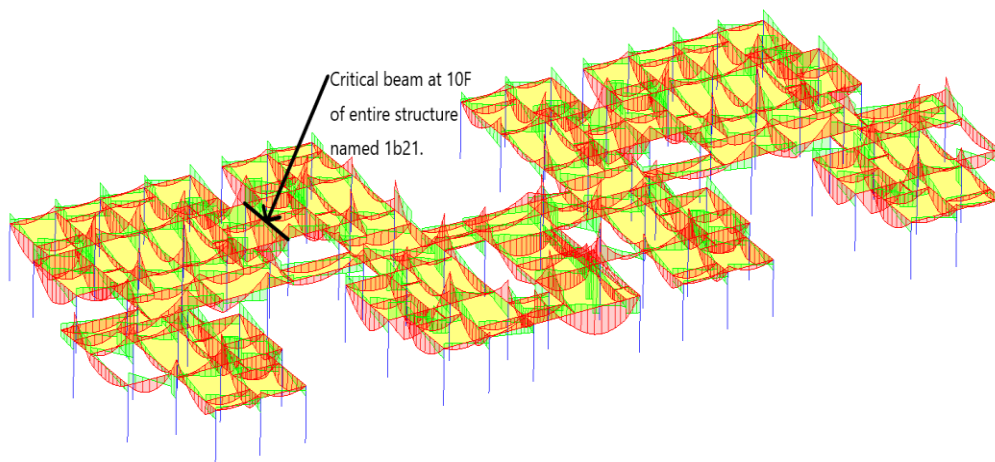
Figure 4.10: Critical beam located at 10th floor.
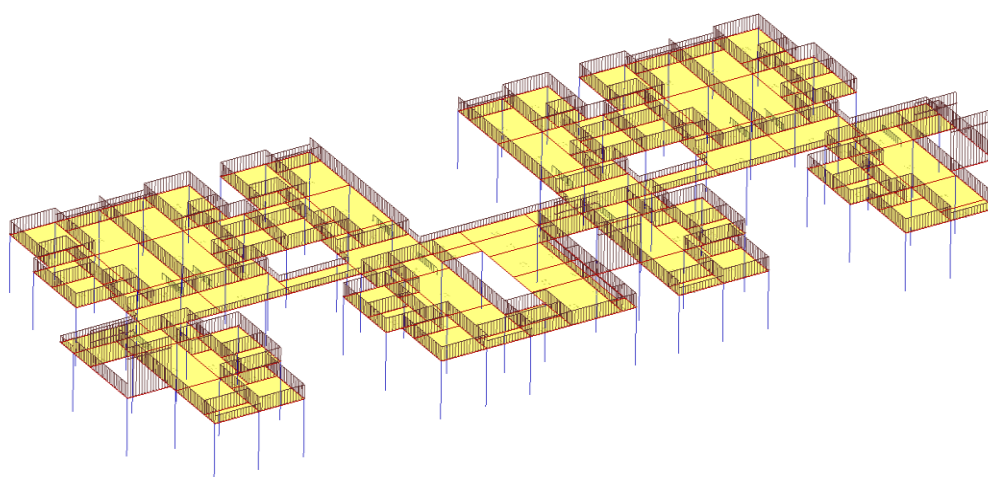
Figure 4.11: 10th floor load distribution diagram.

First, the structural models examined the idealisation of the beam for overall analysis. According to EN 1992-1-1:2004 section 5.3.1, clause 3, as shown in Figure 4.12, stated that a beam member which the span is not less than 3 times the overall section depth. Otherwise, the beam will be considered a deep beam. Hence, there is a total of 2 spans in the 1b21 beam, whereby the smallest span length was measured at 2325 mm, and the depth of the beam was figured at 600 mm. Then, a ratio of the span over beam depth was calculated at 3.875, which is greater than 3. Therefore, the size check of the beam is verified.

5.3   Idealisation of the structure

5.3.1 Structural models for overall analysis

(1)P The elements of a structure are classified, by consideration of their nature and function, as beams, columns, slabs, walls, plates, arches, shells etc. Rules are provided for the analysis of the commoner of these elements and of structures consisting of combinations of these elements.

(2) For buildings the following provisions (3) to (7) are applicable:

(3) A beam is a member for which the span is not less than 3 times the overall section depth. Otherwise it should be considered as a deep beam.

Figure 4.12: EN 1992-1-1:2004 section 5.3.1 clause 3.

Figure 4.13 shows the diagram of the bending and shear force of the 1b21 beam analysed by Esteem 9. The beam experienced a maximum sagging moment of 250.20 kNm, a 0 kNm hogging moment, and the largest shear force of 144.3kN. Meanwhile, the rebar reinforcement design by Esteem 9, as shown in Figure 4.14. The beam has a dimension of 150 mm x 600 mm and a span length of 5400 mm. Esteem 9 also provided 2T12 as compression rebar, 2T16+2T25 as tension rebar, and R6-100 as stirrups.
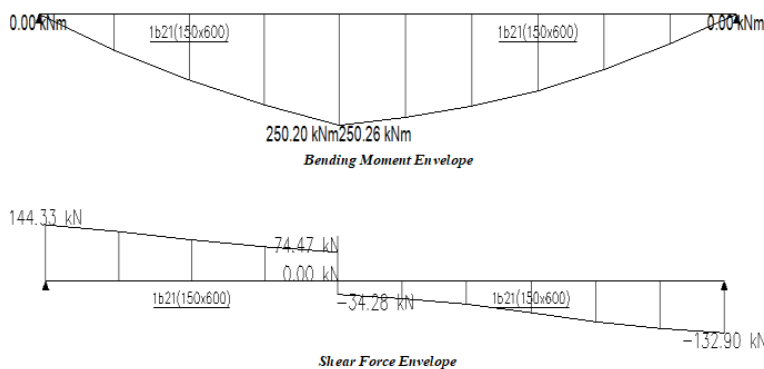
Figure 4.13: Bending and Shear diagram of critical beam.
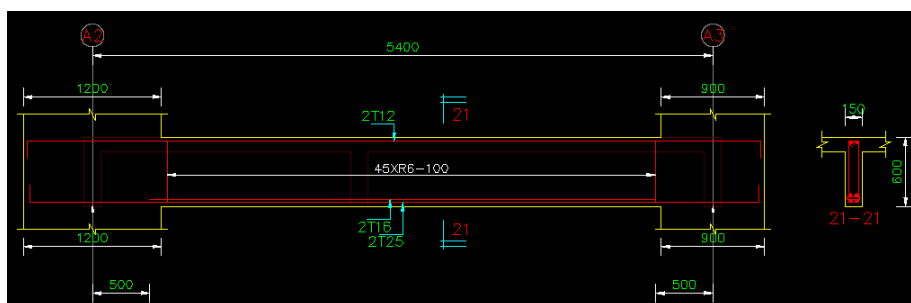
Figure 4.14: Rebar reinforcement design of critical beam.

All the details of the designed critical beam reinforcement were carried forward to manual analysis verification by spreadsheet, as shown in Appendix C. Figure 4.15 shows the key values from beam spreadsheet, Appendix C. From the spreadsheet of the critical beam, the design of the critical span was calculated with compression steel as the k value exceeded 0.167. Two 12 mm diameter rebars provide 226 mm^2 of compression steel to resist the compression of the critical beam. From Esteem 9, two 16 mm and two 25 mm diameter rebars provide 1384 mm^2 of tension steel to carry the sagging moment of the critical beam.

Main Reinforcement

Moment at support generated by Esteem 9, M	=	0 kNm
Moment at center generated by Esteem 9, M	=	250.200 kNm
$k = \dfrac{M}{bd^2 f_{ck}} < 0.167$	=	0.2267

*Hence, Compression steel is required since k > 0.167.

$z = d\left(0.5 + \sqrt{0.25 - \dfrac{k}{1.134}}\right) < 0.95d$	=	0.72 d
	<	0.95 d
z value at max is 0.95d, therefore z value is	=	0.72 d
$x = \dfrac{d - z}{0.4}$	=	374.60 mm
$\dfrac{d'}{x} < 0.38$	=	0.14

*Thus, the compression steel will have yielded.

$f_{sc} = 0.87 f_{yk}$	=	435.00
Area of compression steel		
$A'_s = \dfrac{(K - K_{bal})f_{ck}bd^2}{0.87 f_{yk}(d - d')}$	=	204.94 mm²
Area of tension reinforcement		
$A_{s,req} = \dfrac{K_{bal}f_{ck}bd^2}{0.87 f_{yk} z_{bal}} + A'_s$	=	1349 mm²
Area of provided compression reinforcement	=	2 H 12
by Esteem 9.	=	226 mm²
Area of provided tension reinforcement by	=	2 H 16 and
Esteem 9.		2 H 25
	=	1384 mm²
Check As,prov > As,req and As,prov > As,min and As,prov > As,max.		OK

Figure 4.15: Key values from beam spreadsheet.

Figure 4.16 shows the shear reinforcement from the beam spreadsheet. The verification process of shear reinforcement is done, which Esteem 9 provided R6-100 that consists of 283 mm^2, while the minimum area of steel is calculated at a value of 54.6 mm^2. Hence, the shear reinforcement design by Esteem 9 has overdesign, but it is safe to resist the shear force.

	Shear Reinforcement		
	Shear generated by Esteem 9, Ved	=	144.30 kN
6.2.3	$V_{Rd,max(22)} = \dfrac{0.36b_w d(1 - \frac{f_{ck}}{250})f_{ck}}{\cot\theta + \tan\theta}$	=	228.96 kN
6.2.3	$V_{Rd,max(45)} = \dfrac{0.36b_w d(1 - \frac{f_{ck}}{250})f_{ck}}{\cot\theta + \tan\theta}$	=	329.57 kN
	Check smallest Vrd,max(22) and Vrd,max(45) > Ved		OK
	Check largest Vrd,max(22) and Vrd,max(45) > Ved		OK
	Hence, the value of angle use for design is	=	22
	Therefore, $\cot\theta$	=	2.5
9.2.2(5)	$\dfrac{A_{sw}}{S} = \dfrac{V_{Ed}}{0.78 d f_{yk}\cot\theta}$	=	0.546
	$\dfrac{A_{sw,min}}{S} = \dfrac{0.08 f_{ck}^{0.5} b_w}{f_{yk}}$	=	0.240
	New Asw/s is	=	0.546
	Shear reinforcement provided by Esteem 9 is	=	R 6 - 100
	Asw,prov	=	283 mm²
	Asw,prov/s	=	2.830 mm²
9.2.2(8)	$S_{max} = 0.75\, d$	=	407 mm
	Check Smax > Sprov		OK
	Check Asw,prov/s > New Asw/s		OK

Figure 4.16: Shear reinforcement design check from beam spreadsheet.

Moreover, Figure 4.17 shows deflection check from the spreadsheet. The verification process of deflection is checked with the factor for the structural system, k, which is 1.5 due to the continuous beam's end span. Thus, the calculated modification ratio is 1.026, which results in an allowable deflection of 13.94. By comparison of allowable and actual deflection, allowable deflection is 1.4 times larger than actual deflection, at 9.95. Therefore, the deflection verification is acceptable.

7.4	**Deflection**			
	Percentage of required tension reinforcement,			
	$p = \dfrac{100 A_{s,req}}{bd}$	=	1.657	
	Reference reinforcement ratio,			
	$p_o = \dfrac{\sqrt{f_{ck}}}{1000}$	=	0.005	
	Percentage of required compression reinforcement,			
	$p' = \dfrac{A'_{s,req}}{bd}$	=	0.003	
Table 7.4N	Factor for structural system, K	=	1.5	
7.4.2	Since p > po, equation of (l/d) is			
	$(\dfrac{l}{d})_{allow} = K[11 + 1.5\sqrt{f_{ck}}\,\dfrac{p_o}{p-p'} + \dfrac{1}{12}\sqrt{f_{ck}}\sqrt{\dfrac{p'}{p_o}}]$	=	16.978	
	Modification factor for flange width, b/bw > 3	=	0.8	
	Modification factor for span less than 7m	=	1.0	
	Modification factor for steel area provided,			
	$\dfrac{A_{s,prov}}{A_{s,req}}$	=	1.026 < 1.5	
	New (l/d)allow	=	13.94	
	Actual (l/d)	=	9.95	
	Check (l/d)actual < (l/d)allow			OK

Figure 4.17: Deflection check from beam spreadsheet.

4.4.2   Critical Column

The internal forces of the columns at the lowest level experienced the largest force as all the loads were transferred from the highest floor to the lowest floor. By obtaining the critical column with an orthogon of 4 beams results in Esteem 9, the critical column experienced the largest force determined on the 10th floor named AD1, A7, as shown in Figure 4.18. Due to the nature of a structural building, the column at level 9 should be the largest force, but it was shown that the stump below the 9th floor experienced the largest force. However, this study does not consider the stump's design for manual verification checking.
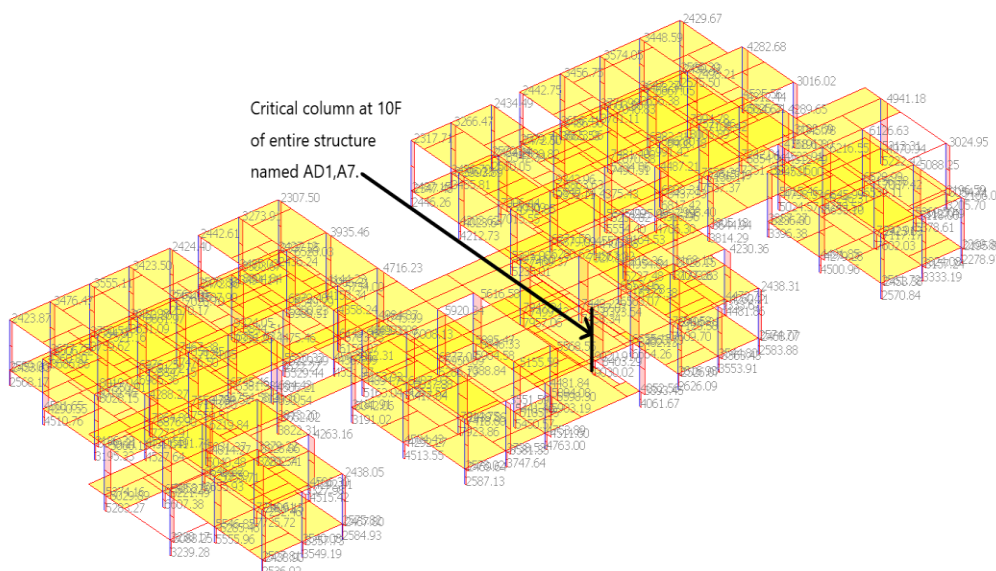
Figure 4.18: Critical column located at 10th floor.

Initially, the structural models examined the idealisation of the column for overall analysis. According to EN 1992-1-1:2004 section 5.3.1, clause 7, as shown in Figure 4.19, stated that a column member in which the section depth does not exceed 4 times its width and the height is at least 3 times the section depth. Otherwise, the column would be considered a wall. Hence, the column depth was determined at 900 mm while the width was measured at 300 mm. A depth ratio over width was calculated at 3, which is smaller than 4. Subsequently, the floor-to-floor height was measured at 3265 mm. By achieving the second criteria in section 5.3.1 clause 7, a ratio of height over depth was identified at 3.63, which is greater than the required value, 3. Therefore, the size check of the column is verified.

(7) A column is a member for which the section depth does not exceed 4 times its width and the height is at least 3 times the section depth. Otherwise it should be considered as a wall.

Figure 4.19: EN 1992-1-1:2004 section 5.3.1 clause 7.

Figure 4.20 (a) and (b) show the diagram of internal force and a bending moment of AD1, A7 column analysed by Esteem 9. The column experienced an axial load of 8403.29 kNm, with the largest bending moment of 75.15 kNm at the z-axis. Meanwhile, the rebar reinforcement design by

Esteem 9, as shown in Figure 4.21. The column has a dimension of 300 mm width with 900 mm depth and a floor-to-floor length of 3265 mm. Esteem 9 also provided 22T32 as reinforcement rebar and R6-125 as stirrups.
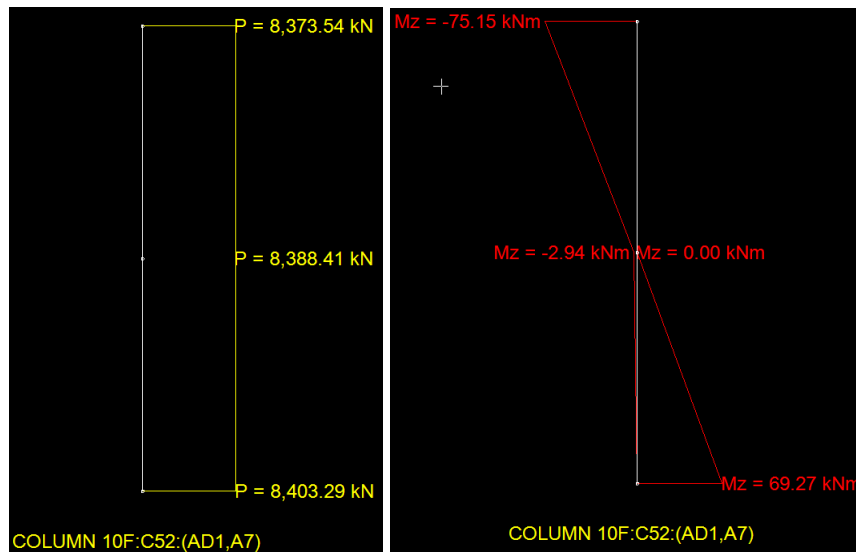
Figure 4.20: (a) Critical column axial load (b) Critical column bending moments.
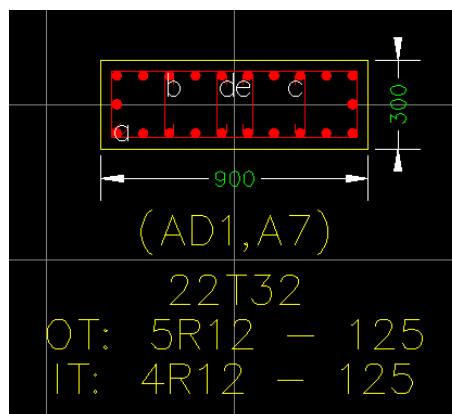
Figure 4.21: Rebar reinforcement design of critical column.

All the details of the designed critical column reinforcement were carried forward to manual analysis verification by spreadsheet, as shown in Appendix D. Figure From the spreadsheet of the critical column, the column was determined as a short column since the value of the calculated slenderness limit, λ_{lim}, exceeded the slenderness ratio, λ on both axes. Figure 4.22 shows the reinforcement design from Appendix D. The design of the minimum area of rebar was utilized at $A_{s,min}$ is 1931.8 mm^2 and As is 13365 mm^2 based on the calculation of the short column. In Esteem 9, it was provided 22T32, which

$A_{s,prov}$ is 17696 mm^2. Thus, the reinforcement design of the critical column in Esteem 9 is acceptable since $A_{s,prov}$ is larger than A_s, $A_{s,min}$, and is smaller than $A_{s,max(lap)}$ and $A_{s,max(away\ lap)}$.

	Reinforcement design			
	d_2	=	63	mm
Refer to	d_2/h	=	0.2	
design chart	$\dfrac{N}{bhf_{ck}}$	=	1.13	
	$\dfrac{M}{bh^2f_{ck}}$	=	0.075	
	Figure 9d Column design chart for rectangular columns $d_z/h = 0.20$			
	$\dfrac{A_s f_{yk}}{bhf_{ck}}$	=	0.99	
	As	=	13365	mm²
	As,prov by Esteem 9	=	22 T 32	
		=	17696	mm²
	$A_{s,min} = \dfrac{0.1N_{Ed}}{0.87f_{yk}} \geq 0.002A_c$	=	1931.8	mm²
	0.002Ac	=	540	mm²
	Check As,min > 0.002Ac		OK	
	As,max (lap)	=	21600	mm²
	As,max (away lap)	=	18900	mm²
	Check As,max(lap) and As,max(away lap) > As,prov		OK	
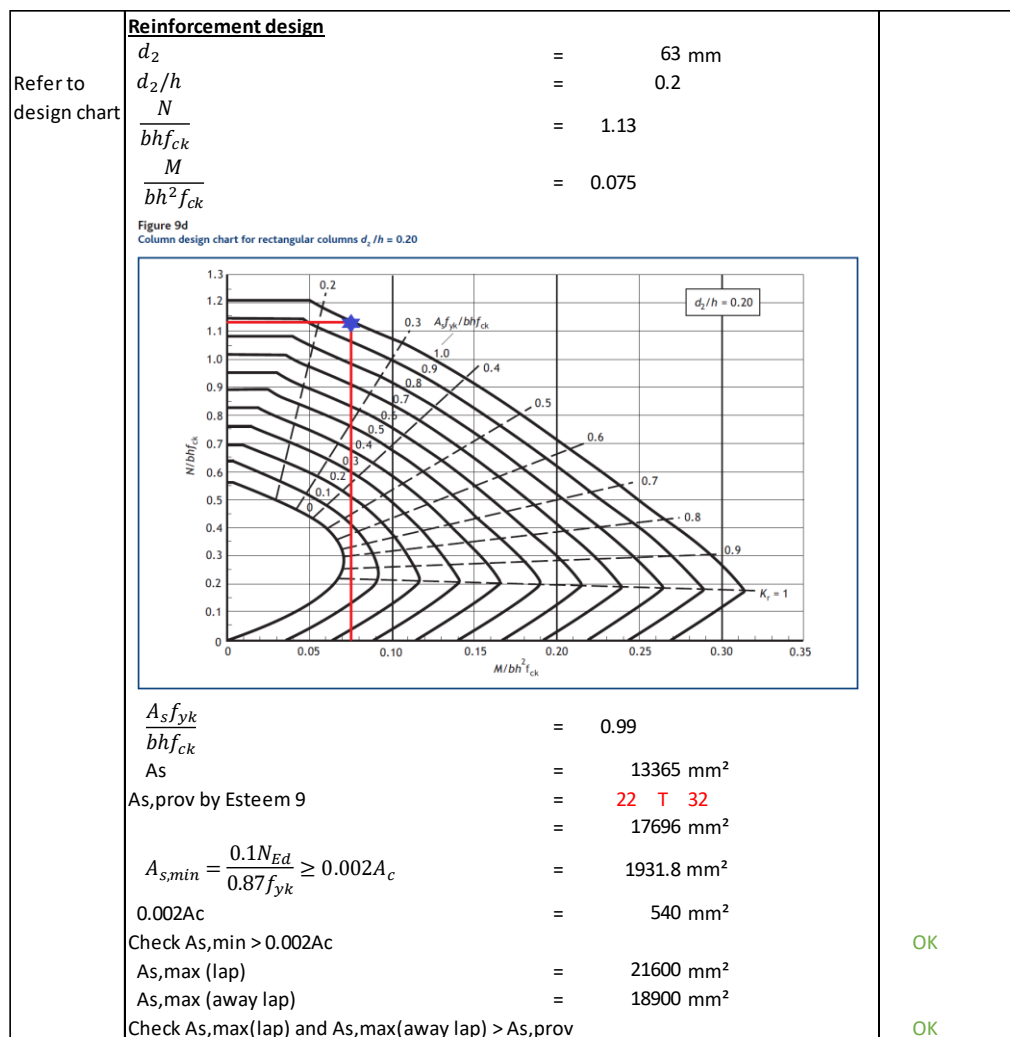
Figure 4.22: Reinforcement design check from column spreadsheet.

Next, Figure 4.23 shows the shear link design from column spreadsheet. The shear link design in the column is based on the design standard of EC2. The minimum shear link diameter is calculated based on the larger of 6 mm rebar or one-fourth of the longitudinal rebar diameter, which is calculated at 8 mm in the spreadsheet. In the meantime, the maximum spacing of the shear link is calculated at 180 mm, while the shear link provided by Esteem 9 is R12-125, which means the result is acceptable.

Shear Link				
Minimum shear link diameter (larger)	=	8 mm	or	6mm
Maximum spacing away from lap region (lesse	=	640 mm	or	300mm
At section 300mm below & above beam and lapped joints,				
$S_{v,max} = 0.6 S_{v,max}$	=	180 mm		
Shear Link provided by Esteem 9	=	R 12 - 125		OK

Figure 4.23: Shear link design check from column spreadsheet.

4.4.3 Critical Slab

By obtaining the slab results in Esteem 9, the largest size of the 10th-floor slab was taken into manual verification check of reinforcement design. Figure 4.24 (a) shows the bending moment at the x-axis, while Figure 4.24 (b) is at the y-axis of the 10th floor. The figures also presented the critical values of up to 11.14 kNm of hogging moment and 7.51 kNm of sagging moment at the y-axis and 9.45 kNm of hogging moment and 7.38 kNm at the x-axis.
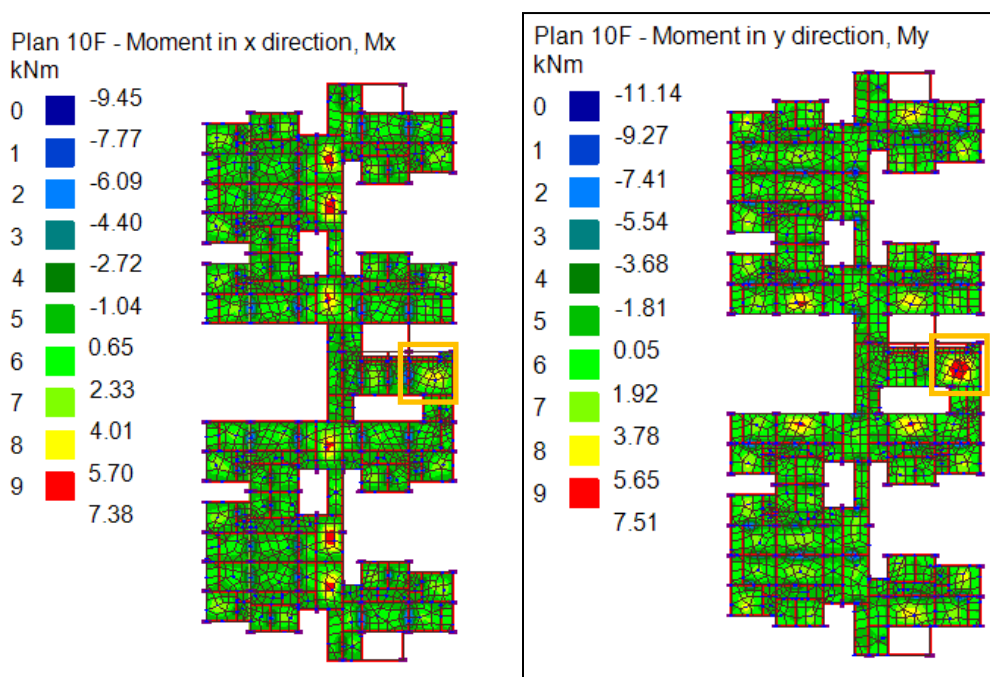
Figure 4.24: (a) Bending moment of slab at x-axis at 10th floor. (b) Bending moment of slab at y-axis at 10th floor.

Initially, the structural models examined the idealisation of the slab for overall analysis. According to EN 1992-1-1:2004 section 5.3.1 clause 4, as shown in Figure 4.25, a slab member for which the minimum dimension of the panel is not less than 5 times the overall slab thickness. Hence, the dimension

of x was measured at 3865 mm, whereas y was measured at 5000 mm. From the dimensions of both panels, the smallest dimension is 3865 mm, whereby the thickness of the slab in the section was figured at 125 mm. Then, a ratio of the smallest dimension panel over slab depth was calculated at 30.95, which is much greater than 5. Therefore, the thickness check of the slab is verified.

5.3   Idealisation of the structure

5.3.1 Structural models for overall analysis

(1)P The elements of a structure are classified, by consideration of their nature and function, as beams, columns, slabs, walls, plates, arches, shells etc. Rules are provided for the analysis of the commoner of these elements and of structures consisting of combinations of these elements.

(2) For buildings the following provisions (3) to (7) are applicable:

(3) A beam is a member for which the span is not less than 3 times the overall section depth. Otherwise it should be considered as a deep beam.

(4) A slab is a member for which the minimum panel dimension is not less than 5 times the overall slab thickness.

Figure 4.25: EN 1992-1-1:2004 section 5.3.1 clause 3.

The critical slab named FS75 with dimensions of 3865 mm in length, 5000 mm in width, and an equal dimension of 125 mm in thickness were all taken into manual verification check in the spreadsheet as shown in Appendix E. Based on the FEM analysis in Esteem 9, and the FS75 slab experienced 4.69 kNm/m in x-axis at span, 6.25 kNm/m in y-axis at span, 1.89 kNm/m in x-axis at support, 0.36 kNm/m in y-axis at support, and a shear force of 23.27 kN. Figure 4.26 (a) shows the slab FS75 bottom rebar reinforcement designed by Esteem 9, while Figure 4.26 (b) shows the top rebar reinforcement.
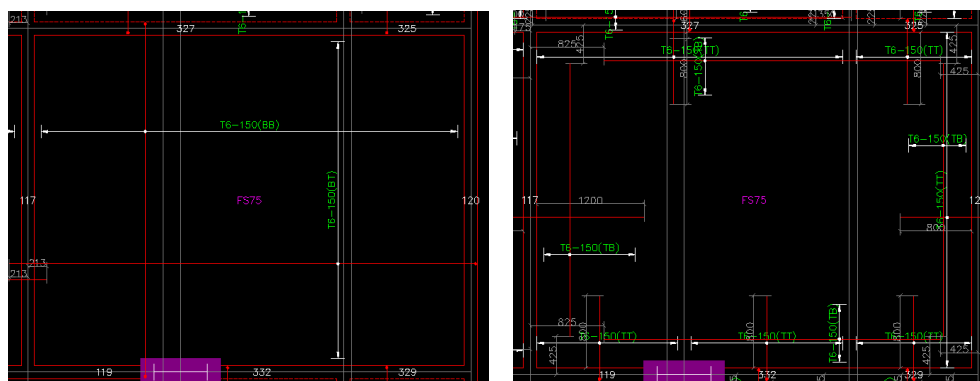
Figure 4.26: (a) Bottom rebar reinforcement design of FS30 slab. (b) Top rebar reinforcement design of FS30 slab.

All the details of the designed critical slab reinforcement were carried forward to manual analysis verification by spreadsheet, as shown in Appendix E. Table 4.3 shows the summarised data from the critical slab spreadsheet. All the areas of provided steel by Esteem 9 are enabled to resist the area of steel reinforcement required, and it is within the limit between the maximum and minimum area of steel mentioned by EC2. In addition, there is no compression steel required as all the k value is within the limit of 0.167.

Table 4.3: Summary data from critical slab spreadsheet.

FS75					
Location	Spreadsheet		Esteem 9	Spreadsheet	
	K value	$A_{s,req}$	$A_{s,prov}$	$A_{s,min}$	$A_{s,max}$
M_{sx} (Sup.)	0.0100	53 mm^2	189 mm^2	117.62 mm^2	5000 mm^2
M_{sx} (Mid.)	0.0248	130 mm^2	189 mm^2	117.62 mm^2	5000 mm^2
M_{sy} (Sup.)	0.0022	11 mm^2	189 mm^2	109.51 mm^2	5000 mm^2
M_{sy} (Mid.)	0.0381	187 mm^2	189 mm^2	109.51 mm^2	5000 mm^2

Figure 4.27 shows deflection and cracking check from critical slab spreadsheet. The checking process of deflection and cracking at the slab followed the design standard of EC2. The factor for the structural system in deflection, k value, is assumed as 1.3 due to the end span of the continuous beam. Then, a good deflection ratio of 5.62 is calculated by allowable deflection over actual. For the checking of crack, the maximum spacing of the main rebar is calculated at 375 mm while the secondary rebar is at 437.5 mm based on the slab must be lower than 200 mm thick.

7.4	**Deflection**			
	Percentage of required tension reinforcement,			
	$p = \dfrac{A_{s,req}}{bd}$	=	0.001	
	Reference reinforcement ratio,			
	$p_o = \dfrac{\sqrt{f_{ck}}}{1000}$	=	0.005	
Table 7.4N	Factor for structural system, K	=	1.3	
7.4.2	Since p < po, equation of (l/d) is			
	$\left(\dfrac{l}{d}\right)_{allow} = K[11 + 1.5\sqrt{f_{ck}}\dfrac{p_o}{p} + 3.2\sqrt{f_{ck}}\left(\dfrac{p_o}{p} - 1\right)^{\frac{3}{2}}]$	=	103.888	
	Modification factor for span less than 7m	=	1.0	
	Modification factor for steel area provided,			
	$\dfrac{A_{s,prov}}{A_{s,req}}$	=	1.449 < 1.5	
	New (l/d)allow	=	150.52	
	Actual (l/d)	=	26.80	
	Check (l/d)actual < (l/d)allow			OK
7.3.3	**Cracking**			
9.3.1	Check h < 200mm.			OK
	Main bar:			
	$S_{max,slabs} = 3h \leq 400mm$	=	375.00	
	Check Smax,slabs < 400mm.			OK
	Secondary bar:			
	$S_{max,slabs} = 3.5h \leq 450mm$	=	437.50	
	Check Smax,slabs < 450mm.			OK

Figure 4.27: Deflection and cracking check from slab spreadsheet.

4.4.4 Stair Reinforcement Design

The load distribution and reinforcement design of stairs were calculated manually in the spreadsheet and then added to Esteem 9. This is because Esteem 9 does not provide the functionality of a stair design. Stair design used the EC2 as the design standard. Figure 4.28 shows the main reinforcement stair design from the stair design spreadsheet. The stairs were designed as U-stairs supported by landing. In the main reinforcement design of landing and flight, the k value is calculated to be lesser than 0.167. Thus, there is no compression steel required in the design. The provided main and secondary rebar were assumed to be H10-300 with the area of steel of 262 mm^2/m while the required steel area is 260.6 mm^2/m. The steel area provided fulfils all the requirements, such as larger than the minimum area of steel and lesser than the maximum area of steel. Then, the deflection ratio of the flight was calculated at a value of 1.85.

6.1	**Main Reinforcement**					
	Effective depth, d	=	h-C-0.5Dbar			
		=	120 mm			
	Design moment, Med					
	k	=	$\dfrac{M}{bd^2 f_{ck}}$			
		=	0.0359	< Kbal =	0.167	
	Thus, Compression reinforcement is not required.					

$$z = d[0.5 + \sqrt{0.25 - \frac{K}{1.134}}]$$

		=	0.97 d		Main Bar :
	z,max	=	0.95 d		H 10- 300
	z,used	=	0.95 d		262 mm²/m
	As	=	$\dfrac{M}{0.87 f_{yk} z}$		
		=	260.58 mm²/m		

9.2.1.1 Minimum and maximum reinforcement area,

As,min	=	$0.26\left(\dfrac{f_{ctm}}{f_{yk}}\right)bd$		Secondary bar:
	=	160.05 mm²/m		H 10- 300
				262 mm²/m
As,max	=	0.04Ac		
	=	6000 mm²/m		

Figure 4.28: Key values of stair design.

In the landing, the area provided of steel is 17H10 (1335 mm^2). From the spreadsheet, the area provided for steel is much higher than the area required for steel, 759 mm^2/m. This is because if a lesser area provided of steel is used in the design, the landing will face a failure in deflection. Thus, it is required to increase the area provided by steel until the deflection is stable. Figure 4.29 shows the deflection check of the stair from the stair design spreadsheet. The spreadsheet calculated the allowable deflection at 28.38, slightly higher than the actual deflection, 27.92. Thus, the stair design can be considered an economical design. Appendix F shows the full version of the stair design.

7.4	**Deflection**	
	Percentage of required tension reinforcement,	
	p $\quad = \dfrac{A_{s,req}}{bd}$	
	$\quad = \quad 0.005$	
	Reference reinforcement ratio,	
	po $\quad = (f_{ck})^{1/3}$	
	$\quad = \quad 0.005$	
Table 7.4N	Factor for structural system, K $\quad = \quad$ 1	
	p $\quad < \quad$ po	
	Thus, use equation 7.16a.	
Eqn. 7.16a	$\dfrac{l}{d} \quad = \quad K[11 + 1.5\sqrt{f_{ck}}\dfrac{po}{p} + 3.2\sqrt{f_{ck}}(\dfrac{po}{p} - 1)^{3/2}$	
	$\quad = \quad 18.922$	
	Modification factor for span less than 7m.	
	$\quad = \quad 1.00$	
	Modification factor for steel area provided,	
	$\quad = \dfrac{A_{s,prov}}{A_{s,req}}$	
	$\quad = \quad 1.76 \quad < \quad 1.5$	
	Therefore allowable span-effective depth ratio,	
	$(l/d)_{allow} \quad = \quad 28.38$	
	$(l/d)_{actual} \quad = \quad 27.92$	OK

Figure 4.29: Deflection check from stair design spreadsheet.

4.5 Quantity Take-Off

The results of quantity take-off were exported out with total cost from Autodesk Revit based on a few parameters inserted into it, whereas the price of materials was referred to Quantity Surveyor Online (2022). In this study, the quantity take-off was sorted by column, slab, beam, and stair on each floor, while the materials were grouped by main rebars, shear links, and concrete. The finding of quantity take-off by structural elements in the Appendix are outlines as follows:

i.   Appendix G - Schedules of structural beam materials take off.

ii. Appendix H - Schedules of structural column materials take off.

iii. Appendix I - Schedules of structural slab materials take off

iv. Appendix J - Schedules of structural stair materials take off

4.5.1 Beam

Appendix G shows the result of the total beam cost and quantity of the rebars, shear links, and concrete used in the BIM model. By summarising in Appendix G, data in Table 4.4 contained the counts of each beam size. There are 4 types of beam sizes which are 150x500, 150x540, 150x600, and 230x600 in terms of millimetres.

Table 4.4: Summary of beam quantity in size.

Beam Size (mm x mm)	Quantity (pcs)
150 x 500	294
150 x 540	108
150 x 600	2604
230 x 600	22
Total	**3028**

Thereupon, data in Appendix G also contained the diameter of main rebar required for the model, varying from T10, T12, T16, T20, T25, and T32. Therefore, the utilised main rebars were generated in terms of meters, which amounted to a total cost of RM431,807.29 for the main rebar category. Meanwhile, the diameter of shear link required for the model ranges from R6, R10, R12, and R16, whereas the total cost is RM123,647.02. Then, the reinforced concrete beam used in the model is grade C25/30 with a total volume of 1,237.26 m^3, while the total cost is RM300,654.18. Hence, the grand total for reinforced concrete beams with main rebars and shear links is RM856,108.48. Table 4.5 shows the summarised cost of the reinforced concrete beams from level 9 to the roof in the model.

Table 4.5: Summary cost of reinforced concrete beam.

Beam Material	Type	Total Quantity	Cost (RM)
Shear Link	R6	149,306.47 m	102,081.65
	R10	10,990.71 m	21,212.21
	R12	111.90 m	311.01
	R16	8.96 m	42.15
Total cost of Shear Link			**123,647.02**
Main Rebar	T10	41,261.03 m	79,634.32
	T12	9,178.33 m	25,508.59
	T16	12,674.86 m	59,623.22
	T20	14,761.33 m	108,497.00
	T25	13,721.07 m	157,579.65
	T32	51.26 m	964.51

Table 4.5 (Continued)

Total cost of Main Rebar			431,807.29
Reinforced Concrete	C25/30	1,237.26 m^3	300,654.17
Grand Total			856,108.48

4.5.2   Column

The total column cost and quantity of the rebars, shear links, and concrete use required to purchase in the BIM model is shown in Appendix H. By concluding Appendix H, data in Table 4.6 contained the counts of each beam size. There are 3 types of beam sizes, which are 300x900, 300x1200, and 200x150 in terms of millimetres.

Table 4.6: Summary of column quantity in size.

Column Size (mm x mm)	Quantity (pcs)
200 x 150	10
300 x 900	1718
300 x 1200	36
Total	1764

Therefore, data in Appendix H also contained the diameter of main rebar required for the model varies from T10, T12, T16, T20, T25, and T32. Therefore, the utilised main rebars were generated in terms of meters, which amounted to a total cost of RM418,053.40 for the main rebar category. Meanwhile, the diameter of shear link required for the model range from R6, R10, and R12, whereas the total cost is RM511,041.27. Then, the reinforced concrete column used in the model is grade C25/30 with a total volume of 1,614.87 m^3, while the total cost is RM392,413.41. Hence, the grand total for reinforced concrete columns with main rebars and shear links was computed at RM1,321,508.08. Table 4.7 shows the summarised cost of the reinforced concrete columns from level 9 to the roof in the model.

Table 4.7: Summary cost of reinforced concrete column.

Column Material	Type	Total Quantity	Cost (RM)
Shear Link	R6	247.53 m	171.99
	R10	6,919.55 m	13,354.81
	R12	179,012.37 m	497,514.47
Total cost of Shear Link			**511,041.27**
Main Rebar	T10	168.19 m	792.45
	T12	51,198.94 m	241,228.41
	T16	4,430.51 m	20,874.76
	T20	1,806.15 m	8,509.86
	T25	8,457.42 m	39,847.91
	T32	7,663.06 m	36,105.19
Total cost of Main Rebar			**418,053.40**
Reinforced Concrete	C25/30	1,614.87 m^3	392,413.41
Grand Total			**1,321,508.08**

4.5.3 Slab

The total slab cost and quantity of the rebars, BRC reinforcement, and concrete use required to be purchased in the BIM model are shown in Appendix I. By concluding Appendix I, data in Table 4.8 contained the counts of each slab thickness. As a result, there is only 1 type of slab thickness designed, which is 125 mm.

Table 4.8: Summary of slab quantity in thickness.

Slab Thickness (mm)	Quantity (pcs)
125	2657
Total	**2657**

Therefore, data in Appendix I also contained the diameter of top and bottom rebar required for the model, varying from T6, T10, and T12. Therefore, the utilised rebars were generated in meters, which amounted to a total cost of RM472,928.81 for the main rebar category. Meanwhile, the type of BRC reinforcement required for the designed 3D model is A7 and A8,

whereas the total cost is computed at RM891.67. Next, the reinforced concrete slab used in the model is grade C25/30, with a total volume of 20,064.08 m^3, while the total cost is RM610,107.39. Hence, the grand total for reinforced concrete slabs with top, bottom rebars and BRC reinforcement was figured at RM1,083,927.87. Table 4.9 shows the summarised cost of reinforced concrete slab from level 9 to the roof in the 3D BIM model.

Table 4.9: Summary cost of reinforced concrete slab.

Slab Material	Type	Total Quantity	Cost (RM)
BRC	A7	64.34 m^2	709.08
	A8	19.47 m^2	280.74
Total cost of BRC reinforcement			**989.82**
Rebar	T6	676,940 m	470,340.97
	T10	1,151 m	2,221.82
	T12	132 m	366.01
Total cost of Rebar			**472,928.81**
Reinforced Concrete	C25/30	20,064.08 m^3	610,107.39
Grand Total			**1,084,026.02**

4.5.4   Stair

The total cast in-situ reinforced concrete stair cost and quantity of the rebars, and concrete required to be purchased in the BIM model are shown in Appendix J. By concluding Appendix J, the total count of stairs was computed at 52 sets, whereby one floor consists of 3 sets of stairs.

As a result, data in Appendix J also contained the diameter required for the model, which varies from R10, and T10. However, the R10 rebar was used for support in the riser, whereas the T10 was designed to resist the bending moment. Therefore, the utilised rebars were generated in meters, which amounted to a total cost of RM31,835.87 for the rebar category. Then, the cast in-situ reinforced concrete stair used in the model is grade C25/30 with a total volume of 85.42 m^3, while the total cost is RM20,756.09. Hence, the total for stairs with rebars and reinforced concrete was calculated at

RM52,591.96. Table 4.10 shows the summarised cost of cast in-situ reinforced concrete stairs from level 9 to the roof in the 3D BIM model.

Table 4.10: Summary cost of reinforced concrete column.

Stair Material	Type	Total Quantity	Cost (RM)
Rebar	R10	3,778 m	7,291.16
	T10	12,717 m	24,544.71
Total cost of Rebar			**31,835.87**
Reinforced Concrete	C25/30	85.42 m^3	20,756.09
Grand Total			**52,591.96**

4.6 Statistical Analysis for Construction Materials Cost and Quantities

4.6.1 Measure of Frequency

As a result, the measure of frequency was conducted by calculating the total quantity from the shear link, rebar, BRC reinforcement, and reinforced concrete, as shown in Table 4.11. In the construction industry, a measure of frequency is essential since it contains data with a grand total quantity of structural elements and its volume. This is because the construction cost can be tracked easily with an accurate and consistent total quantity take-off. The measure of frequency provided a clear picture of the frequency of purchasing construction materials accurately to prevent budget overruns. Thus, accurate material takes off, enabling boosted clear communication or lesser argument that keeps clients updated during trade and will lead to gaining the client's trust.

Table 4.11: Table of frequency measurement.

Structural Material	Type	Total Quantity	Total Volume (m^3)
Shear Link	R6	149,554.00 m	4,229,088.15
	R10	21,688.04 m	1,703,595.19
	R12	179,124.27 m	20,261,104.84
	R16	8.96 m	1,801.78
BRC	A7	64.34 m^2	-
	A8	19.47 m^2	-

Table 4.11 (Continued)

Main Rebar	T10	54,146.61 m	4,253,215.93
	T12	60,377.27 m	6,829,394.27
	T16	17,105.38 m	3,439,686.37
	T20	16,567.49 m	5,205,504.84
	T25	22,178.50 m	10,888,254.90
	T32	7,714.32 m	6,205,027.77
Reinforced Concrete	C25/30	-	23,001.63

4.6.2 Measure of Central Tendency

From the data obtained in Autodesk Revit, central tendency measurement enabled the calculation of the unit price in terms of Ringgit Malaysia per cubic meter. This measurement method is useful for computing the bill of quantity. Besides that, a lower unit price represented a lower cost; therefore, the current measurement enabled the client to overview the unit cost from the tenderers quickly. Table 4.12 shows the unit price of structural elements by using the formula of total cost over total concrete volume. From the graph, the information can be read straightforwardly, such as the unit price of the slab is RM54.03, the beam is RM691.94, the column is RM818.34, and the stair is RM615.72. An example of this project is in the tendering process. The lowest unit price will mostly win the bid compared to other tenderers.

Table 4.12: Table of central tendency.

Structural Element	Total Cost (RM)	Total Concrete Volume (m^3)	RM per m^3
Slab	1,084,026.02	20,064.08	54.03
Beam	856,108.48	1,237.26	691.94
Column	1,321,508.08	1,614.87	818.34
Stair	52,591.96	85.42	615.72

4.6.3 Position

By further analysis of quantity take-off, all the information can be gathered to compute a cumulative cost over level graph known as a line graph. The line

graph is chosen because it shows a more precise picture of changes and trends in the budget over time. Besides that, it enabled to plot of more than one line. In other words, more data sets can be shown on the same axis as a form of comparison. Moreover, the most important part of choosing a line graph is common and effective charts because it is simple, easy to understand and efficient. Figure 4.30 shows the chart of cumulative cost over level.
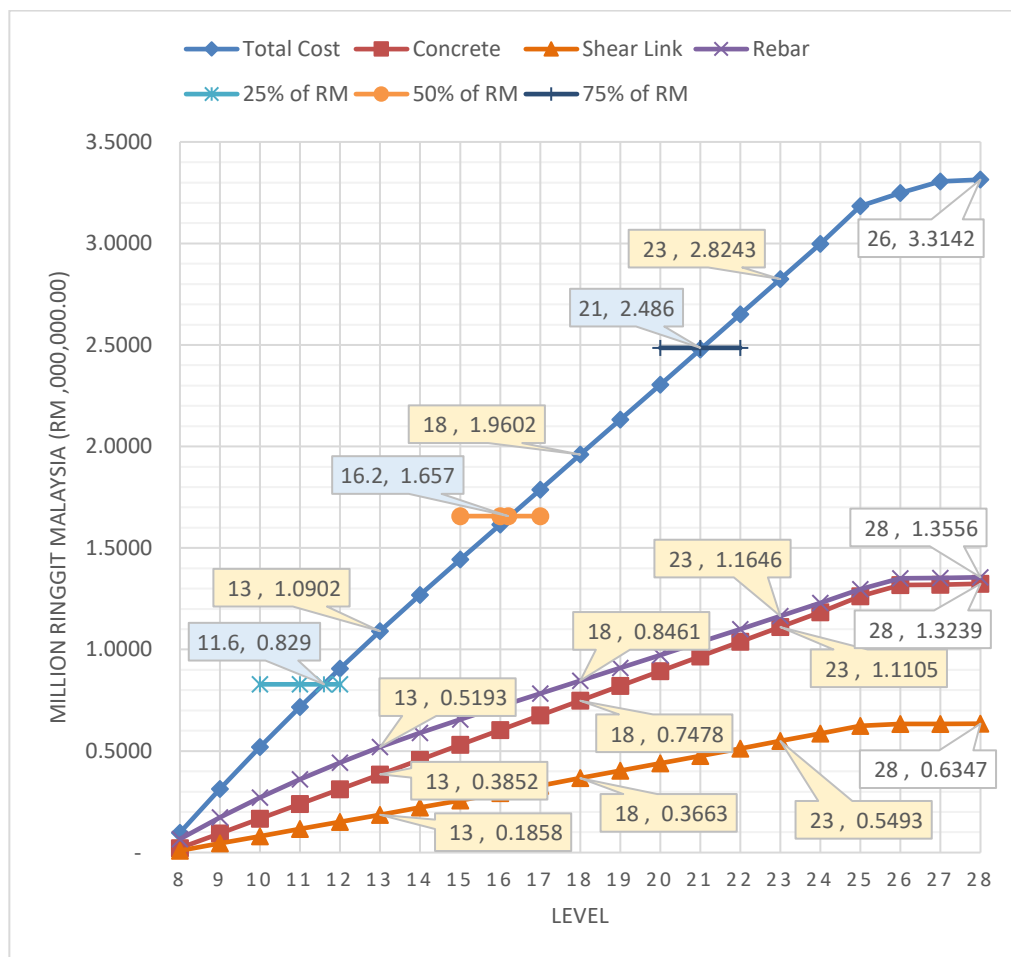
Figure 4.30: Graph of cumulative cost over level.

The graph illustrated the cumulative construction material costs from level 8 to level 26 HRF. It presents four different methods, including the cumulative cost of the total, concrete, rebar, and shear link. Overall, all the line graphs have rapidly increased with no issue since level 8, while the slowdown began at level 26. This is because it had reached the roof floor, level 26 LRF. However, the structural design of the roof floor does not require much concrete and rebar due to the roof floor experiencing the lightest loading.

Besides that, the number of columns, slabs, and beams on the roof floor is much lesser than the typical floor. In addition, the rebar line started to dilatory increase from a rapid increase at level 16. In fact, the lower floor represents higher loading in the column. Thus, the lower the floor, the higher the cost.

Subsequently, the chart shows a blue, yellow, and white call-out box. The white box represented the total cost in terms of millions of RM. Then, the blue call-out box is identified as quartiles of the total cost at 25%, 50%, and 75%. From this information, clients or construction professionals can easily track their money to avoid cost overruns. For example, at coordinate 21, 4.486 in the chart, this is the third quartile of its cost, RM2.486 million, whereas the project should be done until level 21 to determine whether the process of the project is still in control. Moreover, the yellow call-out box is figured as quartiles of levels, known as the project phase. For instance, at coordinate 18, 1.9602, where the medium exists, it can be concluded that when RM1.9602 million is spent on this project, a total of at least 18 floors needs to be constructed.

Lastly, the position graph clearly explains the cash flow with evidence. It enables the decision maker to accomplish tasks such as budget control, cash flow, etc.

4.6.4   Ratio

By concluding all the quantity take-off from the beam, column, slab, and stairs, the ratio method in descriptive statistics enabled to generate a pie of pie chart of total cost by structural elements and materials. Figure 4.31 shows the chart of total cost by structural elements and materials. This chart contains 2 sets of data, whereas the internal chart refers to the entire cost of structural elements in ratio, while the external chart refers to the entire cost of construction materials in the ratio of structural elements.
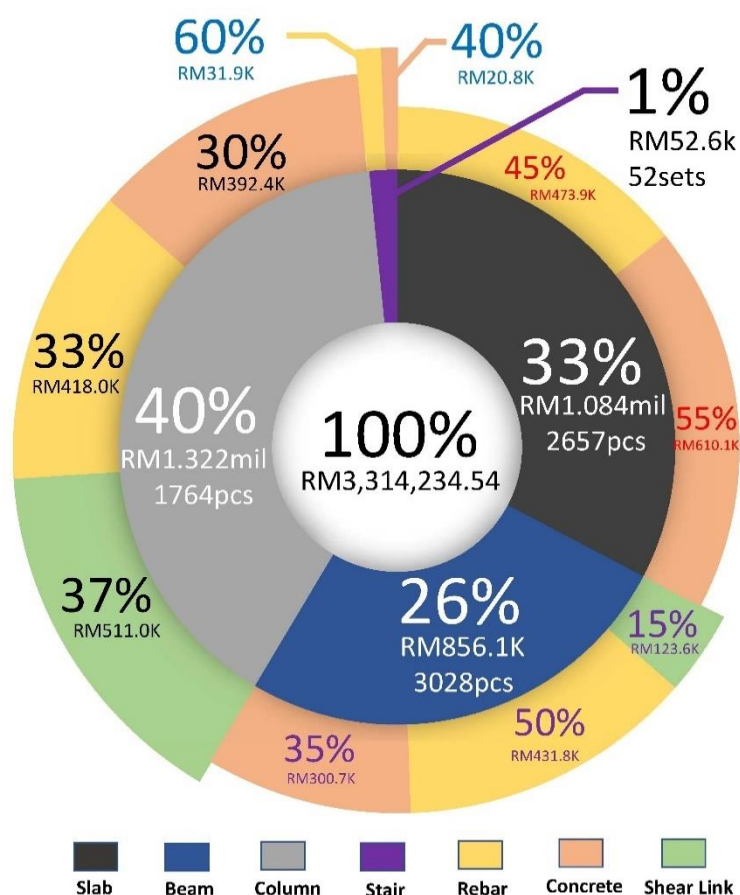
Figure 4.31: Chart of total cost by structural elements and materials.

The internal pie chart showed the percentages of total cost by structural elements. Clearly, the column represents the largest portion, approximately 40% of the total cost, whereby the stairs are undoubtedly the smallest. This is because the design of the column in high-rise reinforced concrete required a greater size of rebar to withstand such a huge axial load. Therefore, the giant load can be concluded that more rebar is used, and hence, it costs more in this study. Beam has the second highest total cost at 26%, whereas slab represents 33% of the total.

Next, the external pie chart showed the percentage of the total material price in its structural elements. For an example of the slab in the chart, it is clear that rebar costs RM473.9k at 45%, whereby the concrete is priced at RM610.1k at 55%.

4.7   Summary

In this research, collaboration and communication of the 3D Revit model were conducted in ShareBIM. The collaboration results discussed 15 model issues, including 3 received and 8 sent model issues. The model issues were categorised into two categories, which are modelling error and clash detection. Then, the structural BIM model was modified in Autodesk Revit due to model issues found after the collaboration study. In this chapter, evidence of before and after modification of the model was shown with explanation. The finalised 3D structural Revit model was sent to perform structural analysis then the result was verified using a spreadsheet known as the manual method based on the design standard of EC2. Hence, the manual verification for structural analysis concluded that all the designs of beams, slabs, and columns were considered safe and passed. Next, quantity and material take-off of the finalised model in Autodesk Revit was performed and computed the total cost of the beam, column, slab, and stairs. Lastly, statistical analysis for concrete, rebar, and shear link was figured by using the descriptive statistics method. Therefore, the total number of structural elements by its size was computed as a table. Then, the descriptive statistics method helped to summarise such massive data of quantity take-off from Autodesk Revit in the form of total cost by structural elements pie of pie chart and cumulative cost over the level graph. In addition, the central tendency measurement was computed whereby the unit cost of a slab is RM54.03 per m^3, a beam is RM691.94 per m^3, a column is RM818.34 per m^3, and a piece of the staircase is RM615.75 per m^3.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, the aim and objectives were accomplished in the early stage of this study. In general, the aim of modelling and quantifying a BIM structural model and describing how ShareBIM was utilised as a coordination platform has been implemented and discussed. The BIM model was built in Autodesk Revit and then exported to ShareBIM for coordination between MEP and the architectural model. During the coordination progress, issues were found and needed to be resolved immediately to proceed. Then, the finalised BIM model was exported to perform structural analysis in Esteem 9. Besides that, the structural analysis results were required to manually examine the spreadsheet based on the design standard of EC2. This procedure is to verify the given size of structural elements based on EC2. Later, the finalised BIM model with reinforcement was proceeded to compute take-off and perform statistical analysis for the cost and quantities of concrete, rebar, and shear links cost and quantities. The objectives of this study were achieved. The key results and findings of this study corresponding to the aim and objectives of this study are outlined as follows:

i. ShareBIM helped with better coordination between structural, architectural, and MEP models. There are a total of 15 issues created and discussed during collaboration. By categorising the 15 issues, there are a total of 3 model issues from the structural model, whereas 2 are considered as clash issues, and the remaining issue is a model error. Thus, further modification was implemented to resolve all the issues related to the structural model.

ii. Further modifications in the BIM structural model were performed to prevent clashes during the second collaboration. This process must be carried out until there is no clash and no error in the next collaboration. The issues, clashes and errors were explained deeply by showing before and after modification figures.

iii.   Manual verification for structural analysis was accomplished to examine the given size of structural elements and designed steel reinforcement in Esteem 9 based on the design standard of EC2. All the results were examined, and it was determined that the design of steel reinforcement in Esteem 9 was greater than manual calculation. This procedure is important to implement because it has been proven that the provided steel reinforcement in structural analysis software must be larger than manual calculation.

iv.   Quantity take-off was performed in Autodesk Revit by sorting the construction materials into structural elements such as slabs, beams, columns, and stairs. Besides, all the procurement data was exported to Microsoft Excel for rearranging and simplifying purposes. Hence, the quantity of the slab by its thickness was cumulated at 2657 pieces, whereas the slab's cost was estimated at RM1,084,026.02. The quantity of beam by its size was cumulated at 3028 pieces, whereby the cost was calculated at RM 856,108.48. The quantity of column by its size was cumulated at 1764 pieces, whereby the cost was calculated at RM 1,321,508.08. The number of stairs from floor to floor was cumulated at 52 sets, which calculated the cost at RM 52,591.96. As a result, the total cost was computed at RM 3,314,234.54.

v.   Statistical analysis for concrete, rebar, and shear link costs and quantities was carried out using the descriptive statistic method. Hence, it enabled the generation of frequency measurements of concrete, rebar, and shear link in the form of a table. Then, the central tendency of structural elements was figured out, whereas the unit cost of the slab is RM54.03 per cubic meter, the beam is RM691.94 per cubic meter, the column is RM818.34 per cubic meter, and the staircase is RM615.72 per cubic meter. Moreover, position measurement was performed and discussed as a cumulative cost over level graph. Lastly, the ratio measurement was implemented and explained in the form of structural elements and materials pie of pie chart.

5.2   Recommendations for future work

This research examines the coordination study of ShareBIM on the structural skeleton of a reinforced concrete building. Several boundary restrictions constrain the outcomes. The following are some recommendations for further study:

   i. The present study does not include the time management known as 4D BIM. Time management can be considered one of the major dimensions in BIM due to time organising completion of the task to prevent any delay in the construction project. It is also important for the project's profitability, whereas the longer it takes, the higher the cost. As a result, future research may explore 4D BIM, which will increase work productivity in the construction industry.

  ii. ShareBIM covers a lot of features, such as CostBIM. CostBIM in ShareBIM refers to coordinating budget control and comparing actual and proposed budgets. This study does not cover the features of CostBIM, and therefore future researchers may do further studies on cost control by utilising BIM soft technology.

 iii. Future studies could examine the same topic as this study but by utilising other BIM coordination software. It enables a comparison between ShareBIM and other BIM coordination software by considering strengths, weaknesses, opportunities, and threats (SWOT) analysis.

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APPENDICES

Appendix A: Detailed parameter setting.
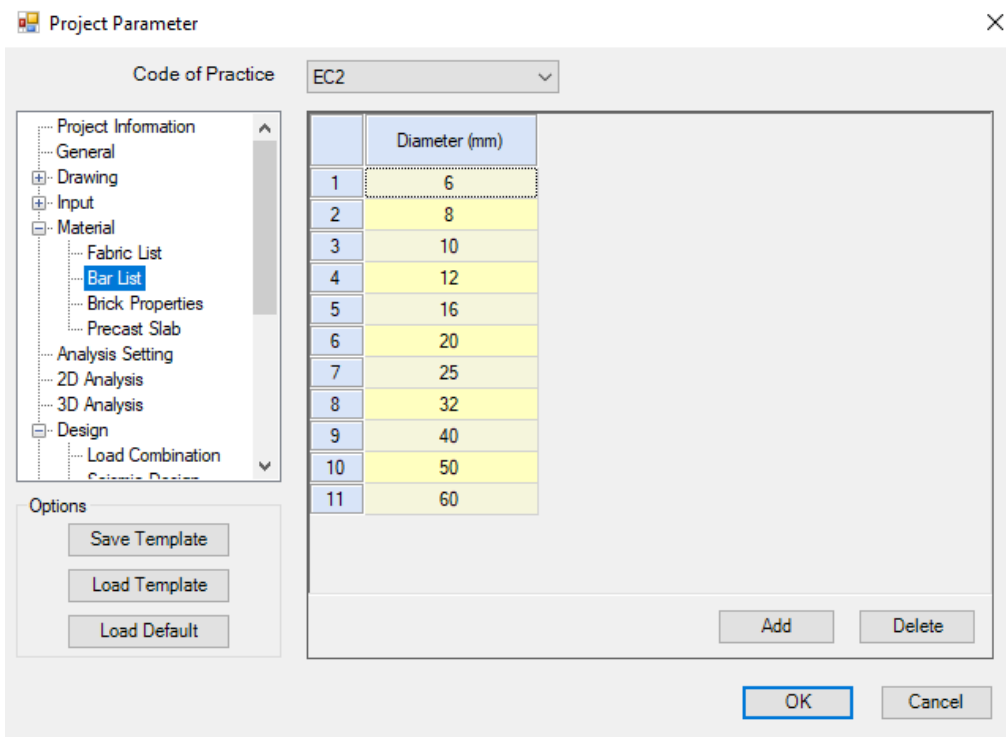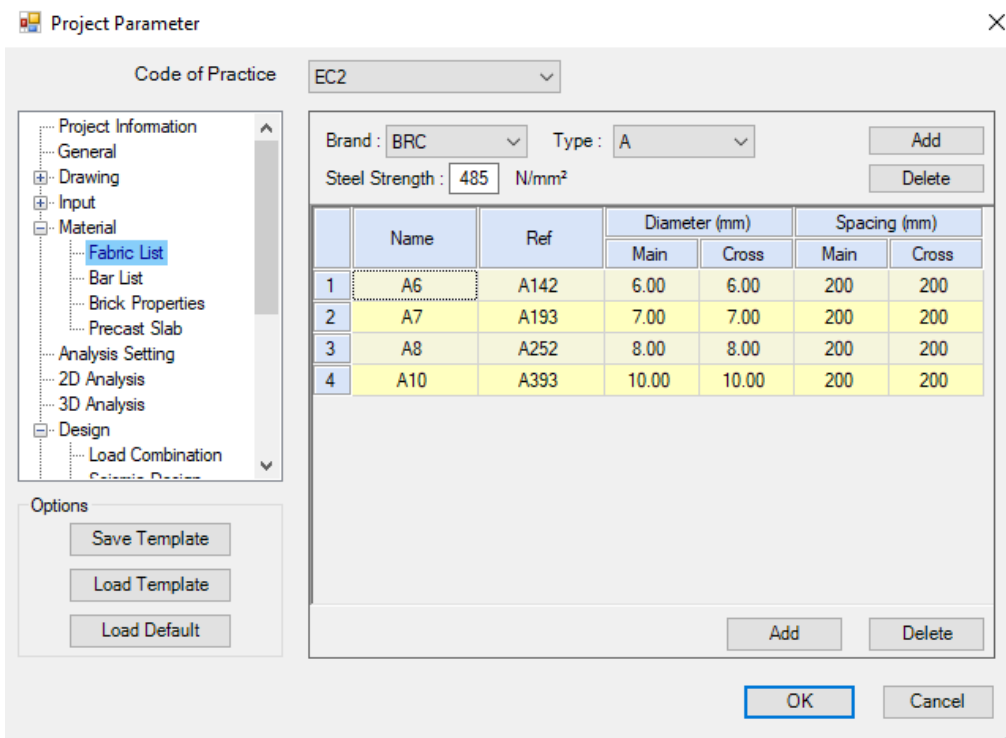
Project Parameter ✕

| Code of Practice | EC2 ▾ |

- Project Information
- General
- ⊞ Drawing
- ⊞ Input
- ⊟ Material
  - Fabric List
  - Bar List
  - Brick Properties
  - Precast Slab
  - **Analysis Setting**
  - 2D Analysis
  - 3D Analysis
- ⊟ Design
  - Load Combination
  - Seismic Design
  - ⊟ Floor
    - Beam
    - Slab
    - Column
    - Wall
  - ⊞ Project
- ⊞ Detailing
- ⊞ Reporting
- Drawing Arrangement
- ⊞ Quantity Take Off

⌄ **Moment Release**	
Maximum Slab Drop Difference	50
Maximum Beam Drop Difference	100
Maximum Beam Width Difference	100
Release Slab Nodes On RC Wall	True
Beam End Release Support	Pin
Beam End Release Beam	Pin
⌄ **Concrete**	
Poisson Ratio	0.2
⌄ **General**	
Structural Stability Index	-0.001
Displacement Limit	500
Allowable Large Displacement Nodes	0
Free Node Contour Value	250
Beam Spring Stiffness Adjustment	1000000
⌄ **Modulus of Elasticity Coefficient**	
Modulus of Elasticity Coefficient	False
Slab Modulus of Elasticity Coefficient	0.5
Beam Modulus of Elasticity Coefficient	0.5
Column Modulus of Elasticity Coefficient	0.7
Wall Modulus of Elasticity Coefficient	0.7
⌄ **Misc**	
Load Verification Tolerance	2
Slab Equivalent Nodal Load	True
Contour Cut Band Width	1000
Interval of Distance	1000
Single Node Column Mesh	False
Rigid Zone Stiffness	100

Poisson Ratio
Concrete Poisson ratio for linear elastic analysis.

Options
- Save Template
- Load Template
- Load Default

OK   Cancel

Project Parameter ✕

| Code of Practice | EC2 ▾ |

- Project Information
- General
- ⊞ Drawing
- ⊞ Input
- ⊟ Material
  - Fabric List
  - Bar List
  - Brick Properties
  - Precast Slab
  - Analysis Setting
  - **2D Analysis**
  - 3D Analysis
- ⊟ Design
  - Load Combination
  - Seismic Design
  - ⊟ Floor
    - Beam
    - Slab
    - Column
    - Wall
  - ⊞ Project
- ⊞ Detailing
- ⊞ Reporting
- Drawing Arrangement
- ⊞ Quantity Take Off

⌄ **2D Analysis**	
Slab Element	Plate
Use Roof Line Method	False
Flat Slab Stiffness Adjustment	False
Slab Stiffness Adjustment	100
Transfer Wall Beam Stiffness Increment	30
Torsion Reduction	99
Torsion Reduction (Virtual Beam)	0
Slab Poisson Ratio	0
⌄ **Analysis Option**	
Upper Column in Sub Frame	True
Fixed Support (Wall)	True
Pin Support (Column)	True
Optimised Pattern Loading	True
⌄ **Slab Mesh**	
Contour Levels	10
Size of Mesh	1000
Curve Mesh Size	400
Type of Mesh	Mix
Number of Elements Per Column	2
Close Node Distance	100

Slab Element
Type of slab element to be used in analysis.

Options
- Save Template
- Load Template
- Load Default

OK   Cancel

Project Parameter

Code of Practice: EC2

2D Analysis	
Slab Element	Plate
Use Roof Line Method	False
Flat Slab Stiffness Adjustment	False
Slab Stiffness Adjustment	100
Transfer Wall Beam Stiffness Increment	30
Torsion Reduction	99
Torsion Reduction (Virtual Beam)	0
Slab Poisson Ratio	0
Analysis Option	
Upper Column in Sub Frame	True
Fixed Support (Wall)	True
Pin Support (Column)	True
Optimised Pattern Loading	True
Slab Mesh	
Contour Levels	10
Size of Mesh	1000
Curve Mesh Size	400
Type of Mesh	Mix
Number of Elements Per Column	2
Close Node Distance	100

2D Analysis

Options:
Save Template
Load Template
Load Default

OK   Cancel

Project Parameter

Code of Practice: EC2

Analysis Options	
Torsion Reduction	99
Torsion Reduction (Virtual Beam)	0
Fixed Support (at wall footing)	True
Pin Support (at column footing)	True
P Delta	False
Alternative Model	True
Alternative Model 4 Node	True
Lateral Load Options	
Wind Load Analysis	False
Notional Load Analysis	False
Notional Load Factor	1.5
Seismic Load Analysis (Static)	False
Seismic Load Factor	0.1
Seismic Distribution Exponent	2
Stage Construction	
Stages of Construction	False
Wall Mesh	
Gradient Effect	True
Mesh Type	Mix
Minimum Size	500
Maximum Size	5000
Contour Levels	10
Use Couple Beam Meshing	True
Couple Beam Depth	1000
Couple Column Depth	500
Strut And Tie	
Left Diagonal Strut (Gravity)	60
Right Diagonal Strut (Gravity)	60
Left Diagonal Strut (Gravity + Wind)	60
Right Diagonal Strut (Gravity + Wind)	60
Shear Contour Check	True
Shear Contour Centroid	15
Shear Difference % Check	10
Allowable Shear Contour Centroid Difference	3
Wind Load	
Maximum Wind Speed, Vs (m/s)	25
Minimum Wind Speed, Vs (m/s)	20
Air Density, p (kg/m3)	1.226
Raft	
Use Raft Foundation	False
Coefficient of Subgrade Reaction	5000
Pad Spring Constant	5000
Size of Mesh	1000
Auto Thickening Area	50
Soil Bearing Pressure	100
Edge Spring Mutiplier Constant	0

Torsion Reduction
Young modulus, E, reduction (%) for beam torsion in 3D analysis.

Options:
Save Template
Load Template
Load Default

OK   Cancel

Project Parameter ✕

Code of Practice	EC2

Project Information
General
⊞ Drawing
⊞ Input
⊞ Material
Analysis Setting
2D Analysis
3D Analysis
⊟ Design
   Load Combination
   Seismic Design
  ⊟ Floor
    Beam
    Slab
    Column
    Wall
  ⊞ Project
⊞ Detailing
⊞ Reporting
Drawing Arrangement
⊟ Quantity Take Off
   Concrete
   Steel Reinforcement
   Fabric Reinforcement
   Others

⌄ **Material**	
fck	25
Ecd	26230
Main Reinforcement	500
Fabric Brand	BRC
⌄ **Main Reinforcement**	
Minimum Main Bar Diameter	6
Maximum Main Bar Diameter	12
Minimum Main Bar Spacing	100
Maximum Main Bar Spacing	250
⌄ **Distribution Reinforcement**	
Minimum Distribution Bar Spacing	100
Maximum Distribution Bar Spacing	250
⌄ **Design**	
Cover	25
Bar Spacing Interval Increment	25
Minimum Steel Percentage, (p%)	0.13
Maximum Steel Percentage, (p%)	4
Minimum Steel Percentage for Fabric	0.13
⌄ **Design Option**	
Use Fabric (Top Fabric)	True
Use Rectangle Fabric	False
Top Fabric for Different Drop	False
Hogging Moment Selection	50
Skip Node Within Column Profile	False
⌄ **Special**	
Auto Deflection Control	True
As Prov/As req Maximum Limit	2
⌄ **Punching Shear Check**	
Enhanced Shear Multiplier	1.5

fck
Characteristic Strength of Concrete (N/mm²).

Options
Save Template
Load Template
Load Default

OK   Cancel

Project Parameter ✕

Code of Practice	EC2

Project Information
General
⊞ Drawing
⊞ Input
⊞ Material
Analysis Setting
2D Analysis
3D Analysis
⊟ Design
   Load Combination
   Seismic Design
  ⊟ Floor
    Beam
    Slab
    Column
    Wall
  ⊞ Project
⊞ Detailing
⊞ Reporting
Drawing Arrangement
⊟ Quantity Take Off
   Concrete
   Steel Reinforcement
   Fabric Reinforcement
   Others

⌄ **Material**	
fck	25
Ecd	26230
Main Reinforcement	500
Shear Reinforcement	250
⌄ **Main Reinforcement**	
Minimum Main Bar Diameter	10
Maximum Main Bar Diameter	32
Maximum Main Bar Spacing	250
Minimum Main Bar Spacing	40
⌄ **Shear Reinforcement**	
Minimum Link Diameter	6
Maximum Link Diameter	20
Minimum Link Spacing	100
Maximum Link Spacing	300
Link Spacing Interval Increment	25
Link Loop	2
Increment Priority	Diameter
⌄ **Design**	
Cover	25
Minimum Compressive Steel Percentag	0.4
Maximum Compressive Steel Percentag	6
Number of Bar Layer Allowed	2
Effective Creep Ratio, φef	2.14
Maximum Relative Stiffness	10
⌄ **Special Design**	
Smallest Column Dimension	225
Minimum Link Diameter	10

fck
Concrete Characteristic Compressive Strength (N/mm²).

Options
Save Template
Load Template
Load Default

OK   Cancel

Project Properties Setting ✕

Floor

Floor	Height (mm)	Concrete Grade (N/mm²)				Column Bar Dia (mm)				Wall Bar Dia (mm)			
		Slab	Beam	Column	Wall	Min		Max		Min		Max	
26TR	2500	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
26MR	1700	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
26LR	4965	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
25F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
24F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
23F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
22F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
21F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
20F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
19F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
18F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
17F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
16F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
15F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
14F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
13F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
12F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
11F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
10F	3265	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
9F	1000	30	30	30	30	10	⌄	32	⌄	12	⌄	25	⌄
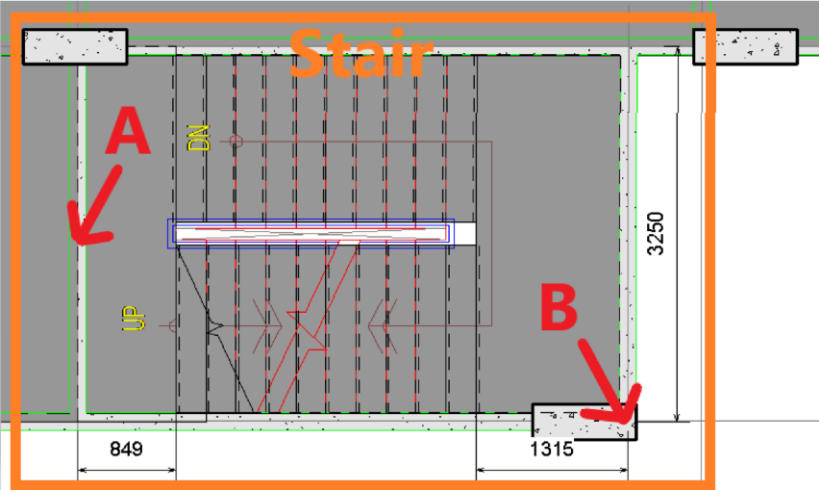
Foundation (N/mm²)

Pile Cap	Pad Footing
30	30

Cancel

OK

Appendix B: Calculation of load cases.

Reference	Calculation

EC 1991-
1-1: 2002
	<u>Single Brick Wall – Dead Load</u>
	
	• Wall thickness = 150mm
	
	• Brick wall density = 22 kN/m^3
	
	• Floor height = 3265mm (9F to 25F)
	
	• $UDL = Density \times thickness \times floor\ height$
	
	    = 22 kN/m^3 x 0.15m (thickness) x 3.265m (floor height)
	
	    = **10.77 kN/m**

EC 1991- 1-1: 2002 Table NA Category C32	**<u>Stair</u>** Landing DL – 3.75 kN/m^2 (Slab S.W) + 1.2 kN/m^2 = 4.95 kN/m^2 LL – 3.0 kN/m^2 Flight DL – 6.2 kN/m^2 (Slab S.W) + 1.2 kN/m^2 = 7.4 kN/m^2 LL – 3.0 kN/m^2 A (UDL) DL – (4.95 kN/m^2 + 7.4 kN/m^2) x (0.85m) = 10.5 kN/m LL – (3.0 kN/m^2 + 3.0 kN/m^2) x (0.85m) = 5.1 kN/m B (Point load in column) DL – (4.95 kN/m^2 + 7.4 kN/m^2) x (1.315m) x (3.25m) = 52.8 kN LL – (3.0 kN/m^2 + 3.0 kN/m^2) x (1.315m) x (3.25m) = 25.6 kN

	Railing at Balcony – Dead Load

BS EN 1993-1-5: 2007	- SHS 30x30x2 (26pcs in the drawing)
	- Weight = 1.74 Kg/m = 0.0171 kN/m
	- height = 900mm
	- $UDL = \dfrac{Weight \; x \; quantity \; x \; height}{length}$
	    $= \dfrac{0.0171 \; kN/m \; x \; 26 \; x \; 0.9}{3.05}$
	    $= \mathbf{0.131 \; kN/m}$

BS EN 1993-1-5: 2007	- SHS 50x50x2 (2pcs in the drawing)
	- Weight = 3.00 Kg/m = 0.03 kN/m
	- Length = 3050mm
	- $UDL = \dfrac{Weight \; x \; quantity \; x \; length}{length}$
	    $= \dfrac{0.03 \; kN/m \; x \; 2 \; x \; 3.05}{3.05}$
	    $= \mathbf{0.06 \; kN/m}$
	- Thus, UDL of railing at balcony = 0.131 kN/m + 0.06 kN/m = **0.191 kN/m**

	Water Tank Beam – Dead load

EC 1991-1-1: 2002	• Tank Size = 9m x 6m x 5m (height) **Water Tank** • Material = steel tank panels of 1.0m x 1.0m x 3mm. • Thickness of panel = 3mm • Steel density = 79 kN/m^3 • Total of 258pcs of panel used. • *Load of tank =* *Density x lenght x width x thickness x pcs used* = 79 kN/m^3 x 1.0m x 1.0m x 0.003m x 258pcs = 61.15kN • $Unit\ weight = \frac{load\ of\ tank}{length\ x\ width}$ $$= \frac{61.15\ kN}{6m\ x\ 9m}$$ $$= \textbf{1.14 kN/m}^2$$
EC 1991-1-1: 2002	**Water + Water Tank** • Water density = 997 kg/m^3 = 9.78 kN/m^3 • *Assume full volume of water. 1st and last beam • $UDL = (Density\ x\ lenght\ x\ water\ height) +$ $(unit\ weight\ of\ water\ tank\ x\ length)$ = (9.78 kN/m^3 x 0.5m x 5m) + (1.14 kN/m^2 x 0.5m) = **25.02 kN/m** Middle beam • $UDL = (Density\ x\ lenght\ x\ water\ height) +$ $+ (unit\ weight\ of\ water\ tank\ x\ length)$ = (9.78 kN/m^3 x 1m x 5m) + (1.14 kN/m^2 x 1.0m) = **50.04 kN/m** **Water Tank Beam – Live load** • Service load = 0.5 kN/m^2 1st and last beam
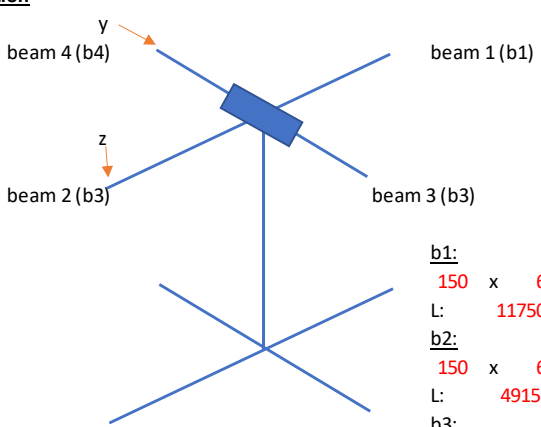
- $UDL = (Service\ Load\ x\ lenght)$

  $= 0.5\ \text{kN/m}^2\ \text{x}\ 0.5\text{m}$

  $= \textbf{0.25 kN/m}$

Middle beam

- $UDL = (Service\ Load\ x\ lenght)$

  $= 0.5\ \text{kN/m}^2\ \text{x}\ 1.0\text{m}$

  $= \textbf{0.5 kN/m}$

Appendix C: Manual verification of critical beam spreadsheet.
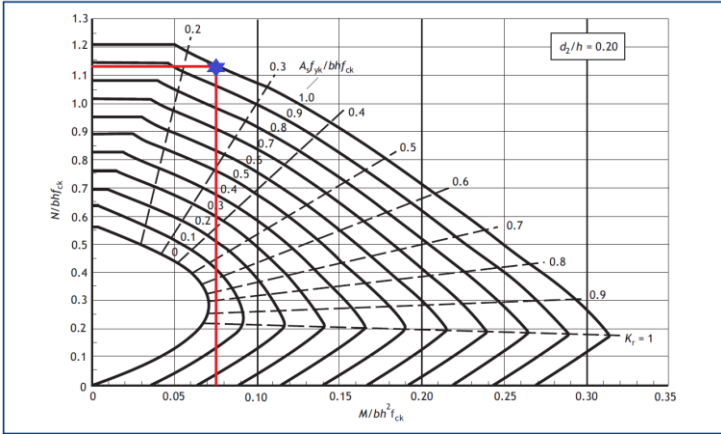
Beam		
Reference	Calculation	Output
	SPAN	
	Design Assumption	
	Design life $\quad = \quad$ 100 years	
	Structural class $\quad = \quad$ S4	
	Exposure class $\quad = \quad$ XC3	
	Fire resistance $\quad = \quad$ R60	
	Size of aggregates $\quad = \quad$ 20 mm	
Table 3.1	Concrete grade $\quad = \quad$ C25/30	
	Unit weight of concrete $\quad = \quad$ 25 N/mm²	
	Characteristic strength of concrete, fck $\quad = \quad$ 25 N/mm²	
	Characteristic strength of steel, fyk $\quad = \quad$ 500 N/mm²	
	Characteristic strength of link, fyw $\quad = \quad$ 250 N/mm²	
Table 3.1	Concrete mean tensile strength, fctm $\quad = \quad$ 2.6	
	Specification	
	b $\quad = \quad$ 150 mm	
	h $\quad = \quad$ 600 mm	
	Tension rebar diameter $\quad = \quad$ 25 mm	
	Compression rebar diameter $\quad = \quad$ 12 mm	
	Shear link diameter $\quad = \quad$ 10 mm	
	Length $\quad = \quad$ 5400 mm	
	Nominal Cover	
Table 4.2	Min. concrete cover regard to bond, $C_{min,b}$ $\quad = \quad$ 25 mm	
Table 4.4N	Min. concrete cover regard to durability, $C_{min,dur}$ $\quad = \quad$ 25 mm	
EN1992-1-2	Min. required axis distance fir R60 fire resistance, a_{sd} $\quad = \quad$ 25 mm	
4.4.1.2	Min. concrete cover regard to fire, $C_{min,fire}$ $\quad = \quad$ 9 mm	
	Allowance in design for deviation,ΔC_{dev} $\quad = \quad$ 10 mm	
	Nominal cover, $C_{nom} = C_{min} + \Delta C_{dev}$ $\quad = \quad$ 35 mm	
	Effective depth of beam, d $\quad = \quad$ 543 mm	
	d' $\quad = \quad$ 51 mm	
	Design Check from Esteem 9	
EN 1992-1-1	Min. area of reinforcement	
9.2.1.1	$A_{s,min} = 0.26\dfrac{f_{ctm}}{f_{yk}}bd$ $\quad = \quad$ 110.02 mm²	
	Maximum area of reinforcement	
	$A_{s,max} = 0.04 A_c$ $\quad = \quad$ 3600 mm²	
	Main Reinforcement	
	Moment at support generated by Esteem 9, M $\quad = \quad$ 0 kNm	
	Moment at center generated by Esteem 9, M $\quad = \quad$ 250.200 kNm	
	$k = \dfrac{M}{bd^2 f_{ck}} < 0.167$ $\quad = \quad$ 0.2267	
	*Hence, Compression steel is required since k > 0.167.	
	$z = d(0.5 + \sqrt{0.25 - \dfrac{k}{1.134}}) < 0.95d$ $\quad = \quad$ 0.72 d	
	$\quad < \quad$ 0.95 d	
	z value at max is 0.95d, therefore z value is $\quad = \quad$ 0.72 d	
	$x = \dfrac{d-z}{0.4}$ $\quad = \quad$ 374.60 mm	
	$\dfrac{d'}{x} < 0.38$ $\quad = \quad$ 0.14	
	*Thus, the compression steel will have yielded.	
	$f_{sc} = 0.87 f_{yk}$ $\quad = \quad$ 435.00	
	Area of compression steel	
	$A'_s = \dfrac{(K - K_{bal})f_{ck}bd^2}{0.87 f_{yk}(d - d')}$ $\quad = \quad$ 204.94 mm²	

	Area of tension reinforcement			
	$A_{s,req} = \dfrac{K_{bal}f_{ck}bd^2}{0.87f_{yk}z_{bal}} + A'_s$	=	1349 mm²	
	Area of provided compression reinforcement	=	2 H 12	
	by Esteem 9.	=	226 mm²	
	Area of provided tension reinforcement by	=	2 H 16 and	
	Esteem 9.		2 H 25	
		=	1384 mm²	
	Check As,prov > As,req and As,prov > As,min and As,prov > As,max.			OK

	Shear Reinforcement			
	Shear generated by Esteem 9, Ved	=	144.30 kN	
6.2.3	$V_{Rd,\max(22)} = \dfrac{0.36b_w d(1-\frac{f_{ck}}{250})f_{ck}}{\cot\theta + \tan\theta}$	=	228.96 kN	
6.2.3	$V_{Rd,\max(45)} = \dfrac{0.36b_w d(1-\frac{f_{ck}}{250})f_{ck}}{\cot\theta + \tan\theta}$	=	329.57 kN	
	Check smallest Vrd,max(22) and Vrd,max(45) > Ved			OK
	Check largest Vrd,max(22) and Vrd,max(45) > Ved			OK
	Hence, the value of angle use for design is	=	22	
	Therefore, $\cot\theta$	=	2.5	
9.2.2(5)	$\dfrac{A_{sw}}{S} = \dfrac{V_{Ed}}{0.78df_{yk}\cot\theta}$	=	0.546	
	$\dfrac{A_{sw,min}}{S} = \dfrac{0.08f_{ck}^{0.5}b_w}{f_{yk}}$	=	0.240	
	New Asw/s is	=	0.546	
	Shear reinforcement provided by Esteem 9 is	=	R 6 - 100	
	Asw,prov	=	283 mm²	
	Asw,prov/s	=	2.830 mm²	
9.2.2(8)	$S_{max} = 0.75\,d$	=	407 mm	
	Check Smax > Sprov			OK
	Check Asw,prov/s > New Asw/s			OK

	Deflection			
7.4	Percentage of required tension reinforcement,			
	$p = \dfrac{100A_{s,req}}{bd}$	=	1.657	
	Reference reinforcement ratio,			
	$p_o = \dfrac{\sqrt{f_{ck}}}{1000}$	=	0.005	
	Percentage of required compression reinforcement,			
	$p' = \dfrac{A'_{s,req}}{bd}$	=	0.003	
Table 7.4N	Factor for structural system, K	=	1.5	
7.4.2	Since p > po, equation of (l/d) is			
	$(\dfrac{l}{d})_{allow} = K[11 + 1.5\sqrt{f_{ck}}\,\dfrac{p_o}{p-p'} + \dfrac{1}{12}\sqrt{f_{ck}}\sqrt{\dfrac{p'}{p_o}}]$	=	16.978	
	Modification factor for flange width, b/bw > 3	=	0.8	
	Modification factor for span less than 7m	=	1.0	
	Modification factor for steel area provided,			
	$\dfrac{A_{s,prov}}{A_{s,req}}$	=	1.026 < 1.5	
	New (l/d)allow	=	13.94	
	Actual (l/d)	=	9.95	
	Check (l/d)actual < (l/d)allow			OK

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Appendix D: Manual verification of critical column spreadsheet.

Column		
Reference	**Calculation**	**Output**
	Column AD1,A7	
	Design Assumption	
	Design life = 100 years	
	Structural class = S4	
	Exposure class = XC3	
	Fire resistance = R60	
	Size of aggregates = 20 mm	
Table 3.1	Concrete grade = C25/30	
	Unit weight of concrete = 25 N/mm²	
	Characteristic strength of concrete, fck = 25 N/mm²	
	Characteristic strength of steel, fyk = 500 N/mm²	
	Characteristic strength of link, fyw = 250 N/mm²	
Table 3.1	Concrete mean tensile strength, fctm = 2.6	
	Specification	
	beam 4 (b4) beam 1 (b1)	
	beam 2 (b3) beam 3 (b3)	
	b1: 150 x 600 mm L: 11750 mm	
	b2: 150 x 600 mm L: 4915 mm	
	b3: 150 x 600 mm L: 5000 mm	
	Column height = 3625 mm	
	Cover= 35 mm b4:	
	Rein. bar diameter = 32 mm 150 x 600 mm	
	Shear link diameter= 12 mm L: 5400 mm	
	Esteem 9 design result	
	Ned = 8403.29 kN Torsion = 95.35 kNm	
	63.09 kNm 75.15 kNm	
	57.77 kNm 69.27 kNm	
	My Mz	
	44.23 kN 37.02 kNm	
	Vy Vz	
	Dimension and Size	
	Column:	
	b = 300 mm	
	h = 900 mm	
	I_z, I_y = 3025 mm	*Clear height

	Moment of inertia				
	Column:				
	I_{zz}	=	1.823E+10 mm^4		
	I_{yy}	=	2.025E+09 mm^4		
	Beam:				
	All beam, I_b	=	2.7E+09 mm^4		

	Stiffness				
	Column:				
	K_{zz}	=	6.02E+06 mm^4		
	K_{yy}	=	6.69E+05 mm^4		
	Beam:				
	K_{b1}	=	2.30E+05 mm^4		
	K_{b2}	=	5.49E+05 mm^4		
	K_{b3}	=	5.40E+05 mm^4		
	K_{b4}	=	5.00E+05 mm^4		

	Relative column stiffness				
	z-axis:				
	Top end: K_2	=	2.90	>	0.1
	Therefore, K_2	=	2.90		
	Bot. end: K_1	=	2.90	>	0.1
	Therefore, K_1	=	2.90		
	y-axis:				
	Top end: K_2	=	0.43	>	0.1
	Therefore, K_2	=	0.43		
	Bot. end: K_1	=	0.43	>	0.1
	Therefore, K_1	=	0.43		
5.8.3.2(2)	Effective length of column,				
	$$I_o = 0.5l \sqrt{(1+\frac{k_1}{0.45+k_1})(1+\frac{k_2}{0.45+k_2})}$$				
	I_{oz}	=	2821.62 mm		
	I_{oy}	=	2251.21 mm		
	Radius of gyration,				
	i_z	=	259.81 mm		
	i_y	=	86.60 mm		
5.8.3.1(1)	Slenderness ratio,				
	λ_z	=	10.86		
	λ_y	=	25.99		

5.8.3.1(1)	**Slenderness limit**				
	$\lambda_{lim} = \frac{20ABC}{\sqrt{n}}$; where				
	A	=	0.70		
	B	=	1.10		
	$C_z = 1.7 - M_{o1}/M_{o2}$	=	2.62		
	$C_y = 1.7 - M_{o1}/M_{o2}$	=	2.62		
	$n = N_{Ed}/(A_c f_{cd})$	=	2.20		
	z-axis:				
	λ_{lim}	=	27.24		
	y-axis:				
	λ_{lim}	=	27.18		
	Check slender or short column				Short Col.

	Longitudinal reinforcement				
	Column moment, $M_{col} = M_{max}\{M_{bot}, M_{top}\}$	=	75.15 kNm		
5.2(7)	$e_i = \frac{l_o}{400}$	=	5.63 mm		
	$M_{02} = M_{col} + N_{Ed} e_i$	=	122.44 kNm		
6.1(4)	$e_0 = \max\{\frac{h}{30}, 20\} \geq 20$	=	20.00 mm		
	$M_{min} = N_{Ed} e_0$	=	168.07 kNm		
5.8.8.2	$M_{Ed} = M_{max}\{M_{02}, M_{min}\}$	=	168.07 kNm		

Refer to design chart	**Reinforcement design**		

Reinforcement design

d_2 = 63 mm

d_2/h = 0.2

$\dfrac{N}{bhf_{ck}}$ = 1.13

$\dfrac{M}{bh^2f_{ck}}$ = 0.075

Figure 9d
Column design chart for rectangular columns d_2/h = 0.20

$\dfrac{A_s f_{yk}}{bhf_{ck}}$ = 0.99

As = 13365 mm²

As,prov by Esteem 9 = 22 T 32

= 17696 mm²

$A_{s,min} = \dfrac{0.1N_{Ed}}{0.87f_{yk}} \geq 0.002A_c$ = 1931.8 mm²

0.002Ac = 540 mm²

Check As,min > 0.002Ac   OK

As,max (lap) = 21600 mm²

As,max (away lap) = 18900 mm²

Check As,max(lap) and As,max(away lap) > As,prov   OK

Shear Link

Minimum shear link diameter (larger) = 8 mm or 6mm

Maximum spacing away from lap region (lesse = 640 mm or 300mm

At section 300mm below & above beam and lapped joints,

$S_{v,max} = 0.6S_{v,max}$ = 180 mm

Shear Link provided by Esteem 9 = R 12 - 125   OK

Appendix E: Manual verification of critical slab spreadsheet.
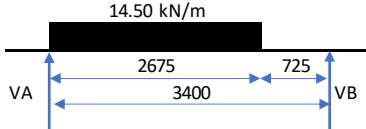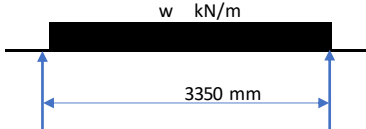
Slab		
Reference	Calculation	Output
	FS 75	
	Design Assumption	
	Design life = 100 years	
	Structural class = S4	
	Exposure class = XC3	
	Fire resistance = R60	
	Size of aggregates = 20 mm	
Table 3.1	Concrete grade = C25/30	
	Unit weight of concrete = 25 N/mm²	
	Characteristic strength of concrete, fck = 25 N/mm²	
	Characteristic strength of steel, fyk = 500 N/mm²	
Table 3.1	Concrete mean tensile strength, fctm = 2.6	
	Specification	
	Bar diameter = 6 mm	
	Long span, ly = 5400 mm	
	Short span, lx = 3350 mm	
	Span ratio, ly/lx < 2 = 1.612 mm	
	*Hence, it is a two way slab.	
	Slab Thickness	
	Minimum thickness for fire resistance = 80 mm	
	Estimated thickness considering deflection control = 134 mm	
	Given drawing slab thickness, h = 125 mm	
	Nominal Cover	
Table 4.2	Min. concrete cover regard to bond, $C_{min,b}$ = 6 mm	
Table 4.4N	Min. concrete cover regard to durability, $C_{min,dur}$ = 25 mm	
EN1992-1-2	Min. required axis distance fir R60 fire resistance, a_{sd} = 10 mm	
4.4.1.2	Min. concrete cover regard to fire, $C_{min,fire}$ = 5 mm	
	Allowance in design for deviation,ΔC_{dev} = 10 mm	
	Nominal cover, $C_{nom} = C_{min} + \Delta C_{dev}$ = 35 mm	
	Effective depth, $d_x = h - C_{nom} - 0.5\emptyset_{bar}$ = 87 mm	
	Effective depth, $d_y = h - C_{nom} - 1.5\emptyset_{bar}$ = 81 mm	
	Main Reinforcement	
	Design Check from Esteem 9	
	Bending moments generated by Esteem 9:	
	Short span at support, Msx = 1.89 kNm/m	
	Short span at midspan, Msx = 4.69 kNm/m	
	Long span at support, Msy = 0.36 kNm/m	
	Long span at midspan, Msy = 6.25 kNm/m	
	Short span	
EN 1992-1-1	Min. area of reinforcement	
9.2.1.1	$A_{s,min} = 0.26 \dfrac{f_{ctm}}{f_{yk}} bd$ = 117.62 mm²/m	
	Maximum area of reinforcement	
	$A_{s,max} = 0.04 A_c$ = 5000 mm²/m	
	At support	
6.1	$k = \dfrac{M}{bd^2 f_{ck}} < 0.167$ = 0.0100	
	*Hence, Compression steel is not required since k < 0.167.	
	$z = d(0.5 + \sqrt{0.25 - \dfrac{k}{1.134}}) < 0.95d$ = 0.99 d	
	< 0.95 d	
	z value at max is 0.95d, therefore z value is = 0.95 d	

Area of tension reinforcement

$$A_{s,req} = \frac{M}{0.87 f_{yk} z}$$ = 53 mm²

Area of provided tension reinforcement by = T 6 - 150 (top.)
Esteem 9. = 189 mm²/m

Check As,prov > As,req and As,prov > As,min and As,prov > As,max. OK

At midspan

6.1
$$k = \frac{M}{bd^2 f_{ck}} < 0.167$$ = 0.0248

*Hence, Compression steel is not required since k < 0.167.

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{1.134}}) < 0.95d$$ = 0.98 d
< 0.95 d
z value at max is 0.95d, therefore z value is = 0.95 d

Area of tension reinforcement

$$A_{s,req} = \frac{M}{0.87 f_{yk} z}$$ = 130 mm²

Area of provided tension reinforcement by = T 6 - 150 (bot.)
Esteem 9. = 189 mm²/m

Check As,prov > As,req and As,prov > As,min and As,prov > As,max. OK

Long span

EN 1992-1-1 | Min. area of reinforcement
9.2.1.1
$$A_{s,min} = 0.26 \frac{f_{ctm}}{f_{yk}} bd$$ = 109.51 mm²/m

Maximum area of reinforcement
$$A_{s,max} = 0.04 A_c$$ = 5000 mm²/m

At support

6.1
$$k = \frac{M}{bd^2 f_{ck}} < 0.167$$ = 0.0022

*Hence, Compression steel is not required since k < 0.167.

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{1.134}}) < 0.95d$$ = 1.00 d
< 0.95 d
z value at max is 0.95d, therefore z value is = 0.95 d

Area of tension reinforcement

$$A_{s,req} = \frac{M}{0.87 f_{yk} z}$$ = 11 mm²

Area of provided tension reinforcement by = T 6 - 150 (top.)
Esteem 9. = 189 mm²/m

Check As,prov > As,req and As,prov > As,min and As,prov > As,max. OK

At midspan

6.1
$$k = \frac{M}{bd^2 f_{ck}} < 0.167$$ = 0.0381

*Hence, Compression steel is not required since k < 0.167.

$$z = d(0.5 + \sqrt{0.25 - \frac{k}{1.134}}) < 0.95d$$ = 0.97 d
< 0.95 d
z value at max is 0.95d, therefore z value is = 0.95 d

Area of tension reinforcement

$$A_{s,req} = \frac{M}{0.87 f_{yk} z}$$ = 187 mm²

	Area of provided tension reinforcement by	=	T 10 - 150 (bot.)	
	Esteem 9.	=	189 mm²/m	
	Check As,prov > As,req and As,prov > As,min and As,prov > As,max.			OK

	Shear Checking			
	Shear generated by Esteem 9, Ved	=	23.27 kN	
	$k = 1 + \sqrt{(\frac{200}{d})} \leq 2.0$	=	2.52	
	Therefore k value at max. 2.0, k is	=	2.0	
	$p_1 = \frac{A_{sl}}{bd} \leq 0.02$	=	0.002	
	Check p1 < 0.02.			OK
6.2.2	Design shear resistance, $V_{Rd.c} = 0.12k\sqrt[3]{100p_1 f_{ck}}\,bd$	=	36.702 kN	
	Min. shear force, $V_{min} = 0.035k^{3/2}f_{ck}^{1/2}bd$	=	43.063 kN	
	Check Vmin > Ved and Vrd,c > Ved.			OK

7.4	**Deflection**			
	Percentage of required tension reinforcement, $p = \frac{A_{s,req}}{bd}$	=	0.001	
	Reference reinforcement ratio, $p_o = \frac{\sqrt{f_{ck}}}{1000}$	=	0.005	
Table 7.4N	Factor for structural system, K	=	1.3	
7.4.2	Since p < po, equation of (l/d) is			
	$(\frac{l}{d})_{allow} = K[11 + 1.5\sqrt{f_{ck}}\frac{p_o}{p} + 3.2\sqrt{f_{ck}}\left(\frac{p_o}{p} - 1\right)^{\frac{3}{2}}]$ =		103.888	
	Modification factor for span less than 7m	=	1.0	
	Modification factor for steel area provided, $\frac{A_{s,prov}}{A_{s,req}}$	=	1.449 < 1.5	
	New (l/d)allow	=	150.52	
	Actual (l/d)	=	26.80	
	Check (l/d)actual < (l/d)allow			OK

	Cracking			
7.3.3	Check h < 200mm.			OK
9.3.1	Main bar: $S_{max,slabs} = 3h \leq 400mm$	=	375.00	
	Check Smax,slabs < 400mm.			OK
	Secondary bar: $S_{max,slabs} = 3.5h \leq 450mm$	=	437.50	
	Check Smax,slabs < 450mm.			OK

Appendix F: Manual calculation of stair spreadsheet.

U-Stair support by landing		
Reference	Calculation	Output
	Specification	

Characteristic Actions:

Permanent, gk   =   1.2 kN/m² (Excluding selfweight)

Variable,   qk   =   3 kN/m²

Materials:

Characteristic strength of concrete, fck   =   25 N/mm²

Characteristic strength of steel fyk   =   500 N/mm²

Unit weight of reinforced concrete   =   25 kN/m³

Assume:

Concrete Cover,   C   =   25 mm

Rebar diameter   =   10 mm

Average Thickness

$$y = h[\frac{(G^2+R^2)^{0.5}}{G}]$$

$$= 173 \text{ mm}$$

$$t = \frac{[y+(y+R)]}{2}$$

$$= 248 \text{ mm}$$

Actions

<u>Landing</u>

Slab selfweight	=	3.75 kN/m²
Permanent load (Excluding selfweight)	=	1.2 kN/m²
Characteristic permanent action, gk	=	4.95 kN/m²
Characteristic variable action, qk	=	3 kN/m²
Design action, nd = 1.35gk + 1.5qk	=	11.18 kN/m²

<u>Flight</u>

Slab selfweight	=	6.20 kN/m²
Permanent load (Excluding selfweight)	=	1.2 kN/m²
Characteristic permanent action, gk	=	7.40 kN/m²
Characteristic variable action, qk	=	3 kN/m²
Design action, nd = 1.35gk + 1.5qk	=	14.50 kN/m²

Analysis & Design of Stair

Effective span, Le = La + 0.5[Lb1 + Lb2]

La	=	Clear distance between supports
Lb1	=	The lesser of width of support 1 or 1.8m
Lb2	=	The lesser of width of support 2 or 1.8m
So, Le	=	3332.5 mm

Consider 1m width,

14.50 kN/m

2675   725

3400

Total action, F = 38.8 kN/m

M

M

Bending moment, M = 12.9 kNm/m

6.1

Main Reinforcement

Effective depth, d	=	h-C-0.5Dbar
	=	120 mm

Design moment, Med

$$k = \frac{M}{bd^2 f_{ck}}$$

= 0.0359 < Kbal = 0.167

Thus, Compression reinforcement is not required.

$$z = d[0.5 + \sqrt{0.25 - \frac{K}{1.134}}]$$

	=	0.97 d
z,max	=	0.95 d
z,used	=	0.95 d
As	=	$\frac{M}{0.87 f_{yk} z}$
	=	260.58 mm²/m

Main Bar :
H 10- 300
262 mm²/m

9.2.1.1

<u>Minimum and maximum reinforcement area,</u>

As,min	=	$0.26\left(\frac{f_{ctm}}{f_{yk}}\right)bd$
	=	160.05 mm²/m

Secondary bar:
H 10- 300
262 mm²/m

As,max	=	0.04Ac
	=	6000 mm²/m

Shear

```
                    14.50 kN/m

              2675              725
     VA            3400              VB
```

	VB	=	11.453 kN/m
	VA	=	27.323 kN/m
	Design Shear, Ved	=	27.323 kN/m
6.2.2	Design shear resistance,		

$V_{Rd,c} = [0.12k(100p_1 f_{ck})^{1/3}]bd$

$k = 1 + (200/d)^{1/2}$

$\quad = 2.291$

k,max $= 2.000$

k,used $= 2.000$

$p_1 = \dfrac{A_{sl}}{bd}$

$\quad = 0.0022$

p1,max $= 0.02$

p1,used $= 0.002$

$V_{Rd,c} = 50708$

$\quad = 50.708$ kN/m

$V,min = [0.035k^{3/2}(f_{ck})^{1/2}]bd$

$\quad = 59.40$ kN/m

$V = 59.40$ kN/m **OK**

7.4	**Deflection**

Percentage of required tension reinforcement,

$p = \dfrac{A_{s,req}}{bd}$

$\quad = 0.0022$

Reference reinforcement ratio,

$po = (f_{ck})^{1/3}$

$\quad = 0.005$

Table 7.4N Factor for structural system, K = 1

$p < po$

Thus, use equation 7.16a.

Eqn. 7.16a

$$\frac{l}{d} = K[11 + 1.5\sqrt{f_{ck}}\frac{po}{p} + 3.2\sqrt{f_{ck}}(\frac{po}{p} - 1)^{3/2}$$

$\quad = 52.054$

Modification factor for span less than 7m.

$\quad = 1.00$

Modification factor for steel area provided,

$\quad = \dfrac{A_{s,prov}}{A_{s,req}}$

$\quad = 1.01 < 1.5$

Therefore allowable span-effective depth ratio,

$(l/d)_{allow} = 52.34$

$(l/d)_{actual} = 28.33$ **OK**

7.3.3	**Cracking**					
9.3.1	h	=	150	<	200 mm	**OK**
	Main bar:					

$S_{max,slabs} = 3h < 400$ mm

$\quad = 400$ mm **OK**

Max. bar spacing $= 300$ mm

Secondary bar:

$S_{max,slabs} = 3.5h < 450$ mm

$\quad = 450$ mm

Max. bar spacing $= 300$ mm **OK**

Analysis & design of landing

Effective span, L = 3350 mm

b = 1315 mm


```
              w   kN/m

              3350 mm
```

	Loading,				
	w	=	26.158 kN/m		
	V	=	43.815 kN/m		
	M	=	36.695 kNm		

6.1	**Main Reinforcement**

Effective depth, $\quad d \quad = \quad$ h-C-0.5Dbar

$\quad\quad\quad\quad\quad\quad\quad = \quad$ 120 mm

Design moment, Med

$$k = \frac{M}{bd^2 f_{ck}}$$

$\quad\quad\quad = \quad$ 0.0775 $\quad < \quad$ Kbal $\quad = \quad$ 0.167

Thus, Compression reinforcement is not required.

$$z = d[0.5 + \sqrt{0.25 - \frac{K}{1.134}}]$$

$\quad\quad\quad\quad = \quad$ 0.93 d

z,max $\quad = \quad$ 0.95 d

z,used $\quad = \quad$ 0.93 d

$$As = \frac{M}{0.87 f_{yk} z}$$

$\quad\quad\quad\quad = \quad$ 758.99 mm²/m

Main Bar :
17 H 10
1335 mm²

9.2.1.1	Minimum and maximum reinforcement area,

$$As,min = 0.26\left(\frac{f_{ctm}}{f_{yk}}\right)bd$$

$\quad\quad\quad\quad = \quad$ 210.47 mm²/m

As,max $\quad = \quad$ 0.04Ac

$\quad\quad\quad\quad = \quad$ 7890 mm²/m

Shear

Design Shear, Ved $\quad = \quad$ 43.815 kN

6.2.2	Design shear resistance,

VRd,c $\quad = \quad [0.12k(100p_1 f_{ck})^{1/3}]bd$

k $\quad = \quad 1 + (200/d)^{1/2}$

$\quad\quad\quad = \quad$ 2.291

k,max $\quad = \quad$ 2.000

k,used $\quad = \quad$ 2.000

$$p1 = \frac{A_{sl}}{bd}$$

$\quad\quad\quad = \quad$ 0.0085

p1,max $\quad = \quad$ 0.02

p1,used $\quad = \quad$ 0.008

VRd,c $\quad = \quad$ 104734

$\quad\quad\quad\quad = \quad$ 104.73 kN

V,min $\quad = \quad [0.035k^{3/2}(f_{ck})^{1/2}]bd$

$\quad\quad\quad = \quad$ 78.11 kN

V $\quad = \quad$ 104.7 kN

OK

7.4	**Deflection**

Percentage of required tension reinforcement,

$$p = \frac{A_{s,req}}{bd}$$

$\quad\quad\quad = \quad$ 0.005

Reference reinforcement ratio,

po $\quad = \quad (f_{ck})^{1/3}$

$\quad\quad\quad = \quad$ 0.005

Table 7.4N	Factor for structural system, K $\quad = \quad$ 1

p $\quad\quad < \quad$ po

Thus, use equation 7.16a.

Eqn. 7.16a	$\frac{l}{d} \quad = \quad K[11 + 1.5\sqrt{f_{ck}}\frac{po}{p} + 3.2\sqrt{f_{ck}}(\frac{po}{p} - 1)^{3/2}$

$\quad\quad\quad\quad = \quad$ 18.922

	Modification factor for span less than 7m.						
		=	1.00				
	Modification factor for steel area provided,						
		=	$\dfrac{A_{s,prov}}{A_{s,req}}$				
		=	1.76	<	1.5		
	Therefore allowable span-effective depth ratio,						
	$(l/d)_{allow}$	=	28.38				
	$(l/d)_{actual}$	=	27.92				OK
	Cracking						
7.3.3	h	=	150	<	200	mm	OK
9.3.1	Main bar:						
	$S_{max,slabs}$	=	3h	<	400	mm	
		=	400 mm				OK
	Max. bar spacing	=	78.438 mm				

Appendix G: Schedules of structural beam materials take off.

Family	Structural Material	Beam Size (mm)	Reference Level	Length (mm)	Count	Volume (m3)	Cost (RM/m3)	Total Cost (RM)
Schedule of Beam Material Take-Off (Concrete)								
Level 9								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	1055	1	0.06	243.00	14.58
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	1575	4	0.33	243.00	80.19
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	1650	5	0.42	243.00	102.06
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	3025	2	0.32	243.00	77.76
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	3725	1	0.17	243.00	41.31
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 9	6775	2	0.81	243.00	196.83
Sub total: 150 x 500mm					**15**	**2.11**		**512.73**
150 x 540mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 9	1060	1	0.06	243.00	14.58
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 9	3915	1	0.23	243.00	55.89
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 9	4970	2	0.60	243.00	145.80
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 9	8960	1	0.61	243.00	148.23
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 9	14575	1	0.88	243.00	213.84
Sub total: 150 x 540mm					**6**	**2.38**		**578.34**
150 x 600mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	1050	1	0.07	243.00	17.01
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	1525	20	1.96	243.00	476.28
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	2075	5	0.71	243.00	172.53
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3060	1	0.21	243.00	51.03
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3100	6	1.26	243.00	306.18
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3145	1	0.21	243.00	51.03
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3155	1	0.23	243.00	55.89
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3250	5	1.26	243.00	306.18
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3350	6	1.37	243.00	332.91
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3425	10	2.33	243.00	566.19
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3450	2	0.51	243.00	123.93
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	3525	4	1.02	243.00	247.86
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	5000	11	3.87	243.00	940.41
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	5150	2	0.85	243.00	206.55
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	5400	21	7.53	243.00	1,829.79
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	5825	2	0.93	243.00	225.99
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	6200	2	0.84	243.00	204.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	6700	2	0.91	243.00	221.13
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	6775	3	1.49	243.00	362.07
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	7975	3	1.61	243.00	391.23
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	8025	2	1.09	243.00	264.87
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	8490	2	1.17	243.00	284.31
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	10400	2	1.62	243.00	393.66
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	10800	2	1.45	243.00	352.35
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	11225	3	2.49	243.00	605.07
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	12275	1	0.90	243.00	218.70
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	12475	14	10.40	243.00	2,527.20
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	13550	2	2.00	243.00	486.00
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	13850	2	1.87	243.00	454.41
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	14750	1	1.12	243.00	272.16
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	20575	1	1.42	243.00	345.06
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 9	23925	5	8.22	243.00	1,997.46
Sub total: 150 x 600mm					**145**	**62.92**		**15,289.56**
Sub total: Level 9					**166**	**67.41**		**16,380.63**
Level 10 - 25								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	1055	16	0.96	243.00	233.28
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	1575	64	5.28	243.00	1,283.04
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	1650	80	6.72	243.00	1,632.96
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	3025	32	5.12	243.00	1,244.16
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	3725	16	2.72	243.00	660.96
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 10 - 25	6775	32	12.96	243.00	3,149.28
Sub total: 150 x 500mm					**240**	**33.76**		**8,203.68**
150 x 540mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 10 - 25	1060	16	0.96	243.00	233.28
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 10 - 25	3915	16	3.68	243.00	894.24
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 10 - 25	4970	32	9.60	243.00	2,332.80
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 10 - 25	8960	16	9.76	243.00	2,371.68

M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 10 - 25	14575	16	14.08	243.00	3,421.44
Sub total: 150 x 540mm					**96**	**38.08**		**9,253.44**
150 x 600mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	1050	16	1.12	243.00	272.16
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	1525	320	31.36	243.00	7,620.48
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	2075	80	11.36	243.00	2,760.48
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3060	16	3.36	243.00	816.48
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3100	96	20.16	243.00	4,898.88
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3145	16	3.36	243.00	816.48
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3155	16	3.68	243.00	894.24
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3250	80	20.16	243.00	4,898.88
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3350	96	21.92	243.00	5,326.56
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3425	160	37.28	243.00	9,059.04
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3450	32	8.16	243.00	1,982.88
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	3525	64	16.32	243.00	3,965.76
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	5000	176	61.92	243.00	15,046.56
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	5150	32	13.60	243.00	3,304.80
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	5400	336	120.48	243.00	29,276.64
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	5825	32	14.88	243.00	3,615.84
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	6200	32	13.44	243.00	3,265.92
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	6700	32	14.56	243.00	3,538.08
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	6775	48	23.84	243.00	5,793.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	7975	48	25.76	243.00	6,259.68
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	8025	32	17.44	243.00	4,237.92
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	8490	32	18.72	243.00	4,548.96
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	10400	32	25.92	243.00	6,298.56
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	10800	32	23.20	243.00	5,637.60
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	11225	48	39.84	243.00	9,681.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	12275	16	14.40	243.00	3,499.20
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	12475	224	166.40	243.00	40,435.20
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	13550	32	32.00	243.00	7,776.00
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	13850	32	29.92	243.00	7,270.56
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	14750	16	17.92	243.00	4,354.56
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	20575	16	22.72	243.00	5,520.96
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 10 - 25	23925	80	131.52	243.00	31,959.36
Sub total: 150 x 600mm					**2320**	**1006.72**		**244,632.96**
Sub total: Level 10 - 25					**2656**	**1078.56**		**262,090.08**
Level 26 LRF								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	1055	1	0.07	243.00	17.01
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	1575	4	0.42	243.00	102.06
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	1650	5	0.53	243.00	128.79
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	3025	2	0.41	243.00	99.63
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	3725	1	0.19	243.00	46.17
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 LRF	6775	2	0.81	243.00	196.83
Sub total: 150 x 500mm					**15**	**2.43**		**590.49**
150 x 540mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 26 LRF	1060	1	0.07	243.00	17.01
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 26 LRF	3915	1	0.26	243.00	63.18
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 26 LRF	4970	2	0.67	243.00	162.81
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 26 LRF	8960	1	0.61	243.00	148.23
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 540	Level 26 LRF	14575	1	1.01	243.00	245.43
Sub total: 150 x 540mm					**6**	**2.62**		**636.66**
150 x 600mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	1050	1	0.07	243.00	17.01
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	1525	16	1.57	243.00	381.51
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	2075	5	0.71	243.00	172.53
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3060	1	0.21	243.00	51.03
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3100	6	1.26	243.00	306.18
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3145	1	0.21	243.00	51.03
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3155	1	0.23	243.00	55.89
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3250	5	1.26	243.00	306.18
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3350	6	1.40	243.00	340.20
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3425	8	1.86	243.00	451.98
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3450	2	0.51	243.00	123.93
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	3525	4	1.02	243.00	247.86
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	5000	11	3.87	243.00	940.41
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	5150	2	0.84	243.00	204.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	5400	21	7.53	243.00	1,829.79
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	5825	2	0.93	243.00	225.99
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	6200	2	0.84	243.00	204.12
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	6700	2	0.91	243.00	221.13
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	6775	3	1.49	243.00	362.07

M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	7975	3	1.61	243.00	391.23
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	8025	2	1.09	243.00	264.87
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	8490	2	1.17	243.00	284.31
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	10400	2	1.62	243.00	393.66
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	10800	2	1.42	243.00	345.06
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	11225	3	2.49	243.00	605.07
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	12275	1	0.90	243.00	218.70
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	12475	14	10.48	243.00	2,546.64
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	13550	2	2.00	243.00	486.00
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	13850	2	1.87	243.00	454.41
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	14750	1	1.12	243.00	272.16
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	20575	1	1.42	243.00	345.06
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 600	Level 26 LRF	23925	5	8.23	243.00	1,999.89
Sub total: 150 x 600mm					**139**	**62.14**		**15,100.02**
230 x 600mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	230 x 600	Level 26 LRF	6700	22	16.07	243.00	3,905.01
Sub total: 230 x 600mm					**22**	**16.07**		**3,905.01**
Sub total: Level 26 LRF					**182**	**83.26**		**20,232.18**
Level 26 MRF								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 MRF	3250	6	1.14	243.00	277.02
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 MRF	6090	2	0.68	243.00	165.24
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 MRF	7475	2	0.83	243.00	201.69
Sub total: 150 x 500mm					**10**	**2.65**		**643.95**
Sub total: Level 26 MRF					**10**	**2.65**		**643.95**
Level 26 HRF								
150 x 500mm								
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	1100	1	0.06	243.00	14.58
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	3250	1	0.20	243.00	48.60
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	3345	2	0.41	243.00	99.63
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	3355	1	0.21	243.00	51.03
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	3395	1	0.22	243.00	53.46
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	6295	2	0.74	243.00	179.82
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	6830	3	1.19	243.00	289.17
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	9900	2	1.20	243.00	291.60
M_Concrete-Rectangular Beam	Concrete, Cast-in-Place - C25	150 x 500	Level 26 HRF	17930	1	1.15	243.00	279.45
Sub total: 150 x 500mm					**14**	**5.38**		**1,307.34**
Sub total: Level 26 HRF					**14**	**5.38**		**1,307.34**
Grand total:					**3028**	**1237.26**		**300,654.18**

					Total Bar Length (mm)	Volume (cm3)	Total Weight (kg)	Cost (RM/kg)	Total Cost (RM)
			Schedule of Beam Material Take-Off (Rebar and Shear Link)						
Family	Type	Host Category	Base Level	Bar Diameter					
Level 9									
Rebar Bar	6R	Structural Framing	Level 9	6	8256685.33	233482.55	1832.84	3.08	5,645.14
Rebar Bar	10R	Structural Framing	Level 9	10	455945.54	35814.52	281.14	3.13	879.98
Rebar Bar	12R	Structural Framing	Level 9	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8717211.19**	**269815.16**	**2118.05**		**6,537.85**
Rebar Bar	10T	Structural Framing	Level 9	10	2273331.52	178570.19	1401.78	3.13	4,387.56
Rebar Bar	12T	Structural Framing	Level 9	12	387377.73	43817.07	343.96	3.13	1,076.61
Rebar Bar	16T	Structural Framing	Level 9	16	866073.91	174157.07	1367.13	2.98	4,074.06
Rebar Bar	20T	Structural Framing	Level 9	20	747232.68	234780.51	1843.03	2.98	5,492.22
Rebar Bar	25T	Structural Framing	Level 9	25	596591.83	292889.30	2299.18	2.98	6,851.56
Sub total: Main Bar					**4870607.67**	**924214.14**	**7255.08**		**21,882.00**
Sub total: Level 9					**13587818.87**	**1194029.30**	**9373.13**		**28,419.85**
Level 10									
Rebar Bar	6R	Structural Framing	Level 10	6	8261816.37	233627.64	1833.98	3.08	5,648.65
Rebar Bar	10R	Structural Framing	Level 10	10	458399.25	36007.26	282.66	3.13	884.72
Rebar Bar	12R	Structural Framing	Level 10	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8724795.94**	**270152.99**	**2120.70**		**6,546.10**
Rebar Bar	10T	Structural Framing	Level 10	10	2318158.34	182091.34	1429.42	3.13	4,474.08
Rebar Bar	12T	Structural Framing	Level 10	12	341932.67	38676.69	303.61	3.13	950.31
Rebar Bar	16T	Structural Framing	Level 10	16	861618.53	173261.15	1360.10	2.98	4,053.10
Rebar Bar	20T	Structural Framing	Level 10	20	764696.92	240267.77	1886.10	2.98	5,620.58
Rebar Bar	25T	Structural Framing	Level 10	25	588273.15	288805.35	2267.12	2.98	6,756.02
Sub total: Main Bar					**4874679.60**	**923102.29**	**7246.35**		**21,854.09**
Sub total: Level 10					**13599475.54**	**1193255.29**	**9367.05**		**28,400.18**
Level 11									
Rebar Bar	6R	Structural Framing	Level 11	6	8282516.22	234212.99	1838.57	3.08	5,662.80
Rebar Bar	10R	Structural Framing	Level 11	10	469811.51	36903.69	289.69	3.13	906.74
Rebar Bar	12R	Structural Framing	Level 11	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8756908.05**	**271634.78**	**2132.33**		**6,582.27**
Rebar Bar	10T	Structural Framing	Level 11	10	2330887.46	183091.21	1437.27	3.13	4,498.64
Rebar Bar	12T	Structural Framing	Level 11	12	331418.32	37487.39	294.28	3.13	921.08
Rebar Bar	16T	Structural Framing	Level 11	16	834007.58	167708.92	1316.52	2.98	3,923.21
Rebar Bar	20T	Structural Framing	Level 11	20	802860.36	252258.73	1980.23	2.98	5,901.09
Rebar Bar	25T	Structural Framing	Level 11	25	588273.15	288805.35	2267.12	2.98	6,756.02
Sub total: Main Bar					**4887446.88**	**929351.59**	**7295.41**		**22,000.05**
Sub total: Level 11					**13644354.93**	**1200986.37**	**9427.74**		**28,582.33**
Level 12									
Rebar Bar	6R	Structural Framing	Level 12	6	8269172.81	233835.67	1835.61	3.08	5,653.68
Rebar Bar	10R	Structural Framing	Level 12	10	488357.86	38360.51	301.13	3.13	942.54
Rebar Bar	12R	Structural Framing	Level 12	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8762110.99**	**272714.27**	**2140.81**		**6,608.95**
Rebar Bar	10T	Structural Framing	Level 12	10	2322747.89	182451.85	1432.25	3.13	4,482.93
Rebar Bar	12T	Structural Framing	Level 12	12	347232.64	39276.18	308.32	3.13	965.04
Rebar Bar	16T	Structural Framing	Level 12	16	758477.07	152520.64	1197.29	2.98	3,567.92
Rebar Bar	20T	Structural Framing	Level 12	20	888695.99	279228.28	2191.94	2.98	6,531.99
Rebar Bar	25T	Structural Framing	Level 12	25	588573.37	288952.74	2268.28	2.98	6,759.47
Sub total: Main Bar					**4905726.96**	**942429.68**	**7398.07**		**22,307.34**
Sub total: Level 12					**13667837.95**	**1215143.95**	**9538.88**		**28,916.29**
Level 13									
Rebar Bar	6R	Structural Framing	Level 13	6	8252657.98	233368.66	1831.94	3.08	5,642.39
Rebar Bar	10R	Structural Framing	Level 13	10	495491.94	38920.89	305.53	3.13	956.31
Rebar Bar	12R	Structural Framing	Level 13	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8752730.24**	**272807.64**	**2141.54**		**6,611.42**
Rebar Bar	10T	Structural Framing	Level 13	10	2308941.93	181367.39	1423.73	3.13	4,456.29
Rebar Bar	12T	Structural Framing	Level 13	12	364243.00	41200.25	323.42	3.13	1,012.31
Rebar Bar	16T	Structural Framing	Level 13	16	722538.18	145293.76	1140.56	2.98	3,398.86
Rebar Bar	20T	Structural Framing	Level 13	20	922832.23	289953.89	2276.14	2.98	6,782.89
Rebar Bar	25T	Structural Framing	Level 13	25	588573.37	288952.74	2268.28	2.98	6,759.47
Sub total: Main Bar					**4907128.71**	**946768.03**	**7432.13**		**22,409.82**
Sub total: Level 13					**13659858.95**	**1219575.67**	**9573.67**		**29,021.24**

Level 14

Rebar Bar	6R	Structural Framing	Level 14	6	8191909.90	231650.83	1818.46	3.08	5,600.85
Rebar Bar	10R	Structural Framing	Level 14	10	538289.94	42282.68	331.92	3.13	1,038.91
Rebar Bar	12R	Structural Framing	Level 14	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8734780.16**	**274451.59**	**2154.45**		**6,652.49**
Rebar Bar	10T	Structural Framing	Level 14	10	2247072.13	176507.52	1385.58	3.13	4,336.88
Rebar Bar	12T	Structural Framing	Level 14	12	431986.02	48862.80	383.57	3.13	1,200.58
Rebar Bar	16T	Structural Framing	Level 14	16	716390.10	144057.45	1130.85	2.98	3,369.94
Rebar Bar	20T	Structural Framing	Level 14	20	903376.89	283841.02	2228.15	2.98	6,639.89
Rebar Bar	25T	Structural Framing	Level 14	25	626011.17	307332.36	2412.56	2.98	7,189.43
Sub total: Main Bar					**4924836.31**	**960601.15**	**7540.72**		**22,736.72**
Sub total: Level 14					**13659616.47**	**1235052.74**	**9695.16**		**29,389.21**

Level 15

Rebar Bar	6R	Structural Framing	Level 15	6	8240017.33	233011.21	1829.14	3.08	5,633.75
Rebar Bar	10R	Structural Framing	Level 15	10	542569.75	42618.85	334.56	3.13	1,047.17
Rebar Bar	12R	Structural Framing	Level 15	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8787167.40**	**276148.15**	**2167.76**		**6,693.64**
Rebar Bar	10T	Structural Framing	Level 15	10	2227752.21	174989.94	1373.67	3.13	4,299.59
Rebar Bar	12T	Structural Framing	Level 15	12	465799.53	52687.52	413.60	3.13	1,294.56
Rebar Bar	16T	Structural Framing	Level 15	16	710586.00	142890.32	1121.69	2.98	3,342.63
Rebar Bar	20T	Structural Framing	Level 15	20	836591.16	262856.94	2063.43	2.98	6,149.01
Rebar Bar	25T	Structural Framing	Level 15	25	714768.17	350906.50	2754.62	2.98	8,208.76
Sub total: Main Bar					**4955497.07**	**984331.21**	**7727.00**		**23,294.55**
Sub total: Level 15					**13742664.47**	**1260479.36**	**9894.76**		**29,988.19**

Level 16

Rebar Bar	6R	Structural Framing	Level 16	6	8240215.55	233016.82	1829.18	3.08	5,633.88
Rebar Bar	10R	Structural Framing	Level 16	10	555409.15	43627.39	342.48	3.13	1,071.95
Rebar Bar	12R	Structural Framing	Level 16	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8800205.02**	**277162.29**	**2175.72**		**6,718.56**
Rebar Bar	10T	Structural Framing	Level 16	10	2231939.57	175318.85	1376.25	3.13	4,307.67
Rebar Bar	12T	Structural Framing	Level 16	12	502192.07	56803.95	445.91	3.13	1,395.70
Rebar Bar	16T	Structural Framing	Level 16	16	662444.07	133209.55	1045.70	2.98	3,116.17
Rebar Bar	20T	Structural Framing	Level 16	20	810053.23	254518.73	1997.97	2.98	5,953.96
Rebar Bar	25T	Structural Framing	Level 16	25	788953.02	387326.62	3040.51	2.98	9,060.73
Sub total: Main Bar					**4995581.97**	**1007177.71**	**7906.35**		**23,834.23**
Sub total: Level 16					**13795786.99**	**1284340.00**	**10082.07**		**30,552.79**

Level 17

Rebar Bar	6R	Structural Framing	Level 17	6	8221119.43	232476.82	1824.94	3.08	5,620.82
Rebar Bar	10R	Structural Framing	Level 17	10	576809.77	45308.41	355.67	3.13	1,113.25
Rebar Bar	12R	Structural Framing	Level 17	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8802509.52**	**278303.31**	**2184.68**		**6,746.80**
Rebar Bar	10T	Structural Framing	Level 17	10	2222708.57	174593.76	1370.56	3.13	4,289.86
Rebar Bar	12T	Structural Framing	Level 17	12	534468.29	60454.78	474.57	3.13	1,485.40
Rebar Bar	16T	Structural Framing	Level 17	16	643879.46	129476.43	1016.39	2.98	3,028.84
Rebar Bar	20T	Structural Framing	Level 17	20	750508.62	235809.81	1851.11	2.98	5,516.30
Rebar Bar	25T	Structural Framing	Level 17	25	868725.78	426490.06	3347.95	2.98	9,976.88
Sub total: Main Bar					**5020290.72**	**1026824.84**	**8060.58**		**24,297.28**
Sub total: Level 17					**13822800.25**	**1305128.15**	**10245.26**		**31,044.09**

Level 18

Rebar Bar	6R	Structural Framing	Level 18	6	8192788.34	231675.67	1818.65	3.08	5,601.45
Rebar Bar	10R	Structural Framing	Level 18	10	596781.64	46877.20	367.99	3.13	1,151.80
Rebar Bar	12R	Structural Framing	Level 18	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8794150.30**	**279070.96**	**2190.71**		**6,765.98**
Rebar Bar	10T	Structural Framing	Level 18	10	2218576.35	174269.17	1368.01	3.13	4,281.88
Rebar Bar	12T	Structural Framing	Level 18	12	556493.69	62946.11	494.13	3.13	1,546.62
Rebar Bar	16T	Structural Framing	Level 18	16	631404.65	126967.90	996.70	2.98	2,970.16
Rebar Bar	20T	Structural Framing	Level 18	20	763528.04	239900.51	1883.22	2.98	5,611.99
Rebar Bar	25T	Structural Framing	Level 18	25	880659.79	432348.92	3393.94	2.98	10,113.94
Sub total: Main Bar					**5050662.52**	**1036432.61**	**8136.00**		**24,524.59**
Sub total: Level 18					**13844812.82**	**1315503.57**	**10326.70**		**31,290.57**

Level 19

Rebar Bar	6R	Structural Framing	Level 19	6	8217164.16	232364.97	1824.07	3.08	5,618.12

Rebar Bar	10R	Structural Framing	Level 19		10	611499.02	48033.25	377.06	3.13	1,180.20
Rebar Bar	12R	Structural Framing	Level 19		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8833243.51**	**280916.31**	**2205.19**		**6,811.05**
Rebar Bar	10T	Structural Framing	Level 19		10	2196445.93	172530.83	1354.37	3.13	4,239.17
Rebar Bar	12T	Structural Framing	Level 19		12	569698.58	64439.75	505.85	3.13	1,583.32
Rebar Bar	16T	Structural Framing	Level 19		16	625459.92	125772.48	987.31	2.98	2,942.20
Rebar Bar	20T	Structural Framing	Level 19		20	776566.92	243997.32	1915.38	2.98	5,707.83
Rebar Bar	25T	Structural Framing	Level 19		25	888689.41	436290.96	3424.88	2.98	10,206.15
Sub total: Main Bar						**5056860.75**	**1043031.34**	**8187.80**		**24,678.66**
Sub total: Level 19						**13890104.25**	**1323947.64**	**10392.99**		**31,489.72**
Level 20										
Rebar Bar	6R	Structural Framing	Level 20		6	8211258.29	232197.96	1822.75	3.08	5,614.08
Rebar Bar	10R	Structural Framing	Level 20		10	622911.29	48929.68	384.10	3.13	1,202.23
Rebar Bar	12R	Structural Framing	Level 20		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8838749.89**	**281645.73**	**2210.92**		**6,829.04**
Rebar Bar	10T	Structural Framing	Level 20		10	2188937.23	171941.02	1349.74	3.13	4,224.68
Rebar Bar	12T	Structural Framing	Level 20		12	569698.58	64439.75	505.85	3.13	1,583.32
Rebar Bar	16T	Structural Framing	Level 20		16	602408.88	121137.20	950.93	2.98	2,833.76
Rebar Bar	20T	Structural Framing	Level 20		20	783934.12	246312.10	1933.55	2.98	5,761.98
Rebar Bar	25T	Structural Framing	Level 20		25	910484.96	446991.21	3508.88	2.98	10,456.47
Sub total: Main Bar						**5055463.77**	**1050821.27**	**8248.95**		**24,860.20**
Sub total: Level 20						**13894213.66**	**1332467.01**	**10459.87**		**31,689.24**
Level 21										
Rebar Bar	6R	Structural Framing	Level 21		6	8189734.05	231589.30	1817.98	3.08	5,599.37
Rebar Bar	10R	Structural Framing	Level 21		10	641908.48	50421.91	395.81	3.13	1,238.89
Rebar Bar	12R	Structural Framing	Level 21		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8836222.84**	**282529.30**	**2217.86**		**6,850.99**
Rebar Bar	10T	Structural Framing	Level 21		10	2210088.10	173602.42	1362.78	3.13	4,265.50
Rebar Bar	12T	Structural Framing	Level 21		12	538935.99	60960.13	478.54	3.13	1,497.82
Rebar Bar	16T	Structural Framing	Level 21		16	582378.36	117109.30	919.31	2.98	2,739.54
Rebar Bar	20T	Structural Framing	Level 21		20	838632.95	263498.47	2068.46	2.98	6,164.02
Rebar Bar	25T	Structural Framing	Level 21		25	910484.96	446991.21	3508.88	2.98	10,456.47
Sub total: Main Bar						**5080520.35**	**1062161.53**	**8337.97**		**25,123.34**
Sub total: Level 21						**13916743.20**	**1344690.83**	**10555.82**		**31,974.33**
Level 22										
Rebar Bar	6R	Structural Framing	Level 22		6	8178719.65	231277.83	1815.53	3.08	5,591.84
Rebar Bar	10R	Structural Framing	Level 22		10	660454.82	51878.73	407.25	3.13	1,274.69
Rebar Bar	12R	Structural Framing	Level 22		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8843754.79**	**283674.65**	**2226.85**		**6,879.25**
Rebar Bar	10T	Structural Framing	Level 22		10	2197796.85	172636.94	1355.20	3.13	4,241.78
Rebar Bar	12T	Structural Framing	Level 22		12	540092.61	61090.96	479.56	3.13	1,501.04
Rebar Bar	16T	Structural Framing	Level 22		16	553737.98	111350.06	874.10	2.98	2,604.81
Rebar Bar	20T	Structural Framing	Level 22		20	857599.32	269457.71	2115.24	2.98	6,303.42
Rebar Bar	25T	Structural Framing	Level 22		25	921397.40	452348.54	3550.94	2.98	10,581.79
Sub total: Main Bar						**5070624.17**	**1066884.20**	**8375.04**		**25,232.84**
Sub total: Level 22						**13914378.96**	**1350558.85**	**10601.89**		**32,112.09**
Level 23										
Rebar Bar	6R	Structural Framing	Level 23		6	8185229.18	231461.91	1816.98	3.08	5,596.29
Rebar Bar	10R	Structural Framing	Level 23		10	660454.82	51878.73	407.25	3.13	1,274.69
Rebar Bar	12R	Structural Framing	Level 23		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8850264.32**	**283858.73**	**2228.29**		**6,883.70**
Rebar Bar	10T	Structural Framing	Level 23		10	2169588.12	170421.15	1337.81	3.13	4,187.33
Rebar Bar	12T	Structural Framing	Level 23		12	549783.70	62187.13	488.17	3.13	1,527.97
Rebar Bar	16T	Structural Framing	Level 23		16	528872.61	106349.94	834.85	2.98	2,487.84
Rebar Bar	20T	Structural Framing	Level 23		20	873780.34	274541.78	2155.15	2.98	6,422.36
Rebar Bar	25T	Structural Framing	Level 23		25	930407.59	456771.97	3585.66	2.98	10,685.27
Sub total: Main Bar						**5052432.36**	**1070271.97**	**8401.64**		**25,310.77**
Sub total: Level 23						**13902696.68**	**1354130.70**	**10629.93**		**32,194.47**
Level 24										
Rebar Bar	6R	Structural Framing	Level 24		6	8184229.10	231433.63	1816.75	3.08	5,595.60
Rebar Bar	10R	Structural Framing	Level 24		10	657602.16	51654.65	405.49	3.13	1,269.18
Rebar Bar	12R	Structural Framing	Level 24		12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link						**8846411.58**	**283606.37**	**2226.31**		**6,877.51**

Rebar Bar	10T	Structural Framing	Level 24	10	2160339.27	169694.65	1332.10	3.13	4,169.48
Rebar Bar	12T	Structural Framing	Level 24	12	542124.30	61320.76	481.37	3.13	1,506.68
Rebar Bar	16T	Structural Framing	Level 24	16	522415.39	105051.46	824.65	2.98	2,457.47
Rebar Bar	20T	Structural Framing	Level 24	20	889598.90	279511.97	2194.17	2.98	6,538.62
Rebar Bar	25T	Structural Framing	Level 24	25	930708.06	456919.49	3586.82	2.98	10,688.72
Sub total: Main Bar					**5045185.92**	**1072498.34**	**8419.11**		**25,360.97**
Sub total: Level 24					**13891597.51**	**1356104.71**	**10645.42**		**32,238.49**
Level 25									
Rebar Bar	6R	Structural Framing	Level 25	6	8175692.39	231192.23	1814.86	3.08	5,589.77
Rebar Bar	10R	Structural Framing	Level 25	10	659027.68	51766.62	406.37	3.13	1,271.93
Rebar Bar	12R	Structural Framing	Level 25	12	4580.32	518.09	4.07	3.13	12.73
Sub total: Shear Link					**8839300.39**	**283476.94**	**2225.29**		**6,874.43**
Rebar Bar	10T	Structural Framing	Level 25	10	2131694.28	167444.59	1314.44	3.13	4,114.20
Rebar Bar	12T	Structural Framing	Level 25	12	504578.52	57073.89	448.03	3.13	1,402.33
Rebar Bar	16T	Structural Framing	Level 25	16	572912.65	115205.86	904.37	2.98	2,695.01
Rebar Bar	20T	Structural Framing	Level 25	20	894117.50	280931.72	2205.31	2.98	6,571.84
Rebar Bar	25T	Structural Framing	Level 25	25	952153.06	467447.64	3669.46	2.98	10,935.00
Sub total: Main Bar					**5055456.02**	**1088103.69**	**8541.61**		**25,718.38**
Sub total: Level 25					**13894756.41**	**1371580.64**	**10766.91**		**32,592.81**
Level 26 LRF									
Rebar Bar	6R	Structural Framing	Level 26 LRF	6	8504970.89	240503.57	1887.95	3.08	5,814.90
Rebar Bar	10R	Structural Framing	Level 26 LRF	10	1298985.19	102035.29	800.98	3.13	2,507.06
Rebar Bar	12R	Structural Framing	Level 26 LRF	12	34038.75	3850.19	30.22	3.13	94.60
Rebar Bar	16R	Structural Framing	Level 26 LRF	16	8960.17	1801.78	14.14	2.98	42.15
Sub total: Shear Link					**9846955.00**	**348190.83**	**2733.30**		**8,458.70**
Rebar Bar	10T	Structural Framing	Level 26 LRF	10	2851297.60	223969.43	1758.16	3.13	5,503.04
Rebar Bar	12T	Structural Framing	Level 26 LRF	12	1034318.95	116993.89	918.40	3.13	2,874.60
Rebar Bar	16T	Structural Framing	Level 26 LRF	16	1234660.52	248275.41	1948.96	2.98	5,807.91
Rebar Bar	20T	Structural Framing	Level 26 LRF	20	581330.00	182653.89	1433.83	2.98	4,272.82
Rebar Bar	25T	Structural Framing	Level 26 LRF	25	394141.52	193498.85	1518.97	2.98	4,526.52
Rebar Bar	32T	Structural Framing	Level 26 LRF	32	51259.37	41230.57	323.66	2.98	964.51
Sub total: Main Bar					**6147007.96**	**1006622.04**	**7901.98**		**23,949.39**
Sub total: Level 26 LRF					**15993962.96**	**1354812.87**	**10635.28**		**32,408.10**
Level 26 MRF									
Rebar Bar	6R	Structural Framing	Level 26 MRF	6	317610.91	8981.40	70.50	3.08	217.15
Sub total: Shear Link					**317610.91**	**8981.40**	**70.50**		**217.15**
Rebar Bar	10T	Structural Framing	Level 26 MRF	10	170394.13	13384.46	105.07	3.13	328.86
Rebar Bar	12T	Structural Framing	Level 26 MRF	12	14697.12	1662.42	13.05	3.13	40.85
Rebar Bar	20T	Structural Framing	Level 26 MRF	20	30574.87	9606.62	75.41	2.98	224.73
Sub total: Main Bar					**215666.11**	**24653.50**	**193.53**		**594.44**
Sub total: Level 26 MRF					**533277.02**	**33634.90**	**264.03**		**811.59**
Level 26 HRF									
Rebar Bar	6R	Structural Framing	Level 26 HRF	6	732963.84	20726.75	162.71	3.08	501.13
Sub total: Shear Link					**732963.84**	**20726.75**	**162.71**		**501.13**
Rebar Bar	10T	Structural Framing	Level 26 HRF	10	282337.11	22177.58	174.09	3.13	544.91
Rebar Bar	12T	Structural Framing	Level 26 HRF	12	51259.72	5798.09	45.52	3.13	142.46
Rebar Bar	16T	Structural Framing	Level 26 HRF	16	44598.78	8968.28	70.40	2.98	209.79
Rebar Bar	20T	Structural Framing	Level 26 HRF	20	44823.17	14083.44	110.56	2.98	329.45
Rebar Bar	25T	Structural Framing	Level 26 HRF	25	53201.21	26118.47	205.03	2.98	610.99
Sub total: Main Bar					**476219.99**	**77145.86**	**605.60**		**1,837.61**
Sub total: Level 26 HRF					**1209183.83**	**97872.61**	**768.30**		**2,338.75**
Grand total: Shear Link					**160418045.90**	**5099868.15**	**40033.97**		**123,647.02**
Grand total: Main Bar					**91647895.82**	**18243427.01**	**143210.90**		**431,807.29**
Grand total:					**252065941.72**	**23343295.16**	**183244.87**		**555,454.30**

Appendix H: Schedules of structural column materials take off.

Schedule of Column Material Take-Off (Concrete)								
Family	Structural Material	Type	Base Level	Length (mm)	Count	Volume (m3)	Cost (RM)	Total Cost (RM)
Level 8								
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 900	Level 8	3625	95	85.37	243.00	20,744.91
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 1200	Level 8	3625	2	2.35	243.00	571.05
Sub total: Level 8					**97**	**87.72**		**21,315.96**
Level 9 - 24								
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 900	Level 9 - 24	3265	1520	1365.92	243.00	331,918.56
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 1200	Level 9 - 24	3265	32	37.60	243.00	9,136.80
Sub total: Level 9 - 24					**1552**	**1403.52**		**341,055.36**
Level 25								
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 900	Level 25	4405	95	115.28	243.00	28,013.04
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 1200	Level 25	4405	2	3.17	243.00	770.31
Sub total: Level 25					**97**	**118.45**		**28,783.35**
Level 26 LRF								
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	200 x 150	Level 26 LRF	4300	10	1.29	243.00	313.47
M_Concrete-Rectangular-Column	Concrete, Cast-in-Place - C25	300 x 900	Level 26 LRF	1800	8	3.89	243.00	945.27
Sub total: Level 26 LRF					**18**	**5.18**		**1,258.74**
Grand total:					**1764**	**1614.87**		**392,413.41**

Schedule of Column Material Take-Off (Rebar and Shear Link)									
Family	Type	Host Category	Base Level	Bar Diameter	Total Bar Length (mm)	Volume (cm3)	Total Weight (kg)	Cost (RM/kg)	Total Cost (RM)
Level 8									
Rebar Bar	12R	Structural Column	Level 8	12	3339340.57	377719.49	2965.10	3.13	9,280.76
Sub total: Shear Link					**3339340.57**	**377719.49**	**2965.10**		**9,280.76**
Rebar Bar	12T	Structural Column	Level 8	12	1384457.23	156598.73	1229.30	3.13	3,847.71
Rebar Bar	20T	Structural Column	Level 8	20	97371.14	30594.01	240.16	2.98	715.69
Rebar Bar	25T	Structural Column	Level 8	25	2373864.51	1165419.11	9148.54	2.98	27,262.65
Rebar Bar	32T	Structural Column	Level 8	32	1755706.92	1412206.37	11085.82	2.98	33,035.74
Sub total: Main Bar					**5611399.80**	**2764818.22**	**21703.82**		**64,861.79**
Sub total: Level 8					**8950740.37**	**3142537.71**	**24668.92**		**74,142.54**
Level 9									
Rebar Bar	12R	Structural Column	Level 9	12	10543548.97	1192601.91	9361.93	3.13	29,302.83
Sub total: Shear Link					**10543548.97**	**1192601.91**	**9361.93**		**29,302.83**
Rebar Bar	12T	Structural Column	Level 9	12	1459293.15	165063.57	1295.75	3.13	4,055.69
Rebar Bar	16T	Structural Column	Level 9	16	38994.87	7841.40	61.56	2.98	183.43
Rebar Bar	20T	Structural Column	Level 9	20	259656.92	81584.20	640.44	2.98	1,908.50
Rebar Bar	25T	Structural Column	Level 9	25	2101593.29	1031750.96	8099.25	2.98	24,135.75
Rebar Bar	32T	Structural Column	Level 9	32	1431536.33	1151459.11	9038.95	2.98	26,936.08
Sub total: Main Bar					**5291074.56**	**2437699.24**	**19135.94**		**57,219.46**
Sub total: Level 9					**15834623.53**	**3630301.15**	**28497.86**		**86,522.29**
Level 10									
Rebar Bar	10R	Structural Column	Level 10	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 10	12	10328502.54	1168277.58	9170.98	3.13	28,705.16
Sub total: Shear Link					**10486882.74**	**1180718.34**	**9268.64**		**29,010.84**
Rebar Bar	12T	Structural Column	Level 10	12	1496710.55	169295.92	1328.97	3.13	4,159.69
Rebar Bar	16T	Structural Column	Level 10	16	389945.58	78413.38	615.55	2.98	1,834.32
Rebar Bar	25T	Structural Column	Level 10	25	1454949.30	714289.17	5607.17	2.98	16,709.37
Rebar Bar	32T	Structural Column	Level 10	32	1331872.45	1071294.27	8409.66	2.98	25,060.79
Sub total: Main Bar					**4673477.87**	**2033292.74**	**15961.35**		**47,764.16**
Sub total: Level 10					**15160360.61**	**3214011.08**	**25229.99**		**76,775.00**
Level 11									
Rebar Bar	10R	Structural Column	Level 11	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 11	12	10142090.16	1147192.10	9005.46	3.13	28,187.08
Sub total: Shear Link					**10300470.35**	**1159632.87**	**9103.12**		**28,492.76**
Rebar Bar	12T	Structural Column	Level 11	12	1870887.90	211619.87	1661.22	3.13	5,199.61
Rebar Bar	16T	Structural Column	Level 11	16	38994.87	7841.40	61.56	2.98	183.43
Rebar Bar	20T	Structural Column	Level 11	20	227199.60	71386.11	560.38	2.98	1,669.94
Rebar Bar	25T	Structural Column	Level 11	25	791288.08	388472.99	3049.51	2.98	9,087.55
Rebar Bar	32T	Structural Column	Level 11	32	1250329.26	1005704.84	7894.78	2.98	23,526.45
Sub total: Main Bar					**4178699.72**	**1685025.22**	**13227.45**		**39,666.98**
Sub total: Level 11					**14479170.08**	**2844658.09**	**22330.57**		**68,159.74**
Level 12									
Rebar Bar	10R	Structural Column	Level 12	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 12	12	10043176.87	1136003.82	8917.63	3.13	27,912.18
Sub total: Shear Link					**10201557.06**	**1148444.59**	**9015.29**		**28,217.86**
Rebar Bar	12T	Structural Column	Level 12	12	1983141.22	224317.07	1760.89	3.13	5,511.58
Rebar Bar	16T	Structural Column	Level 12	16	155978.23	31365.35	246.22	2.98	733.73
Rebar Bar	20T	Structural Column	Level 12	20	292113.83	91782.17	720.49	2.98	2,147.06
Rebar Bar	25T	Structural Column	Level 12	25	459457.61	225564.97	1770.69	2.98	5,276.64
Rebar Bar	32T	Structural Column	Level 12	32	969458.15	779785.61	6121.32	2.98	18,241.52
Sub total: Main Bar					**3860149.04**	**1352815.16**	**10619.60**		**31,910.54**
Sub total: Level 12					**14061706.10**	**2501259.75**	**19634.89**		**60,128.40**
Level 13									
Rebar Bar	10R	Structural Column	Level 13	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 13	12	10182035.91	1151710.45	9040.93	3.13	28,298.10
Sub total: Shear Link					**10340416.11**	**1164151.21**	**9138.59**		**28,603.78**
Rebar Bar	12T	Structural Column	Level 13	12	2319901.18	262408.66	2059.91	3.13	6,447.51
Rebar Bar	16T	Structural Column	Level 13	16	218369.40	43911.46	344.71	2.98	1,027.22

Rebar Bar	20T	Structural Column	Level 13	20	64914.23	20396.05	160.11	2.98	477.12
Rebar Bar	25T	Structural Column	Level 13	25	476474.57	233919.24	1836.27	2.98	5,472.07
Rebar Bar	32T	Structural Column	Level 13	32	670466.36	539290.96	4233.43	2.98	12,615.63
Sub total: Main Bar					**3750125.74**	**1099926.37**	**8634.42**		**26,039.56**
Sub total: Level 13					**14090541.84**	**2264077.58**	**17773.01**		**54,643.34**
Level 14								
Rebar Bar	10R	Structural Column	Level 14	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 14	12	10301873.17	1165265.48	9147.33	3.13	28,631.16
Sub total: Shear Link					**10460253.36**	**1177706.24**	**9244.99**		**28,936.83**
Rebar Bar	12T	Structural Column	Level 14	12	2604276.33	294574.90	2312.41	3.13	7,237.85
Rebar Bar	16T	Structural Column	Level 14	16	233967.35	47048.03	369.33	2.98	1,100.59
Rebar Bar	20T	Structural Column	Level 14	20	227199.60	71386.11	560.38	2.98	1,669.94
Rebar Bar	25T	Structural Column	Level 14	25	459457.61	225564.97	1770.69	2.98	5,276.64
Rebar Bar	32T	Structural Column	Level 14	32	217448.61	174905.22	1373.01	2.98	4,091.56
Sub total: Main Bar					**3742349.49**	**813479.24**	**6385.81**		**19,376.58**
Sub total: Level 14					**14202602.85**	**1991185.48**	**15630.81**		**48,313.41**
Level 15								
Rebar Bar	10R	Structural Column	Level 15	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 15	12	10355133.04	1171289.81	9194.63	3.13	28,779.18
Sub total: Shear Link					**10513513.24**	**1183730.57**	**9292.29**		**29,084.85**
Rebar Bar	12T	Structural Column	Level 15	12	2866200.37	324201.66	2544.98	3.13	7,965.80
Rebar Bar	16T	Structural Column	Level 15	16	249565.29	50184.59	393.95	2.98	1,173.97
Rebar Bar	20T	Structural Column	Level 15	20	259656.92	81584.20	640.44	2.98	1,908.50
Rebar Bar	25T	Structural Column	Level 15	25	306305.16	150376.69	1180.46	2.98	3,517.76
Rebar Bar	32T	Structural Column	Level 15	32	36241.38	29150.83	228.83	2.98	681.93
Sub total: Main Bar					**3717969.12**	**635497.96**	**4988.66**		**15,247.95**
Sub total: Level 15					**14231482.36**	**1819228.54**	**14280.94**		**44,332.80**
Level 16								
Rebar Bar	10R	Structural Column	Level 16	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 16	12	10474970.30	1184844.84	9301.03	3.13	29,112.23
Sub total: Shear Link					**10633350.50**	**1197285.61**	**9398.69**		**29,417.91**
Rebar Bar	12T	Structural Column	Level 16	12	3240378.85	366525.73	2877.23	3.13	9,005.72
Rebar Bar	16T	Structural Column	Level 16	16	210570.42	42343.18	332.39	2.98	990.53
Rebar Bar	20T	Structural Column	Level 16	20	259656.92	81584.20	640.44	2.98	1,908.50
Rebar Bar	25T	Structural Column	Level 16	25	34033.94	16708.54	131.16	2.98	390.86
Sub total: Main Bar					**3744640.12**	**507161.66**	**3981.22**		**12,295.62**
Sub total: Level 16					**14377990.62**	**1704447.26**	**13379.91**		**41,713.52**
Level 17								
Rebar Bar	10R	Structural Column	Level 17	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 17	12	10581492.31	1196893.76	9395.62	3.13	29,408.28
Sub total: Shear Link					**10739872.50**	**1209334.52**	**9493.28**		**29,713.95**
Rebar Bar	12T	Structural Column	Level 17	12	3651973.60	413082.04	3242.69	3.13	10,149.63
Rebar Bar	16T	Structural Column	Level 17	16	93587.06	18819.24	147.73	2.98	440.24
Rebar Bar	20T	Structural Column	Level 17	20	32456.91	10197.96	80.05	2.98	238.56
Sub total: Main Bar					**3778017.58**	**442099.24**	**3470.48**		**10,828.43**
Sub total: Level 17					**14517890.08**	**1651433.76**	**12963.76**		**40,542.39**
Level 18								
Rebar Bar	10R	Structural Column	Level 18	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 18	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					**10753187.75**	**1210840.64**	**9505.10**		**29,750.96**
Rebar Bar	12T	Structural Column	Level 18	12	3689392.13	417314.52	3275.92	3.13	10,253.63
Rebar Bar	16T	Structural Column	Level 18	16	93587.06	18819.24	147.73	2.98	440.24
Sub total: Main Bar					**3782979.19**	**436133.76**	**3423.65**		**10,693.86**
Sub total: Level 18					**14536166.95**	**1646974.39**	**12928.75**		**40,444.82**
Level 19								
Rebar Bar	10R	Structural Column	Level 19	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 19	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					**10753187.75**	**1210840.64**	**9505.10**		**29,750.96**
Rebar Bar	12T	Structural Column	Level 19	12	3689392.13	417314.52	3275.92	3.13	10,253.63
Rebar Bar	16T	Structural Column	Level 19	16	93587.06	18819.24	147.73	2.98	440.24

Sub total: Main Bar					3782979.19	436133.76	3423.65		**10,693.86**
Sub total: Level 19					14536166.95	1646974.39	12928.75		**40,444.82**
Level 20									
Rebar Bar	10R	Structural Column	Level 20	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 20	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					10753187.75	1210840.64	9505.10		**29,750.96**
Rebar Bar	12T	Structural Column	Level 20	12	3689392.13	417314.52	3275.92	3.13	10,253.63
Rebar Bar	16T	Structural Column	Level 20	16	93587.06	18819.24	147.73	2.98	440.24
Sub total: Main Bar					3782979.19	436133.76	3423.65		**10,693.86**
Sub total: Level 20					14536166.95	1646974.39	12928.75		**40,444.82**
Level 21									
Rebar Bar	10R	Structural Column	Level 21	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 21	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					10753187.75	1210840.64	9505.10		**29,750.96**
Rebar Bar	12T	Structural Column	Level 21	12	3689392.13	417314.52	3275.92	3.13	10,253.63
Rebar Bar	16T	Structural Column	Level 21	16	93587.06	18819.24	147.73	2.98	440.24
Sub total: Main Bar					3782979.19	436133.76	3423.65		**10,693.86**
Sub total: Level 21					14536166.95	1646974.39	12928.75		**40,444.82**
Level 22									
Rebar Bar	10R	Structural Column	Level 22	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 22	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					10753187.75	1210840.64	9505.10		**29,750.96**
Rebar Bar	12T	Structural Column	Level 22	12	3689392.13	417314.52	3275.92	3.13	10,253.63
Rebar Bar	16T	Structural Column	Level 22	16	93587.06	18819.24	147.73	2.98	440.24
Sub total: Main Bar					3782979.19	436133.76	3423.65		**10,693.86**
Sub total: Level 22					14536166.95	1646974.39	12928.75		**40,444.82**
Level 23									
Rebar Bar	10R	Structural Column	Level 23	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 23	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					10753187.75	1210840.64	9505.10		**29,750.96**
Rebar Bar	12T	Structural Column	Level 23	12	3651973.60	413082.04	3242.69	3.13	10,149.63
Rebar Bar	16T	Structural Column	Level 23	16	132581.31	26660.51	209.29	2.98	623.67
Sub total: Main Bar					3784554.91	439742.55	3451.98		**10,773.30**
Sub total: Level 23					14537742.66	1650583.18	12957.08		**40,524.26**
Level 24									
Rebar Bar	10R	Structural Column	Level 24	10	158380.20	12440.76	97.66	3.13	305.68
Rebar Bar	12R	Structural Column	Level 24	12	10594807.56	1198399.87	9407.44	3.13	29,445.28
Sub total: Shear Link					10753187.75	1210840.64	9505.10		**29,750.96**
Rebar Bar	12T	Structural Column	Level 24	12	3577138.81	404617.32	3176.25	3.13	9,941.65
Rebar Bar	16T	Structural Column	Level 24	16	210570.42	42343.18	332.39	2.98	990.53
Sub total: Main Bar					3787709.23	446960.51	3508.64		**10,932.18**
Sub total: Level 24					14540896.98	1657801.15	13013.74		**40,683.14**
Level 25									
Rebar Bar	10R	Structural Column	Level 25	10	4249381.50	333788.92	2620.24	3.13	8,201.36
Rebar Bar	12R	Structural Column	Level 25	12	8556552.71	967848.79	7597.61	3.13	23,780.53
Sub total: Shear Link					12805934.21	1301637.71	10217.86		**31,981.89**
Rebar Bar	12T	Structural Column	Level 25	12	2645649.00	299254.65	2349.15	3.13	7,352.84
Rebar Bar	16T	Structural Column	Level 25	16	1860666.51	374157.71	2937.14	2.98	8,752.67
Rebar Bar	20T	Structural Column	Level 25	20	69108.89	21714.01	170.46	2.98	507.96
Sub total: Main Bar					4575424.40	695126.37	5456.74		**16,613.46**
Sub total: Level 25					17381358.61	1996764.08	15674.60		**48,595.35**
Level 26 LRF									
Rebar Bar	6R	Structural Column	Level 26 LRF	6	247533.25	6999.75	54.95	3.13	171.99
Rebar Bar	10R	Structural Column	Level 26 LRF	10	294461.32	23129.94	181.57	3.13	568.31
Sub total: Shear Link					541994.56	30129.68	236.52		**740.30**
Rebar Bar	10T	Structural Column	Level 26 LRF	10	168191.79	13211.46	103.71	3.13	324.61
Rebar Bar	16T	Structural Column	Level 26 LRF	16	128787.30	25897.58	203.30	2.98	605.82
Rebar Bar	20T	Structural Column	Level 26 LRF	20	16819.18	5284.59	41.48	2.98	123.62

Sub total: Main Bar	313798.26	44393.63	348.49		1,054.06
Sub total: Level 26 LR	855792.83	74523.31	585.01		1,794.36
Grand total: Shear Link	186179448.45	20798977.20	163271.97		511,041.27
Grand total: Main Bar	73724285.81	17578706.88	137992.85		418,053.40
Grand total:	259903734.26	38377684.08	301264.82		929,094.67

Appendix I: Schedules of structural slab materials take off.

Family	Structural Material	Type	Level	Count	Material: Volume (m2)	Cost (RM/m3)	Total Cost (RM)
		Schedule of Slab Material Take-Off (Concrete)					
Level 9							
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	1.28	243.00	38.88
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	1.52	243.00	46.17
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	1.60	243.00	48.60
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	9	1.68	243.00	459.27
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	1.84	243.00	111.78
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	9	2.72	243.00	743.58
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	2.80	243.00	85.05
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	3.20	243.00	97.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	10	3.36	243.00	1,020.60
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	7	4.08	243.00	867.51
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	4.16	243.00	252.72
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	4.24	243.00	257.58
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	10	4.40	243.00	1,336.50
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	5.04	243.00	153.09
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	5.20	243.00	157.95
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	5.36	243.00	162.81
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	10	5.44	243.00	1,652.40
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	3	6.56	243.00	597.78
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	8	6.80	243.00	1,652.40
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	6.88	243.00	417.96
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	10	7.20	243.00	2,187.00
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	7.76	243.00	235.71
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	8.08	243.00	490.86
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	9.12	243.00	277.02
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	8	9.44	243.00	2,293.92
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	9.52	243.00	578.34
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	9.60	243.00	583.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	10.00	243.00	303.75
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	11.36	243.00	345.06
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	8	11.76	243.00	2,857.68
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	11.84	243.00	359.64
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	3	11.92	243.00	1,086.21
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	8	12.00	243.00	2,916.00
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	4	16.16	243.00	1,963.44
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	16.24	243.00	986.58
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	17.60	243.00	534.60
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	2	17.84	243.00	1,083.78
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	7	17.92	243.00	3,810.24
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	1	19.20	243.00	583.20
Sub total: Level 9				**147**	**1107.36**		**33,636.06**
Level 10 - 26 LRF							
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	1.28	243.00	660.96
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	1.52	243.00	784.89
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	1.60	243.00	826.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	153	1.68	243.00	7,807.59
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	1.84	243.00	1,900.26
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	153	2.72	243.00	12,640.86
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	2.80	243.00	1,445.85
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	3.20	243.00	1,652.40
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	170	3.36	243.00	17,350.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	119	4.08	243.00	14,747.67
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	4.16	243.00	4,296.24
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	4.24	243.00	4,378.86
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	170	4.40	243.00	22,720.50
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	5.04	243.00	2,602.53
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	5.20	243.00	2,685.15
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	5.36	243.00	2,767.77
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	170	5.44	243.00	28,090.80
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	51	6.56	243.00	10,162.26
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	136	6.80	243.00	28,090.80
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	6.88	243.00	7,105.32
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	170	7.20	243.00	37,179.00
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	7.76	243.00	4,007.07

Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	8.08	243.00	8,344.62
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	9.12	243.00	4,709.34
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	136	9.44	243.00	38,996.64
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	9.52	243.00	9,831.78
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	9.60	243.00	9,914.40
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	10.00	243.00	5,163.75
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	11.36	243.00	5,866.02
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	136	11.76	243.00	48,580.56
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	11.84	243.00	6,113.88
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	51	11.92	243.00	18,465.57
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	136	12.00	243.00	49,572.00
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	68	16.16	243.00	33,378.48
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	16.24	243.00	16,771.86
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	17.60	243.00	9,088.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	34	17.84	243.00	18,424.26
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	119	17.92	243.00	64,774.08
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 9 to 26 LRF	17	19.20	243.00	9,914.40
Sub total: Level 10 - 26 LRF				**2499**	**18803.36**		**571,813.02**
Level 26 MRF							
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 MRF	1	5.28	243.00	160.38
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 MRF	1	5.36	243.00	162.81
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 MRF	2	14.24	243.00	865.08
Sub total: Level 26 MRF				**4**	**39.12**		**1,188.27**
Level 26 HRF							
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	3.68	243.00	111.78
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	11.20	243.00	340.20
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	11.36	243.00	345.06
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	20.16	243.00	612.36
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	20.40	243.00	619.65
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	22.80	243.00	692.55
Floor	Concrete, Cast-in-Place - C25	Insitu Concrete 125mm	Level 26 HRF	1	24.64	243.00	748.44
Sub total: Level 26 HRF				**7**	**114.24**		**3,470.04**
Grand total:				**2657**	**20064.08**		**610,107.39**

Schedule of Slab Material Take-Off (Rebar and Shear Link)										
Family	Type	Host Category	Base Level	Bar Diameter	Total Bar Length (mm)	Volume (cm3)	Total Weight (kg)	BRC Area (m2)	Cost (RM/kg) or (RM/m2)	Total Cost (RM)
Level 9										
Rebar Bar	6T	Floor	Level 9	6	37560674.88	1062140.76	8337.81	-	3.13	26,097.33
Sub total: Rebar					**37560674.88**	**1062140.76**	**8337.81**			**26,097.33**
Sub total: Level 9					**37560674.88**	**1062140.76**	**8337.81**			**26097.33**
Level 10 - 25										
Rebar Bar	6T	Floor	Level 10 -25	6	600970798.12	16994252.23	133404.88	-	3.13	417,557.27
Sub total: Rebar					**600970798.12**	**16994252.23**	**133404.88**			**417,557.27**
Sub total: Level 10 - 25					**600970798.12**	**16994252.23**	**133404.88**			**417557.27**
Level 26 LRF										
Rebar Bar	6T	Floor	Level 26 LRF	6	35711549.97	1009851.21	7927.33	-	3.13	24,812.55
Rebar Bar	10T	Floor	Level 26 LRF	10	1151196.65	90426.50	709.85	-	3.13	2,221.82
Rebar Bar	12T	Floor	Level 26 LRF	12	131696.31	14896.43	116.94	-	3.13	366.01
Sub total: Rebar					**36994442.94**	**1115174.14**	**8754.12**			**27,400.39**
BRC	A7	Floor	Level 26 LRF	7	-	-	93.25	15.20	11.02	167.46
Sub total: BRC							**93.25**	**15.20**		**167.46**
Sub total: Level 26 LRF							**8847.37**	**15.20**		**27,567.85**
Level 26 MRF										
Rebar Bar	6T	Floor	Level 26 MRF	6	594781.66	16819.24	132.03		3.13	413.26
Sub total: Rebar					**594781.66**	**16819.24**	**132.03**			**413.26**
BRC	A7	Floor	Level 26 MRF	7	-	-	54.65	8.91	11.02	98.15
BRC	A8	Floor	Level 26 MRF	8	-	-	148.97	19.47	14.42	280.74
Sub total: BRC							**203.62**	**28.37**		**378.89**
Sub total: Level 26 MRF							**335.65**	**28.37**		**792.14**
Level 26 HRF										
Rebar Bar	6T	Floor	Level 26 HRF	6	2102122.56	59443.82	466.63		3.13	1,460.56
Sub total: Rebar					**2102122.56**	**59443.82**	**466.63**			**1,460.56**
BRC	A7	Floor	Level 26 HRF	7	-	-	246.94	40.24	11.02	443.47
Sub total: BRC							**246.94**	**40.24**		**443.47**
Sub total: Level 26 HRF							**713.58**	**40.24**		**1,904.04**
Grand total: Rebar					**678222820.15**	**19247830.19**	**151095.47**			**472,928.81**
Grand total: BRC							**543.81**	**83.81**		**989.82**
Grand total:							**151639.28**	**83.81**		**473,918.63**

Appendix J: Schedules of structural stair materials take off.

Schedule of Stair Material Take-Off (Concrete)							
Family	Structural Material	Thickness (mm)	Base Level	Count	Volume (m3)	Cost (RM)	Total Cost (RM)
Level 8							
Cast-In-Place Stair	Monolithic Stair	150	Level 8	3	4.93	243.00	1,197.50
Sub total: Level 8				**3**	**4.93**		**1,197.50**
Level 9 - 24							
Cast-In-Place Stair	Monolithic Stair	150	Level 9 - 24	48	78.85	243.00	19,160.06
Sub total: Level 9 - 24				**48**	**78.85**		**19,160.06**
Level 25							
Cast-In-Place Stair	Monolithic Stair	150	Level 25	1	1.64	243.00	398.52
Sub total: Level 25				**1**	**1.64**		**398.52**
Grand total:				**52**	**85.42**		**20,756.09**

Schedule of Stair Material Take-Off (Rebar and Shear Link)									
Family	Type	Bar Diameter	Bar Length	Quantity	Total Bar Length	Volume (cm3)	Total Weight (kg)	Cost (RM/kg)	Total Cost (RM)
Level 8 Stair									
Rebar Bar	10R	10	470	462	217140	17056.35	133.89	3.13	419.08
Sub total: 10R				**462**	**217140**	**17056.35**	**133.89**		**419.08**
Rebar Bar	10T	10	1400	114	159600	12536.58	98.41	3.13	308.03
Rebar Bar	10T	10	2280	21	47880	3760.97	29.52	3.13	92.41
Rebar Bar	10T	10	2700	14	37800	2969.19	23.31	3.13	72.95
Rebar Bar	10T	10	3010	7	21070	1655.05	12.99	3.13	40.67
Rebar Bar	10T	10	3050	54	164700	12937.19	101.56	3.13	317.87
Rebar Bar	10T	10	4260	21	89460	7027.08	55.16	3.13	172.66
Rebar Bar	10T	10	4710	14	65940	5179.59	40.66	3.13	127.27
Rebar Bar	10T	10	5020	7	35140	2760.25	21.67	3.13	67.82
Sub total: 10T				**252**	**621590**	**48825.89**	**383.28**		**1,199.68**
Sub total: Level 8 Stair				**714**	**838730**	**65882.24**	**517.18**		**1,618.76**
Level 9 Stair									
Rebar Bar	10R	10	470	462	217140	17056.35	133.89	3.13	419.08
Sub total: 10R				**462**	**217140**	**17056.35**	**133.89**		**419.08**
Rebar Bar	10T	10	1400	141	197400	15505.77	121.72	3.13	380.98
Rebar Bar	10T	10	1480	54	79920	6277.72	49.28	3.13	154.25
Rebar Bar	10T	10	2280	21	47880	3760.97	29.52	3.13	92.41
Rebar Bar	10T	10	2700	14	37800	2969.19	23.31	3.13	72.95
Rebar Bar	10T	10	3010	7	21070	1655.05	12.99	3.13	40.67
Rebar Bar	10T	10	3050	54	164700	12937.19	101.56	3.13	317.87
Rebar Bar	10T	10	4300	21	90300	7093.07	55.68	3.13	174.28
Rebar Bar	10T	10	4710	14	65940	5179.59	40.66	3.13	127.27
Rebar Bar	10T	10	5020	7	35140	2760.25	21.67	3.13	67.82
Sub total: 10T				**333**	**740150**	**58138.78**	**456.39**		**1,428.50**
Sub total: Level 9 Stair				**795**	**957290**	**75195.13**	**590.28**		**1,847.58**
Level 10 - 24 Stair									
Rebar Bar	10R	10	470	6930	3257100	255845.21	2008.38	3.13	6,286.24
Sub total: 10R				**6930**	**3257100**	**255845.21**	**2008.38**		**6,286.24**
Rebar Bar	10T	10	1400	2115	2961000	232586.55	1825.80	3.13	5,714.77
Rebar Bar	10T	10	1480	810	1198800	94165.74	739.20	3.13	2,313.70
Rebar Bar	10T	10	2280	315	718200	56414.61	442.85	3.13	1,386.14
Rebar Bar	10T	10	2700	210	567000	44537.85	349.62	3.13	1,094.32
Rebar Bar	10T	10	3010	105	316050	24825.73	194.88	3.13	609.98
Rebar Bar	10T	10	3050	810	2470500	194057.78	1523.35	3.13	4,768.10
Rebar Bar	10T	10	4300	315	1354500	106395.98	835.21	3.13	2,614.20
Rebar Bar	10T	10	4710	210	989100	77693.81	609.90	3.13	1,908.98
Rebar Bar	10T	10	5020	105	527100	41403.71	325.02	3.13	1,017.31
Sub total: 10T				**4995**	**11102250**	**872081.74**	**6845.84**		**21,427.48**
Sub total: Level 10 - 24 Stair				**11925**	**14359350**	**1127926.94**	**8854.23**		**27,713.73**
Level 25 Stair									
Rebar Bar	10R	10	600	144	86400	6786.72	53.28	3.13	166.75
Sub total: 10R				**144**	**86400**	**6786.72**	**53.28**		**166.75**
Rebar Bar	10T	10	1400	35	49000	3848.95	30.21	3.13	94.57
Rebar Bar	10T	10	1470	9	13230	1039.22	8.16	3.13	25.53
Rebar Bar	10T	10	1480	18	26640	2092.57	16.43	3.13	51.42
Rebar Bar	10T	10	2560	7	17920	1407.62	11.05	3.13	34.59
Rebar Bar	10T	10	3050	18	54900	4312.40	33.85	3.13	105.96
Rebar Bar	10T	10	3420	7	23940	1880.49	14.76	3.13	46.20
Rebar Bar	10T	10	4360	7	30520	2397.35	18.82	3.13	58.90
Rebar Bar	10T	10	5320	7	37240	2925.20	22.96	3.13	71.87

Sub total: 10T	108	253390	19903.78	156.24		489.05
Sub total: Level 25 Stair	252	339790	26690.50	209.52		655.80
Grand total:	13686	16495160	1295694.82	10171.20		31,835.87