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BIM for Structural Engineers and Fabricators

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The final year project aimed at analyzing the advantages of Building Information Modeling for structural engineers and fabricators. In order to reach the goal, the final year project started with a definition Building Information Modeling (BIM), an analysis of the differences between Building Information Modeling process and Computer-Aided Design process as well as an introduction of BIM advantages based on the model, including schedule planning, schedule analysis, clash detection, cost estimation and facility management.

The benefits of BIM for structural engineers and fabricators was emphasized in the second part of the project with the use of Tekla Structures software which is one of the BIM software. With the design features provided by Tekla Structures software, a 3D structural model of pre-engineered building was created to see how beneficial BIM tool is for structural engineers and various different types of drawings generated from the model to analyze how it would be valuable for fabricators. The drawings, such as assembly drawing, contain useful information needed for fabrication process, resulting in reducing unnecessary waste of construction materials in the future.

The thesis can be used for both people who are interested in Building Information Modeling and for structural engineers with an aim of getting to know Tekla Structure software and how the structural modeling process progresses on the software.

Keywords	BIM, tekla structures software, pre-engineered building, structural modelling

Contents

List of Abbreviations

BIM	Building Information Modeling
CAD	Computer-Aided Design
PEB	Pre-Engineered Building
CDE	Common Data Environment

1 Introduction

The use of Building Information Modeling (BIM) is gaining popularity in the construction industry and becoming an industry standard in many countries, including Finland. In the past, 2D drawings were used to represent a floor plan or a section of the building but was not able to show a 3D visualization of the project. However, everything changed when BIM was introduced to the construction industry. BIM is applicable and beneficial in every phase of the project from planning, design to fabrication, construction and maintenance activities. With BIM, project team members can work together on one building model rather than different sets of drawings.

The objective of the project is to analyze the benefits of BIM for structural engineers and fabricators by working on one of the BIM software, Tekla Structures software. The thesis provided a step-by-step guidance of the structural modeling process as well as an analysis of its benefits for structural engineers and fabricators.

The thesis approaches the concept of BIM with an introduction of different BIM dimensions, including 4D BIM refers to construction planning, 5D BIM refers to cost estimation and 6D BIM is for facility management.

2 Building Information Modeling

2.1 What is Building Information Modeling?

Building Information Modeling (BIM) is a modeling technology and an associated set of processes to produce, communicate and analyze building models. With Building Information Modeling, multiple stakeholders, architects, engineers and construction professionals can work in a collaborative way to implement every stage of the project from planning, design to construction and maintenance by using one coherent system of building model rather than separate sets of drawings [1.p.16].

Building models are described as:

- Building components consist of data attributes which can be used for work processes.
- Models that updates changes implemented to a component automatically in all views and in associated geometries.
- All views and drawings generated from the model are produced in a coordinated way. [1.p.16.]

Information is the heart of Building Information Modeling. The information gathered from the conception stage to the completion stage of the project can be stored and accessed easily. The information can be used to improve accuracy, express design concept from office to construction site among other things.

2.2 How is BIM Information Shared?

Common Data Environment (CDE) is a digital platform for sharing and managing project information. With Common Data Environment, project team members can not only share geometric data but also project-related documents such as contracts, reports, schedules and so forth [2].

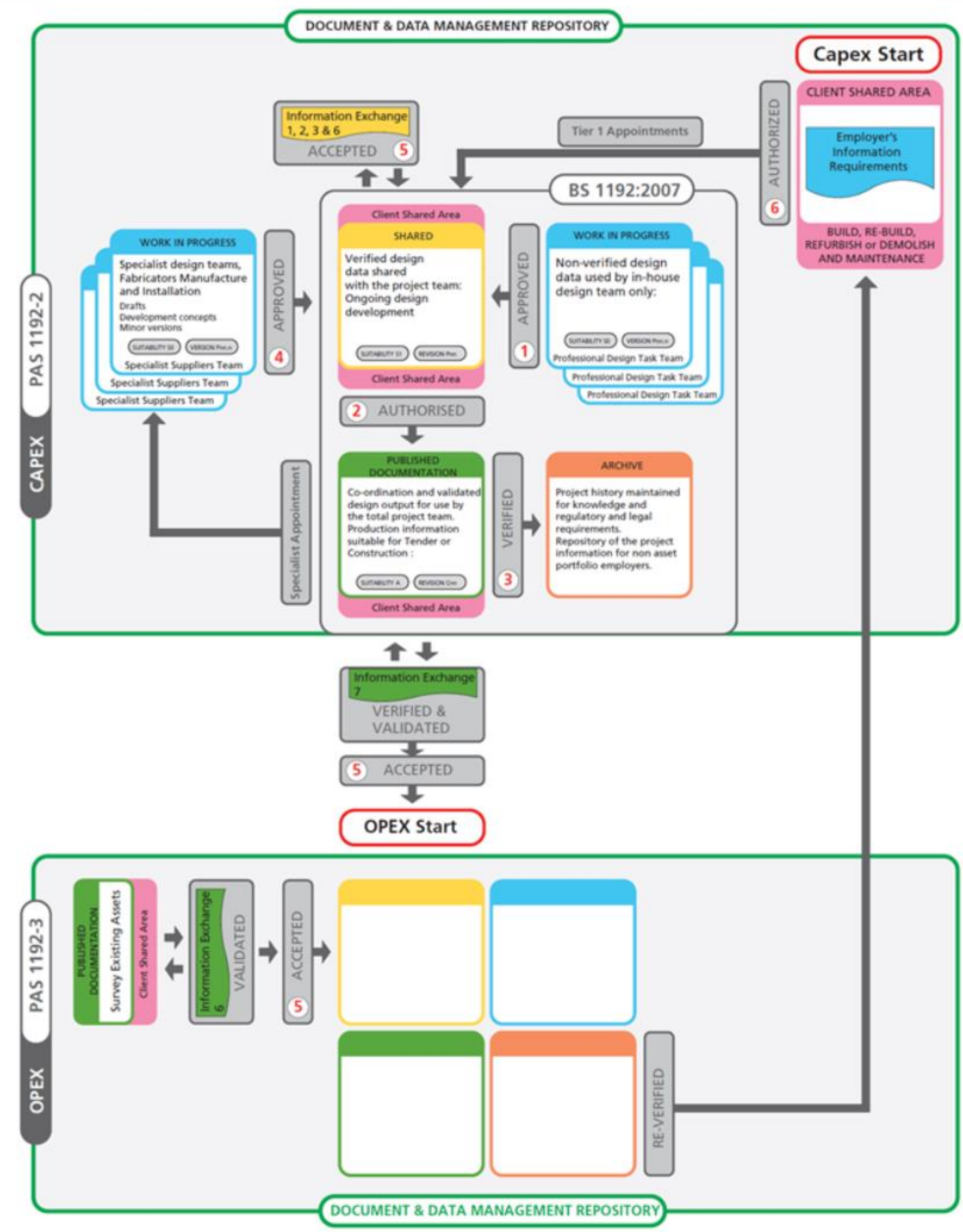


Figure 1. Common Data Environment's structure [3].

Detailed information regarding figure 1 is explained in table 1.

Table 1. Explanation of steps shown in figure 1, with color coding for ease of reference. [3.]

Work in progress (blue)	The section is used to store unapproved information. The information will then be approved at the Approval Gate, shown as number 1 in the figure. In order to pass the approval gate, there are certain checks implemented, including the suitability of model, technical content, standard methods and procedures and getting approval from manager.
Shared (yellow)	All approved information will be moved to a shared area where other organizations use those materials as reference for design development. When all the designs are finished, the information will be moved to an authorized gate, shown as number 2, to be authorized by the manager.
Published (green)	All the published information is stored and verified.
Archive (orange)	A record of the project at key milestones.

The advantages of Common Data Environment are listed below:

- CDE is a digital platform, so every team member can access it easily.
- All shared data is categorized accurately in suitable folders, resulting in saving time, energy and cost.
- CDE can be used to generate documents/ views and project team members can be confident of using the latest and accurate documents of the project. [2.]

2.3 The Difference Between BIM and CAD

In terms of building design, Computer-Aided Design (CAD is used to draw lines to present every section of the building. But with BIM, the designer can just create a 3D model on BIM software and different sections of the model can be generated automatically. This approach results in saving time and energy because designers do not need to draw anything twice [4]. In addition, construction project becomes more complicated in reality, and therefore, the help of BIM tools will be beneficial to imagine how the project would look like in reality.

Let’s draw two walls in BIM and CAD software, shown in figure 2, to understand the differences between two systems.

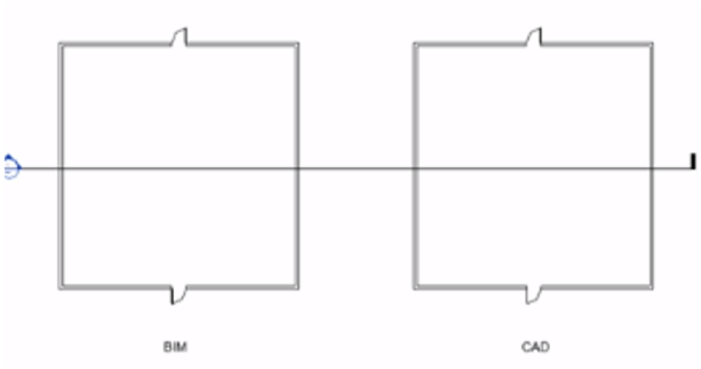


Figure 2. A wall in BIM and CAD systems. [4.]

Figure 2 presents two walls drawn in BIM and CAD system. In CAD system, designer uses two parallel lines to create a wall and in BIM system, designer uses wall element provided from the BIM software.

The main difference between two system is parametric intelligence for objects in BIM, which is explained in sections a, b and c.

a, Objects contain data attributes as shown in figure 3.

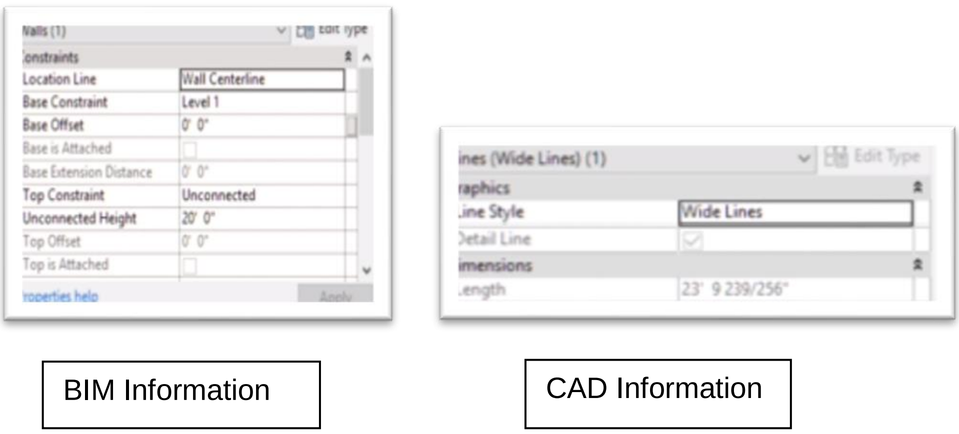


Figure 3. The difference between information gathered. [4.]

Figure 3 presents the information gathered from BIM and CAD systems. While the CAD layout shows only a line type, the BIM system shows information of an actual wall element which contains several parameters used to define the wall. [4.]

b, Objects can automatically modify associated geometries or associated objects when changes are implemented [1 p.17].

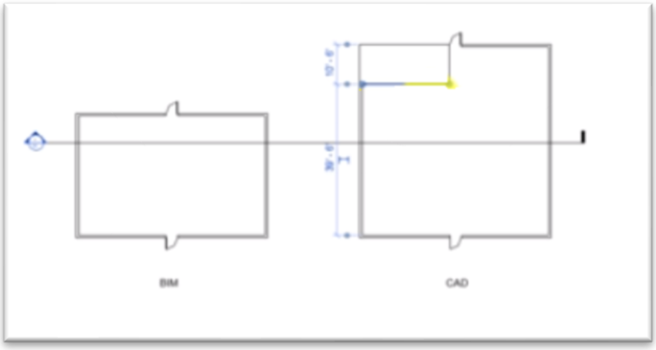


Figure 4. The differences when changes are implemented between two software. [4.]

Figure 4 depicts the difference when changing the wall parameter in BIM and CAD systems. When dragging down a wall in BIM system, the door moves with the wall and the length of other connected walls are shortened in order for the whole wall component to stay connected. However, when dragging down a line in CAD system, the connecting lines remain attached but the parallel line does not move. So with CAD system, whenever changes are implemented in the layout, all of the necessary lines must be selected to move them. This approach results in wasting a tremendous amount of time to implement those changes in the design without knowing exactly whether or not the new updated one will have any mistakes. [4.]

c, A section view is generated automatically from BIM software

Figure 5. Section view is generated from BIM software. [4.]

When opening the section view in BIM and CAD systems, only the BIM layout appears, as shown in figure 5. The BIM tools create a building model with actual building components placed into the model and the building elements appear in all views. [4.]

2.4 What is not BIM Technology?

The modeling solutions that do not use BIM design technology are defined as below:

- Models contain no object information and can be used only for graphic visualization.
- Models that allow changes in one view but cannot automatically modify the changes in other views. This feature makes it difficult to detect errors in the design.
- Models that do not use parametric intelligence, so it is difficult to adjust the objects' positioning or proportions.
- Models that are formed by merging different 2D CAD reference files to represent the building. This approach cannot confirm that the resulting 3D model will be coordinated [1.p.19].

2.5 Advantages of BIM

Building Information Modeling brings many advantages to every phase of the project, from design, preconstruction to fabrication and management. BIM provides software to build the projects virtually, allowing for clash detection between different models, improving coordination amongst project team members as well as supporting for planning activities, model-based cost estimation and facility management of the project. All of these advantages are explained in more detail below.

2.5.1 Improved Coordination and Clash Detection

When 2D paper-based drawings were used in the past, in order to detect clashes and potential conflicts, contractors overlaid multiple 2D drawings on a light table. This approach was time-consuming and prone to errors. As a result, BIM technology provides a clash detection feature to detect clashes, for example between MEP system or HVAC system and structural model and architectural model. By avoiding clashes, the amount of rework, unforeseen problems and last-minute changes are reduced [1.p. 273].

In order to run the clash detection properly, the detailing process of the model needs to be finished completely. At the construction phase, there might be several modelling errors which create conflicts but would not be real issues. However, if the detailing is incorrect, problems would only be discovered at the construction phase, resulting in wasting a huge amount of money and time to resolve. [1.p. 273.]

There are two types of clash-detection technology, including clash-detection within BIM technology and separate BIM integration tool, as illustrated in Table 2.

Table 2. The differences between two tools [1.p. 274].

Clash-detection technology	Clash-detection within BIM technology	Separate BIM integration software
Advantage	Clash-detection feature is included in all BIM design tools, which is convenient for designers to run clash detection in the design phase	Separate BIM integration software for checking clashes, such as Solibri Model Checker, is able to check thoroughly and identify deeply all the soft and hard conflicts of the project regardless of its complexity.
Disadvantage	The feature might not be able to show all of the conflicts due to the lack of its function and ability to check complicated information of the project	Designers cannot fix identified clashes directly on the checker software. In this case, designers have to fix those clashes on the model and run the check again.

Table 2 shows the advantages and disadvantages for clash-detection activity within BIM technology and in separate BIM integration tool. The two different software would be beneficial based on users' need and time. The clash-detection feature within BIM technology allows users to detect conflicts and fix them directly on the model but not all conflicts could be shown. However, the separate BIM software, such as Solibri Model

Checker, allows users to check thoroughly all of the conflicts but the user cannot modify changes in the software, leading to convert the model back and forth between the two software to run the check.

2.5.2 Construction Analysis and Planning

4D Building Information Modeling refers to the 3D model, which contains time and construction schedule information. This approach helps planners visualize the sequential construction phases of the building in association with time period [5].

4D BIM refers to adding scheduling data to the corresponding components and activities of a project information model. By associating data to the graphical representation of specific components/activities, it will not only make the visualization of a project development easier to imagine but it can also show how the structures will be built sequentially over the time period of the project. In terms of planning construction work, this approach brings enormous advantages to the construction site in order to plan and run the construction work safely and logically. It can illustrate whether or not the construction work will be running behind schedule or on time. [5.]

In addition, from the planner's point of view, this approach creates a chance for planners to access and influence the project at the early stage and to provide valuable feedback to the construction project. [5.]

2.5.3 Model-Based Cost Estimation

After adding scheduling data information to components, the next step is to add estimated cost. The whole process is referred to as 5D BIM.

Based on the given data and information related to each component, an estimated cost of each component is produced. There are three different kinds of cost for each component: capital cost, running cost and renewable cost. Capital cost includes purchasing cost and installation cost, followed by is the operation cost of it named as the running cost and the predicted price to renew the component in the future referred to as renewable cost. With the graphical model, the cost estimator can quickly identify quantities of each component on a project, adding rates to those quantities, and hence achieving an overall cost for the project. The approach of linking cost estimation to a 3D model helps cost estimators see costs in three-dimensional form, get notifications whenever changes are made and save time with the automatic counting process of component quantities [6].

Because the whole cost estimation process is based on the given data, hence the data produced by the whole team and is shared within the Common Data Environment need to be accurate. If the information is erroneous, the estimated cost cannot be produced based on the given data. Therefore, there is an essential need for having quantity surveyors and cost estimators. With the help from those professionals, all hidden costs will be quickly identified and the accuracy of shared information from Common Data Environment will be checked. [6.]

There are three kinds of quantity in an information model. The first one is the quantity which is obviously visible in the information model and can be easily counted. The second quantity is the one acquired from the components, such as mouldings around ceiling, which are not always noticeable in the model. The third quality is the non-modelled quantities, such as temporary work. The cost estimator and quantity surveyor need to be professional in this stage in order to determine those non-modelled quantities or hidden quantities of the project in order to provide a precise cost estimation report. [6.]

Another benefit of the 5D BIM model is that the usage of up-to-date shared data within Common Data Environment together with the early influence/feedback/engagement of cost estimators at the beginning stage of a project will provide more accurate reporting of costs at the early stages. [6.]

An example of the cost estimation software is Sigma Estimates shown in figure 6.

Figure 6. Sigma Estimates software [7].

Figure 6 shows features of the Sigma Estimates Software. With the collaboration of Sigma Estimates and BIM 360/Revit software, users can automatically generate 5D models showing construction activities, associated costs, 2D model and 3D model throughout the whole project. The cost estimates can be achieved directly from the software with a single click and the cost data can be stored in the system to be used and analysed for future projects. [7.]

2.5.4 Facility Management

6D BIM is the linking of data attributes to support Facility Management and Operation. The data might be manufacturer information of the component, its installation date, usage guidance on how to maintain/maximize the component and its product information, energy performance and expected lifespan. By adding this kind of information to the information model, facility managers can make decisions at the design stage of a project. In terms of economy, for example, an air conditioner with a lifespan of 8 years could be replaced by the one expected to last 12 years [8].

With the 6D BIM approach, at handover, the information model can be handed over to the end-user with a complete data set rather than giving hundreds of documents like in a traditional approach. Operators can then access this valuable information included in the model to pre-plan for maintenance activities and create a spending profile over the lifespan of the project. The information should be also updated in the in-use stage with updated information on repairs or replacements. [8.]

3 BIM for Structural Engineers

Building Information Modeling (BIM) provides structural engineers with valuable features to improve a structural model, such as enhanced collaboration, constructible modelling and professional documentation.

a, Enhanced Collaboration

BIM software provides possibilities to exchange information amongst applications with different internal formats. Thanks to this feature, structural engineers can coordinate and collaborate effectively and seamlessly with other project team members using industry standard file formats and custom integration links [9].

b, Constructible Modelling

BIM provides software programmes for constructible, fast and intelligent modelling with a high level of detail, even when working on the largest and most complicated models and projects. In addition, after creating a 3D structural model, structural engineers can visualize, explore how the structure will fit together when built as well as recognize problems and clashes before they appear in reality. [9.]

BIM structural software provides unique features to optimize the design ability as well as a broad library consisting of all common elements and materials in conjunction with automated structural and civil calculations. [9.]

c, BIM Documentation

Using BIM structure software allows structural engineers to extract structural documentation, including construction drawings, detailed drawings for steel and concrete reinforcement together with reports and material schedules. With BIM, all the changes will be updated automatically in all associated documents, improving productivity and coordination among different project parties. [9.]

4 BIM for Fabricators

The assembly phase is the priciest stage of the manufacturing process and the one most liable to bottlenecking. The section begins with the current situation of construction industry, followed by negative effects causing the situation and ends with the solutions provided by BIM.

a, Current Situation of Construction Industry

The current construction industry situation is described in figure 7.

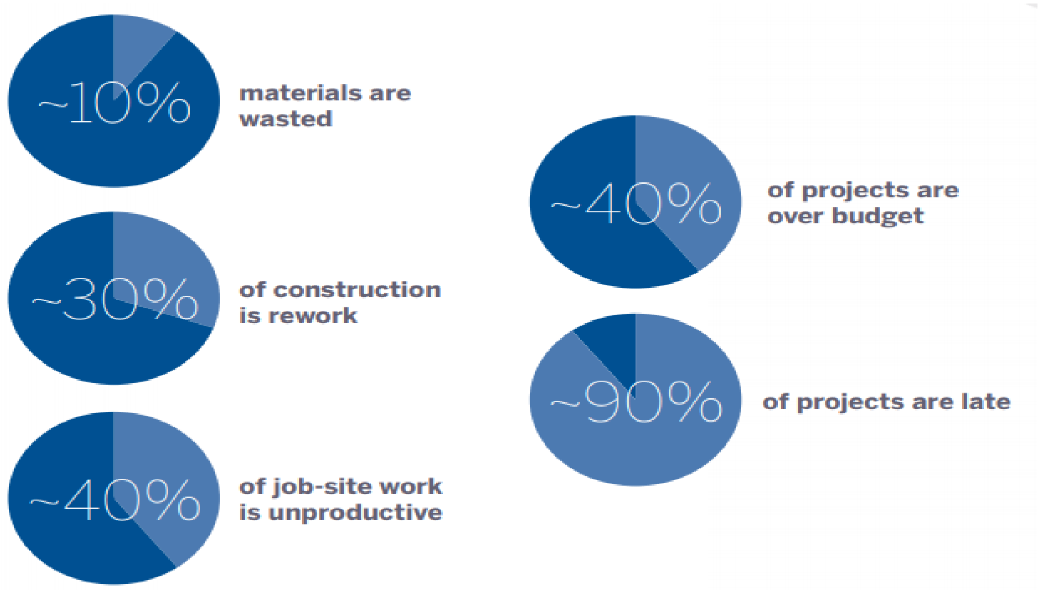


Figure 7. Current construction industry situation [10.p.2].

As shown in figure 7, 10% of construction materials are wasted, 40% of projects exceed the budget and a massive 90 % of projects are late. There are many negative effects that can slow down the assembly phase process are shown below:

- Firstly, skilled blue-collar workers are expensive and far from easy to find, and manual installation is exposed easily to human errors.
- Secondly, the challenge of keeping up with updated technology. As technology changes continuously, the newest technology is not only the most expensive but also the most productive one. In order for a company to be competitive at their fields, the need to update technology is always essential, which will create an economical burden for them.

- In addition, hackers can tamper with the manufacturing process to steel the company’s product information.
- Furthermore, manufacturing process can create environmental consequences. For example, any last-minute changes at the design can turn everything into waste and also lead to pollution released into the environment. [11].

b, Use of Design Model as Basis for Fabricated Components

Offsite fabrication requires considerable planning and accurate design information. Many of the components are fabricated offsite and then transferred to the construction site for assembly. With BIM, the 3D model will consist of detailed information of building components needed for the fabrication process. The precision of BIM helps to fabricate larger components of the design offsite with exact dimensions, ensuring that its dimensions will fit with other items during the construction process.

Furthermore, the complete building model also provides exact quantities for all of the materials and objects needed during the construction process, resulting in saving material usage.

5 Tekla Structures Software

Tekla Structures software is a product of Trimble Solutions Company, an international technology firm with its headquarters in Silicon Valley. The software is one of the most advanced structural software in the world with various functions ranging from creating, combining and managing multi-material models to collaborating and communicating the design. With Tekla Structures software, users can model any kinds of structure from residential buildings, industrial and commercial designs to towers. The software helps to reduce the possibilities of modelling errors, resulting in saving time and money. In addition, when any changes are produced, Tekla Structures automatically modifies its changes in all views [12].

Tekla Structures is ideal for steel detailers and fabricators, bridge engineers, concrete contractors, structural engineers etc.

Tekla Structures software consists of the following features shown as below:

- Easy formation of fundamental subjects, such as column, beam, plate, panel and slab.
- Model all different types of connections.
- Proper modeling assistance, such as 3D grid, a flexible working area and a view list
- List of available applications and components, such as reinforcement and intelligent connection objects, profiles, material grades.
- Diverse tools to form complicated objects, such as staircases.
- The available place to import reference model from other computer-aided programmes, such as AutoCAD, ArchiCAD
- Link to export Tekla Structures file to IFC files…
- The software is able to generate a wide range of drawings, such as master drawing, single-part drawing, assembly drawing, cast-unit drawing and general arrangement drawing.
- Capability to redo and undo when making changes.
- The software is accessible to 17 languages and 32 working environments.
- The software can be used with either a single user or multiple users depending on the need of using the model. If several users using the model at the same time, the Tekla Structures server programme need to be run on one computer. [12.]

Tekla Structures software can be used in modelling and fabrication processes, which is explained in sections a and b below.

a, Modeling Process

The modelling process, shown in Table 3, is the key to supporting the whole project. It is of utmost importance that the design model consists of all needed and up-to-date information for fabricators and site operations.

Table 3. Steps of modeling process in Tekla Structures software

Step	Detailed Information
1: Making a structural model	Designers create a structural model on Tekla based on 2D drawings or reference models imported into the software
2: Efficient detailing	Detailers use application and storage section in Tekla software to design any custom connections and parts
3: Managing changes	During a project, unexpected changes, improvements and revisions from architects, designers and building owners can often happen at any time. If any changes are implemented, connections within the model will automatically adjust, creating an accurate model
4: Working together	Designers can work on the same Tekla model simultaneously and communicate efficiently as if they were sitting in the same office. This kind of platform improves communication and create fault-free models.
5: Avoiding costly site fixes	Clash detection With the help of automatic clash checking tool on Tekla software, clashes will be identified and fixed before causing any postponements in assembly process and construction

Tekla Structures software also contains parametric intelligence, resulting in updating changes automatically, as shown in figure 8.

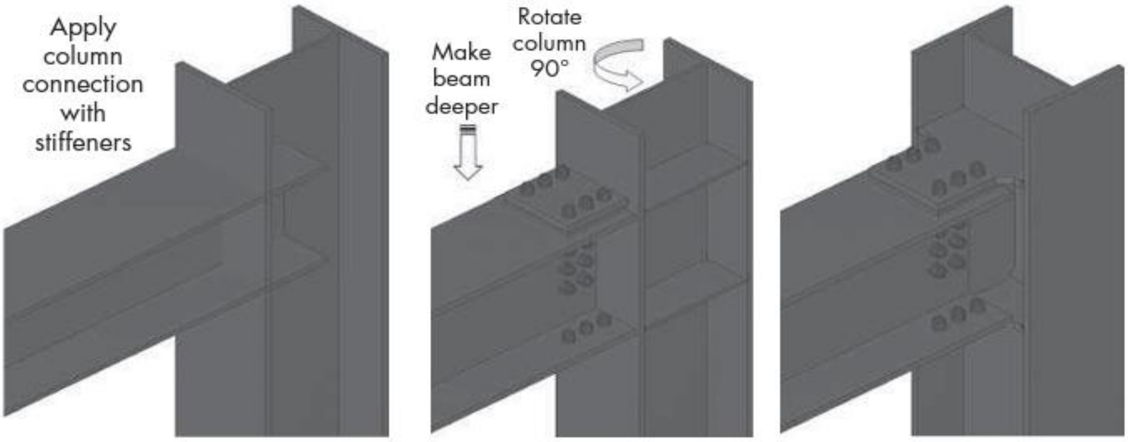


Figure 8. Steel connection in Tekla Structures [1.p.329].

Figure 8 shows the differences when a steel connection is applied between a column and beam. When the column rotates 90º and the beam is made deeper, the software automatically updates the steel connection.

b, Fabrication and Assembly Process

After the designing and detailing process, the models will be used at the factory for manufacturing. The usage of Building Information Modelling helps the fabrication and assembly process to be more productive and profitable.

Advantages of the Tekla model are shown as below:

- When Tekla enters into the steel manufacturing industry, new approaches of data exchange replace the old ones. With Tekla, instead of using hundreds or even thousands of documents, fabricators just need to use the 3D model to access the needed information. A 3D model can be used in conjunction with an automatic welding robot to optimize the assembly process as well as improve the productivity.
- Drawings, reports and CNC information are automatically extracted from the model.
- Tekla software offers automatic layout marking where fabricators can obtain assembly information directly from the model to mark the components

with precise layouts for welds and pieces. This feature can save a huge amount of valuable time and money while reducing the risk of human errors [13].

6 Create Structural Model of Pre-Engineered Building on Tekla Structures Software

6.1 What is Pre-Engineered Building?

Pre-engineered building is a steel structural building consisting of steel structural parts that are manufactured offsite and then shipped to the construction site for erection. Pre-engineered buildings are applicable to many different types of building, such as industrial building, warehouse, distribution center, sports and entertainment areas as well as industrial facilities among others [14].

Pre-engineered building poses a number of advantages:

- The system is fast to build. While foundations and floor slab are being constructed at the site, steel columns and beams can be manufactured at the factory, resulting in time and cost savings. When the foundation and floor slabs are finished, the steel parts will be shipped to the site for erection. There are bolting holes at both ends of each steel part to connect them together.
- The building is flexible to expand easily in length by adding additional structural parts.
- The factory-built characteristic offers unlimited design for steel parts as well as assured steel quality. [14.]

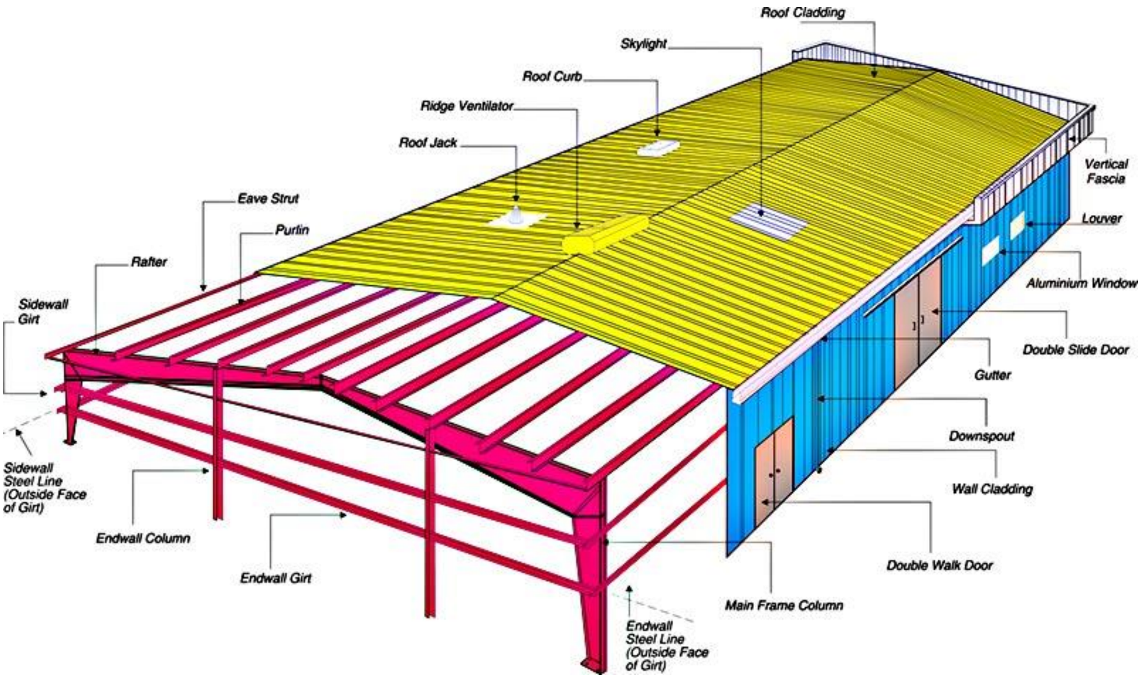


Figure 9. Pre-engineered building structure [15].

The structural system of a pre-engineered building is shown in figure 9. The structural system consists of three main parts shown below:

a, Primary structural frame

The primary frame of a pre-engineered building consists of connected I-shaped beams. The I-shaped beam is manufactured at the factory by welding different steel plates and then different I-shaped beams are bolted together by holes at the end of each part. The whole cutting and welding process is implemented by industrial robots for the sake of accuracy. The operator will insert the drawing of the beam into the machine and the robots do the rest. This approach helps the fabrication to run smoothly and consistently. [14.]

b, Foundation, wall and floor slabs

The foundation for a pre-engineered building is made with conventional concrete systems. With its large size, the pre-engineered building will capture a huge amount of wind force. In order to prevent the structure from uplifting, the foundation system needs to be designed firmly to the ground. In addition, the desired concrete slab thickness is about 200-300 mm. [14.]

c, Cladding and roofing

In order to support the roofing structure, a grid of purlins, usually cold formed Z or C sections, is placed over the primary structure. After the purlin structure, there is a layer of insulation and vapor barriers, usually glass wool or mineral wool. However, the system does not include any inner wall system for putting the insulation. As a result, a layer of wire mesh is first laid over the purlins, and then the insulation and vapor barriers will be placed on top of it. [14.]

The most economical cladding for this system is light metal sheeting with desired thickness of 0.5 mm and is covered by an aluminum-zinc alloy to prevent the cladding from corrosion. The surface of the metal sheeting can be an attractive, durable paint. [14.]

6.2 Start Tekla Structures Software

When Tekla software is launched, a Tekla Structures setup dialog box appears, as shown in figure 10.

Figure 10. Tekla Structures setup dialog box

As shown in figure 10, the setup dialog box consists of an environment, role and configuration section:

- The environment section includes specific information available for every region such as profiles, material grades, connection etc. The project used South-East Asia working environment.
- The role section includes different roles of a project, such as concrete contractor, engineer, steel detailer or concrete detailer. Each type of environment provides equivalent roles to choose. The project used all roles.
- The configuration section provides specific features to meet the requirements of various players in the construction industry. The project used full configuration [16 p.9].

6.3 Create a Grid

When it opens the model for the first time, Tekla Structures software automatically creates a grid, as shown in figure 11.

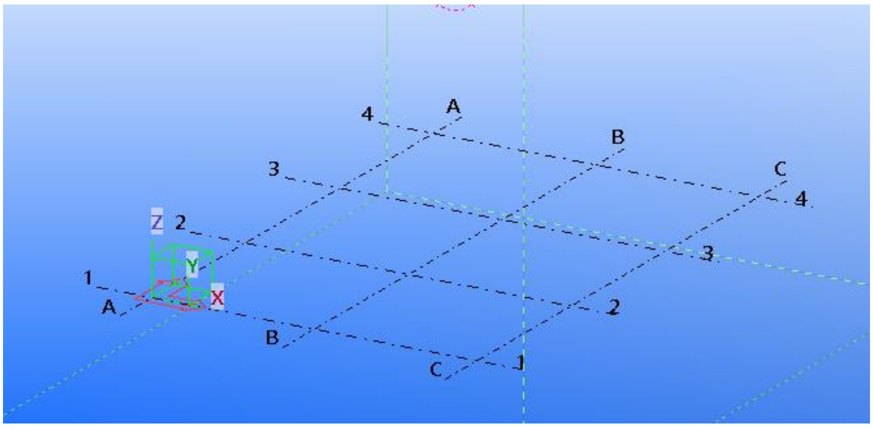


Figure 11. Grid lines at the beginning

The grid line properties were modified by first double-clicking on the available grid lines, followed by changing the values of X,Y,Z coordinates as well as X,Y,Z labels.

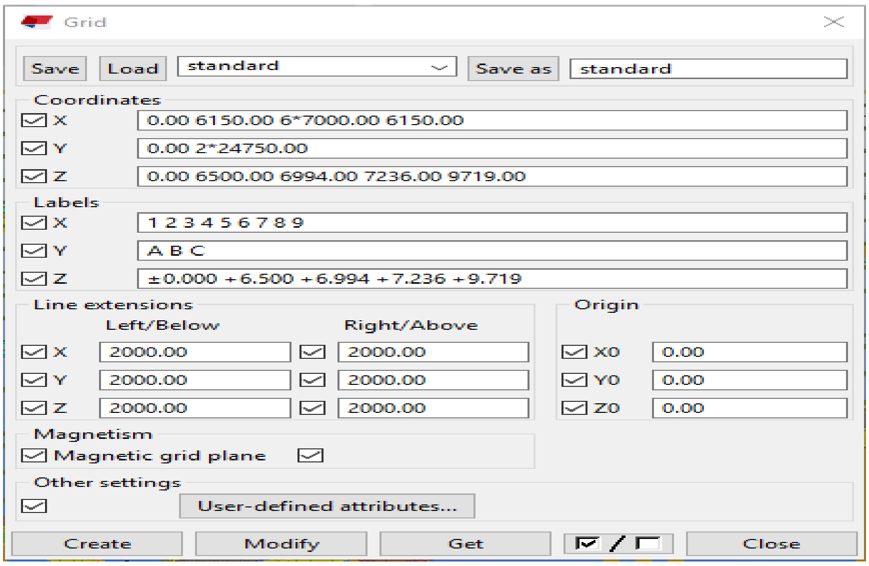


Figure 12. Grid line properties of the project.

The figure 12 shows grid line properties of the project. As shown in the figure, in label sections, the numbers ranging from 1 to 9 were used to label X grid lines while A B C characters were used for Y grid lines. With the help of numbers and characters in the label, the users can easily distinguish between the X axis and Y axis.

6.4 Create Model Views

Steps of generating model views of the project as shown below:

- Single click on the grid line
- Right-click and select Create View→ Along Grid Lines → Create
- A view list appears, as shown in figure 13

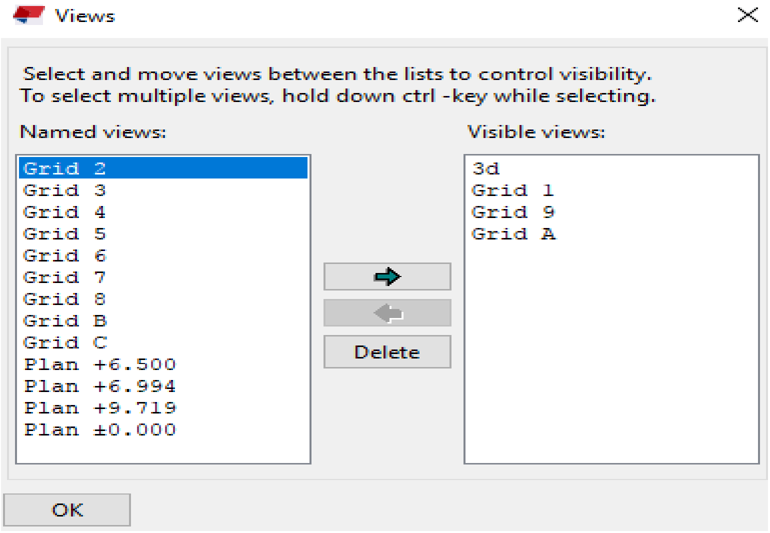


Figure 13. A view list of the project

The view list consists of named views and visible views. Named views are the generated views which represent a model from different locations. Visible views are the selected views which users are currently working on. Each view is shown in its own window within Tekla Structures software.

6.5 Insert PEB Tool

Tekla Company offers a specific tool to support the structural design of pre-engineered buildings (PEB) on Tekla software, named as Pre-Engineered Building Tool. The tool includes various components to create a PEB frame together with PEB connections, as illustrated in figure 14. The PEB tool can be downloaded from the Tekla website.

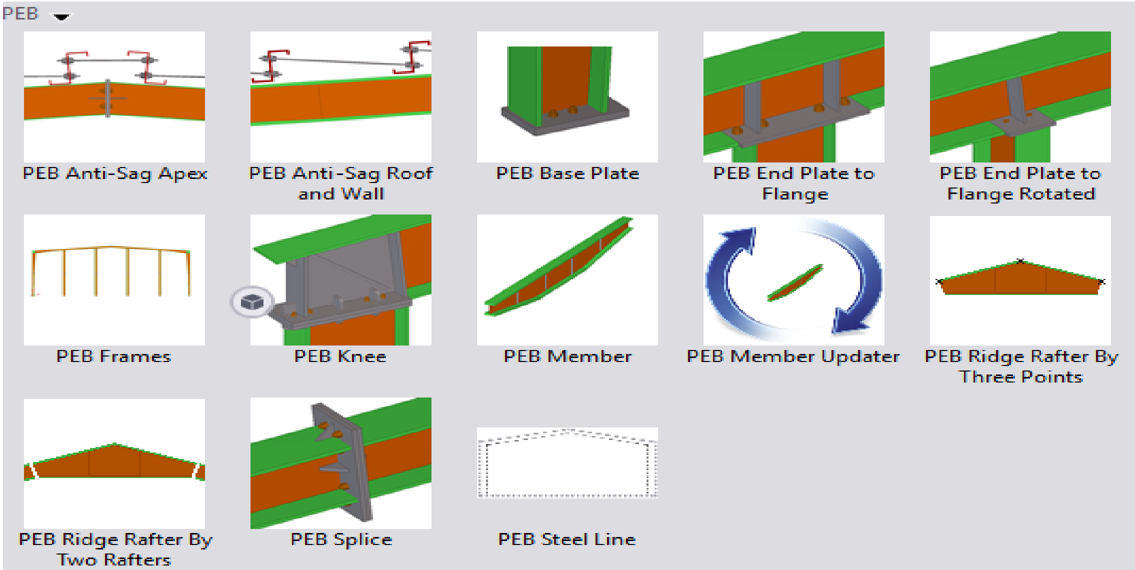


Figure 14. PEB components offered by TEKLA software

The PEB components, shown in figure 14, help users to save time in creating a structural frame, for example PEB Member is used to create columns and rafters, PEB Knee to connect column with rafter, PEB Splice to connect two rafters together and PEB Base Plate to create base plate detail for the column.

6.6 Primary Structural Frame

The primary structural frame of pre-engineered building, as shown in figure 15, was created by using the PEB Member component to create I-shaped columns and rafters.

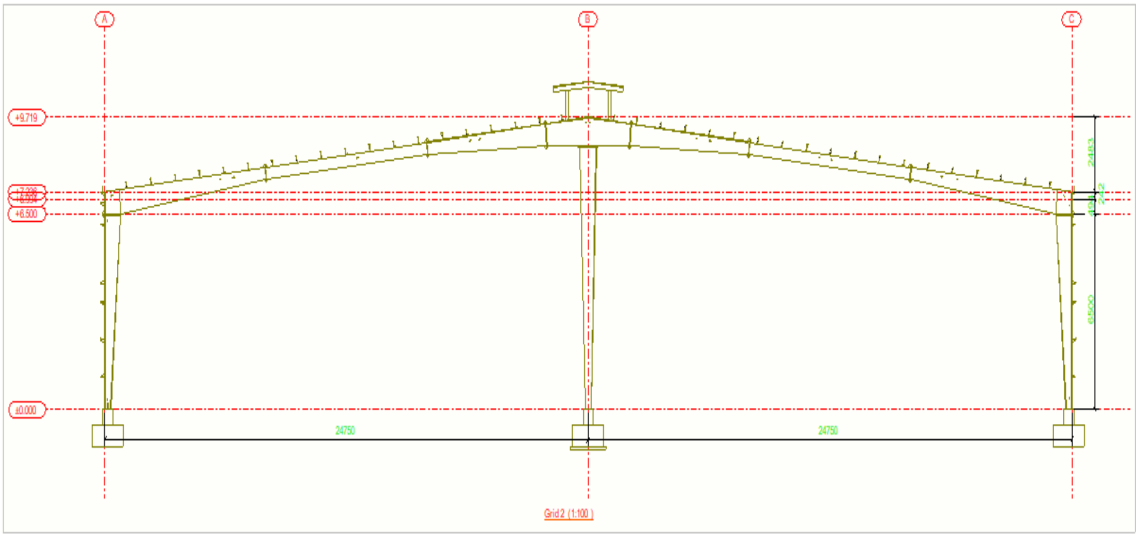


Figure 15. Primary Structural Frame

The PEB Member dialog box contains parameters, parts and assembly sections.

- Parameters section defines the number of depths required and depth values. The column used in the project had two depths, 280mm and 780mm respectively. The column was tapered at the lower part.
- Parts section defines properties of outer flange, inner flange and web. Inner flange and outer flange have the same thickness of 10mm and width of 200mm while web's thickness is 8mm. Material used is SS400.

6.7 Sidewall Girt

Sidewall girts, illustrated in figure 16, work together with column and wall panel to support the vertical load and improve stability

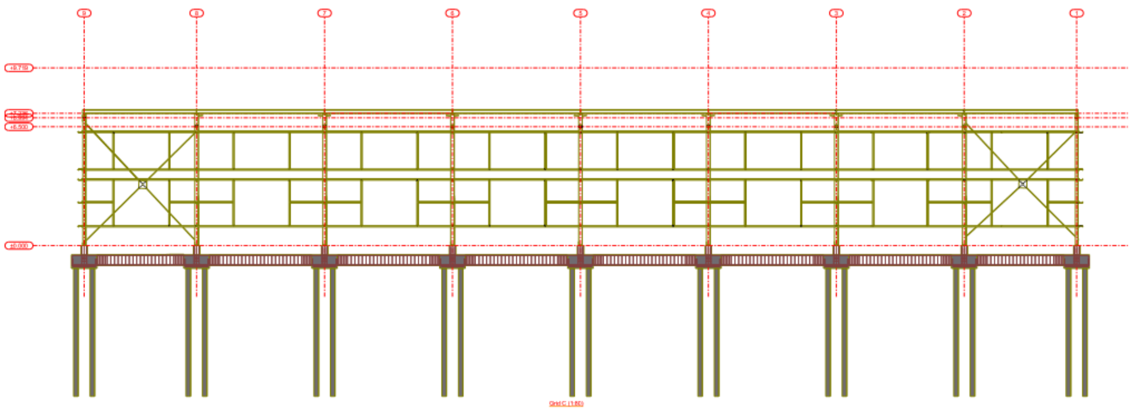
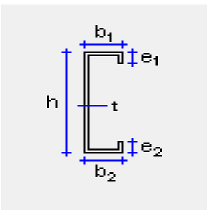


Figure 16. Sidewall girt

With the support of Tekla Structures software, sidewall girt was created by steel beam command. The typical type of girt in steel building construction is cold-formed C or U sections so the project used CC profile and its properties are shown in figure 17.



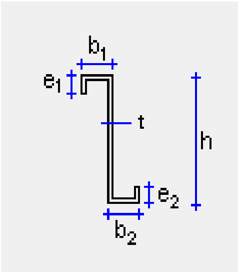
Height	h	200.00	mm
Plate thickness	t	2.00	mm
Edge fold	e	20.00	mm
Width	b	65.00	mm

Figure 17. Properties of sidewall girt

The figure 17 shows dimensions of a CC steel project used in the project. Its height, width and thickness are 200mm, 65mm and 2mm respectively.

6.8 Roof Purlin

In a pre-engineered metal building, a grid of purlins is used to support the roof structure and is placed horizontally over the primary structure. Purlins run along the span of the roof. With the support of Tekla Structures software, a purlin was created by steel beam command. The typical type of purlin in steel building construction is cold-formed C, Z or U sections so the project used ZZ profile for purlin and its properties are shown in figure 18.



Height	h	200.00	mm
Plate thickness	t	2.00	mm
Edge fold 1	e1	15.00	mm
Flange width 1	b1	62.00	mm
Edge fold 2	e2	15.00	mm
Flange width 2	b2	68.00	mm

Figure 18. Properties of ZZ profile

The two purlins were connected using a cold rolled overlap connection. The connection is available in the Applications and components catalog.

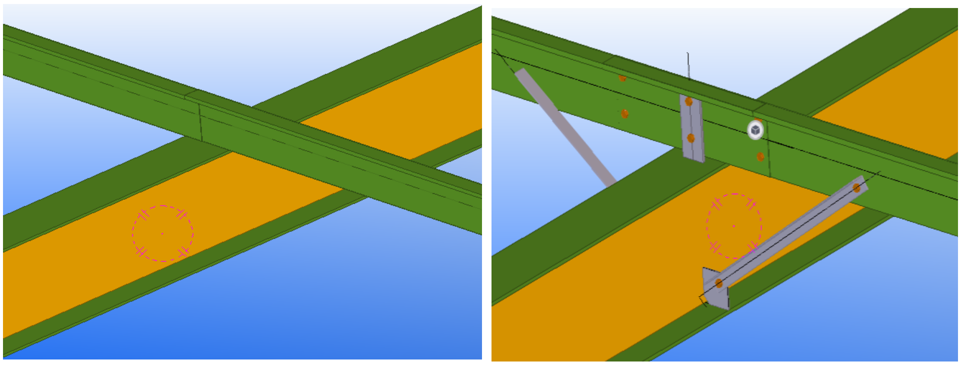


Figure 19. Before and After installing a cold rolled overlap connection

As shown in figure 19, in order to create purlin-to-purlin connection successfully, the two purlins should have the same depth and their center-lines should not only be co-linear but also be set out to the rafter center-line. After installing the cold rolled overlap connection successfully, the connection automatically extended the purlins to form overlap so the two purlins clashed with each other in the model. If the model runs in Solibri software for a clash check, the purlins should be excluded from the check. [17.] The main function of lapped Z-sections is to increase the strength and rigidity of the roof system.

6.9 Foundation Structure

The foundation structure is a part of the building which connects the structure to the soil. The main function of the foundation structure is not only to support the main structures above but also to transfer loads from it to the ground. More detailed information of the foundation structure is shown below.

6.9.1 Footing Structure

The concrete foundation structure includes a pedestal, pad footing and pile as shown in figure 20.

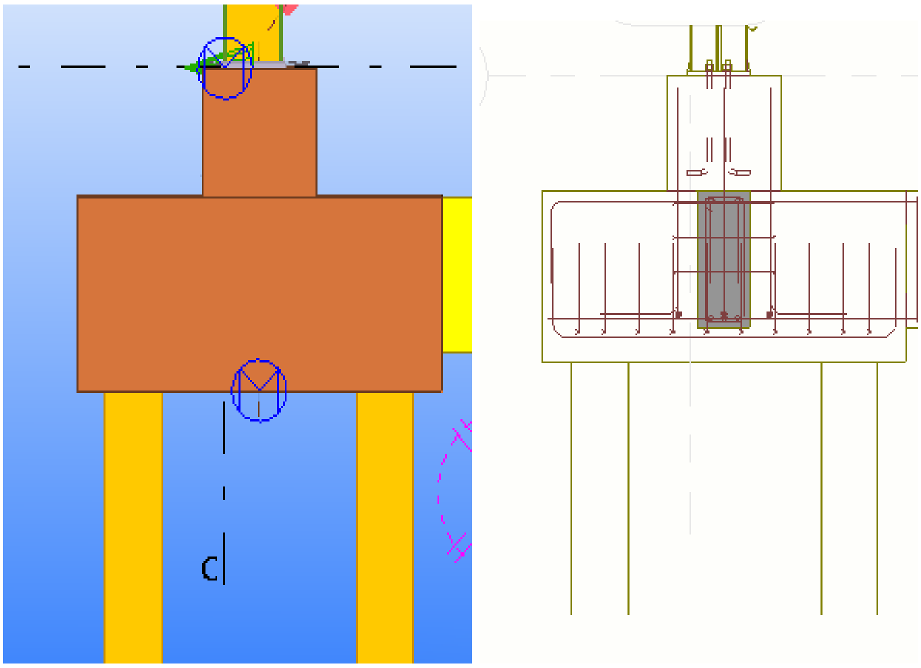


Figure 20. Foundation structure of the project

A pedestal was made by selecting concrete column feature from the ribbon. The length, width and height of the pedestal are 350mm, 350mm and 500mm respectively. The pedestal was designed as a transitional part between a column and a pad footing to spread load from the column on top of the footing. This approach reduces the intensity of bearing capacity directly to the pad footing. In addition, the pedestal can prevent corrosion between columns and soil.

A pad footing was placed under the pedestal and made by the concrete pad footing command on the ribbon. The dimensions of the pad footing are 1600mm length * 1400mm width * 750 mm height. The function of the pad footing is to transfer concentrated load from the columns and frame structures to the soil layer.

Pile was made from concrete column feature on the ribbon. The dimensions of pipe are 250mm length*250mm width * 7000mm height. The function of pile is also to transit load to the soil layer. Depending on the location of the column, there are a number of equivalent pipes in the foundation structure

6.9.2 Column Base Connection

A column was attached to the pedestal using the Tapered column base plate connection as illustrated in figure 21. The connection was found from the Applications and components catalog.

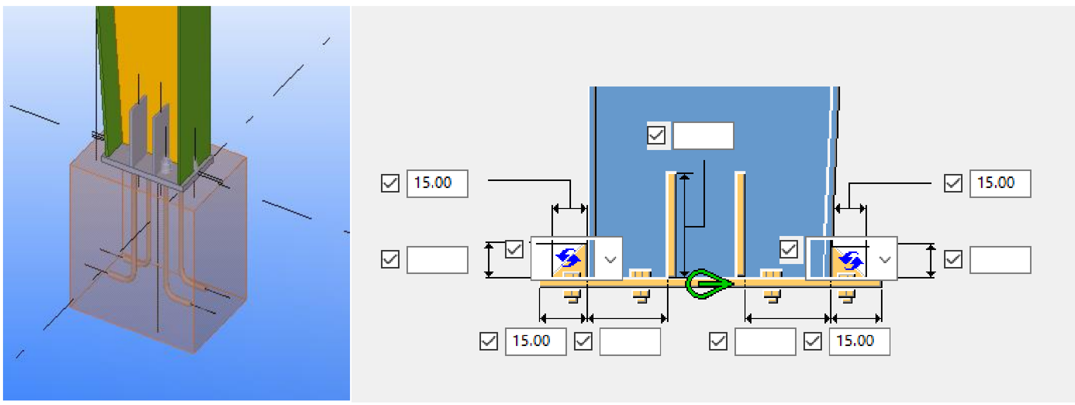


Figure 21. Tapered column base plate connection

The component was used in the design as a connection part between the steel column and the concrete foundation and to transit the structural stresses from the column to the foundation. There are two main parts in the component: a base plate and anchor rods. The anchor rod is necessary to prevent the column from uplifting and to keep the column in position during erection process. The length of the anchor rod is 500mm and the base plate was designed to be suitable with the column.

6.9.3 Starter Bar for Footing

Starter bar for footing, as illustrated in figure 22, is one of the components in the Applications and components catalog. The starter bar is used to resist tensile and shear forces across column-to-foundation joints.

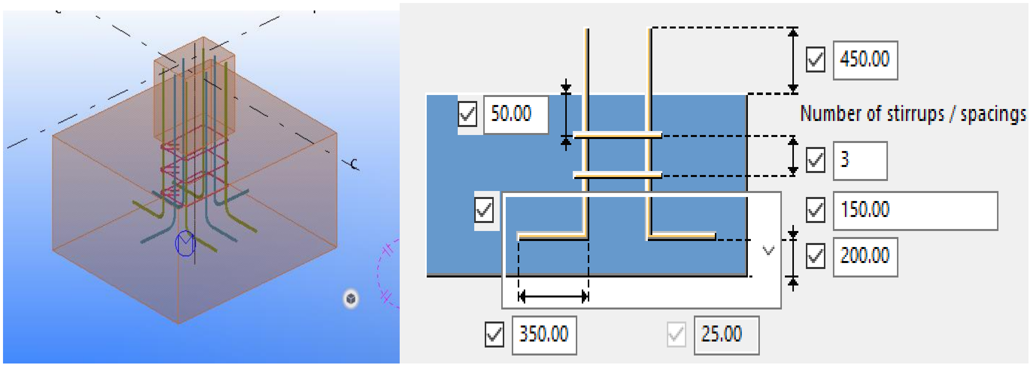


Figure 22. Starter bar for footing

In Tekla Structures software, the user can modify a number of stirrups and stirrup spacing, bar dimensions etc. In the project, the component includes three stirrups, shown as red coloured bar, with spacing of 150mm and its length and width dimensions of the starter bar are 500mm and 350mm respectively. The bending length of the start bar is 350mm.

6.9.4 Pad Footing Reinforcement

Pad footing reinforcement can be selected from the Applications and components catalog. In the pad footing reinforcement dialog box, the user can modify the properties of the primary bar, secondary bar and lacer bar to create the component.

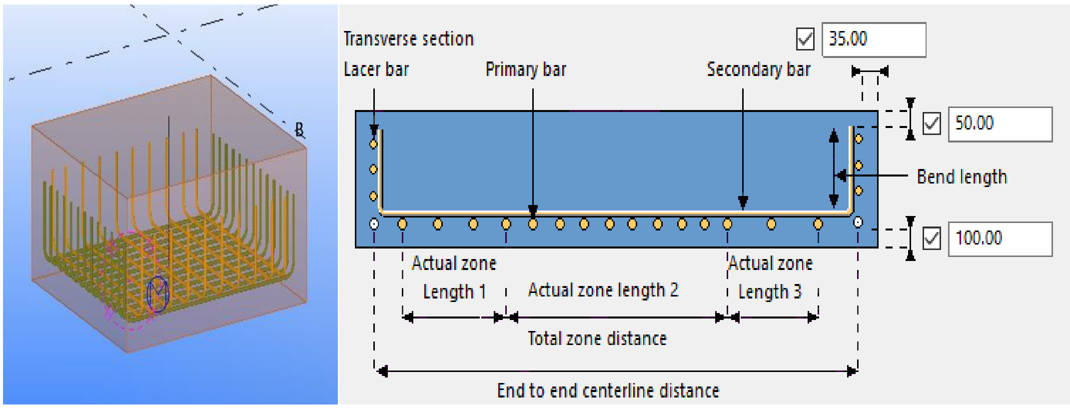


Figure 23. Pad footing reinforcement of the project

As illustrated in figure 23, in order to distinguish amongst the primary bar, secondary bar and lacer bar, different colours were applied automatically on the software. The diameter sizes of the primary bar and secondary bar are 20mm and 18mm respectively. Bending radius is the radius that the bar can bend without damaging it or shortening its life. The bending radius was set to 2.5 times bigger than the diameter size so the bending radius of the primary bar and secondary bar is approximately 50mm. Spacing is the spacing interval between two bars and was set to 150mm.

6.9.5 Foundation Beam

As shown in figure 24, under each column is an independent footing and a beam is used to connect the two pad footings. A foundation beam is used when distance between two footings is so great.

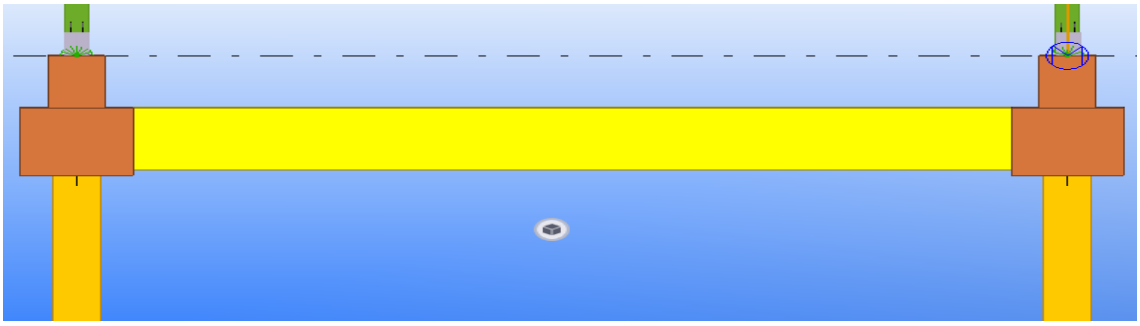


Figure 24. Foundation beam between two footings

In Tekla Structures software, the strap beam was made by choosing concrete beam command from the ribbone. The dimensions of the strap beam are 5450mm length * 230mm width * 600mm height.

6.9.6 Continuous Beam Reinforcement

One characteristic of concrete building material is that it is strong in compression but very weak in tension. As a result, in order to resist load in a structure, there should be steel reinforcement within the concrete structure. The reinforcing steel can absorb tensile and shear stresses caused by wind forces or earthquakes. Hence, the tensile strength of steel together with the compressive strength of concrete will create a great reinforced concrete to resist the load [18].

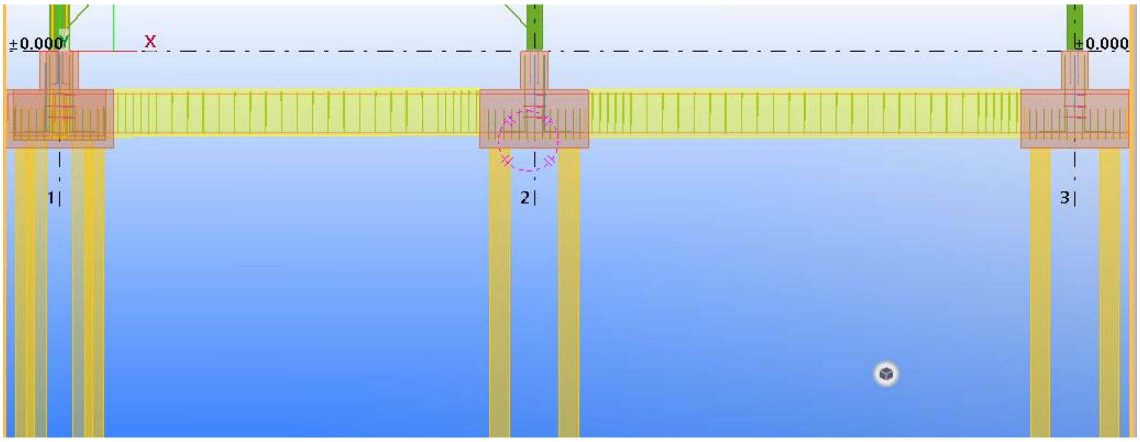


Figure 25. Continuous beam reinforcement

The continuous beam reinforcement is illustrated in figure 25. Continuous beam reinforcement command was selected from the Applications and components catalog. The command was used to reinforce the whole concrete beams on each side of the structure. With the command, the user can create main top and bottom bars, stirrups, additional top and bottom bars etc.

In the reinforced concrete beams, there are two main top bars and three main bottom bars with the diameter size of 20mm. Bending radius is 2.5 times bigger than the diameter size so the bending radius is 50mm and the bending length is 300mm.

6.10 Generate Drawings

Tekla Structures software allows users to extract different types of drawings according to the users' needs.

a, For fabricators

Single-part drawing and assembly drawing are used to show fabrication information. The single-part drawing shows the fabrication information for one part and usually without welds, while the assembly drawing shows the fabrication information for one assembly. The assembly includes a main part and secondary parts which are either welded or bolted to the main part. The paper size for a single-part drawing is usually A4 while an assembly drawing is A3 [19].

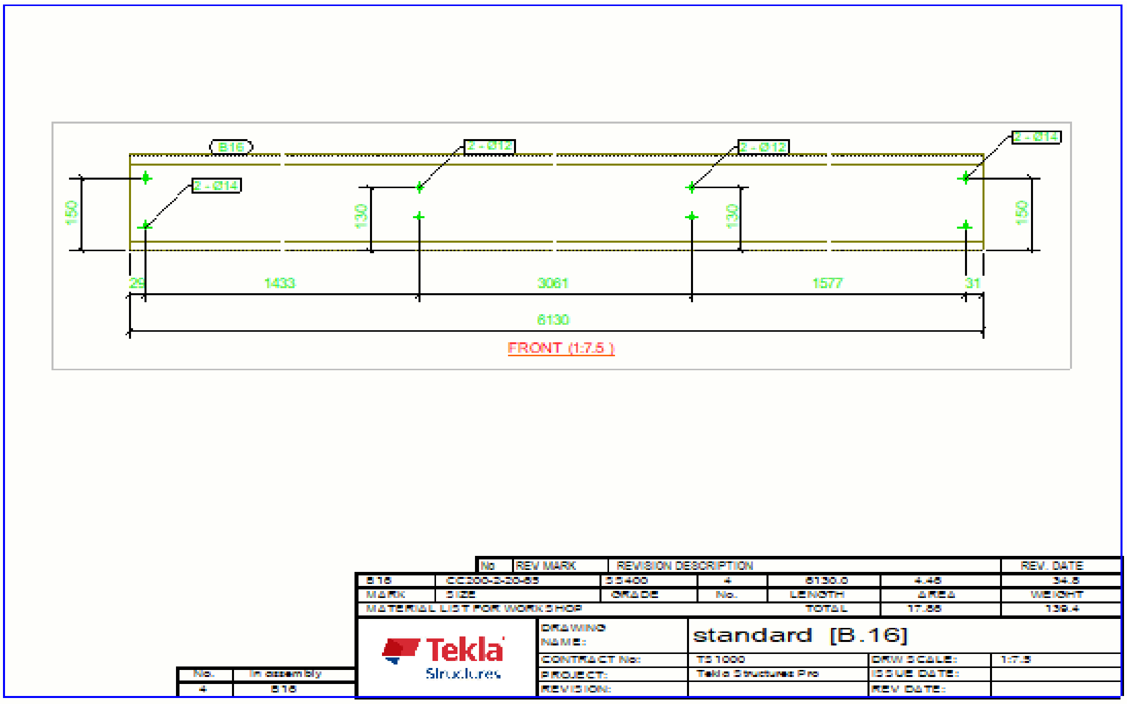


Figure 26. Assembly drawing of CC profile

The assembly drawing of CC profile as shown in figure 26 can deliver the steel profile's dimensions, its material, length, total number of assemblies, dimensions of bolts as well as the number of bolts used in the profile among others, which are considered as useful information for fabricators.

b, For Consulting Structural Engineers

A general arrangement drawing (GA drawing) is used to record information needed to understand the general structural arrangements of the building. The general arrangement drawing can be presented in the form of a plan drawing and an elevation drawing. The plan drawing is the drawing generated when the user looks from the top of a building towards the ground and the elevation drawing is generated when the user looks from one side of the building [20]. Examples of GA drawing extracted from the project can be seen in figure 27 and figure 28.

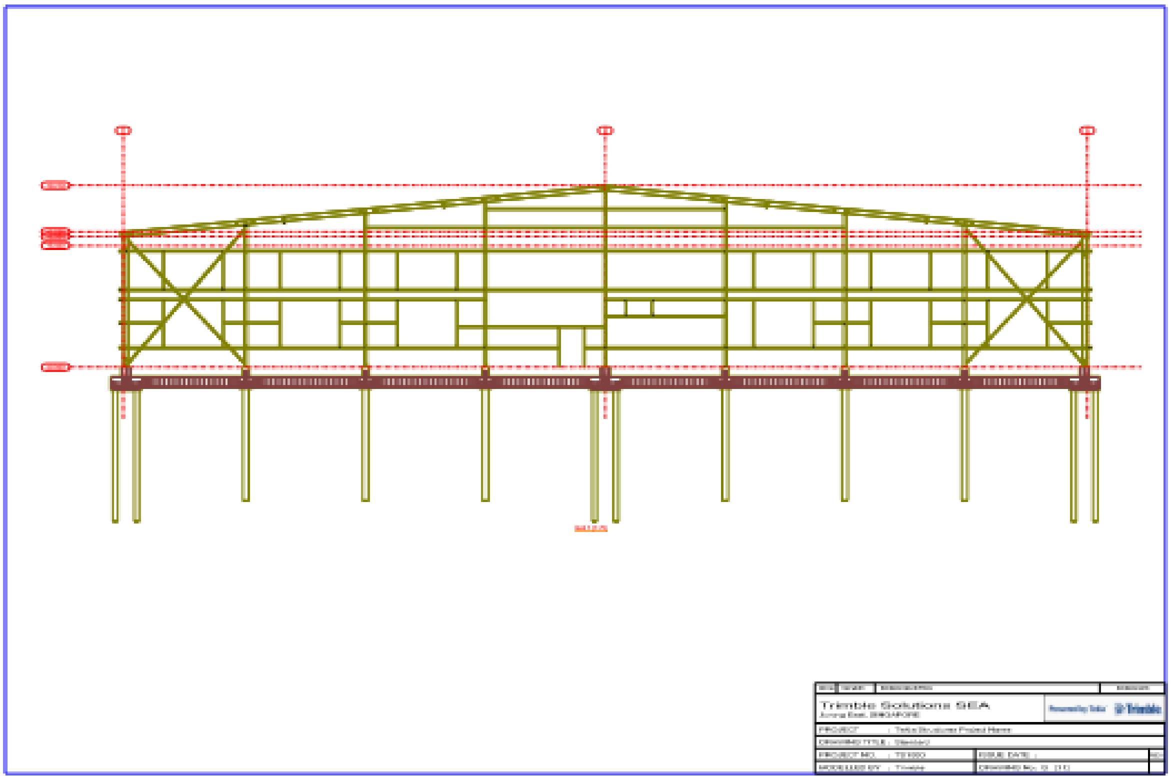


Figure 27. Elevation drawing generated from one side of the project

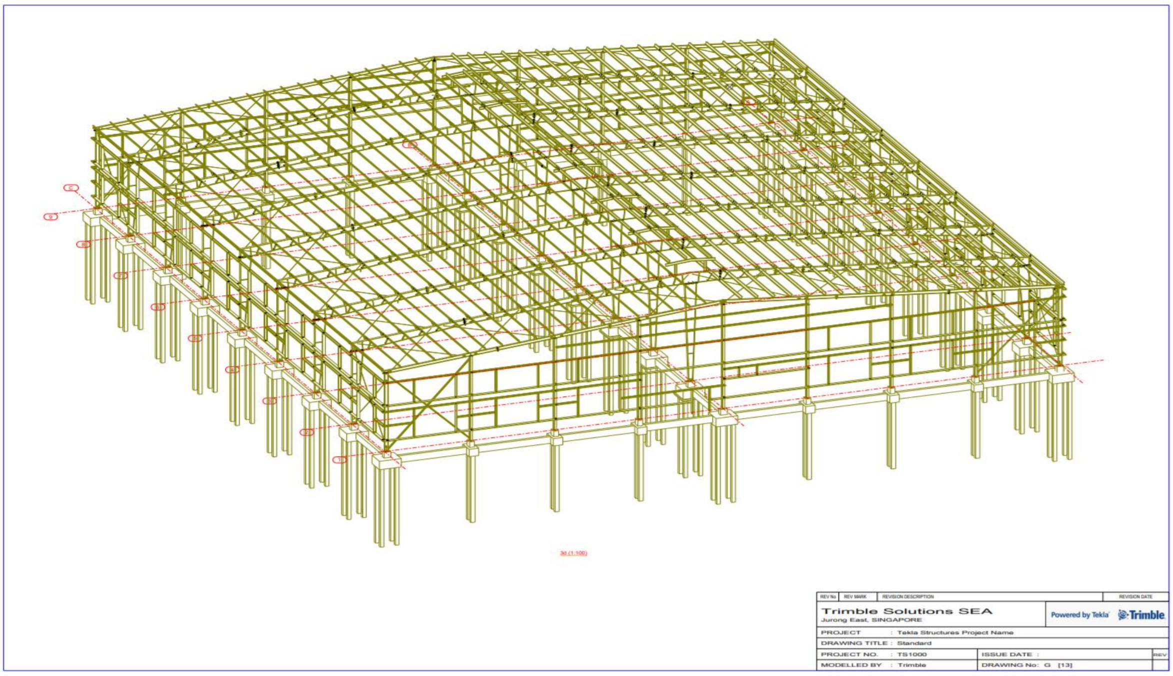


Figure 28. Plan drawing generated from GA drawing feature of the project.

Apart from designers and structural engineers of the project, the elevation drawing shown in figure 27 and the plan drawing shown in figure 28 provide other project team members an overall picture of how the project would look like in reality.

7 Conclusion

The thesis was written with the purpose of introducing Building Information Modeling, its advantages in general and its specific benefits for structural engineers and fabricators.

With BIM, architects, engineers and construction professionals can work on the same model to plan, design, construct and operate buildings. The thesis also analyses the differences between BIM and CAD in terms of parametric intelligence. Parametric intelligence in BIM provides designers with data attributes and critical information for fabrication process, resulting in saving time and energy. Based on BIM models, clash detection, schedule planning, schedule analysis, cost estimation and facility management can be produced and used.

BIM provides different types of software according to the users' needs. One of the BIM software is Tekla Structures. The thesis introduces the benefits of Tekla Structures software for structural engineers and fabricators together with the concept of pre-engineered building. From the thesis, Tekla Structures software provides unique features to optimize the design ability, a broad library consisting of all elements and the ability to extract model-based drawings and object information. For structural engineers, the thesis can be used as a source of how to construct a structural model on Tekla Structures software and different kinds of drawings for different user needs.

The reason why pre-engineered building is recommended in the thesis is its benefits in the construction process. Steel elements can be fabricated in the factory, while the foundation structure is being built at the construction site, resulting in saving construction time of the project. In addition, with the use of Tekla Structures software, the accurate assembly information can be generated and helped to fasten the fabrication process of pre-engineered building, leading also to environmental protection when erroneous fabricated parts are eliminated.

An important area for further research would be structural analysis using BIM software to determine that the deformation in a structure will not exceed the permissible limitations and collapse will not happen.

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