

**CHALLENGES IN BIM IMPLEMENTATION ON LEVEL OF
DEVELOPMENT (LOD) 300**

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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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September 2021

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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ABSTRACT

Building Information Modelling (BIM) is a process that building infrastructure and digital information are created and managed within one 3D model throughout the whole building life cycle. However, there are some problems faced when implementing BIM such as the lack of human resources, financial considerations, and process difficulties. Thus, the aim of the research is to analyse the challenges for client in implementing BIM in the project. The objectives of this research are identifying the vital BIM implementation process during the construction stage, analyse the clashes in the project, and apply a solution to solve the challenges in the 3D model with LOD 300. In this research, Autodesk Revit is used to generate 3D models of residential houses which are five units of double storey terrace house and two units of double storey semi-detached house located in Sarikei, Sarawak. The finalized 3D models are then exported to two structural analysis software, Esteem and Tekla Tedds to perform structural analysis. However, the models of the building were manually drawn due to the compatibility of the software. Eurocode 2 is chosen for the design standard for the structural analysis in the software. Besides that, the static loads such as dead loads and live loads are determined in the 3D models based on Uniform Building by Law 1994. Throughout the analysis, the structural behaviour of the 3D models are collected and studied to improve any necessary of the structural members. After the modifications in Esteem and Tekla Tedds, the 3D models in Autodesk Revit are redesigned to match the modifications made in Esteem and Tekla Tedds. Then, architectural models of the buildings performed clash detection in Autodesk Revit. Architectural models has more elements presented than structural models. Thus, it is important for the architectural models to ensure no clashes between elements and other elements are detected in the models. There were a total of 205 clashes in the architectural models whereas there was only one clash occurred in the structural models. Furthermore, modifications have been made to improve the 3D models by relocating the elements in the correct position and deleting unnecessary elements in the models. Lastly, clash detection is performed again to ensure no interferences detected in the 3D models by Autodesk Revit. This research concludes that the clashes can be detected by Autodesk Revit without searching it manually with our eyes which is not fully accurate compared to the software.

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LIST OF SYMBOLS / ABBREVIATIONS

2D	2 Dimensions
3D	3 Dimensions
4D	4 Dimensions
5D	5 Dimensions
6D	6 Dimensions
7D	7 Dimensions
AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
BDA	Building Design Advisor
BDS	Building Description System
BIM	Building Information Modelling
BPM	Building Product Model
BS	British Standard
CAD	Computer-Aided Design
CDE	Common Data Environment
CEO	Chief Executive Officer
CIDB	Construction Industry Development Board
COBie	Construction Operation Building Information Exchange
CQ	Commercial Quality
EC2	Eurocode 2
EdCAAD	Integrated CAAD System
EN	English
fcu	Compressive Strength of Concrete
GBM	Generic Building Model
GDP	Gross Domestic Product
GDS	Global Distribution System
IFC	Industry Foundation Classes
LOD	Level of Development / Level of Detail
MEP	Mechanical, Electrical and Plumbing
MPS	Model Progression Specification
O&M	Operation and Maintenance

PWD	Public Work Department
RM	Ringgit Malaysia
RMK11	Rancangan Malaysia ke-11
RUCAPS	Riyadh University Computer Aided Production System

Chapter 1

INTRODUCTION

1.1 General Introduction

The BIM system started way back in the earliest days of computing. In 1962s, Douglas C. Englebart was first written the foundation of BIM recorded in the paper to give an uncanny vision of future architect (Green, 2016). As time goes by, many design researchers were influenced in other countries and started developing their software. Englebart's vision became reality as the first successful developments to create a building database was Building Description System (BDS) in the early 1970s (RIB International, 2017). Charles Eastman is the creator of BDS (RIB International,2017). Graphical user interface, orthographic and perspective views were used by the program which allows the user to get information by attributes (RIB International, 2017). However, BDS is limited to design choices including structural and architectural which leads to lack of popularity in the construction firm (RIB International, 2017).

There were also many systems developed in England that gained supports and were used to constructure projects in the early 1980's (Quirk, 2012). The systems included GDS, EdCAAD, Cedar, RUCAPS, Sonata and Reflex (Quirk, 2012). A new program called Building Product Model (BPM) was soon developed in the 1989s which provides designing, estimation and construction processes from the project throughout its life cycle (RIB International, 2017). In the AEC industry, integrating information is important for design and construction management but BPM only focused on product information (RIB International, 2017). In the beginning of 1993, Lawrence Berkeley National Lab developed a software environment called Building Design Advisor (BDA) (Quirk, 2012). Throughout the building design process from the start, theoretical and schematic stages to the detailed specification of building parts and systems, this software helps the integrated use of numerous analysis and visualization tools (Papamichael, et al., 1997). BDA acts as a data manager and process controller as it uses object-oriented that represent the building (Papamichael, et al., 1997). The capabilities of BDA can benefit building designers from its multiple tools given.

As the development were in a rapid pace in the United States, Gábor Bojár, a physicist who developed ArchiCAD in 1982 in Budapest, Hungary (Etiido, 2020). This software can add multiple features such as doors, windows, slabs, and many others (Etiido, 2020). The software Radar CH which used same technology as the Building Description System was released in 1984 for Apple Lisa Operating System (Quirk, 2012). It later became ArchiCAD which it was the first BIM software available on a personal computer (Quirk, 2012). Generic Building Model (GBM) was developed in 1995s to integrate information in a project which allows stakeholders in project to cooperate (RIB International, 2017).

In 2000, a company called Charles River Software developed a program called Revit (Solomon, 2016). Revit can design and document a building by architects and other building professionals (Solomon, 2016). Soon, BIM software became a methodology that is fully developed we know today (Kuijpers, 2018). Autodesk obtained Revit Technology Corporation in 2002. Instead of using DWG-format, Revit became the basis of future developments for Autodesk in 2003 (Kuijpers, 2018). Figure 1.1 shows the development of BIM definition (RIB International, 2017).

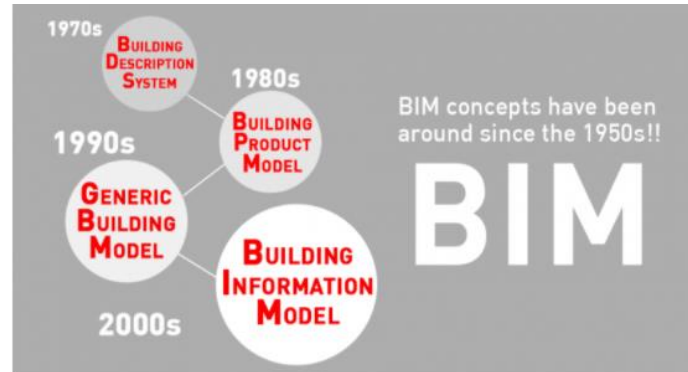


Figure 1.1: The Development of BIM Definition (RIB International, 2017).

By comparing the BIM design and traditional 2-dimension design, BIM design has more advantages such as accurate visualisation, less rework, more effective communication, work faster and improve conflict resolution (Small Business Exchange Inc, 2018). Therefore, application of BIM is considered as the future trend in construction industry. In 2007, Malaysian construction industry was introduced to BIM by Director of Public Work Department (PWD) (Haron, et al., 2017). BIM Committee was established by PWD to search suitable BIM tools to be used in

construction project (Ahmad Latiffi, et al., 2013). BIM Committee used Autodesk as their BIM tool to improve their practices from 2D to 3D in 2010 and their practices are provided for the construction industry from 2011 onwards (Ahmad Latiffi, et al., 2013). This movements show that the government cares about the adoption of BIM in the industry to prevent fall behind of other countries. Figure 1.2 shows the roadmap for BIM Maturity and implementation process in Malaysia (myBIM Malaysia, 2017).

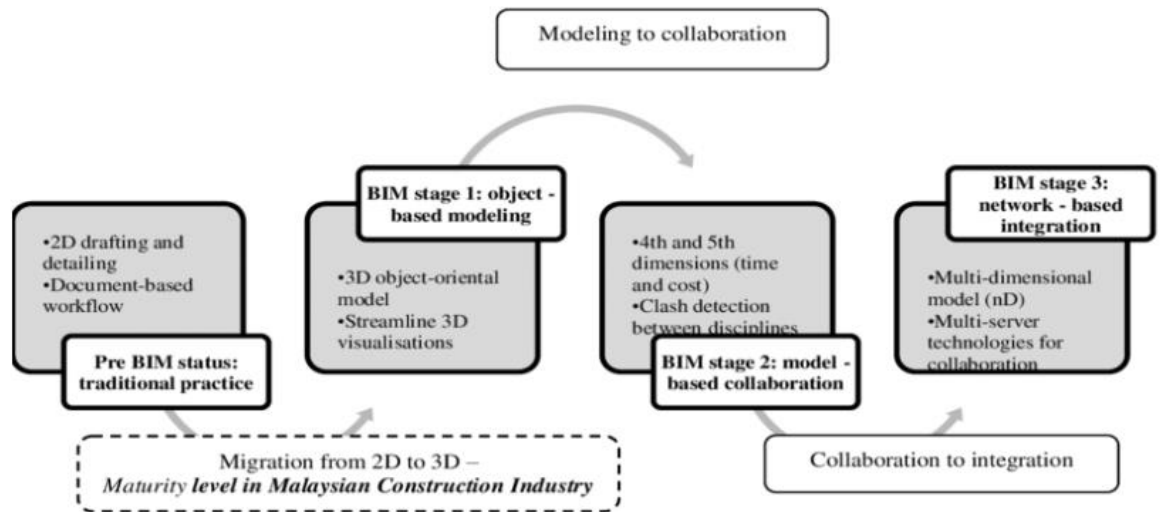


Figure 1.2: Roadmap for BIM maturity and implementation process in Malaysia (Roshana Takim, et al., 2009).

1.2 Problem Statement

In the construction industry, BIM has no doubt in lowering the construction time and save more materials through improving the conflict resolution in the design phase. The stakeholders of a project directly derive the information needed from the model by building a model in the BIM's software. In the construction industry, BIM is used as a methodology for construction in many developed countries. Figure 1.3 shows the BIM adoption in construction industry (Haron, et al., 2017).

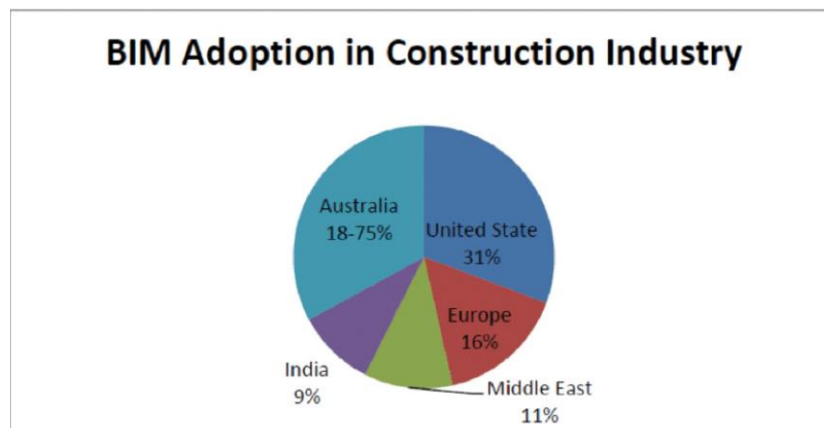


Figure 1.3: The BIM Adoption in Construction Industry (Haron, et al., 2017).

The implementation of BIM in projects is decided by the Malaysian government in 2016 (Haron, et al., 2017). However, the rate of BIM adoption is still low in Malaysia as the industry has not fully accepted it. This is due to there were many challenges faced by the construction industry that reduce the rate of BIM adoption in Malaysia. Some contractors on construction company and property development in Malaysia did not adopt BIM for building industry (Kong, et al., 2020). CIDB had studied the adoption and awareness of BIM among the contractors in Malaysia (Kong, et al., 2020). Figure 1.4 shows the percentage of adoption and awareness of BIM in Malaysia (Kong, et al., 2020).

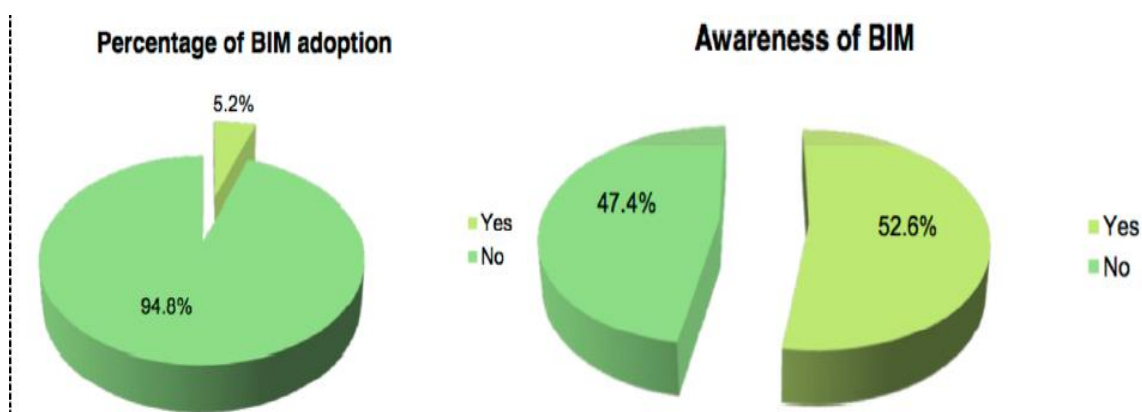


Figure 1.4: Percentage of Adoption and Awareness of BIM in Malaysia (Kong, et al., 2020).

Firstly, the importance and benefits of BIM implementation is needed to be spread among the Malaysian construction industry so that the work processes will be quicker and simpler during the construction stage. Besides that, input of needed

parameter in the building of BIM model and clash detection is needed to be identified. Then, the inputs are needed to be studied from the previous research, standards, or guidelines so that the results are generated accurately. Next, strategies in performing clash analysis are needed to be investigate in 3D BIM modelling and identify the errors in the 3D model. Lastly, various solutions are needed to be identified to solve the errors in the 3D model.

1.3 Aim and Objectives

The aim of this research is to analyse the challenges for client in implementing BIM in the project.

The objectives are:

- i. To Identify the vital BIM implementation process during construction stage.
- ii. To analyse the clashes in a project.
- iii. To apply a solution to solve the challenges in the 3D model with LOD 300.

1.4 Scope and Limitation of the Study

The scope of this research is to build the structural BIM's model based on a real structure of Sarikei, Sarawak's double storey terrace house and double storey semi-detached house in Autodesk Revit. Once the model is generated in Autodesk Revit, it will undergo clash detection to determine any errors are presented.

There are some limitations of study in this research. Firstly, the architectural and structural plans given by the supervisor are hard to analyse due to the plans are scanned instead of getting the softcopy of the plan. The plans are hard to analyse due to the clearness of the words and dimensions of the structure. Besides that, it was my first-time using Autodesk Revit and it takes time to learn before creating a BIM model. Tutorials on the Internet and consultation with my friend who used Autodesk Revit teach me to create the BIM model, but it takes a lot of time to learn. Not only that, the information of the buildings are also not fully given which makes the BIM model not generated completely such as the roof plan, descriptions for windows and doors, and descriptions for stairs.

1.5 Contribution of Study

The findings from this paper will benefit the construction industry in term of the derivation of information from BIM's model to undergo clash detection. By deriving the information from the BIM's model, structural engineers only required to build the model once in the BIM software. This will save up a lot of time because changes in construction drawing occurs frequently in the construction industry.

Besides, from the result of this research, engineers from the industry can have a clearer picture about how identify the clashes occurred in the project. This will help the engineers to have a better preliminary planning on the structural members during the design stage of a construction project. In addition, the findings of this research can provide useful information to the construction industry who consider adopting BIM in their project.

1.6 Importance of the Study

This research will give carry out clash detection in Autodesk Revit using the information derived the BIM's model. From the analysis, the clashes between elements from a model will be defined. Through the analysis, overlapping of elements from a model will cause structure to fail can be identified. Although the model being manufactured off-site, conflicts can be minimized by clash detection as all the elements are fit perfectly into each other.

1.7 Chapter Outline

There are five chapters included in this paper:

Chapter 1 is the introduction of BIM and its history. This chapter included the importance of the study, problem statement, aims and objectives, scopes and limitations of the study and contribution to the society.

Chapter 2 is the literature review. A brief introduction for Building Information Modelling (BIM) Lifecycle, Level of Development (LOD), Building Information Modelling (BIM) Dimensions, and BIM tools are described in this chapter. Besides that, the BIM adoption in Malaysia is introduced together with the government effort, challenges of BIM adoption, and benefits of BIM. Lastly, the modelling and clash

detection of project from different parties are studied and how information from different parties is exchange to each other during the lifecycle of the project.

Chapter 3 is the methodology and the flow of works throughout the research. In this research, Autodesk Revit, Esteem, and Tekla Tedds will be the software involved. Step by step procedures in both software will described and explained in this chapter.

Chapter 4 is the results and discussions. This chapter consists of all the results and outcomes of this research. In this chapter, the results are discussed in terms of defining static load of the 3D models, designing stairs, structural analysis, and clash detection. The errors from structural analysis and clash detection are modified to prevent any further issue when running the analysis.

Chapter 5 is the conclusions and recommendation. The chapter conclude the results in this research and confirm the unity between the objectives and the final results. Besides, in this chapter, recommendations are also proposed for the research or study in the future.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

There are many definitions of BIM by different authors on the internet as the definition of BIM varies from time to time. For example, BIM is a visual database that collects data from every construction to work with each other more efficiently (Josseaux, 2018). BIM is a process that building infrastructure and digital information are created and managed within one 3D model throughout the whole building life cycle such as building, bridge and other more (designingbuildings.co.uk, 2020). Objects that have intelligence, geometry and data are used by BIM to create 3D model (Woon, 2015). BIM software can update the 3D model to reflect the changed elements from the model (Sarah, 2018). Stakeholders can make decision based on the integrated information from the model (Sarah, 2018).

Another definition for BIM is a physical and functional characteristic of a facility presented by a digital software according to the US National Building Information Model Standard Project Committee (Cherkaoui,2017). Information as BIM is a shared knowledge resource can be gathered to make decisions during the lifecycle of the project from earliest conception to demotion. Information in the BIM is inserted, extracted, updated, or modified by different stakeholders at various phase of the project's lifecycle to help each other (Cherkaoui, 2017).

Clash detection in BIM is one of the most important phases in the project lifecycle. Clash occurs in the design phase when the components in the 3D BIM model is not coordinated well where two or more components interfere each other (McPartland, 2016). Before BIM was introduced, project teams had to overlay the drawing to identify the errors which was a tedious process. Figure 2.1 shows the clash of components in the BIM model (Massantini ,2018).

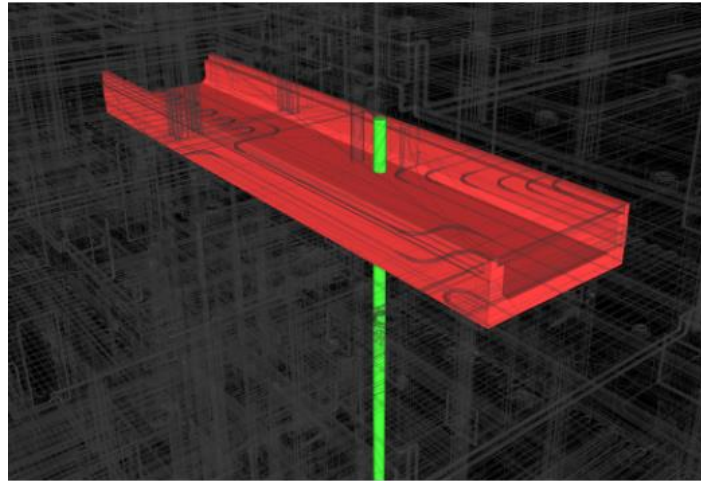


Figure 2.1: The Clash of Components in BIM Model (Massantini ,2018).

Clash detection will be studied in this research. Throughout the research, building information modelling (BIM) model of terrace houses are built and used for clash detection analysis. For clash detection analysis, Autodesk Revit is chosen as the method to identify all the instances of clashes in the model when all other models are combined into a single entity. Once they are identified, solutions are provided to solve these clashes.

2.2 Building Information Modelling (BIM) Life Cycle

All suitable information and specification regarding to the project are integrated by modern BIM modelling that can provide accurate data to the project teams with cost of the project, constraints of programming and location of service (Cherkaoui, 2017). Overall management of the project in all its stages are necessary as different project teams handle specific tasks in different stages in life cycle of projects (Cherkaoui, 2017). This life cycle of Building Information (BIM) includes the steps from designing, to building, to operation lastly. There are ten phases included are programming, conceptual, detailed design, analysis, documentation, fabrication, construction 4D/5D, construction logistics, operation and maintenance and renovation. A huge span of time and collaboration with BIM are needed to collect a lot of accurate data (Moilanen, 2019). Figure 2.2 shows the life cycle of Building Information Modelling (BIM) (Cherkaoui,2017).



Figure 2.2: Life Cycle of building Information Modelling (BIM) (Cherkaoui,2017).

2.2.1 Design Phase

The first phase of the BIM life cycle is design phase which includes programming, conceptual design, and detailed design. The project teams are required to determine what kind of structure is needed to be built and how and who build it (Milovidova, 2014). So many inputs are necessary to be obtained from the project teams for the programming process (Milovidova, 2014). At the earliest stage of project, project management and procurement services such as bills of quantities based on detailed design produced are provided by the project teams (Medium, 2017). This allows the teams to improve their accuracy of decision and develop performance goals (Bimgenia, 2012). Not only that, cost and preliminary schedule is developed in earlier stages and more accurate compared to traditional project methods. They can be linked to BIM to allow the project team to adapt the cost of the design decisions (Milovidova, 2014).

Next, there will be different options suggested from the project teams and needed to test their design to determine the team main decision (Milovidova, 2014). The project teams needed to optimize the design as the scope and price of the project are fixed (Milovidova, 2014). The project teams can compare their design options such as material choices on the 3D model which allows them to control the cost and long-

term maintenance concerns (Moilanen, 2019). The decision making will be better where the project teams collaborate to help to improve the quality and reduce risk (Bimgenia, 2012). The preliminary schedule is further developed to improve it and the agreement for prefabrication is achieved by the project team's decision (Milovidova, 2014). At the end of design phase, all the design decision is finalized. All building elements and systems are defined and coordinated such as fixtures and equipment (Milovidova, 2014). This last phase will have a longer period as it has more decision to achieve compared to traditional design development. Figure 2.3 shows the design phase throughout the construction project (Ryan, 2020).



Figure 2.3: Design Phase throughout the Construction Project (Ryan, 2020).

2.2.2 Build Phase

The next phase after design phase is build phase. The project teams including constructors, trade contractors and suppliers will analyse how the structure will be built (Milovidova, 2014). They had to ensure that the entire project is well defined and coordinated at the beginning. Accurate 3D model can help to minimize unnecessary documents and interferences during construction (Bimgenia, 2012). Some systems of the project able to commence its prefabrication as the object sizes are fixed (Milovidova, 2014). This allows the fabricator to produce the materials needed earlier for the project. Structural engineer also saves time to trace the structural design process and documentation through an analysis of the model (Bimgenia, 2012).

Since conflicts such as design and clashes have been solved through BIM, on-site construction administration work will be less needed (Milovidova, 2014). Project

teams will have better understanding of the design since this information is easily accessible to everyone. Once the building is finished constructed, a complete BIM is provided to the owner for their long-term use for building maintenance (Milovidova, 2014). Figure 2.4 shows the build phase throughout the construction project (Ryan, 2020).



Figure 2.4: Build Phase throughout the Construction Project (Ryan, 2020).

2.2.3 Operation Phase

The last phase of the BIM life cycle is operation phase. The preparation of construction and the cost of the project are enabled through 4D and 5D (Milovidova, 2014). Construction equipment and labour only subcontractors will be hired to help in the project (Medium, 2017). The site will be supervised by the project or site managers while the safety of the site will be handled by the site security (Medium, 2017). The project teams can utilize the materials efficiently which creates less waste produced during the early planning (Bimgenia, 2012). Accurate information is also spread among the teams which gives them better understanding of the project (Milovidova, 2014). Hence, less conflicts will be occurred.

The changes in the project can be minimized and operational revenue will not be lost (Bimgenia, 2012). The budget and schedule of the construction will be completed (Bimgenia, 2012). The commission process of the project begins after the

building is completed where the facility management team will be provided with the BIM data (Moilanen, 2019). Site management team able to identify the best practices for maintaining the structure when any maintenance of the building is updated in the BIM files (Moilanen, 2019). The BIM model and BIM software should update if any repair or improvement is done to the building (Moilanen, 2019). Complete virtual building is provided to the owners for operational and renovation purposes (Medium, 2017).

2.3 Level of Development (LOD)

Model Progression Specification (MPS) concept was presented by Vico Software in 2004 to ease the management of information within BIM models (Singh, 2016). LOD was first known as “Level of Detail” that establish the progressive dependable of information (Singh, 2016). A similar concept that described five different levels of development about the detailing levels in a BIM model was soon presented by American Institute of Architects (AIA) in 2008 (United-BIM, 2017). All the parameters and details that linked with digital model are obtainable for the masses at every stages of the design process (United-BIM, 2017). Now, an addition of LOD 350 is added and most of elements in a model must reach at least up to LOD 350(United-BIM, 2017). The definition of LOD can be separated into two different concepts which are level of development and level of detail. Level of development of a BIM model is a solid decision is needed to be made based the amount of information which is suitable to the concrete development of the project (Trace Software, 2020). All information from the BIM element is designed by the level of detail (Trace Software, 2020).

The design requirement at each stage of is indicated by the LOD by the American Institute of Architects (AIA) (Truecadd.com, 2021). There are six stages of LOD starting from LOD 100 up to LOD 500. LOD 100 is the pre-design stage where parameters are defined such as area, volume, and location (Truecadd.com, 2021). LOD 200 is the schematic design where quantity, size, shape, and location of the elements from a general model are approximately identified (Truecadd.com, 2021). At LOD 300 which is the detailed design, the quantity, size, and location of the element are precisely defined (Srinsofttech.com, 2021).

At construction documentation as LOD 350, information about element connection with other parts and different systems and model detail are described (Srinsofttech.com, 2021). LOD 400 is the fabrication and assembly stage where the elements from the model are fabricated and assembled completely according to the detailed information (Srinsofttech.com, 2021). Lastly, LOD 500 is the as-built model that presents the model with real-life functions of elements in a real building (Truecadd.com, 2021). Figure 2.5 shows the Level of Development (LOD) stages in Building Information Modelling (BIM) (Srinsofttech.com, 2021).

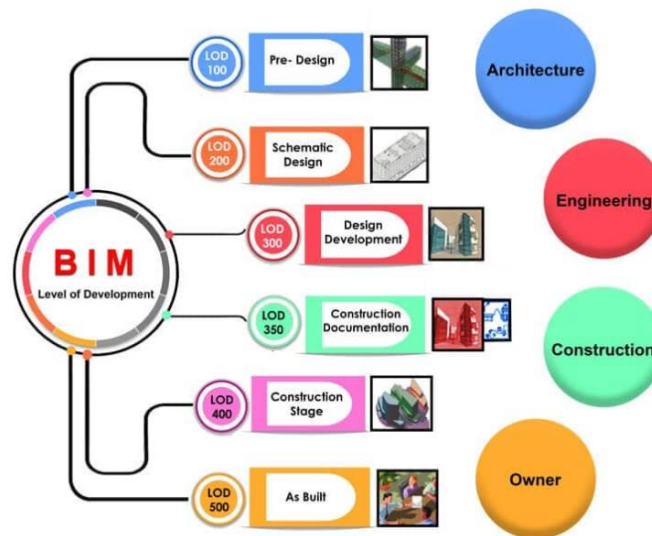


Figure 2.5: Level of Development (LOD) Stages in Building Information Modelling (BIM).

2.4 Building Information Modelling (BIM) dimensions

Information of models can be created by Building Information Modelling (BIM) throughout the whole lifecycle of a project. The level of development (LOD) in a BIM model escalated to different levels as the project passes through different stages. BIM model is utilized for pre-defined specific purposes known as use-cases because specific parameters are needed to add into the BIM as the different stages of the project have specific requirements needed to be achieved. BIM dimensions can be clarified as pre-defined used cases. Information about the model can be enhanced by these dimensions to further understand the project. BIM technology in the current era has grown from basic 3D and 4D dimensions up to 5D, 6D and 7D dimensions to improve the AEC industry in the future. BIM dimensions able to figure out the project cost,

timeline, and the time for the project to complete. Figure 2.6 shows the different level of BIM dimension (Microweber, 2021).



Figure 2.6: The different level of BIM dimensions (Microweber, 2021).

2.4.1 3D BIM

3D BIM is the most commonly form of BIM. Graphical and non-graphical information are gathered by 3D BIM to build the 3D models and this information can be shared in a Common Data Environment (CDE) (3D Repo BIM Online, 2019). To prevent the unnecessary rework costs and the construction work being takes place, precise inputs of information must be provided by the collaborating parties so they can identify and solve the issues. Project teams able to co-operate together effectively from a single source.

2.4.2 4D BIM

Time-related information connected to various components from the 3D model to enable detail scheduling in the construction process is involved in 4D BIM (Mills, 2016). This information can be included with construction and installation period, curation of material and interdependencies between various work tasks (Mills, 2016). Planners able to create an accurate time schedules from an earlier stage in the project compared to traditional workflow based on these data. Planners can also visualise how the project will progress over time (Ernstsen, 2019).

2.4.3 5D BIM

Cost data are added to the BIM model by 5D BIM. Cost data such as purchase cost, running cost and renewal cost are associated with every part in the BIM model (Ernstsen, 2019). BIM model can calculate the total project cost by multiplying the amount of each part of the model with its cost (Ernstsen, 2019). 5D BIM can assist in creating an accurate cost estimates and how the potential changes can affect the cost during the planning and design stage (Ernstsen, 2019). Project teams can identify the issues by using 5D BIM to compare predicted and actual expenditures (Ernstsen, 2019).

2.4.4 6D BIM

6D BIM is known as sustainability process where it is used to make the structure sustainable and energy efficient. This information allows stakeholders to analyse the amount of energy being consumed by the structure and produce an estimation of energy usage during the initial design phase. Energy consumption in long run will decrease and enhance the operational management after the construction is finished (Schoen, 2020).

2.4.5 7D BIM

Project life cycle information or facilities management is also known as 7D BIM process. Designer will develop a model and consistently updating it until it reaches as-built model throughout the construction process. So, precise data needed to be captured and recorded throughout the construction process. Data includes expected lifespan, operation, and maintenance (O&M) manuals and warranty information are also contained in the model for future maintenance Hence, better decision can be made to monitor the lifecycle of the building and optimizing its cost efficiency. (CONSTRUCTION LIFECYCLE, 2018). Facilities managers able to plan the maintenance activities in advance with the amount of data contained in the model (3D Repo BIM Online, 2019).

2.5 BIM tools suggestion

Many companies have designed software that helps them to work within a BIM framework because it is difficult to collect relevant information when working on a building project (Haron, et al., 2017). There is a lot of BIM software available in the market such as Bentley Architecture, Autodesk Revit, Vector Works, ArchiCAD, Tekla Structure etc. These software have additional information like time, cost, manufacturer's details, sustainability, and maintenance information which are different than architectural drafting tools such as AutoCAD (Haron, et al., 2017). Users from different disciplines can use different BIM tools that suits their field. Figure 2.7 shows the BIM tools that used by different users in Malaysia Construction Industry suggested by Public Works Department (Haron, et al., 2017).

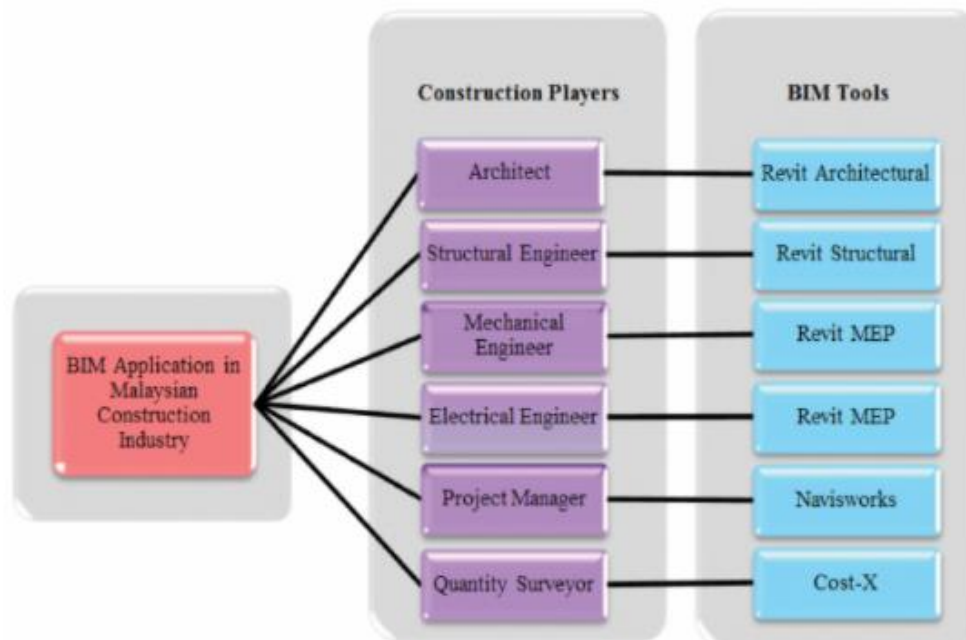


Figure 2.7: BIM Tools that used by Different User in Malaysia Construction Industry suggested by Public Works Department (Haron, et al., 2017).

2.5.1 Autodesk Revit

Autodesk Revit is a building information modelling software for wide array of users such as architects, designers, construction, and project managers (Kai, 2020). It offers a wide flexibility for the users to make and modify their own content. Users can design a building structure and its components in 3D, get information from the building model

and interpret the model in 2D drafting element (Haron, et al., 2017). Revit also can act as a collaboration tool across multidisciplinary teams in a project. Figure 2.8 shows Autodesk Revit Logo (SeekLogo, 2014).



Figure 2.8: Autodesk Revit Logo (SeekLogo, 2014).

2.5.2 Tekla Structures

Tekla Structures was developed by Trimble and XSteel which is a steel structural modelling software (Kai, 2020). Glass, steel, wood, concrete and other building materials can be used by Tekla (Kai, 2020). Tekla Structures is also one of the most advanced structural BIM software that allows users to create, combine, manage, and share 3D models consisted with construction information. Figure 2.9 shows Tekla Structures Logo (Teklastructures.support.tekla.com, 2021).



Figure 2.9: Tekla Structures Logo (Teklastructures.support.tekla.com, 2021).

2.5.3 ArchiCAD

ArchiCAD is mostly used by architects, designers, engineers, and urban planners for a large range of projects. ArchiCAD is more accessible for beginners to learn as its functions are straightforward (Kai, 2020). It is one of the longest-standing BIM software on the market for 30 years (Kai, 2020). ArchiCAD is suitable for architects as it provides algorithmic design tools and large model support to allow the users to

design in higher quality (BIMES, 2015). ArchiCAD's analysis tools can solve the problem in the earliest stage of the design which makes the design to be more accurate (BIMES, 2015). Figure 2.10 shows Graphisoft Archicad Logo (BIMES, 2015).



Figure 2.10: Graphisoft Archicad Logo (BIMES, 2015).

2.6 BIM adoption in Malaysia

In the construction field, the implementation of BIM is increasing worldwide which it allows the evolution of the construction industry to be greatly influenced (Mamter, et al., 2017). The implementation of BIM is considered important as it has wide range of benefits in the construction projects which helps to expand the productivity across the stakeholders (Roger, et al., 2015). However, the adoption of BIM in Malaysia is still low, and it is estimated that only 10 percent of the construction projects used BIM according to the Construction Industry Transformation Plan (Mamter, et al., 2017).

Nevertheless, Malaysia as a developing country is still in the middle of BIM adoption. Malaysia economy such as Gross Domestic Product (GDP) is contributed approximately three to five percent annually by the construction industry in Malaysia (Othman, et al., 2020). Therefore, construction industry in Malaysia plays an important role to the nation's economy. The role of adoption of BIM played by governments is very important as they are the main initiator and paymaster (Roger, et al., 2015). Since 2007, Malaysian construction industry has been trying to enhance their construction performance through the introduction of BIM (Othman, et al., 2020). About 10 percent of the public projects at the budget above RM50 million during 2007 trying to implement BIM by Malaysian Public Work Department (PWD) under Rancangan Malaysia ke-11 (RMK11) (Othman, et al., 2020). Sooner in 2018, any public project at the budget above RM100 million is mandated to use BIM (Othman, et al., 2020).

Currently, the BIM implementation in different phases in PWD's projects has a total of 18 projects included according to the PWD Director-General, Datuk Seri Dr

Roslan Md Taha (Othman, et al., 2020). Figure 2.11 shows the BIM Implementation Phases in four PWD's BIM Projects (Othman, et al., 2020).

Project	Concept design	Prelim. design	Detailed design	Procurement	Construction	As-Build
National Cancer Institute Putrajaya					√	√
SMK Meru Raya Ipoh Perak		√				
Health Clinic Maran Pahang		√	√	√	√	√
MACC Selangor Shah Alam	√	√	√	√	√	√

Figure 2.11: BIM Implementation Phases in four PWD's BIM Projects (Othman, et al., 2020).

2.7 Malaysian government effort

The Malaysian government has been putting a lot of efforts to help the construction industry in Malaysia by encouraging the use of BIM. In 2017, CIDB announced that the upcoming five public projects that worth more than RM500 million will be adopting BIM by 2020 (The Malaysian Reserve, 2017). BIM have been implemented by leading property developers such as Brasfield & Gorrie and Sunway Property in their construction development according to CIDB CEO Datuk Ahmad Asri Abdul Hamid. This results in multiple interests are shown in BIM by developers around Malaysia (The Malaysian Reserve, 2017). Clients have also increased their demand on designers and builders to equip BIM which triggers the architectural firms to show interest in BIM training. CIDB also launched a new MyBIM Centre located in Sunway Putra Mall, Kuala Lumpur in 2017. This MyBIM Centre is to encourage and expand

the usage of BIM in the Malaysian construction industry (The Malaysian Reserve, 2017). It is also act as a reference hub for construction professionals which supply them with the latest information on the BIM software. Figure 2.12 shows MyBIM Studio (Cidbec.com.my, 2017).



Figure 2.12: MyBIM Studio (Cidbec.com.my, 2017).

BuildingSMART Malaysian Chapter was created by the government to spread the awareness of the importance of collaboration and interdependency and enforce BIM adoption in Malaysia with the support from CIDB (Woon, 2015). Figure 2.13 Shows the collaborative framework for BIM adoption in Malaysia (Woon, 2015).

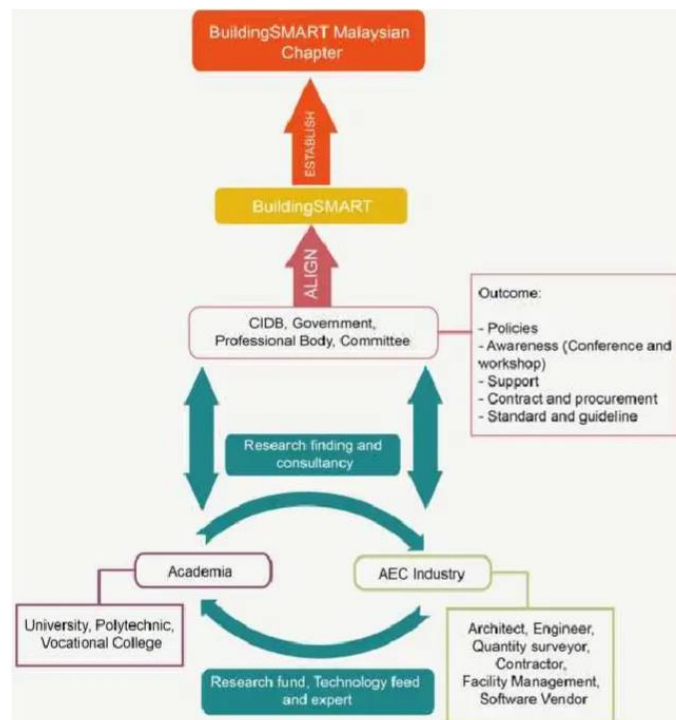


Figure 2.13: Collaborative Framework for BIM Adoption in Malaysia (Woon, 2015).

In 2019, Ministry of Work Secretary General, Datuk Dr Syed Omar Sharifuddin Syed Ikhsan announced that all 20 local authorities with city status in Malaysia must use BIM in their initial project submission stage by 2021 (Nurafizah Amiruddin, 2019). The government is collaborating with four authorities such as Putrajaya Corporation, Petaling Jaya City Council, Melaka Historical City Council, and Kangar Municipal Council to run four public projects in 2019 (Nurafizah Amiruddin, 2019). Advance technology such as BIM is required a large attention by the construction industry as it is a key changer to ensure the construction industry's competitiveness on local and international fronts are maintained consistently (Nurafizah Amiruddin, 2019). All developers including both public and private are needed to mandate BIM adoption in the future according to Syed Omar Sharifuddin (Nurafizah Amiruddin, 2019).

In 2020, works minister Datuk Seri Fadillah Yusof expected the Malaysian construction industry to implement BIM within the next five years as it can help the industry to be sustainable in long run (Afiq Aziz, 2020). Public Works Department (JKR) Strategic Plan 2021-2025 is released to the public and its purpose is to increase the BIM adoption up to 50 percent in 2021 and 80 percent by 2025 (Afiq Aziz, 2020).

2.8 Challenges in adopting BIM

There is no doubt that BIM offers a lot benefit to the construction industry, but difficulties are also faced in implementing BIM. Before implementing BIM in construction industry of any country, the implementation of BIM is a very challenging task and barriers are required to be managed to able to succeed. However, these challenges and barriers are different from country to country which depends on the industry environment (Gardezi, et al., 2014). The challenges and barriers that Malaysia is facing in adopting BIM are the expenses needed, lack of skilled human resource, and process difficulties (Roger, et al., 2015).

2.8.1 Financial considerations

Initial investment is required for BIM implementation as it is one of the barriers to BIM implementation. New and upgraded hardware are required to run the intensive

processes in BIM (Roger, et al., 2015). The current Malaysia price for Autodesk Architecture, Engineering & Construction Collection is RM22777 per every 3 years. Not only that, other costs such as training and software updates also hinder the implementation of BIM in the Malaysian construction industry (Cidb.gov.my., 2016). Figure 2.14 Shows the rank of challenges in BIM adoption (Cidb.gov.my., 2016).

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 2.14: The rank of Challenges in BIM Adoption (Cidb.gov.my., 2016).

2.8.2 Human resource

The awareness and interests in BIM have been expanding in many organizations in Malaysia. However, lack of BIM trainings and knowledge on BIM, and less awareness of BIM benefits affects the rate of BIM adoption in Malaysia (Cidb.gov.my., 2016). Figure 2.15 shows the percentage of respondents interested in using BIM within an organization (Cidb.gov.my., 2016).



Figure 2.15: The Percentage of Respondents Interested in Using BIM within an Organization (Cidb.gov.my., 2016).

Currently, CIDB has myBIM centre that helps construction professionals to prepare the implementation of BIM in their organization through short courses and trainings, but only limited amount of BIM professionals are capable of adopting BIM (Cidb.gov.my., 2016). Many respondents believes that BIM adoption will give benefits to their organization. However, there is not concrete evidence that proofs BIM adoption is beneficial to the organization (Cidb.gov.my., 2016). Besides that, this makes many organizations being uncertain of BIM that could enhance the organization's productivity.

2.8.3 Process difficulties

The readiness to change for an organization is also a factor that affects the adoption of BIM in Malaysia (Cidb.gov.my., 2016). A revolutionary shift in the work processes and technology within the organization are required by BIM so that the organization can maintain their pace in the transition process (Cidb.gov.my., 2016). Majority of the respondents are willing to change to adopt BIM but changing the traditional culture within the organization will be difficult.

People with a set of skill and knowledge of BIM are needed to be developed by the organizations during the transformation phase. However, multiple challenges are observed that can hinder the adoption of BIM in Malaysia such as the lack of time for experimentation and implementation in fast-paced projects and insufficient references to help in implementing BIM. Figure 2.16 shows the rank of challenges in process perspective (Cidb.gov.my., 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 2.16: Rank of Challenges in Process Perspective (Cidb.gov.my., 2016).

2.9 Benefits of BIM

Central focus on the collaboration between team projects during the building process is one of the main benefits from BIM. Nonetheless, the time saving, reduction of cost and higher quality are also a positive impact by implementing BIM within an organization. There are also many benefits coming from BIM which helps a lot in the construction progress. The benefits of BIM will be explained further below.

2.9.1 Enhance collaboration and communication

With the latest technology, BIM models allows users to share and collaborate with other project teams compared to traditional process where it uses paper drawing sets (Hall, 2018). This improves the communication among the project teams and other parties involved in the project (Reyes, 2021). BIM is also known as a single source of truth as all the information are shared and stored in one place (Reyes, 2021). This allow them to access the latest project information in any given time (Hall, 2018).

2.9.2 Better coordination and clash detection

Before any construction begin, BIM helps to coordinate trades and subcontractors better that detects internal or external clashes and MEP within the model (Hall, 2018). BIM 360 Glue also offers an automated clash detection that reduce the time for rework needed on any job given (Construction Tuts, 2019). Proper planning can be prepared by BIM before any onsite development (Hall, 2018). Any unforeseen issues and last-minutes changes can be avoided through simple evaluation and commenting across multiple disciplines (Construction Tuts, 2019).

2.9.3 Reduce risk and cost

Before the construction phase begins, BIM can provide cost estimation of the construction. There is multiple ways that BIM can save a lot of money such as closer collaboration with contractors can lead to reductions in tender risk premiums, lower insurance costs and lower risk of claims (Construction Tuts, 2019). More prefabrication and less waste on unused materials can be achieved by overwiewing the project better before it begins (Hall, 2018). Instead of onsite development of

prefabricated components, they can be simply bolted in place (Construction Tuts, 2019). Many companies use BIM and construction technology to reduce the labour cost on documentation work and miscommunication (Construction Tuts, 2019).

2.9.4 Shorter project lifecycles

The entire project timeframe can be reduced by BIM which helps decrease in adjustments, reiterations, mistakes, and exclusions (Construction Tuts, 2019). This also helps in reduction of money needed to spend on project overall and boost up the eventual return on investment (Reyes, 2021). Buildings can be designed quickly through BIM and allow the construction to start earlier. Project can be speed up by improved workflow and other efficiencies.

2.9.5 Project visualization during the planning stage

Proper project planning and visualization can be prepared by BIM tools at the preconstruction stage (Hall, 2018). Before construction begin, clients can experience how the space will be used and place which gives the chances to make changes by using 3D visualizations and space-use simulations. Overview of the project from the beginning before commencement helps to reduce the risk of time consuming and expenses in the future (Construction Tuts, 2019).

2.9.6 Improve work productivity and prefabrication

Production drawings or databases for manufacturing purposes can be generated easily using BIM tools which increases the use of prefabrication and modular development technology (Hall, 2018). Offsite detailing, developing, and designing in a controlled environment can reduce waste, increase efficiency, and minimize the cost of labour and resource used (Construction Tuts, 2019).

2.10 Modelling between different parties

2.10.1 Architectural Model

In the schematic design, architects will draft the shape and size of the building including the general layout plan and simple exterior design in 2D CAD. The site layout plan can be created by introducing location of building and the surrounding structures such as pools, walkways, and driveways. Once the model is finalized, it will be sent to the client for agreement before proceeding to the next phase, design development.

In the design development phase, architects will select materials to be used for the interior design such as doors, roofs, and walls. Once the materials are selected, a 3D BIM model will be generated with all the specifications including interior and exterior design of the building. Next, architects will work together with other engineers in the construction document phase to check all the technical and engineering design. In Figure 2.17 and Figure 2.18, these are the examples of what architects draw in their software to allow the engineers to visualise the building going to be construct.

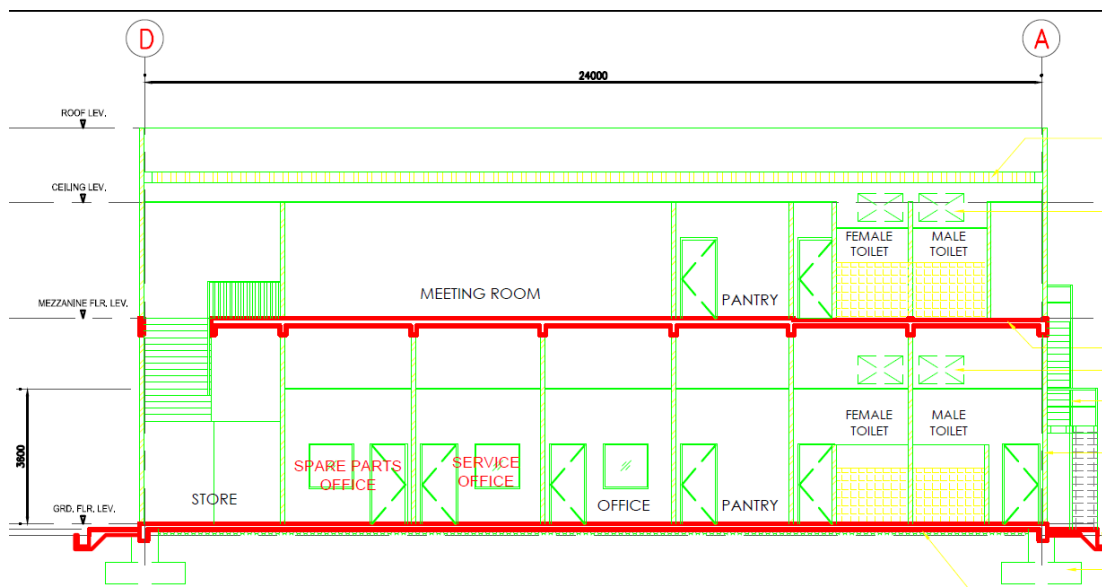


Figure 2.17: Floor View of Architectural Drawing of A Showroom's Office.

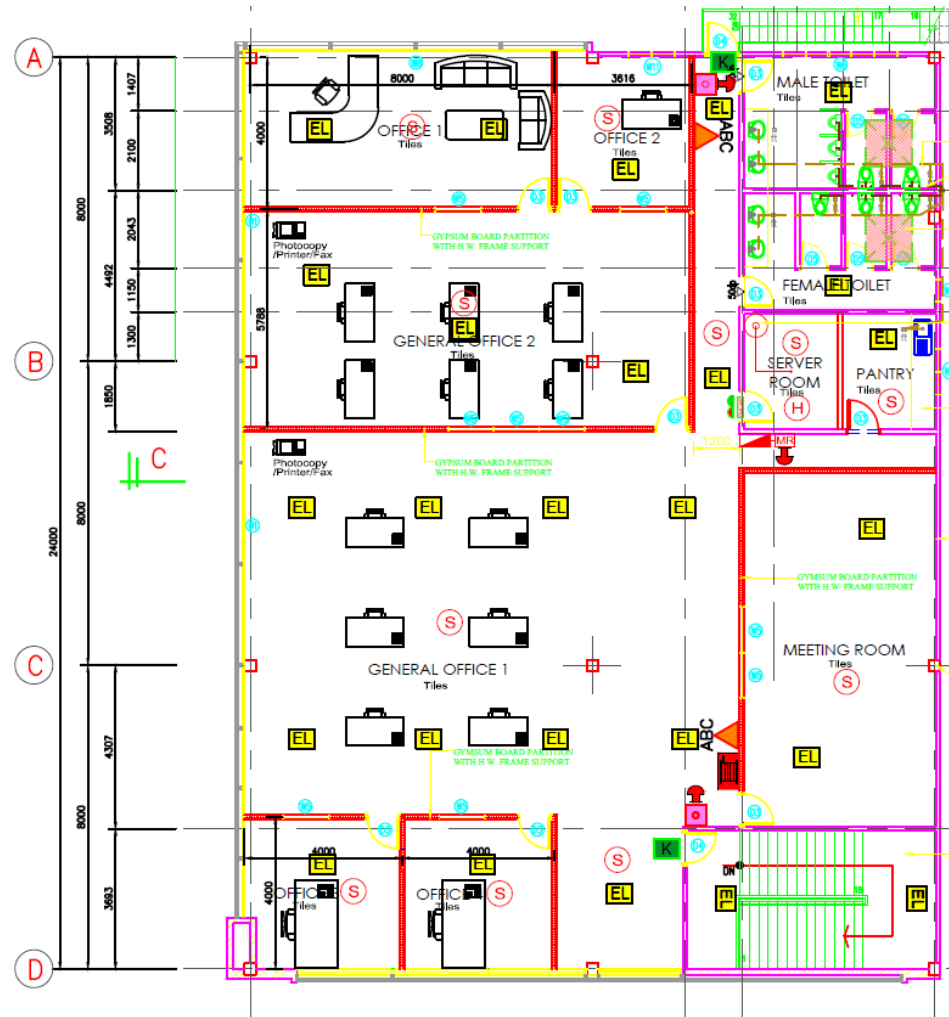


Figure 2.18: Section View of Architectural Drawing of A Showroom's Office.

2.10.2 Structural Model

Once the architectural model is finalized, initial design of building elements will be developed based on the code recommendation by structural engineers. The dimensions of each building elements is identified after completing the initial design. A 3D model will be generated with the building elements after all the loads acting on the structure is defined. The 3D model will undergo structural analysis to calculate the internal forces of each element in the structure.

Occasionally, some dimensions of the members are insufficient to support the gravity load. So, the dimension of the members will be redesign according to the relevant code and re-run the analysis. Internal forces will be obtained, and modification may repeat based on the new forces obtained. After finalizing the dimension of the

members, structural plans will be generated with detailed description such as rebar detailing and other detailed drawings. Figure 2.19 shows the rebar detailing in the wall (ESTEEM Load, 2014) and Figure 2.20 shows the detailing of a ground beam.

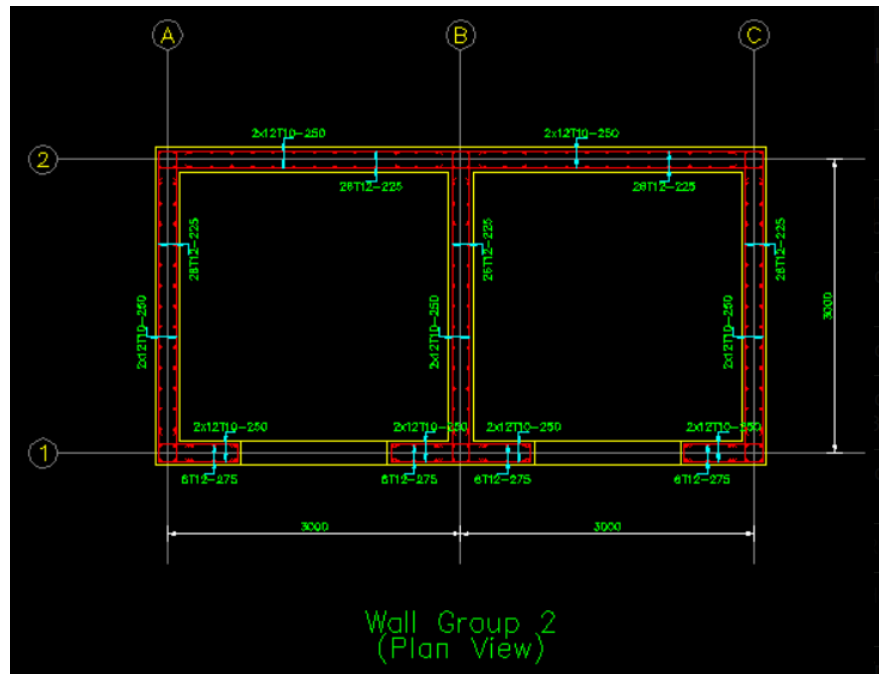


Figure 2.19: Rebar Detailing in the Wall (ESTEEM Load, 2014).

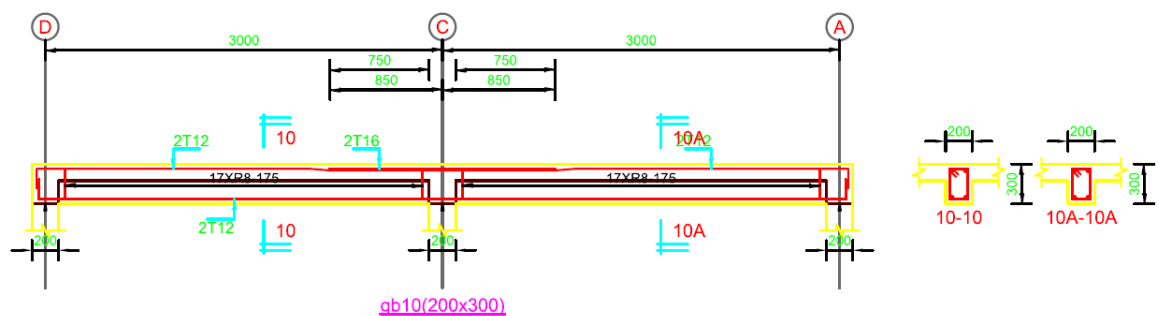


Figure 2.20: Detailing of A Ground Beam.

2.10.3 MEP Model

MEP team determine the size required for the equipment to be installed in the building while maintaining the operating revenue during the conceptual design phase. Once the size of equipment is determined, this information will be sent to the architect and structural engineers to create a perfect amount of space needed to allow the equipment

to be functioned in the building. MEP teams also need to consider the combination of systems to be deploy in the building such as production of hot water where the energy between the heat pumps and make-up boilers is needed to be maintain. This helps the cost, functionality, and usability are balanced overall for the users in the building.

The multidisciplinary design team can start laying out the equipment such as boilers, chillers, air handling units, and etc since it was finalized in the conceptual design phase. Output such as 2D plans, 3D models, equipment specifications, system load and size calculations are needed to be generated during the schematic design phase to produce a summary report. Once the report is generated, MEP team will work with 3D Modellers to ensure the output is coordinated and finalizing the calculations in the final design plan of the building. Blueprints are often needed for submission to the authorities to get permit. Once the authorities approved the submission, this construction process will run smoothly. Figure 2.21: Diagrammatic Sketch of Plumbing System of a terrace house.

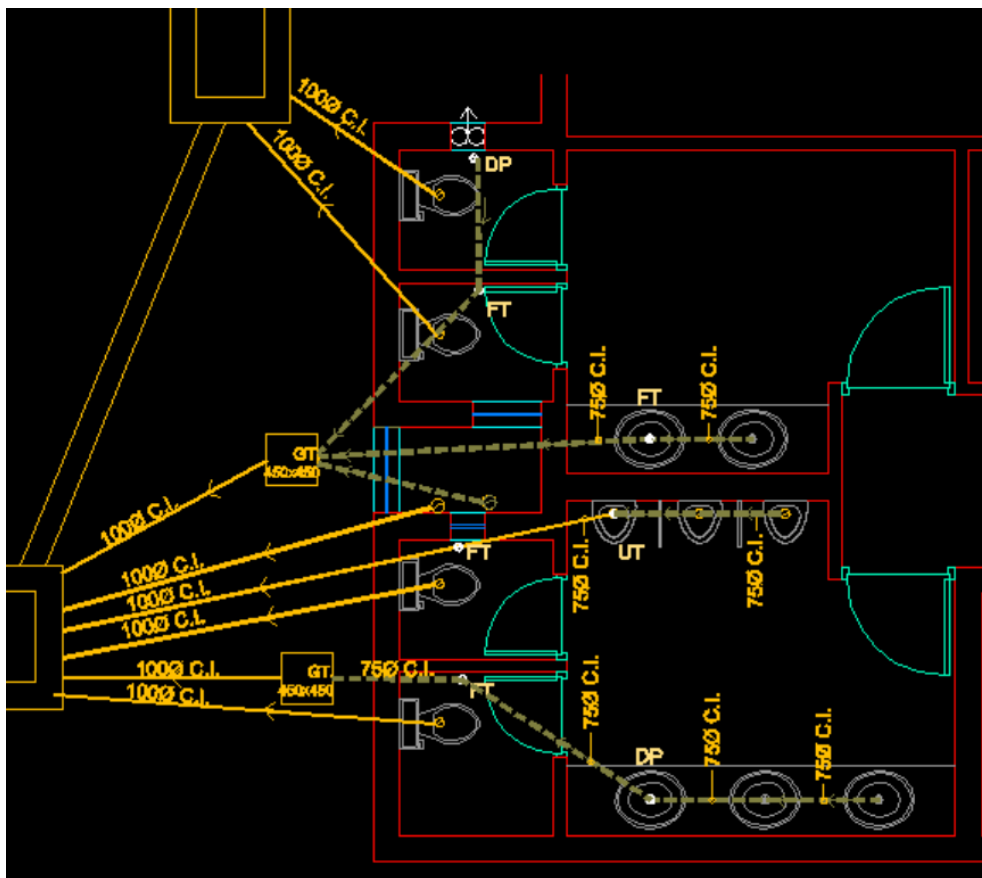


Figure 2.21: Diagrammatic Sketch of Plumbing System.

2.11 Clash detection

Clash detection is considered one of the most important part in the BIM modelling process. Design models can be created independently from different professionals such as architects, structural engineers, and MEP engineers (HVAC, Electrical and Plumbing) and clash detection will be commenced once all the models are finalized (United-BIM, 2020). Clash detection can help to detect and eliminate all clashes from individual models to combined model for Virtual Design and Construction projects (United-BIM, 2020).

Clashes can be ranged from architectural to structural, mechanical, electrical, plumbing and fire sprinkler. Clashes can be categorized into three levels depending on the importance of the design which are C1 (Low), C2 (Moderate), and C3 (High). Clash report can be generated by merging two or more design models together into a single model in any BIM applications such as Autodesk Revit, ArchiCAD, Tekla, Navisworks and etc. The BIM application will display all the potential clashes between the design models used with status details and level condition after running the clash detection. Figure 2.22 Shows the clash report between two elements in a combined design model (United-BIM, 2020).

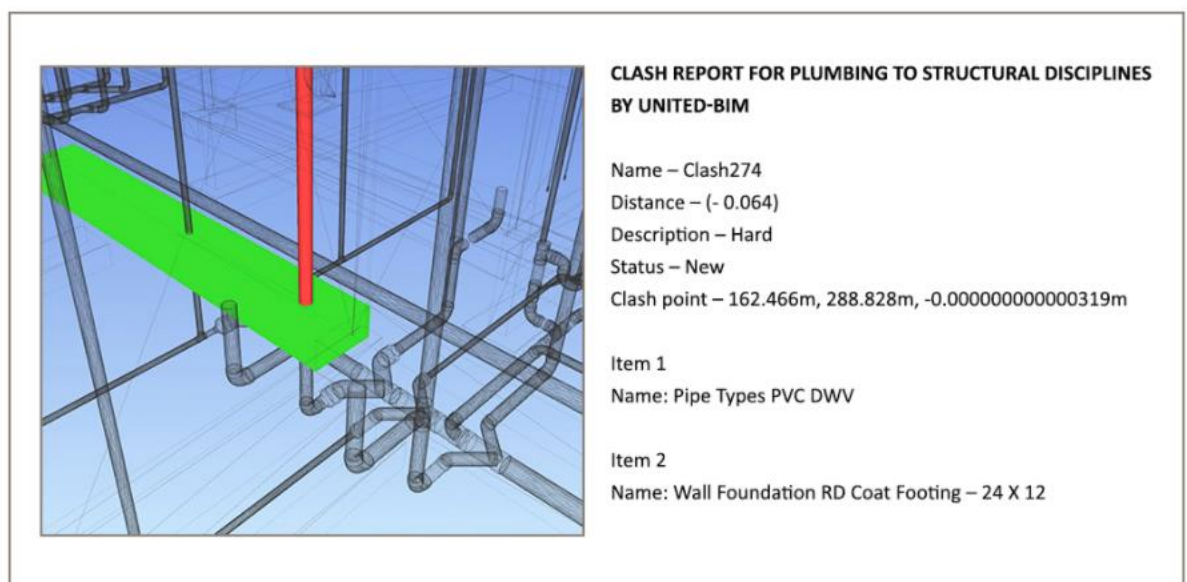


Figure 2.22: Clash Report between two Elements in a Combined Design Model (United-BIM, 2020).

Once the clash detection reports are generated, there are numerous ways to solve the issues such as adjusting the position of rebar and other discipline objects, adjusting the length and spacing of rebar, changing the shape code of rebar, and cutting or trimming the rebar (Chidambaram, 2019). To determine which solutions to be used, collaboration meetings are organised and conducted by project stakeholders to discuss, review solutions and solve the identified clashes between different disciplines issues. By using the knowledge of the participants in the collaboration meeting, the design information discrepancies are discussed among each other and providing recommendations and solutions. The various design clashes and the participant's proposed solutions will be explained by using the 3D models created in the collaboration meetings (Chidambaram, 2019).

Once the final decision is made in the meeting, BIM coordinator will record all the decisions and issues that made in the meeting. BIM coordinator will how the issues to be resolve and assigning people to take accountability for implementing the recommendations to the issues. After the changes in the 3D model, clash detection will be performed again, and it will be updated so it can be shared with all project stakeholders. This process will be repeated until all the clashes are solved and the final 3D model will not contain any clashes between different discipline (Chidambaram, 2019).

2.12 Unified information model

Unified information model is a process that allows different data sources to be consolidated to make a single data narrative within a data warehouse (Sisense, 2021). Project teams are able to determine the methods, practices, and architectural patterns as the best outcomes to solve any issues faced in the project. Unified information model can act as a central data server which coupled with networking technologies to allow users to exchange information among each other (Wang, et al., 2014). Information are extracted and expanded by the unified information model which then store as architectural information, structural information, and other related information (Wang, et al., 2014). Figure 2.23 shows the different information structured in the unified information model (Wang, et al., 2014).

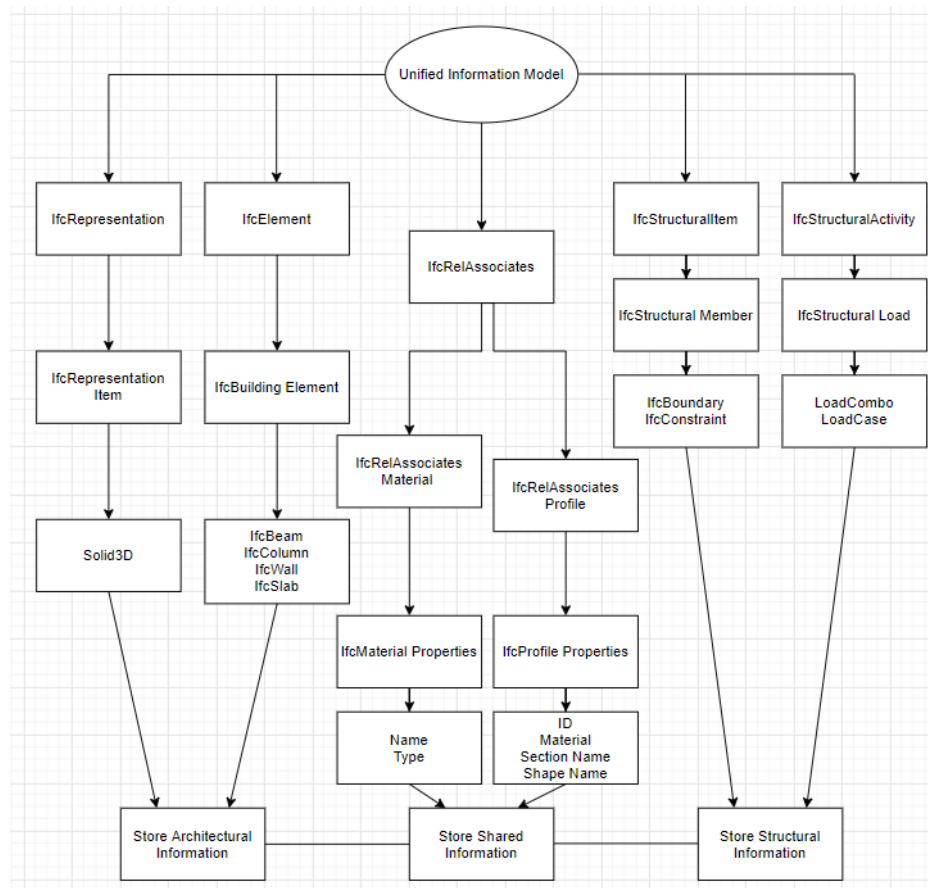


Figure 2.23: The Different Information Structured in the Unified Information Model (Wang, et al., 2014).

According to Figure 2.23, all the elements that make up a building are comprised by the extracted architectural information whereas the structural information only includes all structural elements such as *IfcBeam*, *IfcColumn*, *IfcWall*, and *IfcSlab*. Other related information are also added into the structural information including boundary conditions, structural loads, and load cases. Besides that, the materials and profile properties are consisted under *IfcRelAssociates* entity. Due to the availability of structure and content of the unified information model, transformation among different building models are enabled that consisted of architectural model, structural model, and structural analysis model.

2.12.1 Open and Close BIM

Closed BIM is where all key project stakeholders use the same software of a BIM application within an organization. BIM application from the same vendor such as Autodesk used by different trades can be classified as closed BIM. For example, architectural elements can be modelled by architects in Revit Architecture, architectural BIM model is used as a reference by structural engineer to define the building's structure with Revit Structure while building services element is modelled by MEP engineers with Revit MEP. This method is restrictively for project participates to collaborate with a certain BIM tools where no file conversion is needed. Even though this approach is not suitable for most cases, but problems of inter-operability posed by different software solution on the same project can be minimized.

Open BIM is a universal approach to realization, operation, and collaborative design of the buildings using file format according on open standards and workflows (Designingbuildings.co.uk., 2020). It allows all key project participants to collaborate and exchange project information with each other using any BIM tools they use (Archilantis, 2020). This allows project participates to use the software that are suitable for them which helps them control their own design data better while collaborating with others (Designingbuildings.co.uk., 2020). Throughout the life cycle of the project, project information are accessible to all project teams by open BIM on a timely basis to allow project teams to make better decision in different phases of the project from design phase to hand-over to renovation and demolition. Not only that data of 3D BIM model is limited in the information exchange, but parametric data such as specifications, quantity take-offs, material procurement, cost estimation, and construction phasing are included as well. Figure 2.24 shows the open BIM connection to multiple software (Mata, 2017).

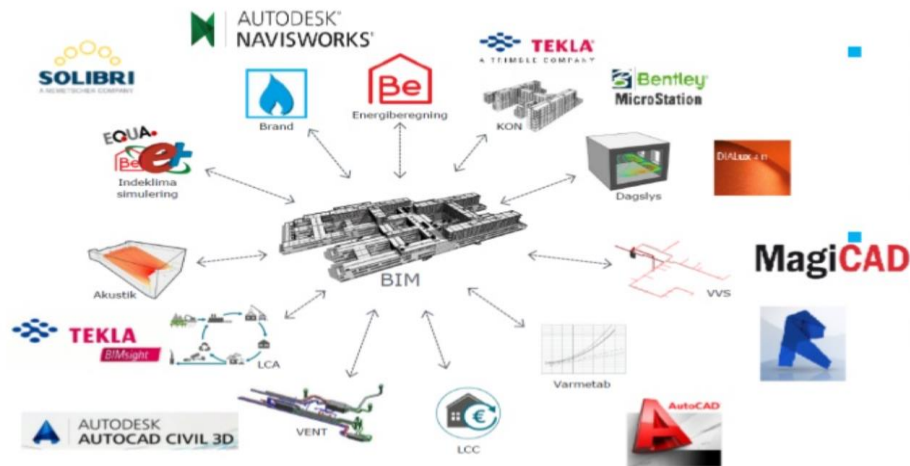


Figure 2.24: The Open BIM Connection to Multiple Software (Mata, 2017).

Many developed protocols and open standards such as Industry Foundation Classes (IFC) and Construction Operation Building Information Exchange (COBie) have been led by open BIM to help the construction industry (Archilantis, 2020). Geometric and non-design data can be exchange between applications that support open BIM through IFC while Facility Management data can be exchange through COBie (Archilantis, 2020).

2.12.2 Industry Foundation Classes (IFC)

Industry Foundation Classes (IFC) is a data format that allows construction and facility management data to be exchange across various software applications (Designingbuildings.co.uk. 2020). Data model of the building can be processed by IFC throughout its whole life cycle starting from design phase to construction phase, passing through renovation and demolition (BibLus., 2017). IFC format offers a huge advantage to the construction industry which allows collaboration between different professionals to share and exchange data through a standard format in the construction process (BibLus., 2017). Collaboration between multidisciplinary due to information flowing consistently in the construction process helps to minimize errors and costs of the project, saves time, and produce higher quality (BibLus., 2017).

2.13 Size Checking for Structural Members

In general, there are mainly four types of structural members consisted in a building which includes beams, columns, slabs, and footings. Beam is a horizontal structural element that withstand vertical loads, shear forces, and bending moments while column is a vertical structural member that carry loads mainly in compression. Slab is a horizontal structural element which act as a flat surface. Lastly, footing is a structural member that transmit the entire load of the building to the underlying soil.

During the design phase, architects will first draw out the 2D building plan of the project in their own software. Once it is completed, it will be sent to different project teams to be used. For the engineering team, they will first create a 3D model of the 2D building plan drew by the architects. Then, it will undergo structural analysis to determine which structural members is in critical condition. Once they determine the critical structural members, the critical structural members will be replaced by changing the size of the structural members. To change the size of the critical structural members, there are some parameters are needed for Eurocode checking.

For column, parameters included factored load on the column, steel grade, and concrete grade while total depth of the beam, effective depth of beam and width to depth ratio for beam. The parameters will then be change in the parameter setting in the software, increase the size of the structural members, and then generate a calculation report to check whether the structural members is able to withstand the load of the building or not. The process of increasing the size of the critical structural members is repeated until it is able to withstand the building.

2.14 Summary

Malaysian construction industry find it difficult to adopt BIM tools as they have to faced multiple challenges. Government in Malaysia also has been supporting the BIM adoption to Malaysia, but their effort was not effective enough to make a drastic change in the Malaysian construction industry. There is no doubt that implementing BIM in Malaysia is a challenge, however, it has a lot of functions and features that allows the work processes to be done quicker and effective. Thus, BIM adoption also has many benefits to the construction industry.

Researchers can model a structure easily by using BIM application. Information from the parties can be exchanged and shared among each other so that researcher can derive the information for their own needs throughout the construction project.

In this research, Autodesk Revit is used to model a double storey semi-detached house and a double storey terrace house in Sarawak. Autodesk Revit is chosen due to its popularity in the construction industry, and it is also highly recommended by many civil engineers. Once the models are finalized, they will undergo clash detection to identify any clashes occurred in the model.

Chapter 3

METHODOLOGY AND WORK PLAN

3.1 General Introduction

Before constructing a BIM model, planning was necessary to achieve the project's aim and objectives within the given constraints of time. Planning helps to avoid future complication while generating the BIM model, which means every step and detail should be well prepared and understood to ensure the project runs smoothly. In this chapter, a double storey terrace house and a double storey semi-detached house are selected as the building to be studied. Structural information of the building is required before generating the BIM model and clash detection is required to be performed. Therefore, civil and structural plan for the building is obtained from the previous researcher that conducted the research.

Besides that, works such as generating a BIM model and defining clash detection will be included in this research.

3.2 Project Task and Activities

3.2.1 Flow Chart for Project Methodology

In this research, the workflow for the entire project will be shown in Figure 3.1. Firstly, the problem statements of BIM and the objectives are studied. Problems such as BIM adoption rate in Malaysia, the challenges to adopt BIM in Malaysia and awareness of BIM in Malaysia are studied and explained in chapter 2. Then, the history of BIM and the BIM's functions and features are researched and studied for literature review writing in chapter 2 such as BIM life cycle, BIM dimensions, BIM benefits and etc.

Furthermore, BIM models are generated in Autodesk Revit by referring the architectural and structural plans given by the supervisor. After the BIM model is created, the dimensions of the elements are check again to ensure its correctness before performing clash detection. The BIM model is then undergone clash detection to determine any clashes occurred in the model. The model is modified to improve the structure and run clash detection again. Once the clash detection report is displayed,

the result is obtained and use for further study in chapter 4. The result is then use for report writing for the remaining chapters.

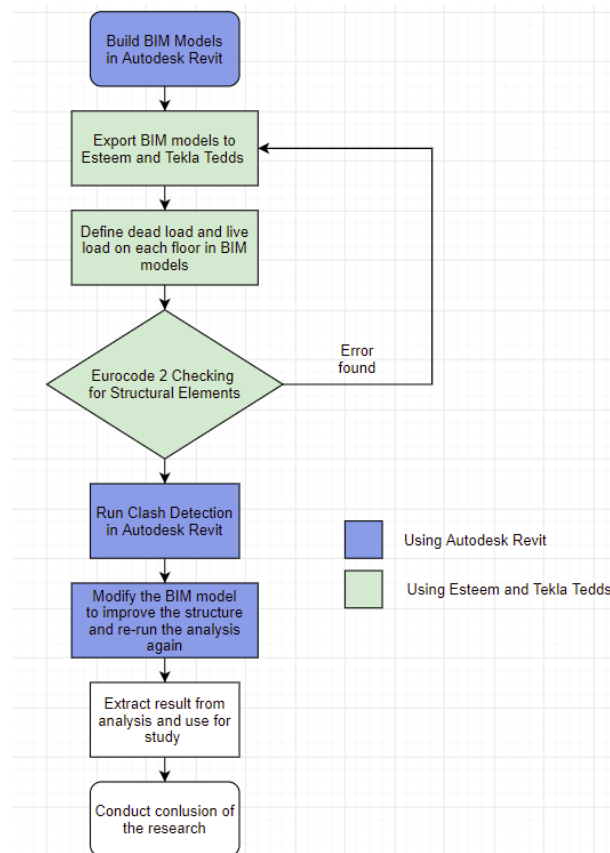


Figure 3.1: Workflow for Entire Project.

3.3 Building a BIM Model

3.3.1 In Structural Plan

In this research, there will be two types of residential building used to make BIM models. The residential buildings are double storey terrace house and double storey semi-detached house, which is located at Sarikei, Sarawak. To create a BIM model of both different houses, structural components and architectural components of the BIM model will be built to fully understand how the building look likes.

First and foremost, gridlines and elevations for each level are drawn in Autodesk Revit to not only indicate the position of the structure components to be placed, but also simplifies the process for other parts to do. In Figure 3.2, it shows the grid line button and the drawn grid line of the building. After that, the elevation of

each floor is determined in Autodesk Revit based on Figure 3.3. Once both grid lines and levels of the building are identified, beams and columns will be added into the BIM model.

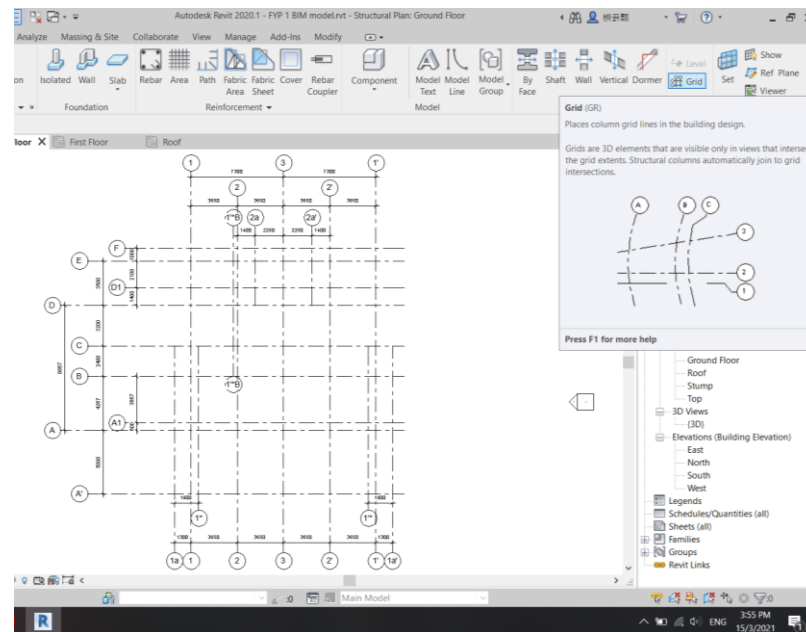


Figure 3.2: Grid line Button and Drawn Grid line of The Building.

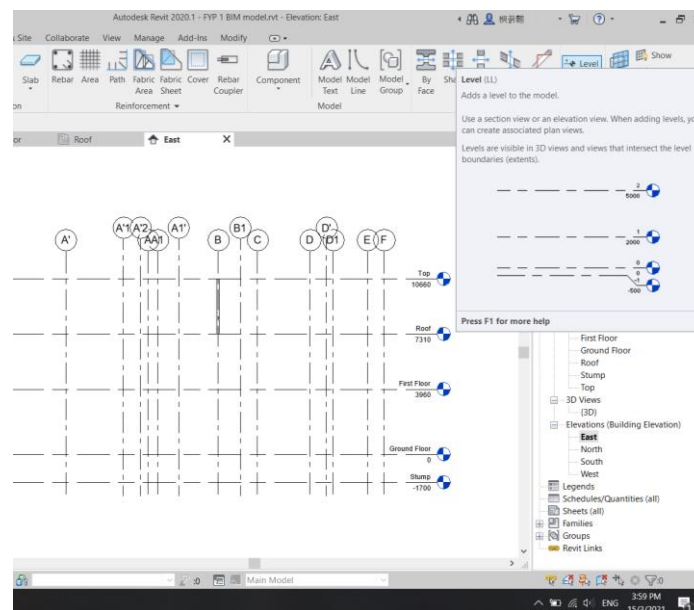


Figure 3.3: Elevation Button and Drawn Levels of The Building.

The columns of every level will be first placed before beams to simply the workflow. This is because beams are harder to determine their elevation and placed them correctly compared to columns. By identifying the location of the columns, beams will be easier to add and join with the columns. To add columns into the BIM model, columns are selected at the structural section and added them into the location according to the structural plan given. According to Figure 3.4, it shows the column button at structural section and the columns are placed at the correct location according to the structural plan.

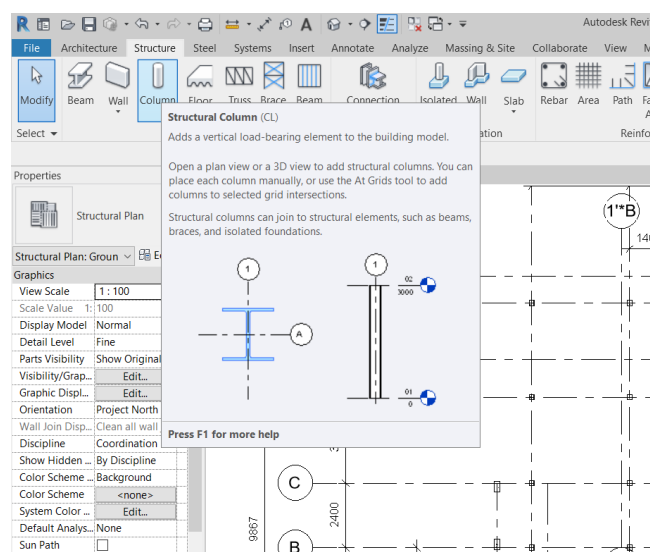


Figure 3.4: Structural Column Button and Drawn Columns of The Building.

Beams will be added after all the columns in every level are placed. To add beams into the BIM model, beams are also selected at the structural section and added them into the correct location. The beam button at structural section and beams added according to the structural plan are shown in Figure 3.5. The materials and dimensions of beam and column can be change in Autodesk Revit. The residential building uses concrete for both beam and column. Thus, the material of the beam and column need to change to suit the requirement given. To change the material of the building components, select all the beams and columns added and change its properties by finding the concrete material files given in Autodesk Revit. Based on Figure 3.6, concrete is selected as the material for beam and column.

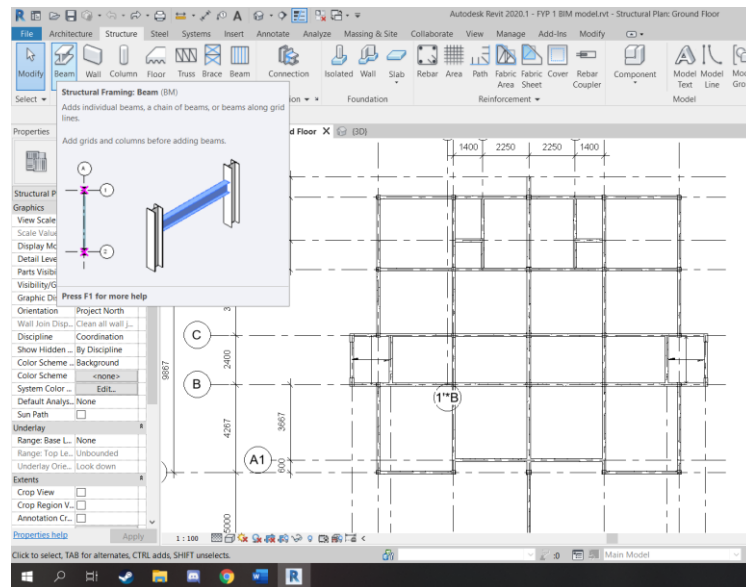


Figure 3.5: Structural Beam Button and The Drawn Beams of The Building.

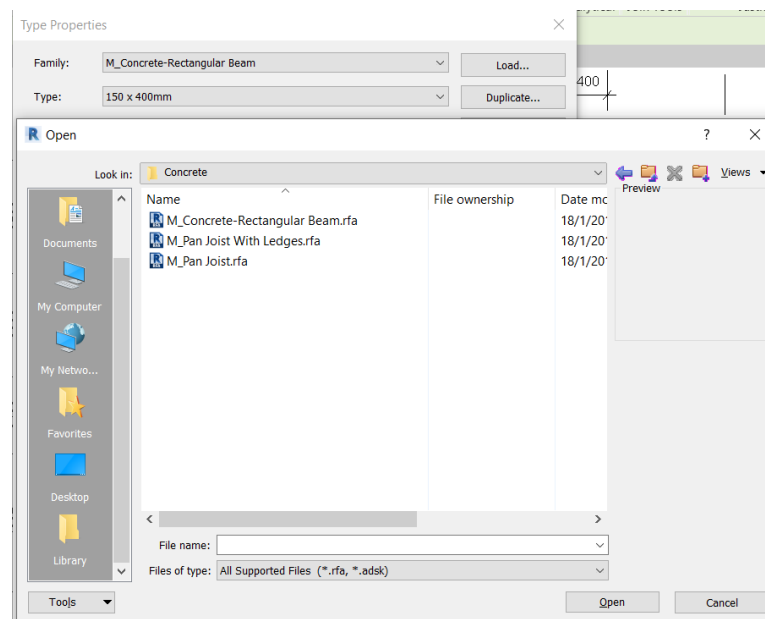


Figure 3.6: Redefining the Beam Material.

Besides that, the dimensions of the column and beam can be added as well if Autodesk Revit does not provide the dimensions you needed. By entering the building components properties, the dimensions based on the structural plan can be added into

Autodesk Revit to make the BIM model accurately. Figure 3.7 shows the redefining of a beam dimension.

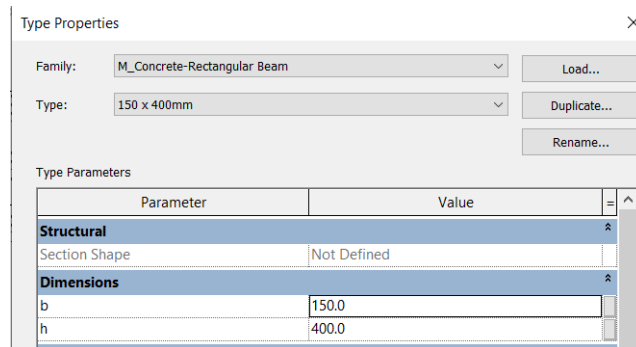


Figure 3.7: Redefining the Beam Dimension.

After that, floors will be added into the BIM model together with the columns and beams. The floor button will be selected at the structural section and edit its thickness according to the plans given. Figure 3.8 shows the floor button and the drawn floors of the building. The position for the floor height can be adjusted to suit the plan given.

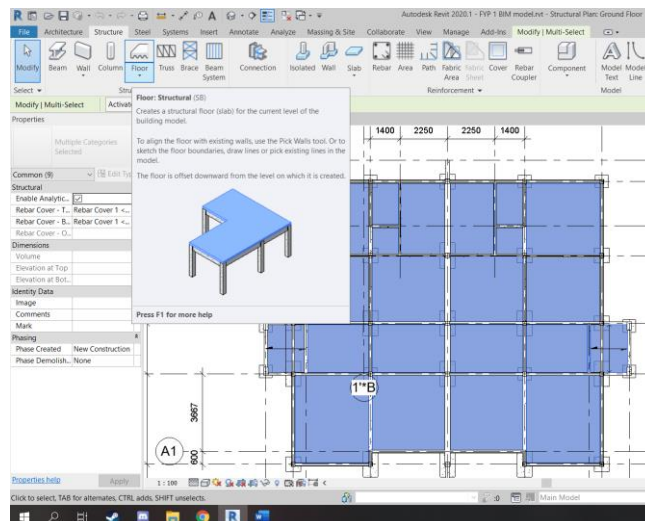


Figure 3.8: Floor Button and Drawn Floors of The Building.

3.3.2 In Architectural Plan

Once all the structural members are added into the BIM model, walls will be added next. Based on Figure 3.9, it shows that wall button is selected at the architectural section and the drawn walls are added to every floor in the BIM model.

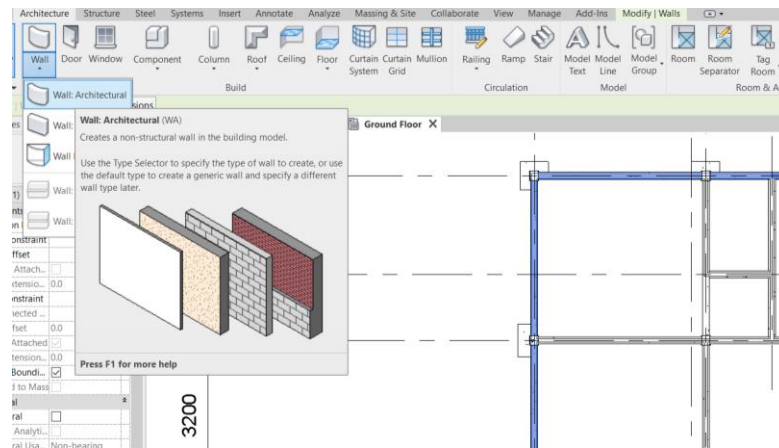


Figure 3.9: Wall Button and Drawn Walls of The Building.

Then, roofs are added into the BIM model. The roof button is selected at the architectural section and the drawn roofs are added to the roof floor and top floor in the BIM model which are shown in Figure 3.10. The walls then connected with the roof to cover the hollow areas which is shown in Figure 3.11. Windows and doors will also be added to make the BIM model more realistic in Figure 3.12. The finalized BIM model for double-storey semi-detached house and double-storey terrace house is shown Figure 3.13 and Figure 3.14.

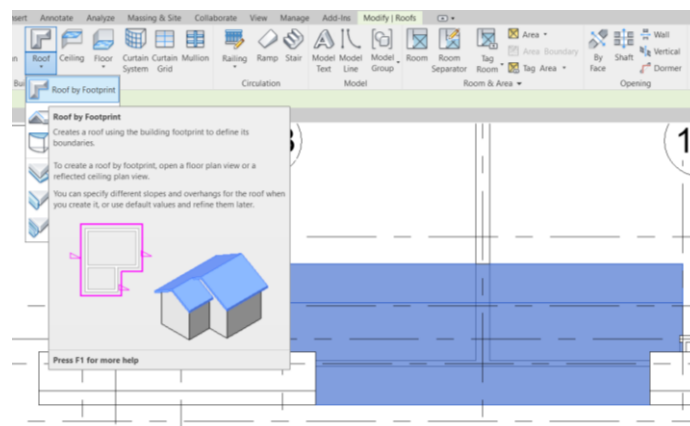


Figure 3.10: Roof Button and Drawn Roofs of The Building.

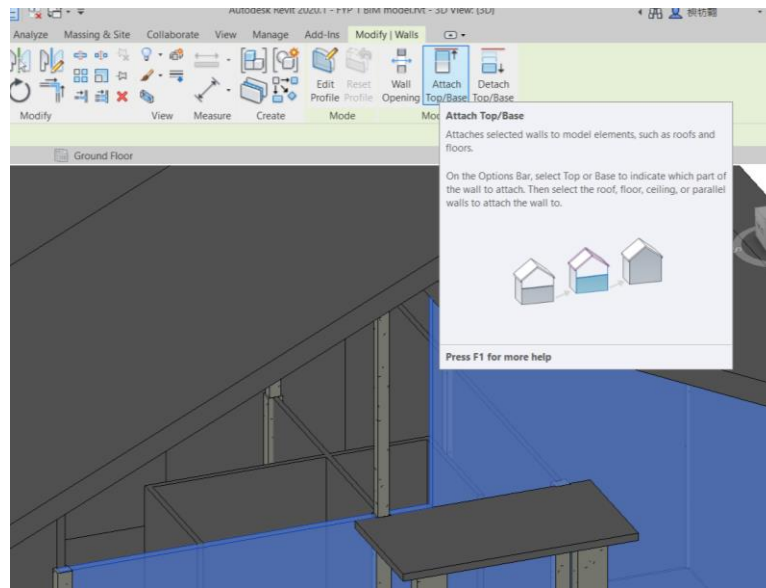


Figure 3.11: Attracting Wall to Roof.



Figure 3.12: Added Doors and Windows.

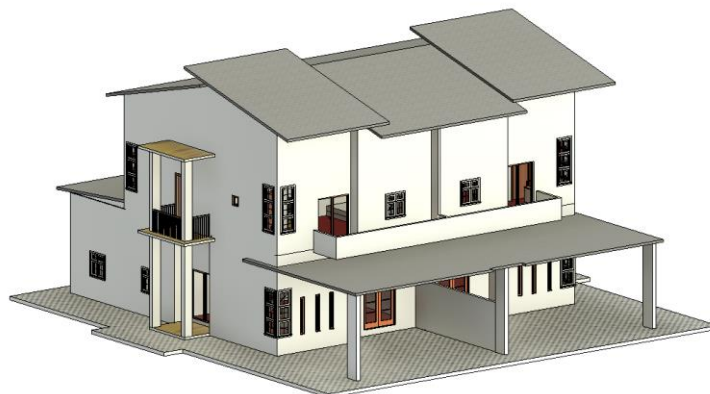


Figure 3.13: Finalized BIM Model of Double-Storey Semi-Detached House.



Figure 3.14: Finalized BIM Model of Double-Storey Terrace House.

3.4 Clash Detection

Clash detection is a process that finds interferences which also known as clashes, existed between elements and other elements in the BIM model. Since the BIM model of double storey semi-detached house is completed, clash detection is performed to check any clashes presented in it. According to Figure 3.15, it shows the button for clash detection at the collaborate section. After a few second clicking the interference check button, the interference report is generated and shows the clashes it found in the BIM model. Figure 3.16 shows the clashes found in the BIM model. The BIM model will then be modified and run clash detection again to avoid clashes. The interference report and the method to modify the BIM model will be used and explained at chapter 4.

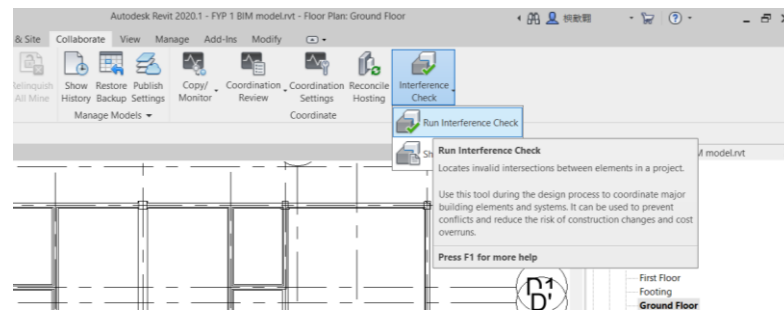


Figure 3.15: Interference Check Button in Autodesk Revit.

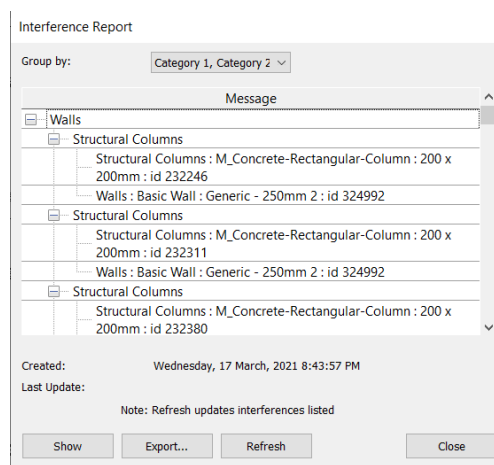


Figure 3.16: Interference Report.

For the structural models, we can either “Switch Join Order” or redraw the shape of the structural members. After everything is fixed, clash detection is re-run again and no clashes detected by Autodesk Revit. Thus, the research for the 3D models are completed. Figure 3.17 shows switch join order and Figure 3.18 shows no interference detected by Autodesk Revit.

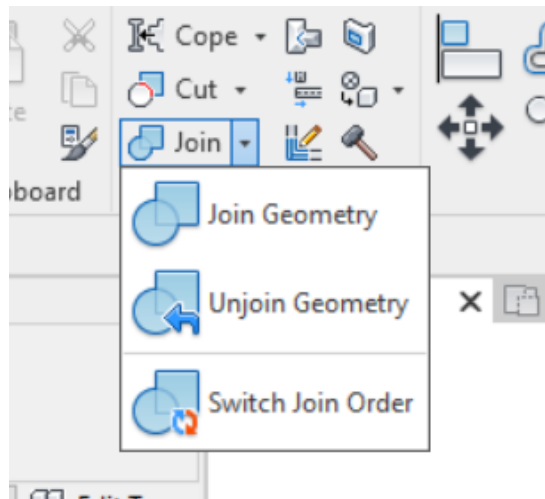


Figure 3.17: Switch Join Order.

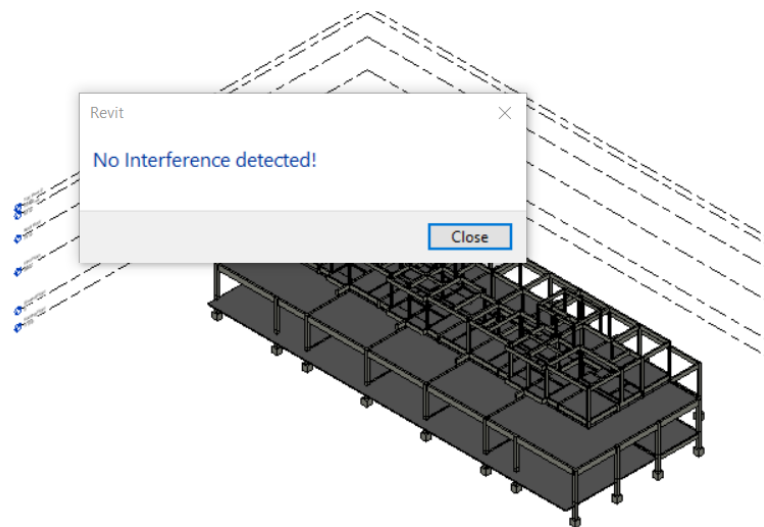


Figure 3.18: No Interference detected by Autodesk Revit.

For architectural model, the clashes between elements and other elements including door, furniture, roof, window, staircase, handrail etc can be fixed by relocating their position correctly in the floor plan and place them properly or we can redraw or resize the elements of the architectural components to fit the model perfectly.

Lastly, for the Eurocode design checking, the structural model will be exported to Esteem and Tekla Tedds to perform structural analysis. The structural

members will be designed based on Eurocode and the size of the rebar set in the software.

3.5 Summary

By extracting all the information from both double storey terrace house and double storey semi-detached house, the BIM model of the entire building will be built in Autodesk Revit. Then, the BIM model is added with all the building components such as beam, column, slab, wall, footing and roof with the correct material and dimension. These parameters determine the accuracy of the result. After that, the finalized BIM model went into clash detection. Clash detection determined the clashes occurred in the BIM model. The detection will be done in few minutes. Desire data such clashes from clash detection are extracted from result and used for further study.

Besides, modification to the building structure will also be done to improve the BIM model by reducing the clashes. The modified structure will be analysed again to check any clashes presents.

Chapter 4

RESULT AND DISCUSSION

4.1 Introduction

Two BIM models of Jalan Punai in Sarikei, Sarawak which have been built in Autodesk Revit are exported to Esteem. However, Esteem does not have the latest extension that can allow Autodesk Revit to export its models to Esteem. Not like other software such as Tekla Structure Design, Naviswork, and Graphisoft, they have an extension that allows models to be exported to each other. The other option instead using an extension is saving the file under IFC format. IFC format also allow other software to gain access to the model as well. Currently, the only BIM models from the versions of 2019 or below in Autodesk Revit are able to send to Esteem. Even though Autodesk Revit 2019 was installed for exportation of BIM models, Autodesk Revit has a disadvantage that it cannot use any BIM models created in its latest versions in 2020 and 2021. Thus, Autodesk Revit 2019 was not able to open the BIM models from its latest version and was left unused. Due to the incompatible between Autodesk Revit and Esteem, structural members in both BIM models will be manually defined by the user in Esteem.

Once all the structural members are defined, static loads such as dead load and live load are added into the floor in both BIM models in Esteem. Then, Eurocode 2 checking is performed to ensure that structural member design is comply to the design guidelines. The stair design will also be discussed in this chapter by using Tekla Tedds. After ensuring all of the structural members are checked, clash detection is conducted in Autodesk Revit to check any interference between structural members or with architectural components.

Besides that, modified structural members for improvement are discussed and proposed in this chapter to improve the clash detection. The modifications are analysed again by clash detection. The finalized result will be collected and used for further discussion and studies.

4.2 Eurocode 2 Checking for BIM models

4.2.1 Properties of Structural Members

Before creating the gridlines and adding structural members into Esteem, the properties of structural members in Esteem needed to be adjusted to suit our design standard. There are multiple design standards featured in Esteem such as BS8110, EN1992 and EC2. Thus, EC2 is chosen to be our design standards. Inside the properties setting of structural members, compressive strength of concrete (f_{cu}), minimum and maximum bar diameter in main reinforcement, and minimum and maximum link diameter in shear reinforcement are adjusted which is shown in Figure 4.1 to Figure 4.4.

Material Properties	
f_{cu}	20
E_c	24597
Modulus of Elasticity Coefficient, C_b	0.5
E_{cr}	12298.5
Main Reinforcement	460
Shear Reinforcement	250
Main Reinforcement	
Minimum Main Bar Diameter	12
Maximum Main Bar Diameter	25
Minimum Main Bar Spacing (Support)	30
Minimum Main Bar Spacing (Mid span)	30
Maximum Main Bar Spacing	155
Area Optimization	False
Shear Reinforcement	
Minimum Link Diameter	6
Maximum Link Diameter	16
Minimum Link Spacing	100
Maximum Link Spacing	250
Stirrup Spacing Interval Increment	25
External Loop	3
Increment Priority	Diameter

Figure 4.1: Properties of Beam.

f_{cu}	20
E_c	20083
Modulus of Elasticity Coefficient, C_s	0.5
E_{cr}	10041.5
Main Reinforcement	460
Fabric Brand	BRC
Main Reinforcement	
Minimum Main Bar Diameter	10
Maximum Main Bar Diameter	20
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, ($\rho\%$)	0.13
Maximum Steel Percentage, ($\rho\%$)	4
Minimum Steel Percentage for Fabric	0.13

Figure 4.2: Properties of Column.

f_{cu}	25
E_c	22454
Modulus of Elasticity Coefficient, C _c	0.7
E _{cr}	15717.8
Main Reinforcement	460
Shear Reinforcement	250
Main Reinforcement	
Minimum Main Bar Diameter	12
Maximum Main Bar Diameter	25
Maximum Main Bar Spacing	250
Minimum Main Bar Spacing	40
Shear Reinforcement	
Minimum Link Diameter	10
Maximum Link Diameter	20
Minimum Link Spacing	100
Maximum Link Spacing	300
Link Spacing Interval Increment	25

Figure 4.3: Properties of Slab.

Material	
f _{cu}	25
E _c	22454
Main Reinforcement	460
Main Reinforcement	
Minimum Diameter	12
Maximum Diameter	20
Minimum Bar Spacing	100
Maximum Bar Spacing	250
Minimum Steel Percentage	0.13
Maximum Steel Percentage	4
Use Single Bar Diameter	True
Design	
Load Allowance	10
Cover	50
Soil Bearing	100
Check Moment at Stump Face	0
Minimum Thickness	300

Figure 4.4: Properties of Pad Footing.

After adjusted their settings, the models of both houses are generated by adding all the structural elements such as beam, column, slab, and pad footing in Esteem. The generated 3D models in Esteem will be used for structural analysis in the further process to ensure that the proposed design by the Wonderful Engineering & Construction Sdn. Bhd. is complied with Eurocode 2 (EC2). However, the static loads of the buildings and the design of the stairs are needed to be checked before performing the structural analysis.

4.2.2 Define Static Loads

For both of the entire rooms in the 3D BIM models, the dead load is calculated with the value of 3.4kN/m^2 based on the equation shown in the Equation 4.1. Dead load of a room can be determined based on the material used. The material used for the slab is reinforced concrete with a unit weight of 24kN/m^3 shown in Table 4.1 (Dlsweb.rmit.edu.au, 2021). Both of the houses have the same slab thickness of 100mm. However, for the imposed load in both BIM models, different rooms will have different value according to the Uniform Building by Law 1984. Table 4.2 and Table 4.3 shows imposed loads in double-storey semi-detached house and double-storey terrace house based on Uniform Building by Law 1984.

Table 4.1: Unit Weight of Different Materials (Dlsweb.rmit.edu.au, 2021).

Material	Unit weight kN/m^3
Plain concrete	23.5
Reinforced concrete	24
Glass	25.5
Mild steel	77
Hardwood	11
Softwood	8

$$\text{Unit weight of material} \times \text{slab thickness} + \text{finishes} = \text{dead load} \quad (4.1)$$

$$24 \frac{\text{kN}}{\text{m}^3} \times 0.1\text{m} + 1 \frac{\text{kN}}{\text{m}^2} = 3.4 \frac{\text{kN}}{\text{m}^2}$$

Table 4.2: Imposed Loads in Double-Storey Semi-Detached House.

Building Rooms	Intensity of Distributed load (kN/m^2)
Balconies	2.0
Corridoes, Hallways and Passageways	2.0
Kitchen	3.0
Dining Room	3.0
Bedroom	1.5
Living Room	3.0
Laundries	2.0
Toilet	2.0

Table 4.3: Imposed Loads in Double-Storey Terrace House.

Building Rooms	Intensity of Distributed load (kN/m ²)
Utility	2.0
Corridoes, Hallways and Passageways	2.0
Kitchen	3.0
Dining Room	3.0
Bedroom	1.5
Living Room	3.0
Laundries	2.0
Toilet	2.0

4.2.3 Stair Design

For the stair design, the proposed design for both double-storey semi-detached house and double-storey terrace house by Wonderful Engineering & Construction Sdn. Bhd. will be generated in Tekla Tedds. This is because Esteem does not have the function to build stairs in their software. Thus, Tekla Tedds was used to generate the load of the stair and added to the 3D models in Esteem. Standard design of BS8110 was chosen in the stair design calculation among the options given because EC2 is not available in Tekla Tedds. Firstly, the lower and upper staircase of double-storey semi-detached house are designed based on the structural plan given and the data are keyed in Tekla Tedds shown in Figure 4.5 to Figure 4.8.

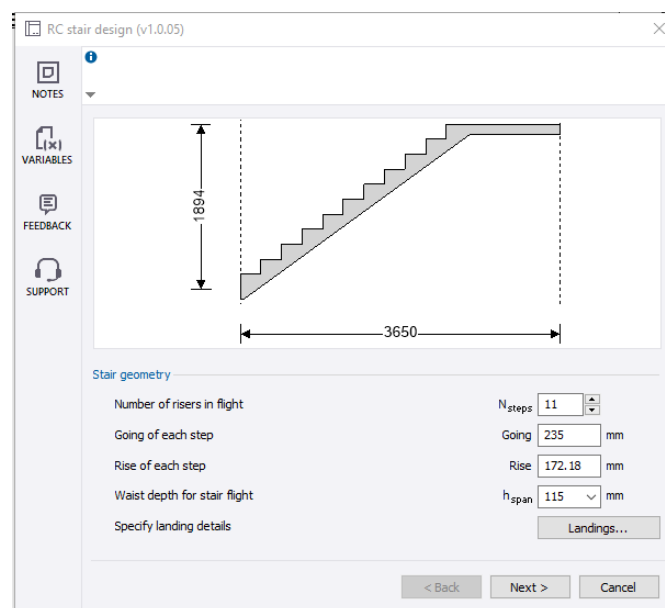


Figure 4.5: Lower Staircase of Double-Storey Semi-Detached House.

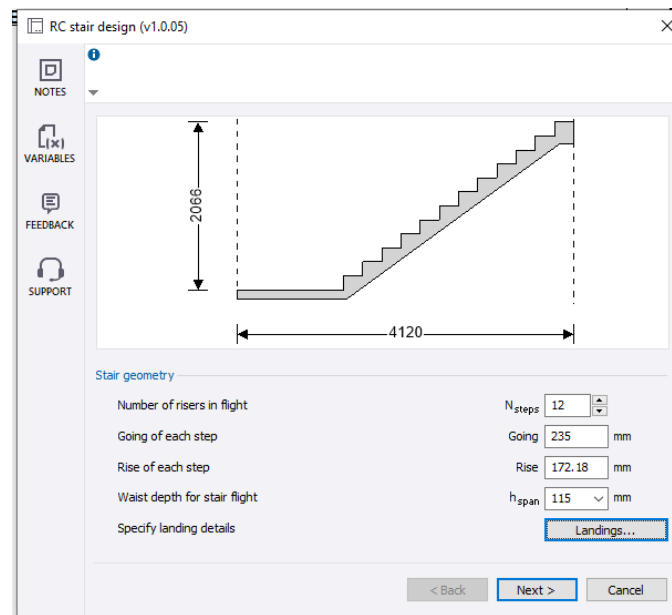


Figure 4.6: Upper Staircase of Double-Storey Semi-Detached House.

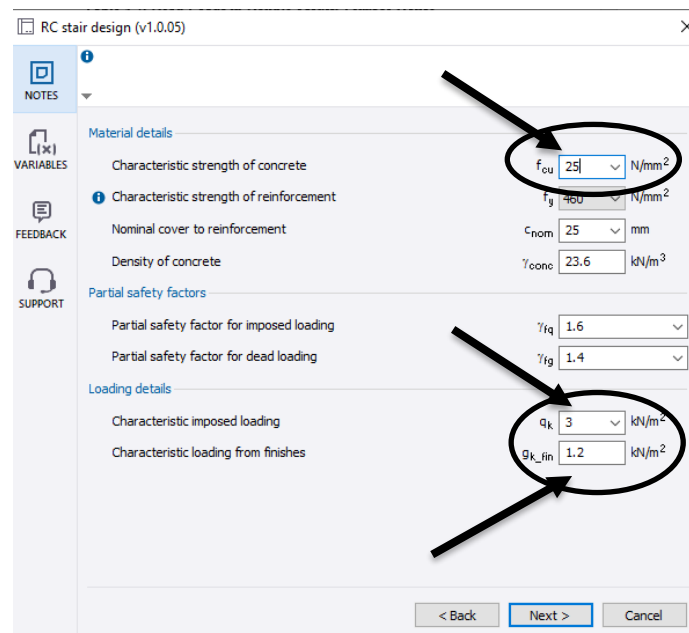


Figure 4.7: Material and Loading Details of Staircase Used.

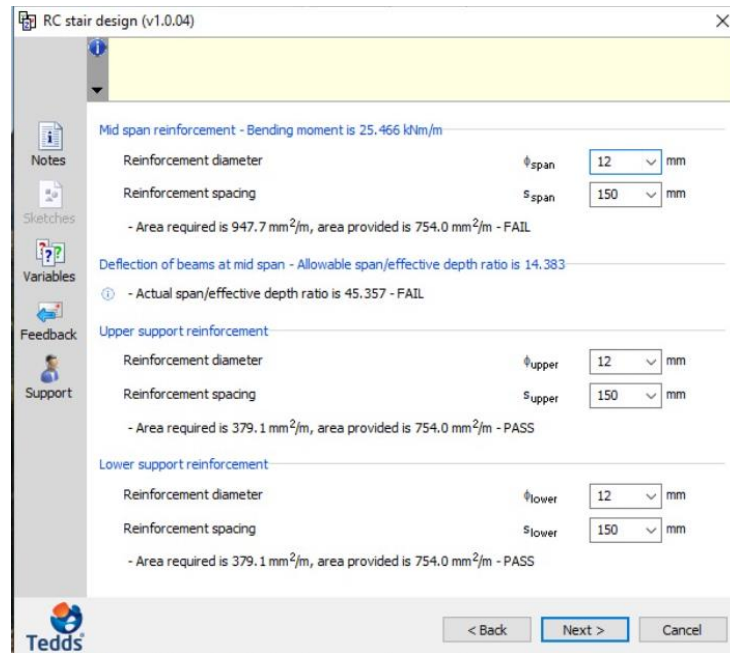


Figure 4.8: Reinforcement Diameter and Spacing of Staircase Used.

After that, the staircase of double-storey terrace house is also generated by Tekla Tedds. The process of generating the staircase is the same as how I did for the previous staircase in double-storey semi-detached house. The lower and upper staircase of double-storey terrace house is also designed based on the structural plan given and the data are keyed in Tekla Tedds shown in Figure 4.9 to Figure 4.12.

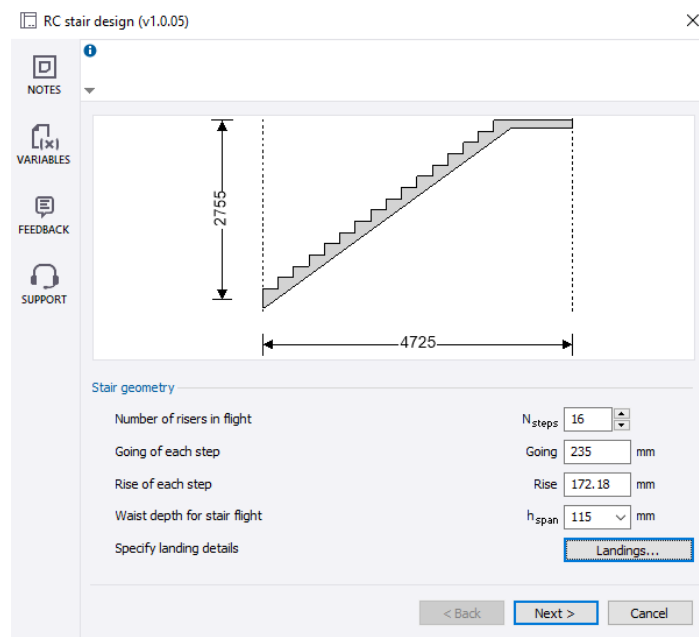


Figure 4.9: Lower Staircase of Double-Storey Terrace House.

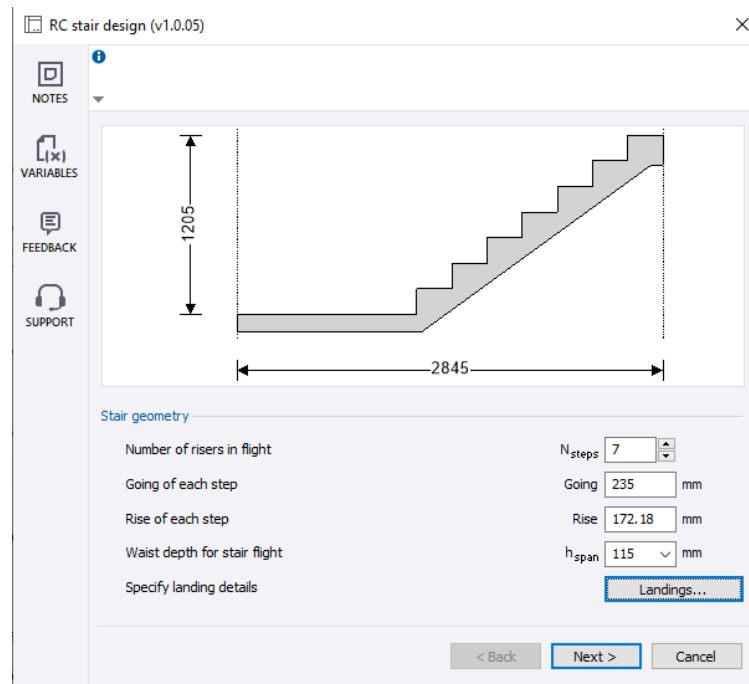


Figure 4.10: Upper Staircase of Double-Storey Terrace House.

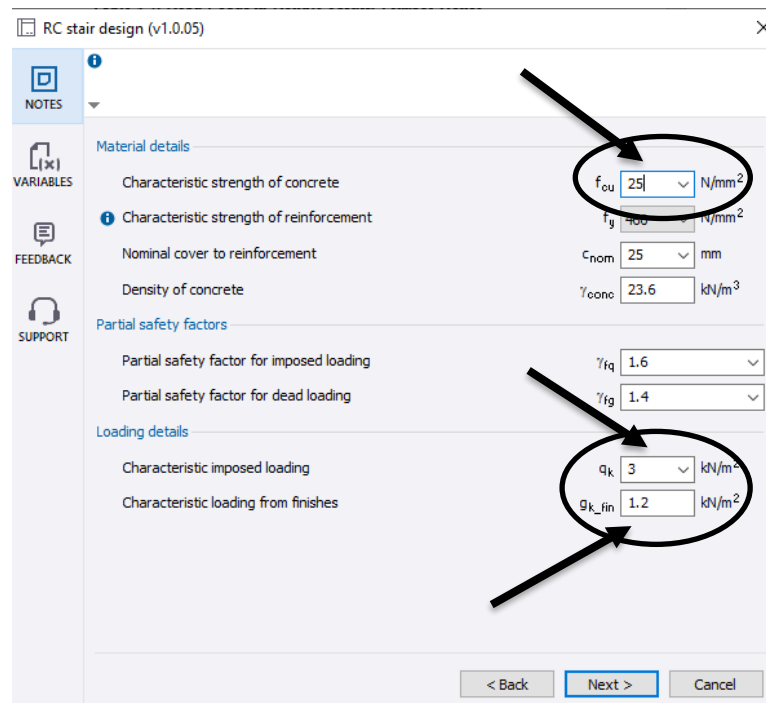


Figure 4.11: Material and Loading Details of Staircase Used.

The screenshot displays the 'RC stair design (v1.0.05)' software interface. On the left, there is a sidebar with icons for NOTES, VARIABLES, FEEDBACK, and SUPPORT. The main area shows the following information:

- Mid span reinforcement - Bending moment is 39.167 kNm/m**
 - Reinforcement diameter: ϕ_{span} 12 mm
 - Reinforcement spacing: s_{span} 150 mm
 - Compression reinforcement is required, beyond scope of calculation
- Deflection of beams at mid span - Allowable span/effective depth ratio is 1.563**
 - Actual span/effective depth ratio is 56.250 - FAIL
- Upper support reinforcement**
 - Reinforcement diameter: ϕ_{upper} 12 mm
 - Reinforcement spacing: s_{upper} 150 mm
 - Area required is 836.1 mm²/m, area provided is 754.0 mm²/m - FAIL
- Lower support reinforcement**
 - Reinforcement diameter: ϕ_{lower} 12 mm
 - Reinforcement spacing: s_{lower} 150 mm
 - Area required is 836.1 mm²/m, area provided is 754.0 mm²/m - FAIL

At the bottom right, there are three buttons: '< Back', 'Next >', and 'Cancel'.

Figure 4.12: Reinforcement Diameter and Spacing of Staircase Used.

Once all the information is keyed, the calculation results of the staircases are produced by Tekla Tedds. Unfortunately, there were some errors occurred in the proposed design by Wonderful Engineering & Construction Sdn. Bhd. The lower staircases of both houses encountered almost the same issues. In double-storey semi-detached house, Tekla Tedds discovered that the area of reinforcement provided was less than tension reinforcement required, and the actual span/effective depth ratio has exceeded the allowable of it which cause to fail in design. Apart from that, in double-storey terrace house, the compression reinforcement is required because actual K_{span} is higher than allowable K'_{span} . Besides that, the area of reinforcement provided for both lower and upper landing support are less than the tension reinforcement required. Thus, it leads to failure of design. The calculation result can be shown in Figure 4.13 and Figure 4.14.

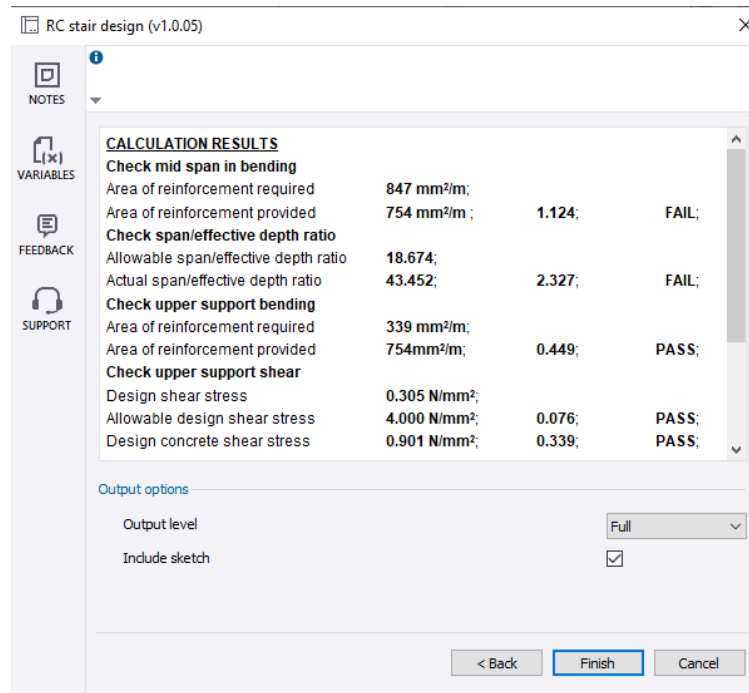


Figure 4.13: Calculation Result for Lower Staircase of Double-Storey Semi-Detached House.

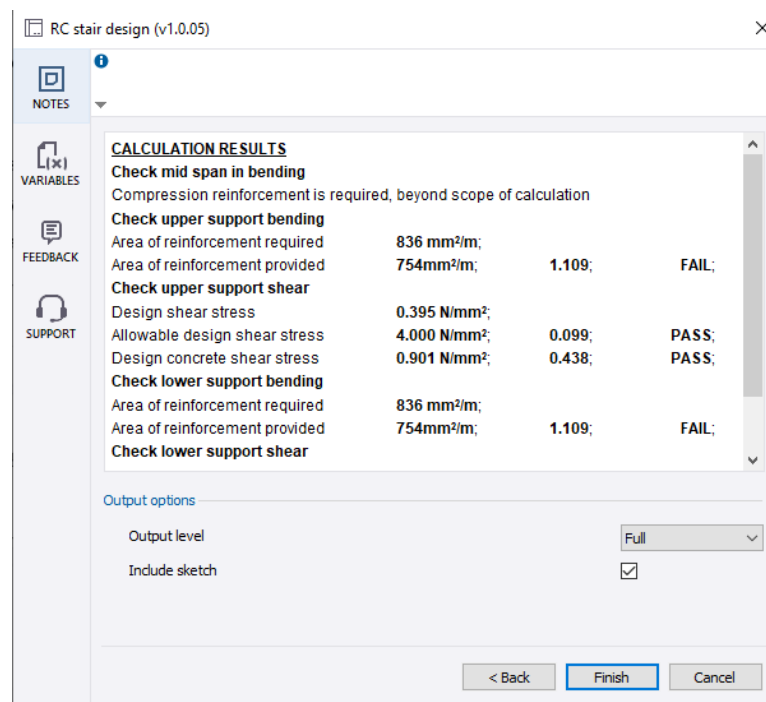


Figure 4.14: Calculation Result for Lower Staircase of Double-Storey Terrace House.

4.2.4 Modification of Staircase

After realizing the errors occurred in those staircases, a quick modification is made to fix the errors. To resolve the errors, a short process of trial and error is performed to produce a suitable result. In the stair geometry of double-storey terrace house, the number of risers in flight has been reduced from 16 to 12. The waist depth for the stair flight is increased from 115mm to 150mm. The going and rise of each step are remain constant. Other information such as material details, partial safety factors, and loading details are remain constant as well. Then, the reinforcement in mid span for bending moment has been changed. The reinforcement spacing can be reduced from 150mm to 100mm. Thus, the area provided from the reinforcement is $1131\text{mm}^2/\text{m}$ which is higher than $643.6\text{mm}^2/\text{m}$ of the area required. Due to the reduction of number of risers in flight, the value of the actual span/effective depth ratio is 31.807 and it is adequate because it does not surpass the allowable span/effective depth ratio which is 32.95. and shows the modification changed in double-storey terrace house. Figure 4.15 and Figure 4.16 shows the modification done for the lower staircase in double-storey terrace house.

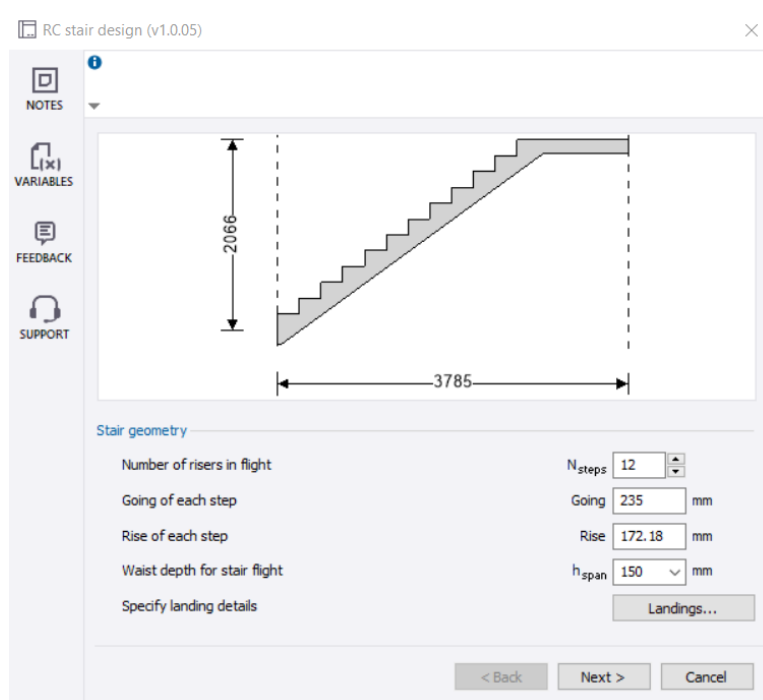


Figure 4.15: Modification of Stair Geometry for Lower Staircase of Double-Storey Terrace House.

RC stair design (v1.0.05)

NOTES

VARIABLES

FEEDBACK

SUPPORT

Mid span reinforcement - Bending moment is 27.700 kNm/m

Reinforcement diameter ϕ_{span} 12 mm

Reinforcement spacing s_{span} 100 mm

- Area required is 643.6 mm²/m, area provided is 1131.0 mm²/m - PASS

Deflection of beams at mid span - Allowable span/effective depth ratio is 32.950

- Actual span/effective depth ratio is 31.807 - PASS

Upper support reinforcement

Reinforcement diameter ϕ_{upper} 12 mm

Reinforcement spacing s_{upper} 150 mm

- Area required is 360.0 mm²/m, area provided is 754.0 mm²/m - PASS

Lower support reinforcement

Reinforcement diameter ϕ_{lower} 12 mm

Reinforcement spacing s_{lower} 150 mm

- Area required is 360.0 mm²/m, area provided is 754.0 mm²/m - PASS

< Back Next > Cancel

Figure 4.16: Modification of Mid Span Reinforcement for Lower Staircase of Double-Storey Terrace House.

Next, for the double-storey semi-detached house, the waist depth for stair flight has been increased from 115mm to 150mm in the stair geometry section. The going of each step, rise of each step, and the number of risers in flight are remain constant. Besides, the material details, partial safety factors, and loading details are unchanged. Lastly, the reinforcement spacing for the mid span reinforcement can be decreased from 150mm to 125mm which allow the value of area provided which is 904.8 mm²/m to surpass the value of 593.6 mm²/m of the area required in mid span. Figure 4.17 and Figure 4.18 shows the modification done for the lower staircase in double-storey semi-detached house.

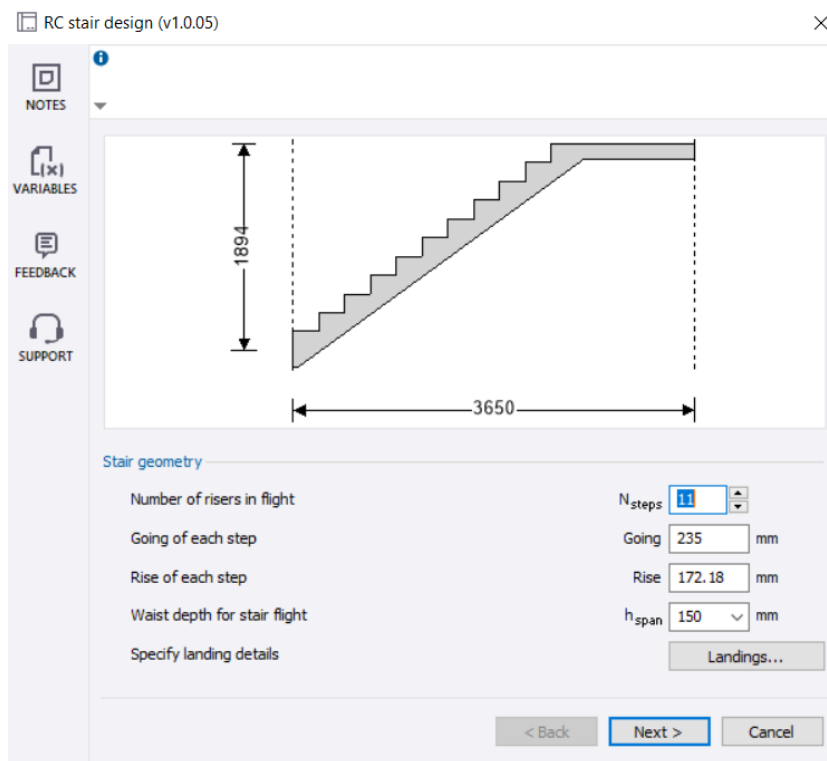


Figure 4.17: Modification of Stair Geometry for Lower Staircase of Double-Storey Semi-Detached House.

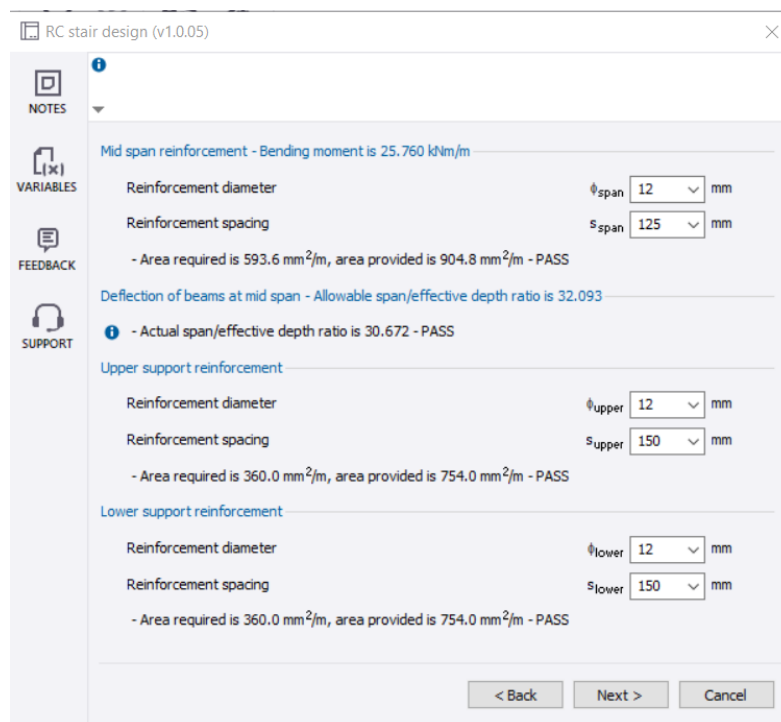


Figure 4.18: Modification of Mid Span Reinforcement for Lower Staircase of Double-Storey Semi-Detached House.

4.3 Structural Analysis

After generated two 3D models of the houses in Esteem, the statics load of each slab is keyed in each room for both 3D models in Esteem. The loads of the stair are also be put into the 3D models in Esteem to get a more accurate result. Once everything is set, the structural analysis is performed in Esteem shown in Figure 4.19.



Figure 4.19: Batch Analysis and Design.

4.3.1 Double-Storey Semi-Detached House

The 3D model of double-storey semi-detached house has performed structural analysis. There were multiple issues found by Esteem. Firstly, the beams at B/1a-1a' and C/1a-1a' in ground floor were failed to support their slab. Since the structure of the buildings are symmetrical, both sides of the beam sections are needed to be fix. This error occurred because that section has a drop of 150mm for both the beams and slabs, and beams are not able to support the dropped slab shown in Figure 4.20 and Figure 4.21.

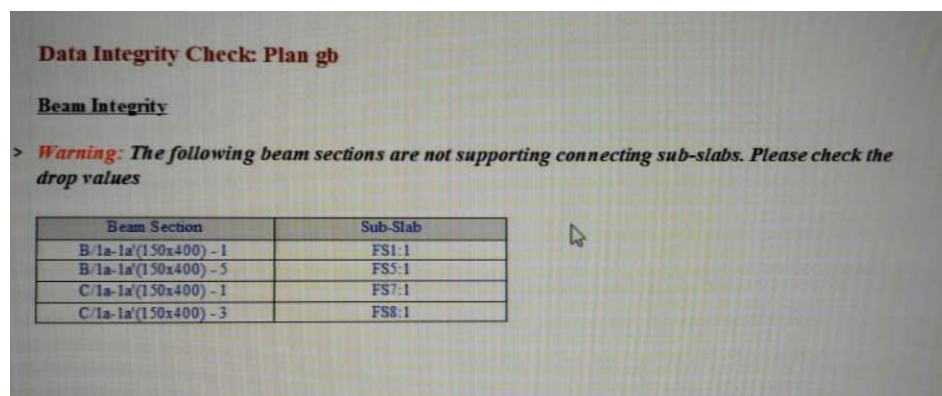


Figure 4.20: Ground Floor Beam Error.

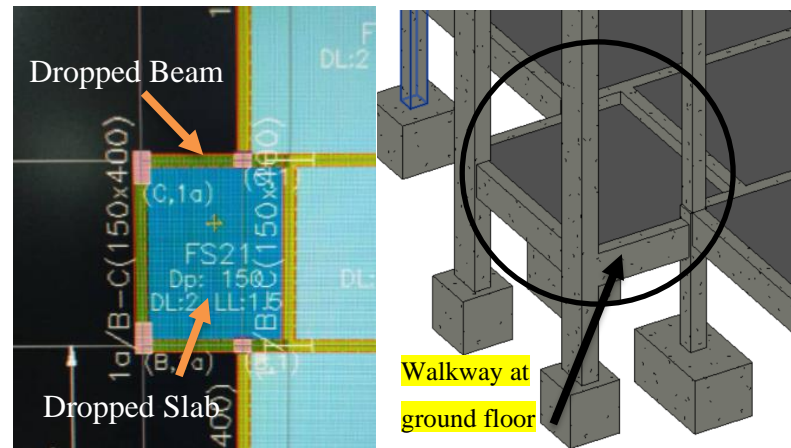


Figure 4.21: Ground Floor Dropped Beams and Slab at Walkway.

To solve this issue, the smaller length of beams on the right side will not be dropped together with the other beams surrounded the slab. By doing this, the slab is able to be supported by the beams surrounded it. Besides, the size of the beam (150mm x 400mm) are maintained. Figure 4.22 shows the fixed ground floor beams.

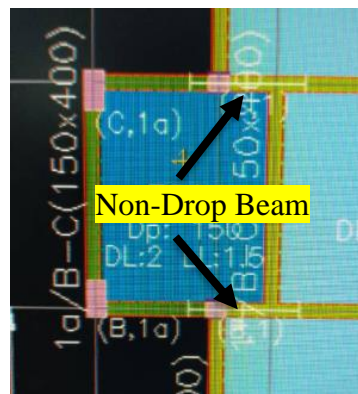


Figure 4.22: Fixed Ground Floor Beams.

At the first floor of this building, the beam section at 3/A'-E was not able to support two slabs at the balcony area which cause the slab edge to become unsupported. The beam section at 3/A'-A has two different dropped beams with different beam sizes. The beam at 3/A'1-A'2 which is the balcony area has a drop of 75mm with the size of 200mm width and 375mm depth. On the other hand, the beam at 3/A-A' has a drop of 560mm with the size of 200mm width and 450mm depth. Due to these requirements shown in structural plan, Esteem was not able to recreate the same design presented

by the structural plan. Esteem does not allow two different beams to be in the same gridline. Thus, the location of the beam will be relocated into another gridline. Apart from that, the beam at A1'/1-1'a and A1'/1-1''a which is the toilet area also do not support their slabs due to the incorrect drop value of the beam. Figure 4.23 and Figure 4.24 shows the location and beam error at first floor.

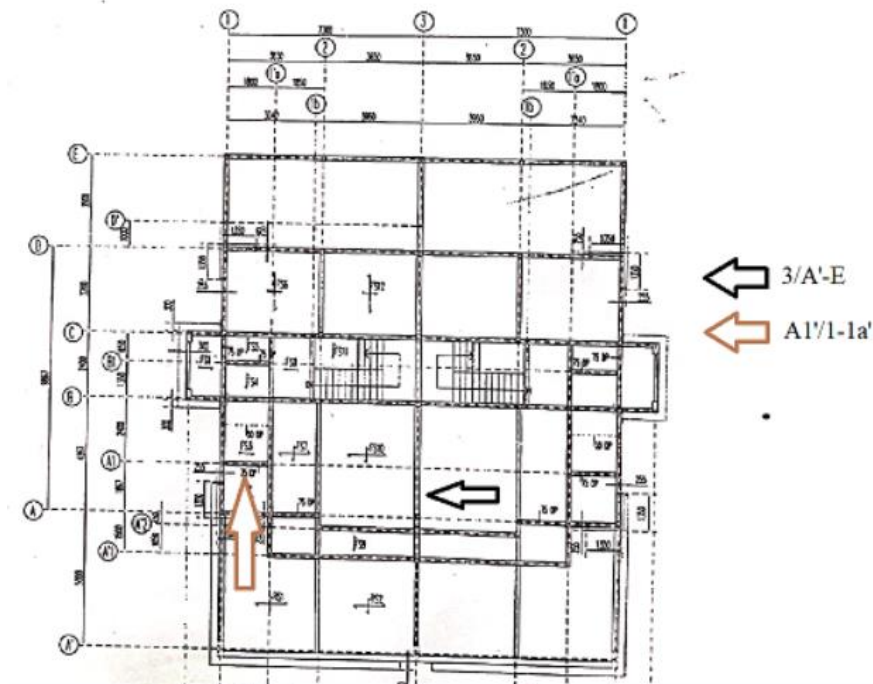


Figure 4.23: Location of Beam Error at First Floor.

Beam Integrity

Error: The following beam sections are not supporting connecting sub-slabs causing free edge. Please check the drop values

Beam Section	Sub-Slab
3/A'-E(200x450/200x450/150x400) - 1	FS1:1
3/A'-E(200x450/200x450/150x400) - 1	FS2:1

Warning: The following beam sections are not supporting connecting sub-slabs. Please check the drop values

Beam Section	Sub-Slab
A1'/1-1'a(150x300) - 1	FS23:1
A1'/1''a-1(150x300) - 1	FS24:1

Figure 4.24: First Floor Beam Error.

The beams at A1'/1-1'a and A1'/1-1''a which is at the toilet are fixed by not dropping the beams which allow the beams to support the dropped slab. The drop value of the beams at A1'/1-1'a and A1'/1-1''a are increased from 75mm to 0mm while maintaining their beam size. Lastly, the error beam section at 3/A'-E was solved by removing the dropped beam at 3/A-A' and increasing the beam size at 3/A'1-A'2 from 200mm width and 375mm depth to 200mm width and 450mm depth. By removing the dropped beam at 3/A-A', there will no supports to carry the roof at that location. Thus, there will be two extra 560mm dropped beam with the size of 200mm width and 450mm depth at 2/A-A' and 2'/A-A'. Since there are beams occupied at 2/A-A' and 2'/A-A', the beam at A'1/1'a-2 will not be able to be added because of the incapability of Esteem. So, the design of the balcony is changed until the beams are able to support the slab. Since the location of beams are relocated into different gridlines, the shape of the slabs are also redesigned to suit the location of the beams. With this modification made for the balcony, it is still resembled a little with the previous design of the balcony. The location of the window and door will be changed as well as the area of the balcony has become smaller. Figure 4.25 shows the before and after of the first-floor balcony design.

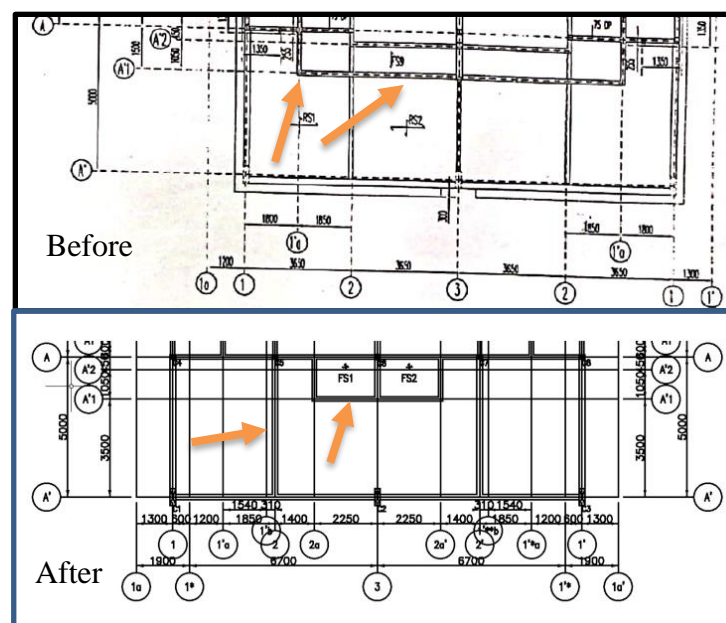


Figure 4.25: The Before And After Of The First-Floor Balcony Design.

In summary, the errors occurred at structural beams and slabs in the double-storey semi-detached houses are redesigned and fixed according to the guidance of Eurocode in Esteem. With these modifications made, Esteem can proceed generating the entire detailing of the structural elements and the structural plan of the house. Table 4.4 shows the modification made in double-storey semi-detached houses.

Table 4.4: Modification Made In Double-Storey Semi-Detached Houses.

Structural Member Modification	Beam	Beam	Beam	Slab
Level	Ground Floor	First Floor	First Floor	First Floor
Building Room	Walkway	Balcony	Toilet	Balcony
Error(s)	Fail to support slab	Fail to support slab	Fail to support slab	Beam failed to support slab
Modification(s)	Increase the drop value of beam	Redesign the size of beam	Increase the drop value of beam	Redesign the shape of slab
Change of Location				
• Before	- B/1a-1a' & C/1a-1a'	- 3/ A'1-A'2	- A1'/1-1'a & A1'/1-1''a	- A-A'1/1'a-3
• After	- B/1a-1a' & C/1a-1a'	- 3/ A'1-A'2	- A1'/1-1'a & A1'/1-1''a	- A-A'1/2a-3
Change of Size				
• Before	- 150mm x 400mm	- 200mm x 375mm	- 150mm x 300mm	- 5500mm x 1500mm x 100mm thk
• After	- 150mm x 400mm	- 200mm x 450mm	- 150mm x 300mm	- 2075mm x 1350mm x 100mm thk
Change of Drop				
• Before	- 150mm	- None	- 75mm	- 75mm
• After	- 0mm	- None	- 0mm	- 75mm
Deleted Structural Member	None	- Beam at 3/A-A'	None	- Beam at 3/A-A'
Added Structural Member	None	- Beam at 2/A-A' and 2'/A-A' (200mm x 450mm)	None	- Beam at 2/A-A' and 2'/A-A' (200mm x 450mm)

4.3.2 Double-Storey Terrace House

Next, there were some errors happened in the 3D model of double-storey semi-detached house when performing structural analysis. First of all, the ground floor beams at A'1/1-2' which is the walkway at car porch were failed due to deflection. This is due to the size of the beam and the drop value of the beam which cause the deflection failure. Not only that, but there is also another ground floor beam deflection failure at E/1-1. So, trial and error is performed on these ground beams to ensure the deflection checking is passable. Figure 4.26 and Figure 4.27 shows the deflection failure and its value at ground floor beam.

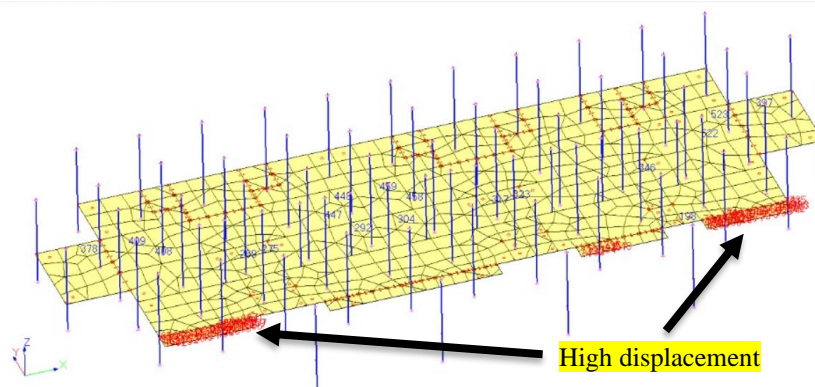


Figure 4.26: The Deflection Failure at Ground Floor Beam.

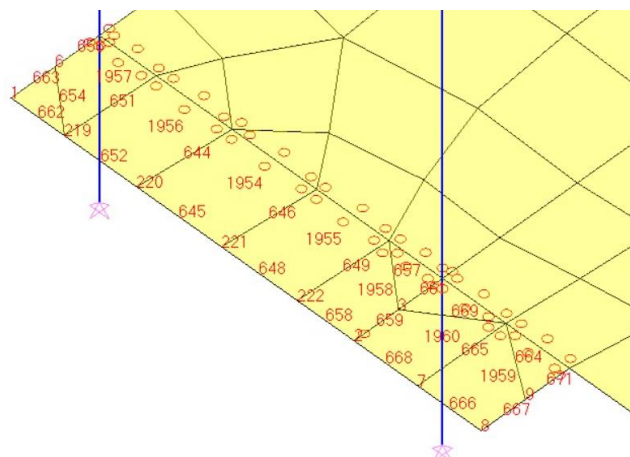


Figure 4.27: The Value of Deflection at Ground Floor Beam.

As mentioned before, the deflection of ground beam can be affected by the drop value and the size of beam. So, the size of beams at 2'/A'1-A, 1/A'1-A, and

A'1/1-2' are changed by increasing the size of beam from 150mm width and 300mm depth into 150mm width and 400mm. Furthermore, the drop value of beams at 2'/A'1-A and 1/A'1-A are also increased from 150mm to 0mm. Next, the ground floor beam at E/1-1 is redesigned by increasing the size of beam from 150mm width and 400mm depth into 200mm width and 500mm depth. With these modifications, the beams are able to pass the deflection checking in Esteem. Figure 4.28 and Figure 4.29 show the modification of ground beams.

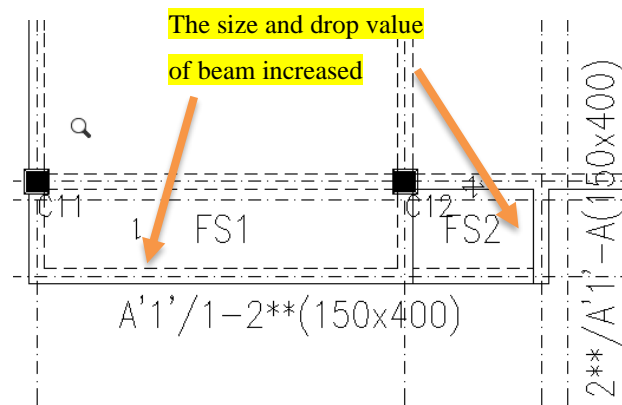


Figure 4.28: The Modification of Ground Beam at 2'/A'1-A and 1/A'1-A.

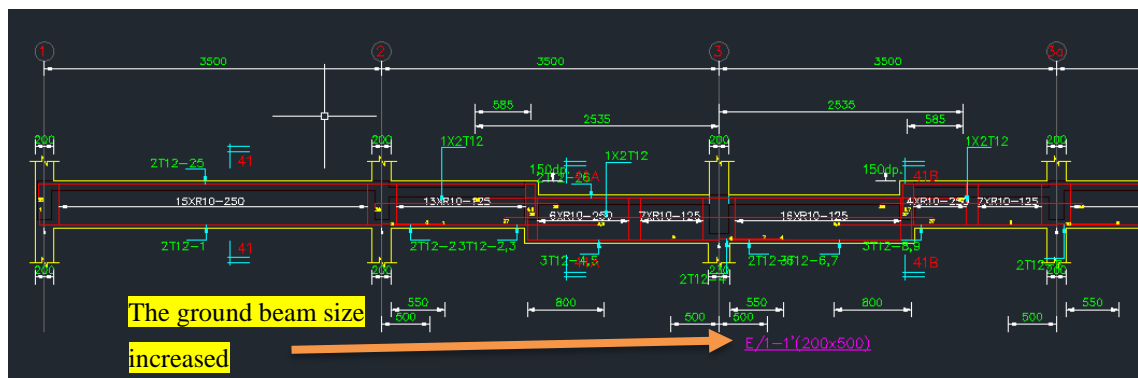


Figure 4.29: The Modification of Ground Beam at E/1-1.

Moreover, the slabs at first floor had an error of not creating a plan stress slab mesh due to the width/length ratio of the slabs are greater than five. The slabs are located at B-B'/3a-4 and B-B'/4-3a. To ensure the width/length ratio of slab is less

than five, the size of the slab is changed. Initially, the size of the slab was 3300mm width and 300mm length and it is reduced to 1225mm width and 300mm length. In addition, a beam with the size of 150mm width and 400mm depth is added to support the load of the slab at $2b/B-B'$ while the beam at $B/2b-2b'$ is deleted. If the beam at $B/2b-2b'$ is not deleted, there will be another slab existed which can cause width/length ratio of the slabs to be greater than five. Thus, the beam is deleted at $B/2b-2b'$. The location of first floor slab error is shown in Figure 4.30 and the modified slab design in first floor is shown in Figure 4.31.

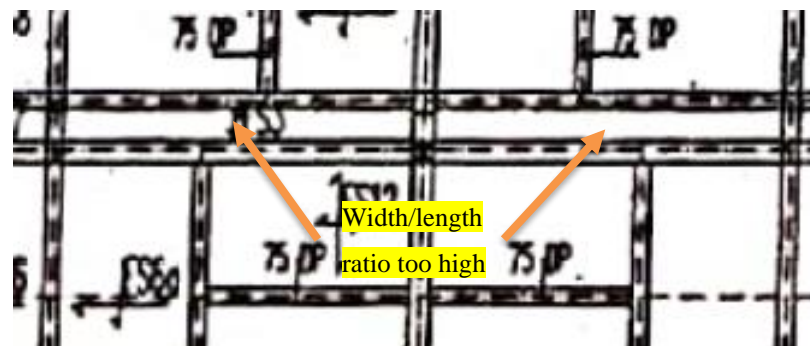


Figure 4.30: Location of First Floor Slabs Error.

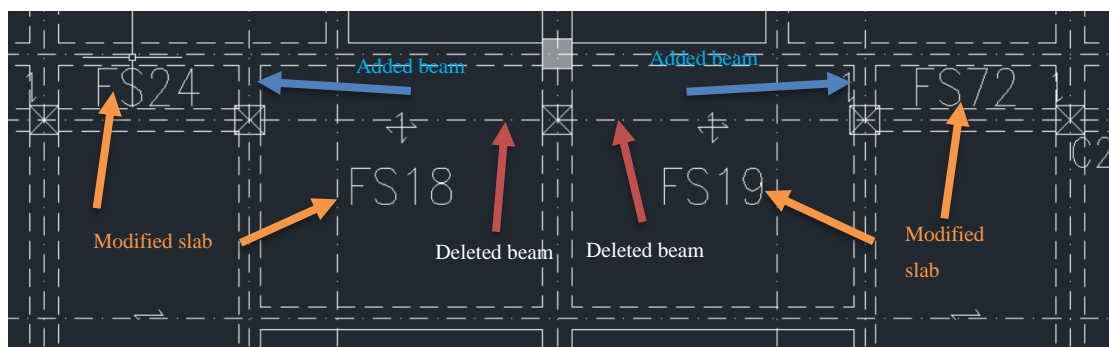


Figure 4.31: Modified Slab Design in First Floor.

In conclusion, the errors occurred at structural beams and slabs in the double-storey terrace houses are pretty low compared to the double-storey semi-detached house. However, the errors in the terrace house are redesigned and fixed according to the guidance of Eurocode in Esteem and the entire detailing of the structural elements

and the structural plan of the house were able to generate in Esteem. All the finalized detailing and plans are exported to AutoCAD for better observation. Table 4.5 shows the modification made in double-storey terrace houses.

Table 4.5: Modification Made In Double-Storey Terrace Houses.

Structural Member	Beam	Beam	Slab
Modification			
Level	Ground Floor	Ground Floor	First Floor
Building Room	Walkway	Utility to Drying Area	Master's Room
Error(s)	Deflection at beam	Fail to support slab	High width/length ratio
Modification(s)	Increase the drop value of beams	Redesign the size of beam	Redesign the dimension of slab
Change of Location <ul style="list-style-type: none"> • Before • After 	<ul style="list-style-type: none"> - 2'/A'1-A, 1/A'1-A, & A'1/1-2' - 2'/A'1-A, 1/A'1-A, & A'1/1-2' 	<ul style="list-style-type: none"> - E/1-1 - E/1-1 	<ul style="list-style-type: none"> - B-B'/3a-4 & B-B'/4-3a - B-B'/3a-4 & B-B'/4-3a
Change of Size <ul style="list-style-type: none"> • Before • After 	<ul style="list-style-type: none"> - 150mm x 300mm - 150mm x 400mm 	<ul style="list-style-type: none"> - 150mm x 400mm - 200mm x 500mm 	<ul style="list-style-type: none"> - 3300mm x 300mm x 100mm thk - 1225mm x 300mm x 100mm thk
Change of Drop <ul style="list-style-type: none"> • Before • After 	<ul style="list-style-type: none"> - 150mm - 0mm 	<ul style="list-style-type: none"> - None - None 	<ul style="list-style-type: none"> - None - None
Deleted Structural Member	None	None	Beam at B/2b-2b'
Added Structural Member	None	None	Beam at 2b/B-B' (150mm x 400mm)

4.4 Clash Detection of Models

After modifying all the errors and performed structural analysis in both 3D models, the previous 3D model designs are recreated again to follow the suggested design by Esteem. Unfortunately, the redesign of the 3D models needed to be created manually in Autodesk Revit as there is no latest extension to export the latest design in Esteem to Autodesk Revit. Then, clash detection which also known as interference checking will be performed in Autodesk Revit once the 3D models are updated. The interference check is capable to check interferences between many different elements in the architectural plan and structural plan which are shown in Figure 4.32 and Figure 4.33.

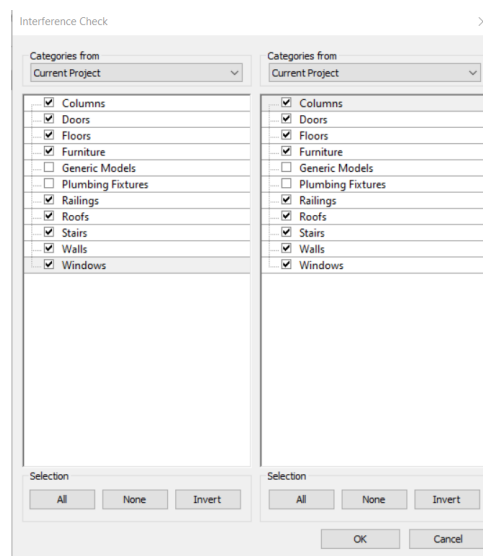


Figure 4.32: Category of Interference Check In Architectural Plan.

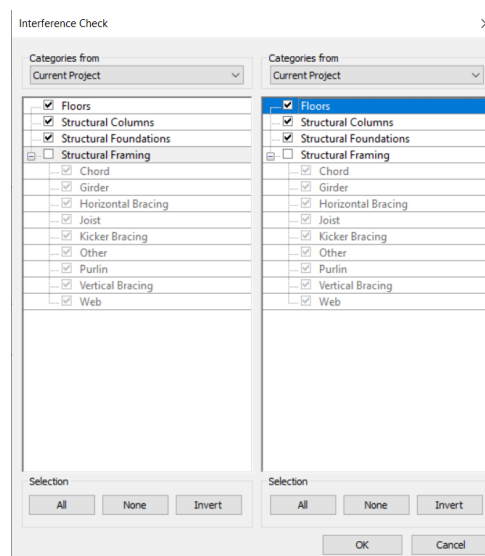


Figure 4.33: Category of Interference Check In Structural Plan.

For the interference check in the architectural plan for both 3D models, there were only a few categories selected to be checked such as the columns, doors, floors, furniture, roofs, stairs, railings, windows, and walls of the 3D models. Besides that, categories such as floors, structural columns, structural foundations, and structural framing were checked for the interference check in the structural plan for both 3D models. Once all the categories were selected in both 3D models, clash detection is performed by clicking the “OK” button. The report of clash detection was generated after a few seconds and there were some interferences detected in both 3D models. Table 4.6 to Table 4.8 shows the clashes detected in both architectural and structural 3D models for both different type of houses.

Table 4.6: Interferences in Architectural Model of Double-Storey Semi-Detached House.

	A	B	NO. CLASHES
	Wall	Other Elements	
1	Wall: brick wall 115mm	Wall: brick wall 115mm	1
2	Wall: brick wall 115mm	Assembled Stair: Stair	2
3	Wall: brick wall 115mm	Door: Single-Flush: 30"x80"	10
4	Wall: brick wall 115mm	Floor: kitchen floor	4
5	Wall: brick wall 115mm	Floor: toilet tile	2
6	Wall: brick wall 115mm	Floor: carpet floor	1
7	Wall: brick wall 115mm	Furniture: Desk: 60"x30"	4
	Floor	Other Elements	
1	Floor: carpet floor	Wall: brick wall 115mm	6
2	Floor: carpet floor	Furniture: M_Chair-Breuer	16
	Stairs	Other Elements	
1	Assembled Stair: Stair	Wall: brick wall 115mm	3
	Railings	Other Elements	
1	Railing: Handrail	Wall: brick wall 115mm	2

Table 4.7: Interferences in Structural Model of Double-Storey Semi-Detached House

	A	B	NO. CLASHES
	Floor	Other Elements	
1	Floor: Concrete 100mm	Structural Framing: M_Concrete Rectangular Beam 150x400mm	1

Table 4.8: Interferences in Architectural Model of Double-Storey Terrace House

	A	B	NO. CLASHES
	Wall	Other Elements	
1	Wall: brick wall 115mm	Wall: brick wall 115mm	8
2	Wall: brick wall 115mm	Floor: car porch	7
3	Wall: brick wall 115mm	Furniture: M_Credenza	5
4	Wall: brick wall 115mm	Floor: carpet floor	5
5	Wall: brick wall 115mm	Furniture: Desk: 60"x30"	25
	Floor	Other Elements	
1	Floor: carpet floor	Wall: brick wall 115mm	5
2	Floor: carpet floor	Furniture: M_Chair-Breuer	50
3	Floor: car porch	Wall: brick wall 115mm	7
	Stairs	Other Elements	
1	Assembled Stair: Stair	Floor: carpet floor	5
	Roof	Other Elements	
1	Basic Roof: 100 roofs	Wall: brick wall 115mm	43

Based on the clashes shown in the 3D models, there are more clashes occurred in architectural models compared to the structural models because architectural models included a lot of different elements which make it harder for the user to keep track on every element presented in the models. For the clashes in the structural models, only one clash was found by Autodesk Revit in the double-storey semi-detached house. There were no clashes found in the terrace model as the user plotted the structural members accurately after gaining experience when plotting the semi-detached models. Since Autodesk Revit is not advanced enough to fix the clashes automatically, the user have to manually fix the clashes by locating the clashes one by one in the models.

4.5 Modification to Improve the Interferences Between Different Elements

In this research, the 3D models will be modified again in Autodesk Revit to improve the interferences between different elements in the models for clash detection. Once the models are modified and updated in Autodesk Revit, clash detection is performed again to the modified 3D models.

First of all, the slab at the balcony of the semi-detached house has clashed into the structural beam on the roof floor. It is suggested that the shaped of the slab is needed to redraw to prevent any interference to the other structural members around

it. By selecting the errored slab, it was edit by adjusting the shape without cutting the roof floor beam shown in Figure 4.34.

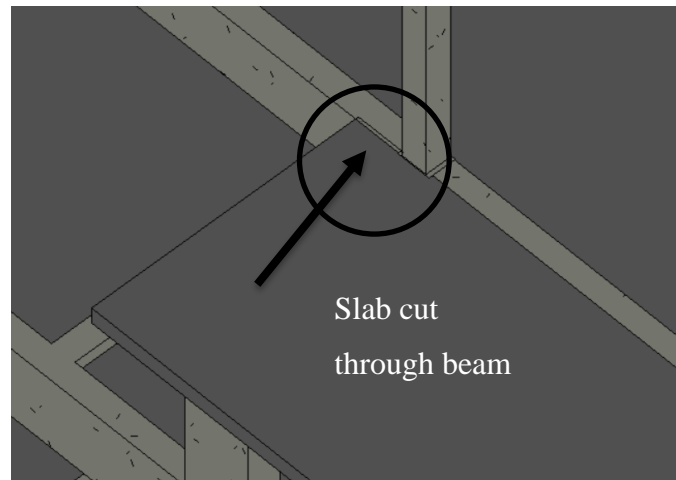


Figure 4.34: Interference between Slab and Beam at Double-Storey Semi-Detached House.

However, there were some other errors I found without the notices from Autodesk Revit. After some quick observation again for the structural 3D model, I realized that Autodesk Revit does not consider that a structural member was cut into another structural member as long it did not clash with each other. As a civil engineer, we know that a structural beam should not cut through column and structural slab should not cut through beam and column. Thus, these errors are manually redrawn again to make the structural members should not cut each other shown in Figure 4.35 and Figure 4.36.

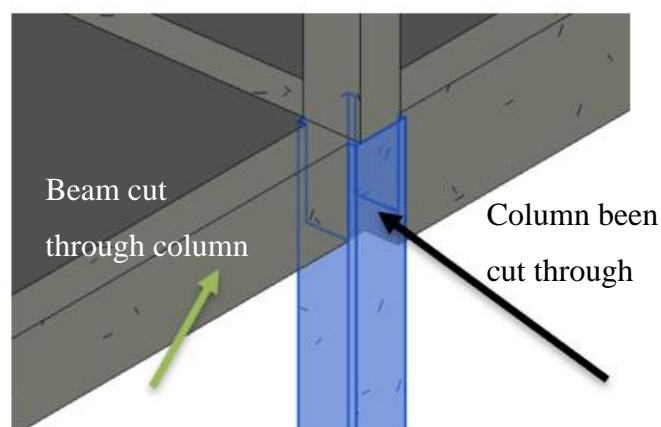


Figure 4.35: Structural Beam Cut Through Structural Column.

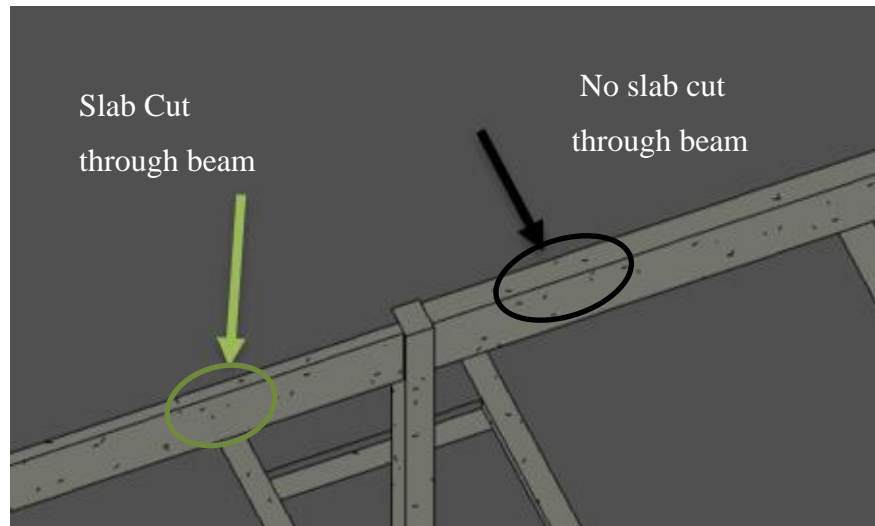


Figure 4.36: Structural Slab Cut Through Structural Beam.

These minor errors can be simply fix by using one of Autodesk Revit's function called "Switch Join Order" where the structural beam, structural column, and structural slab can be joined together in a correct location without cutting other structural members. After finish dealing with the clashes in the structural model, architectural models were investigated more precisely as it has more errors compared to the structural model. In the architectural models of semi-detached house and terrace house, we observed that most of the clashes are against the wall with other elements such as floors, doors, furniture, and stairs. To fix these clashes, we can either relocate the elements or delete unwanted elements to prevent future clashes. Figure 4.38 to Figure 4.41 shows the clashes before and after between wall and other elements.

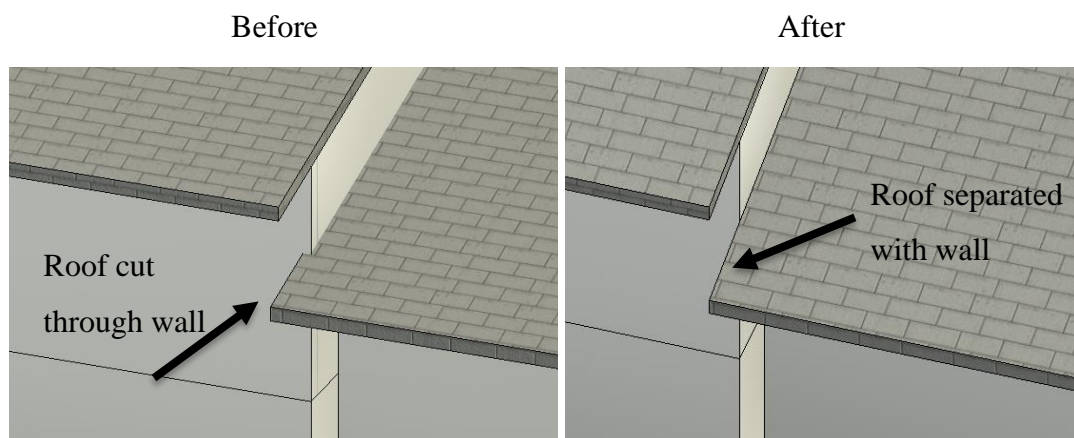


Figure 4.37: Clash Before and After Between Roof and Wall.

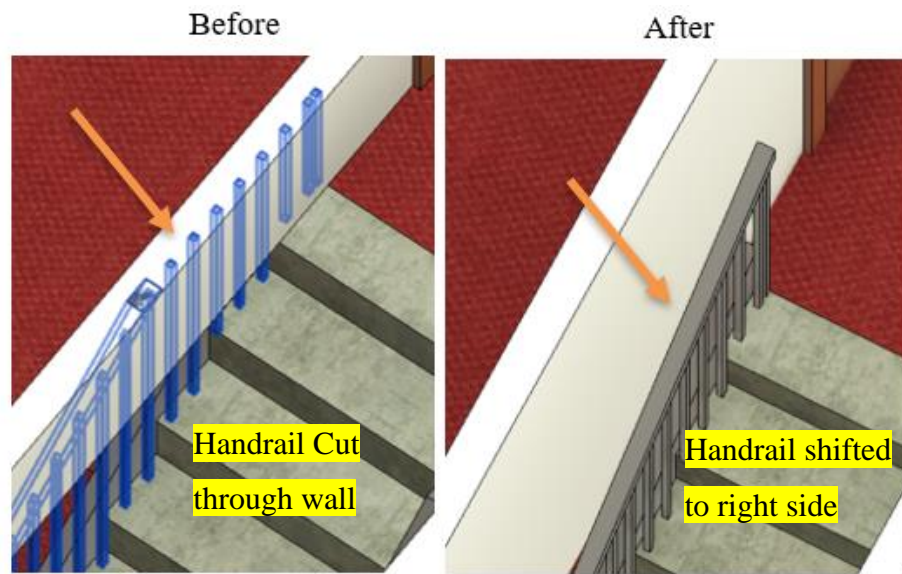


Figure 4.38: Clash Before and After Between Wall and Staircase.

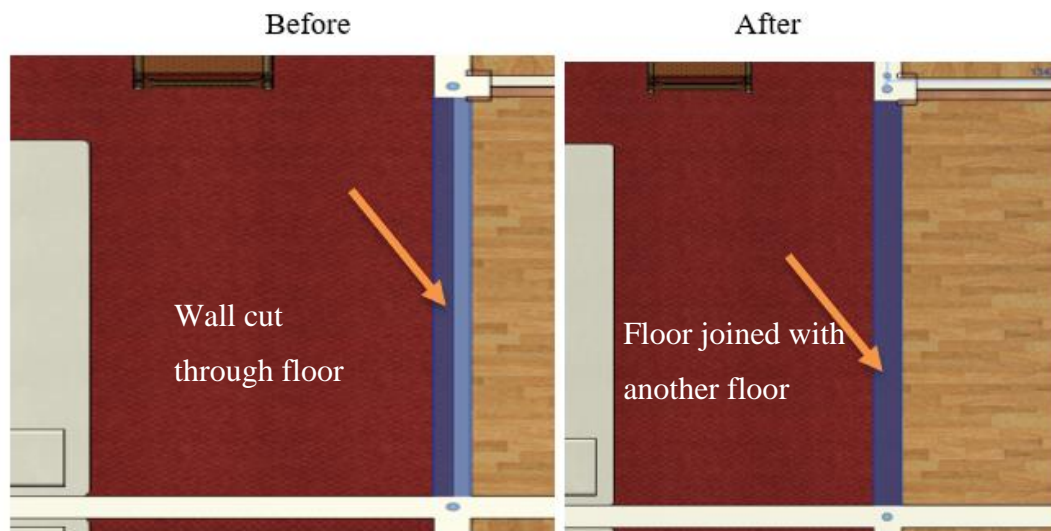


Figure 4.39: Clash Before and After Between Wall and Floor at Plan View.

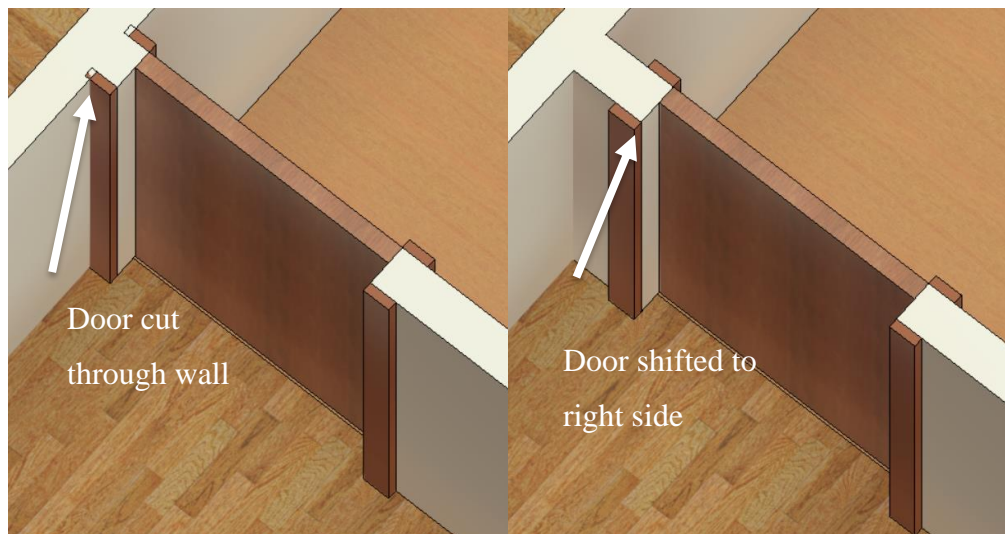


Figure 4.40: Clash Before and After Between Wall and Door.

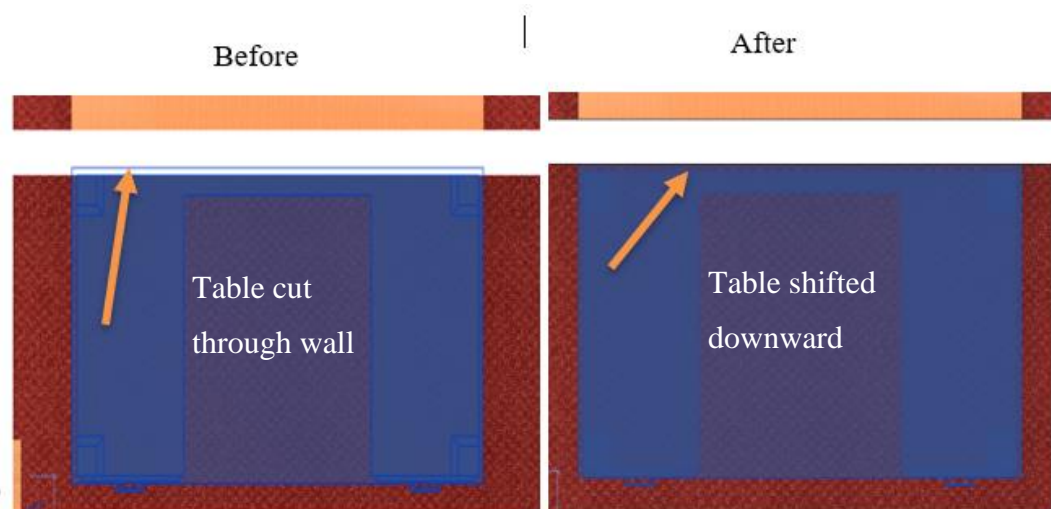


Figure 4.41: Clash Before and After Between Wall and Furniture.

4.6 Cost Comparison between Old Design and New Design of the Project

The cost comparison between the old design of the 3D models and the new design of the 3D models is shown in **Error! Reference source not found.**. Based on **Error! Reference source not found.**, there are two type of steel bar being labelled such as commercial quality (CQ) and British Standard (BS). Even though BS bar is expensive than CQ bar, but the certificate of BS bar will be handed by the supplier or hardware shop after purchasing it (Irfisher.blogspot.com, 2021). Comparing the total cost of the old design of the 3D models and the newer one, the newer design of 3D models is definitely more expensive than the older design due to the increase of steel bar size. However, it is cheaper to get the bundle steel bar together with the remaining pieces left required compared purchasing per piece at a time. Not only that, but the owner of the project can also choose a cheaper option of purchasing CQ bars instead of BS bars if the budget is limited.

Table 4.9: Cost Comparison Between Old Design and New Design of the Houses (Ewarehouse.my, 2021)

Steel Bar	Cost Per Piece (RM)	Cost Per Bundle (RM)	No. Steel Bar Old Design (m)	Total Cost (RM) Old Design	No. Steel Bar New Design (m)	Total Cost (RM) New Design
Mild Steel Round Bar R6 (CQ) 10.5m length	10.50	2800.00 (320 pieces)	Semi-D = 571 Terrace = 408	Semi-D = 5995.50 (per piece) Semi-D = 5435.50 (1 bundle + 251 pieces) Terrace = 4284.00 (per piece) Terrace = 3724.00 (1 bundle + 88 pieces)	Semi-D = 571 Terrace = 408	Semi-D = 5995.50 (per piece) Semi-D = 5435.50 (1 bundle + 251 pieces) Terrace = 4284.00 (per piece) Terrace = 3724.00 (1 bundle + 88 pieces)
Mild Steel Round Bar R8 (CQ) 10.5m length	20.00	1650 (320 pieces)	Semi-D = 2667 Terrace = 6768	Semi-D = 53340.00 (per piece) Semi-D = 15340.00 (8 bundles + 107 pieces) Terrace = 135360.00 (per piece) Terrace = 35610.00 (21 bundles + 48 pieces)	Semi-D = - Terrace = 465	Semi-D = - Semi-D = - Terrace = 9300.00 (per piece) Terrace = 4550.00 (1 bundle + 145 pieces)
Mild Steel Round Bar Y10 (CQ) 12m length	25.00	3200 (147 pieces)	Semi-D = - Terrace = -	Semi-D = - Semi-D = - Terrace = - Terrace = -	Semi-D = 2667 Terrace = 6303	Semi-D = 66675.00 (per piece) Semi-D = 58125.00 (18 bundles + 21 pieces) Terrace = 157575.00 (per piece) Terrace = 137600.00 (43 bundles)
Mild Steel Round Bar Y10 (BS) 12m length	39.00	3700 (137 pieces)	Semi-D = - Terrace = -	Semi-D = - Semi-D = - Terrace = - Terrace = -	Semi-D = 2667 Terrace = 6303	Semi-D = 104013.00 (per piece) Semi-D = 72796.00 (19 bundles + 64 pieces) Terrace = 245817.00 (per piece) Terrace = 170200.0 (46 bundles)
Total Cost (RM)	-	-	-	Semi-D (CQ) = 59335.50 (pieces) Semi-D (CQ) = 20775.5 (bundles & pieces) Terrace (CQ) = 139644.00 (pieces) Terrace (CQ) = 34650.00 (bundles & pieces)	-	Semi-D (CQ BS) = 72670.50 110008.50 (pieces) Semi-D (CQ BS) = 63560.00 78231.50 (bundles & pieces) Terrace (CQ BS) = 171159.00 259401.00 (pieces) Terrace (CQ BS) = 145874.00 178474.00 (bundles & pieces)

4.7 Summary

In this research, both structural analysis and clash detection were conducted and produced some results that can be used for further study. In the structural analysis report, most of the reinforcement in the structural members from the proposed structural plan by Wonderful Engineering & Construction Sdn. Bhd. are about the same as the one proposed by Esteem. However, there are a slight change of the rebar size proposed by Esteem.

For the column schedule, the size of main bars are remained constant while the link bars size are increased from R8-125 C/C to R10-125 C/C. Apart from that, the size of link bars in beam are changed as well by increasing it from R6-150 C/C to R10-250 C/C. The size of main bars and link bars are unchanged for the slabs. The tensile strength of the increased link bar size is used to improve the strength of the structure with the help of the compressive strength of concrete. Structural integrity of the house is also improved by the increased link bar size to withstand the forces. Even though it will increase the budget of the project, but we have to ensure the building is safe for consumers to use. Table 4.10 shows the changes made in different structural members.

Table 4.10: Changes Made in Different Structural Members

Building Type	Semi-Detached		Terrace	
	Before	After	Before	After
Column (Reinforcement)				
• Main Bar	None	None	None	None
• Link Bar	R8-125	R10-125	R8-125	R10-125
Beam (Reinforcement)				
• Main Bar	None	None	None	None
• Link Bar	R6-150	R10-250	R6-150	R10-250
Slab (Reinforcement)				
• Main Bar	None	None	None	None
• Link Bar	None	None	None	None

Furthermore, clash detection is made to check interferences between different elements in the building. We observed that many clashes from architectural models were found in the 3D model of terrace house because it has more units compared to the 3D model of semi-detached house. Thus, more clashes can be seen in the 3D model of terrace house. These clashes are easily to fix by properly relocating the elements in the correct placement. Any unnecessary elements can be deleted.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research, clash detection was carried with the use of building information model (BIM) model. The BIM models are built in Autodesk Revit and then export them to Esteem for structural analysis. However, due to the incapability of Autodesk Revit unable to export its 3D models to Esteem, we have to manually recreate the 3D models again in Esteem. After that, modifications has been made to improve the 3D models for structural analysis in Esteem and any changes in Esteem are updated in Autodesk Revit manually. Clash detection is conducted, and modifications are made to prevent any clashes being detected in the future.

The main objectives for this project was to determine the analyse the challenges for client in implementing BIM in the residential project and it was achieved by learning how BIM works in this research. One of the challenges is the incapability of some software due to absence of extension to export their files to other different software. When exporting 3D models from Autodesk Revit to Autodesk Robot Structural Analysis, the position of the beams and columns are inaccurate. Some of the beams are also not connected to other beams and columns which lead to redraw the 3D models again by the user. Thus, it will waste time just to fix these issues. Apart from that, one of Autodesk Revit disadvantage is it must use the same version with other software to able to export their 3D models. If the user uses Autodesk Revit 2020 to export its model to Autodesk Robot Structural Analysis 2021, it is impossible due to the version of the software. Unlike AutoCAD, the software can save its file in different version of AutoCAD which allow any version of AutoCAD can excess its file. Not only that, but not a lot of people understand how to use Autodesk Revit compared to the traditional software that most construction companies use such as AutoCAD and Esteem. Besides, Esteem provides tutorials in their software, so it is convenient for user to learn instead to searching videos on the Internet. Additionally, Autodesk Revit is not a cheap software for many small construction companies. Autodesk Revit costed around RM7245 per year while AutoCAD costed RM 5945 per

year. For a cheaper option, some small construction companies might go for AutoCAD LT which costed RM1321 per year.

However, the other three objectives in the research are achieved as well. To achieve the first objective, BIM models of semi-detached house and terrace house are built through the help of Autodesk Revit and Esteem. The 3D models in Esteem will undergo structural analysis and check whether the structure can withstand the loads applied to the structural members or not. Apart from that, Tekla Tedds was used to calculate the loads from staircase in both semi-detached house and terrace house and applied to the 3D models in Esteem. Then, modifications are made to improve the structural behaviour of the building in Esteem. The modifications made in Esteem will be the same for the 3D models in Autodesk Revit.

For the second objective, clash detection is conducted for 3D models in Autodesk Revit. Clashes detected by Autodesk Revit are then fixed by redesign the elements in the models and relocate the elements in a correct position. Then, clash detection is carried again to verify no clashes will be detected. Lastly, solution to solve the challenge in the 3D model with LOD 300 is to improve the compatibility of the software by allowing them to export their models to other software. The 3D model file from different software can be saved in IFC format which can allow other software to access the 3D models.

Apart from being able to implement BIM in residential project, other construction projects such as high-rise building, bridges, factories, substations etc can apply BIM as well. Autodesk Revit able to create large scale of 3D models of any construction projects in the world. With this large scale of 3D models, there might be some errors such as clashes between other elements in the building which is hard for engineers to find those clashes and may overlook them. Thus, BIM which has clash detection will be very helpful to detect clashes in these large-scale of projects to prevent any huge accidents happened in the actual construction.

In conclusion, BIM implementation helps civil engineers to coordinate the structural members accurately in a 3D view. The completed models can be exported to other software to perform structural analysis and design. In addition, clash detection in Autodesk Revit contributes a lot for the civil engineers to take note of the clashes

occurred in the models. Thus, it helps to reduce the variation order during the actual construction.

5.2 Recommendation for Future Works

Based on this research, Autodesk Revit and Esteem were not able to communicate because Autodesk Revit uses .rvt file which is a specified language file mainly used for Autodesk Revit only. For other structure analysis software, common file type for BIM is IFC file which allow other software to access their models. Even with the IFC format in Autodesk Revit, Esteem was not able to access the IFC file because the version of Autodesk Revit is too advanced that make Esteem unable to access its file.

The future research should focus on adding extension for data exportation to software that does not have it. For Esteem which does not have an extension to other software including the latest version of Autodesk Revit, it will improve the communication between different software used by other companies. Besides that, being IFC format to export BIM model to other software may cause some issues such as losing the structural elements. Thus, the data storage in IFC format should be improved in the future research to prevent any data loss.

Furthermore, Autodesk Revit should insert Eurocode, British, and Australia standard in the software so it will be convenient to use and learn from one software instead of using more than two software. Autodesk Revit should also add another feature for structural analysis as well since the 3D models can be built in it. Moreover, Autodesk Revit should put some tutorial slides and videos in their software just like Esteem which make other users to understand how the software works instead of relying on videos on YouTube.

Moreover, Autodesk Revit should improve their file system where it can save its file at any version of Autodesk Revit. This allow other users with older version of Autodesk Revit to access the 3D model in the latest version. Apart from that, the exportation between Autodesk Revit and Autodesk Robot Structural Analysis or other software should strengthen as well. Future research should focus on ensuring the data transfer from different software to another must be accurate. Thus, issues of inaccurate position of beams and columns, and unconnected beams will be overcome.

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