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Building Information Modelling: Interoperability Issues

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Abstract— There has been various interoperability issues among Building Information Modelling (BIM) and structural engineering design software programmes but there is still minimum researches to understand, test and evaluate the interoperability issues. This paper provides a better understanding of interoperability issues and its importance in providing more efficient interoperability among programmes for building information modelling to act as platform to exchange information among other disciplines. An attempt has been made by using Autodesk Revit as host of building information modelling whereas ESTEEM 9 and Orion 18 as structural engineering design software to identify interoperability issues arise due to information exchange. The interoperability issues were evaluated and causes of interoperability issues was identified. This research also offers an in-depth understanding of interoperability issues and importance of rectifying these interoperability issues in order for Architecture Engineering Construction (AEC) industry to adopt BIM completely for their projects. The ultimate outcome of this research offers the interoperability issues identified, the causes of interoperability issues and some suggestions to overcome these issues.

Keywords –Building Information Modelling, Interoperability Issues, Structural Engineering, Three-dimensional Model

I. INTRODUCTION

Building Information Model (BIM) is a theoretical method of approach for project design and construction that involves three-dimensional (3D) modelling and parameters of computer-intelligible interchange of information between architectural design and construction disciplines [1]. Adoption of BIM is gaining popularity as a technology platform that allows professionals such as architect and engineering firms to exchange and manage the information effectively.

With BIM technology, the building's precise virtual model, known as the building information model, is composed digitally. Upon completion, the building information model contains precise geometries and supports the data needed to achieve the required design, procurement, manufacturing and construction activities. The model can also be used for operational and maintenance purposes after the completion of construction [2].

It is essential to understand that BIM does not work just as a software; it is an operation and software. BIM not only means that the use of three-dimensional intelligent models but also makes significant changes in the workflow and handover process of a project. BIM represents a new paradigm within Architecture Engineering Construction (AEC) industry, a role that encourages the integration of all stakeholder roles in a project [2]. It has the potential to promote players who, in the past, considered themselves to be more efficient and harmonious between rivals. BIM also supports the concept of integrated project delivery, which is a new project delivery approach to people, systems and business structures and practices that incorporates a collaborative process to reduce waste and optimize efficiency through all stages of the project lifecycle [2].

Unfortunately, BIM has been subjected to interoperability issues over the past few years. To date, there has been little effort is taken to understand, test, and evaluate interoperability issues between major building structural design tools and prebuilt modelling software. Most consulting firms and construction companies are reluctant to adopt BIM completely due to these issues. BIM supports the exchange of information, using advanced 3D software solutions directly for their design collaboration, without absence of unbiased and creditable demonstration of its feasibility and value. Since 3D models are almost never available to engineering consulting firms, they have experienced the inexperienced effort to generate 3D models by interpreting the 2D drawings provided by the architect [3]. During the regeneration process, problems caused by data duplication, inconsistencies and erroneous in readings often occurs. On the positive side, data regeneration requires the modeler to systematically check all aspects of the project from the point of view of build ability and installation in order to make corrections during the replication process.

There is gathering of the evidence to prove that even this inherently inefficient process offers significant advantages over the traditional two-dimensional process. Considering the benefits of 3D modelling even with minimal interoperability, it is clear that moving structural design directly top rebuilt modelling software will allow building information to be delivered more quickly, flexibly, efficiently and economically than today.

As mentioned above, the prebuilt modelling software has a lot of functions in the AEC world but this research will focus mainly on its interoperability issues. Therefore, specific objectives of this study are: (1) To identify the interoperability issues, arise from the convey and delivery of information between structural engineering design software and prebuilt modelling software; (2) To evaluate the interoperability issues, arise from the exchange and delivery of information between prebuilt modelling software and structural engineering design software; (3) To provide suggestions to overcome the interoperability issues arise.

Rest of the paper is organized as follows, Section I contains the Introduction to building information modelling, Section II contains the Related Works from previous researchers, Section III contain the Methodology used to conduct the simulation experiment, Section IV describes the Results and Discussion obtained throughout the experiment and Section V contains Conclusion and Future Scope for other researches to continue the research work done.

II. RELATED WORK

A. Building Information Modelling (BIM)

Construction projects nowadays are becoming increasingly complex and difficult to manage [4]. The complexity develops with interdependence of different stakeholders, such as financial institutions, authorities, architects, engineers, lawyers, contractors, suppliers and industry [5]. As reaction of the pair increasingly complex projects, information and communication technology (ICT) has been developing at a very rapid process to overcome the complexity [5]. A major shift in ICT in the construction industry over the past decade has been the diffusion of the building information model (BIM) in industry and academia as a new computer-aided design (CAD) paradigm [6].

BIM has become a trend technology which commonly referred to platform of exchanging information between disciplines is used in some form by most people in the industry. Usage of BIM is commonly found in a project that has wide scope of work and advanced complexity. Besides usage of BIM to such large-scale projects, BIM is also used on individual components of projects of a smaller scale. McGraw Hill Construction’s recent survey found that 45% of architects, engineers, contractors and building owners used BIM for 30% or more of their projects in 2008. The use of BIM is expected to continue to grow substantially over the next few years [7].

B. Tradisional Two-dimensional (2D) CAD Drawings

Computer Aided Design (CAD) systems was adopted in Architect Engineering Construction (AEC) industry but refused by Mechanical Computer Aided Design (MCAD) software. The major companies which using CAD system in the market includes DesignCAD, DrafixCAD, TurboCAD, GenericCAD, Microstation, CadKey and AutoCAD [6]. AutoCAD is claimed to be the most popular among the AEC industry where 56% of the industries worldwide are using AutoCAD for their practice [8]. In Malaysia, almost 93% of the companies and institutions are using AutoCAD to produce CAD drawings. However, the popularity gain by AutoCAD is nothing since all the major operation systems underneath are using CAD systems.

C. Benefits of BIM over Two-dimensional CAD

Even if BIM is still in its early stages of application, significant improvements have been achieved with respect to traditional 2D drawings [9]. As BIM's features recommended, BIM does an improved job in data structures, modelling/drawing entities, observing/editing, altering schedules, views/plan generation and scheduling than traditional CAD drawings. Table 1 shows the most direct and tangible benefits of a single file structure, where all building information resides in a single file. As a result, the difference between the view / schedule is eliminated, and the time in response to the change is shortened.

Table 1. Essential Features of BIM vs. Traditional 2D Drafting

	Traditional 2D Drafting by Default	Essential Features of BIM by Default
Data Structure	project may consist of hundreds of separate CAD files. Each file represents a 2D view or schedule.	A project only has a single building data model containing all the views and schedules.
Modelling/ Drawing entities	Use graphic primitives such as points, lines, arcs, circles and blocks to draw the 2D views	Use object-based and parametric building elements to build the model
View/ Schedule Production	Each 2D view/schedule is produced manually.	All the views/schedules are automatically generated from the single model.
Viewing/ Editing	Able to view and edit each file in 2D only.	Able to view and edit a project in 2D, 3D or both.
Scheduling	Unable to tabulate the building	Able to tabulate the building information

	information.	such as quantities, areas, windows and doors.
Change actions	A change in a view/schedule has no effect on all other views/schedules. All the relevant updates have to be done manually.	A change in a view/schedule is reflected instantly and automatically in all other views/schedules.

Source: Compiled from AutoCAD and Revit.

Building Information Modelling also promotes the extraction of environment related to downstream applications in the project construction. Some of the applications that included in BIM are evaluation of design alternatives, pre-construction cost estimation, collaboration of multi-disciplines, sustainability studies and energy efficiency [9]. University of Salford is currently researching on 3D to nD modelling in order to optimise the time, constructability, maintainability, accessibility, cost and relevant aspects with object-based 3D Models [10].

D. Interoperability of Building Information Modelling

In BIM, the building model is derived as an open standard data file, which can be imported from a variety of modules. However, the accuracy of BIM is affected due to lack of dynamic data links [11]. This means that information reflected by BIM may not be accurate. Table 2 shows the interoperability of Autodesk Revit among other formats:

Table 2. Interoperability of Autodesk Revit among other formats

Import formats:	Export formats:
Autodesk Revit files (Rvt, Rfa)	Autodesk Revit files (Rvt, Rfa)
ACAD files (DWG, DXF, DGN or SAT)	ACAD files (DWG, DXF, DGN or SAT)
Industry Foundation Classes (IFC)	Open Database Connectivity (ODBC)
	Image and Animations
	Green Building XML schema (gbXML)
	Industry Foundation Classes (IFC)

Source: Obtained from Hands-on Operation in Autodesk Revit (2014).

III. METHODOLOGY

This chapter will be discussing about the sets of data that has been used throughout the simulation experiment. It includes the procedures to obtain the information required to design the bungalow project, total number of structural elements that has been tested, parameters that has been considered to design the structural elements, software programmes that used to design structural elements and complete sets of procedures of the simulation experiment. Figure 1 will give an overview of the stages that have been undergone to obtain the interoperability issues.

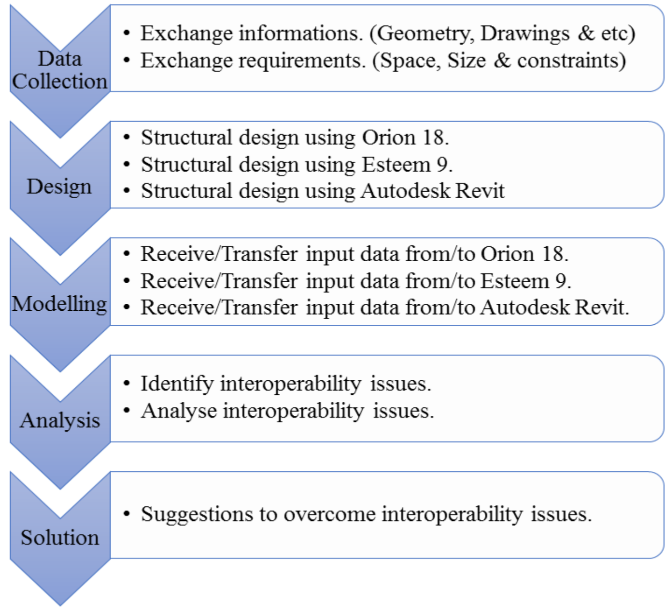

Figure. 1: Research Methodology Stages

A. Data Requirement

The simulation experiment devised to further investigate the interoperability issues which arises from exchanging information between prebuilt modelling and structural design engineering software. The following structural elements that listed in Table 3.1 been identified and examined to proceed further study in interoperability issues arises in this particular project.

Table A. Structural Elements List

Structural Elements	Number of structural elements tested
Slab	88 Nos
Masonry Wall	40 Nos
Beam	416 Nos
Column	90 Nos
Pad Footing	45 Nos

B. Software Programmes

1) Tekla Orion 18

Orion was developed for the analysis, design and drawing of concrete building structures. Unlike general structural analysis programs, Orion specializes in accurate analysis, rapid data preparation, automatic reinforced concrete design, and automatic preparation of engineering drawings and details. The Orion building system allowed to have the following common structural features such as the geometry of a building system is typically formed primarily by horizontal beams and vertical columns, standard cross-sections for column and beam, load applied can be placed in vertical (static and applied) or horizontal (wind, earth pressure or earthquake) directions and floor layouts from one floor to the next floor are allowed to be repeated (in whole or in part). In addition, different preferences can be maintained and automatically used for analysis and design purposes.

This is to allow beam flanges to be ignored in the analysis, but then used to enhance the design (sagging moments only) without any need for re-modelling. In summary, the Orion model allows to create CAD drawings, design floorboards, and break down floor loads onto beams, analyse building frames, and design continuous beams and columns, walls and foundations (mats, bars and rafts) to automatically generate RC detail drawings.

2) Esteem 9

Esteem is a structural design software that allows users to generate data or analyse data that can be used to design structural elements. Using the Esteem module, engineers can predict and design structures more accurately and faster than with manual calculations.

For modelling, Esteem 9 has equipped with floor key plan input with fully integrated project management and status control of analysis and design. It also has non-orthogonal floor key plan grids and intelligent input shortcuts such as auto data and data checking. In analysis standpoint, it has automatic adaptive mesh generation for well-graded triangular and quadrilateral shell elements where engineer do not require to do manual calculations. Moreover, Esteem 9 has Eurocode database which will ensure full compliance of structural elements.

Finally, Esteem 9 is user-friendly software. It comprises toolbars and shortcuts which help the designer to speed up the design proceed. A checking tool was also added to cross reference any duplicate structural elements to reduce percentage of error during design process.

3)Autodesk Revit

Autodesk Revit builds information modelling software for architects, engineers, designers, and contractors that developed by Autodesk. It allows users to design buildings and structure components in 3D by using the 2D drawing element annotations. The model allows user to access building information from the building model's database. Revit is a 4D BIM able to plan and track the various stages of the life cycle of the building, from concept to construction and subsequent demolition.

Revit can be used as a very powerful collaboration tool between different disciplines in the architectural design field. Use Revit's different disciplines to approach the program from a unique perspective. Each of these views is focused on the task of completing the discipline. The company that uses the software first checks the existing workflow process to determine if this well-designed collaboration tool is needed.

C. Procedures of Experiment

For initial procedure in the simulation experiment, bungalow house architectural drawing was selected to be used as the project to prepare the structural design that was used to build up the 3D modelling. The design was ensured the replication of accurate reflection of 2D geometry design that provided by architect which is a standard workflow that followed in AEC industry. Then the geometry of bungalow house was transferred to Tekla Orion 18.

Once the structural model complete, the input of the 'Tekla Orion 18' was transferred to 'Autodesk Revit' to build up the three-dimensional building modelling. At this stage, the model will reflect the 3D geometry as defined in the drawings that requested by the architect. However, the model was examined thoroughly to identify the interoperability issues.

After the examination of model complete, the information in 'Autodesk Revit' was transferred to 'Esteem 9' for identification of the interoperability issues arise from this procedure.

The same procedure was repeated to identify the interoperability issues arise from the input of 'Esteem 9'. The results were also analysed and the errors arise from interoperability was stated.

Another model was generated in 'Autodesk Revit' using the same bungalow project as a further step to identify the interoperability issues. The model was then transferred to both 'Esteem 9' and 'Orion 18' to investigate the interoperability issues. The results were then derived and discussed.

Finally, the interoperability issues were listed and possible causes was identified once the procedure stated above completed. Some suggestion was provided in order to avoid the interoperability issues based on the analysis conducted. Figure 2 illustrates the procedures of the experiment in flowchart for further understanding.

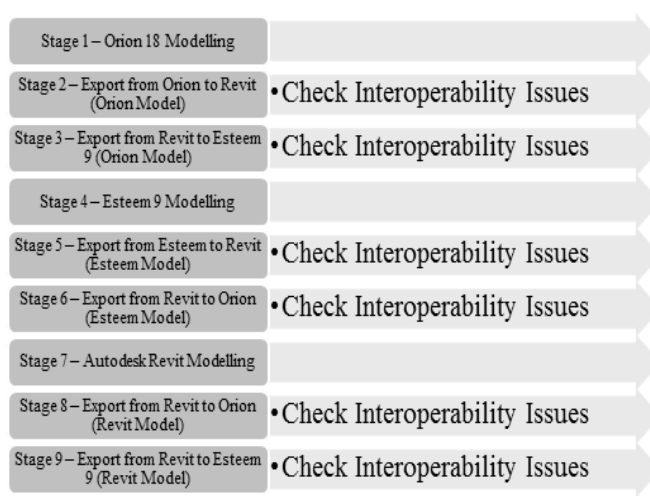

Figure 2. Procedures of Experiment

IV. RESULTS AND DISCUSSION

A. Input Values

The following Table 4 indicates the input values that was standardized for three programs.

Table 4. Input Variables for Three Programmes

Structural Element	Orion 18	Esteem 9	Autodesk Revit
Slab	150	150	150
Beam	250 x 650	250 x 650	250 x 650
Column	125 x 500	125 x 500	125 x 500
Masonry Wall	125	115	No Input
Pad Footing	1800 x 1200 x 450	1800 x 1200 x 450	1800 x 1200 x 450

Note: All units are in mm unless stated.

As indicated in the table above, these are some of information that was input into programmes respectively. The size of the structural element was standardized in order to speed up the design process. The following chapter explains the results in further.

B. Results & Discussions

1) Interoperability Issues for Stage 2.

The following interoperability issues are for stage 2 which was raised by Autodesk Revit as a result of conveying information from Orion 18. The model which was used for this information convey is based on Orion 18 model that has been done during stage 1. Table 5 is an attempt to explain the interoperability issues.

Table 5. Summary of Errors Detected for Stage 2.

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	3 Missing
Gridline	126	Nil
Slab	88	88 Missing
Beam	416	Nil
Column	180	Nil
Masonry Wall	40	40 Missing
Pad Footing	45	45 Missing

a) Floor Level Interoperability Issue for Stage 2.

In stage 2 of the simulation experiment, the floor levels in the model was not detected automatically. The base reference for Orion 18 is different from Autodesk Revit which causes the model generated has interoperability in term of floor level. Based on model generated, it has been concluded that Autodesk Revit interprets Level 1 as Foundation Level. This causes the transferred model information to have errors where floor levels have discrepancy. Thus, Autodesk Revit created floor level 1 and level 2 with an offset of 1100mm. Figure 3 illustrates the discrepancy from East elevation view for further understanding.

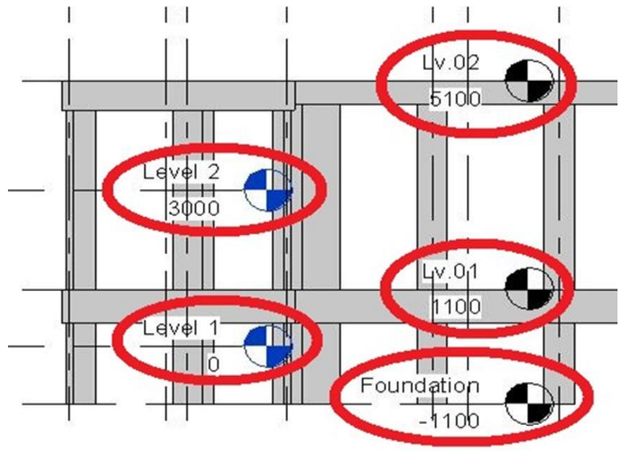

Figure 3. Interoperability Issue for Floor Levels in Stage 2.

b) Slab Interoperability Issue for Stage 2.

All the slab panels in the generated model has interoperability issues. The information passed from Orion 18 was not interpreted properly where there are no slab panels found in plan view of the floor level 01 and level 02. In contradictory, the slab panels were appeared in 3-dimensional view. Even though slab panels appeared in 3-dimensional view, the option to select and edit the panel was still missing. Thus, Autodesk Revit has interoperability issues to read the slab panel as a structural element. Figure 4 shows the view in 3-dimensional view and floor plan on level 01 for further understanding of the interoperability issue.

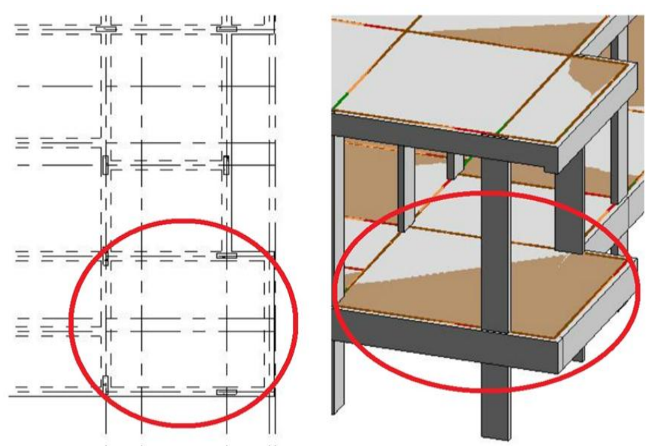

Figure 4. Interoperability Issue for Slab Panel in Stage 2.

c) Masonry Wall Interoperability Issue for Stage 2.

All the masonry walls in the generated model has interoperability issues. In Orion 18, option to select a brick wall was found to design the bungalow house where the information was not interpreted by Autodesk Revit due to built-in option. Autodesk Revit was programmed without considering the brick wall. Option ‘Wall’ found in Autodesk Revit is to model a shear wall. The contradictory scenario causes the model to be generated without an external and internal masonry walls. This indicates that, Autodesk Revit has an interoperability issue with masonry wall. Figure 5 shows the view of model generated in 3-dimensional view indicating no masonry wall found.

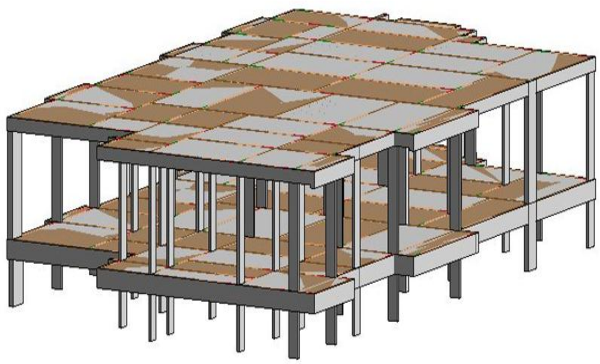

Figure 5. Interoperability Issue for Slab Panel in Stage 2.

d)Pad Foundation Interoperability Issue for Stage 2.

All the pad foundation in the Autodesk Revit generated model was missing. In Orion 18, the foundation of the bungalow house was designed to be pad foundation. During the convey and interpretation, the pad foundation was missing which is considered to be a very serious interoperability issue for this simulation model. The scenario of missing pad foundation for all the column indicating the interpreted information is not accurate. During the analysis of model, it has been found that Autodesk Revit understand Level 1 as the ground level whereas in Orion 18, Level 1 is referred to be first floor. The contradictory scenario leads the model to be generated without the pad foundation. Figure 6 highlights the missing information of pad foundation in plan view and 3-dimensional view.

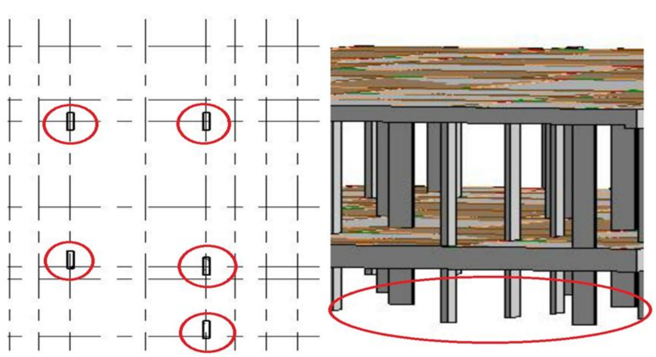

Figure 6. Interoperability Issue for Slab Panel in Stage 2.

2)Interoperability Issues for Stage 3.

The following interoperability issues are for stage 3 which was raised by Esteem as a result of conveying information from Autodesk Revit. The model used for this information convey is based on Orion 18 model that was done during stage 1. Table 6 is an attempt to explain the interoperability issues.

Table 6. Summary of Errors Detected for Stage 3.

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	2 Additional
Gridline	126	Nil
Slab	88	Nil
Beam	416	Nil
Column	180	Nil
Masonry Wall	40	40 Missing
Pad Footing	45	45 Missing

a) Floor Level Interoperability Issue for Stage 3.

There were 5 floor levels that has been detected by Esteem 9 due to convey of information from Autodesk Revit. The floor level was indicated as Level Foundation, Level 1, Level 01, Level 2 & Level 02 with height of 3000mm, 1100mm, 1100mm, 1900mm & 2100mm respectively. In other word, the floor height from Level 01 to Level 02 has height of 4000mm as required. But, the height of stump from Level 01 to foundation level is 4100mm which is not accurate. The input of stump in Orion 18 was 1100mm which is not reflected accurately by Esteem 9. This means there is additional floor height of 3000mm from Level 01 to Level Foundation. Besides that, there is an intermediate floor Level 1 and Level 2 which was conveyed from Autodesk Revit. This caused the columns to be generated as different elements instead of one whole element with height of 4000mm. Figure 7 illustrates the discrepancy in 3-dimensional view for further understanding.

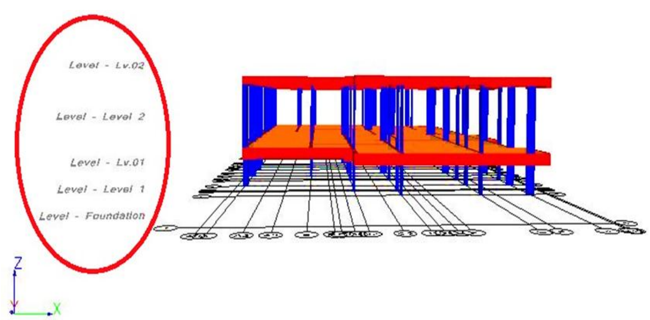

Figure 7. Interoperability Issue for Slab Panel in Stage 2.

b)Masonry Wall Interoperability Issue for Stage 3.

All the masonry walls in the generated model has interoperability issues. Esteem 9 has a build-in option to select a brick wall for consideration of loading. It is understood that information conveyed by Autodesk Revit does not contain information regarding masonry wall which causes the interoperability issue. Therefore, the model was generated without any internal and external masonry wall. Figure 8 shows the view of model generated in 3-dimensional view indicating no masonry wall found.

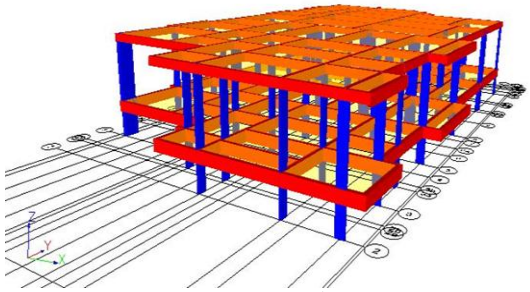

Figure 8. Interoperability Issue for Stage 3 Masonry Wall.

c) Pad Foundation Interoperability Issue for Stage 3.

All the pad foundation in the Esteem 9 generated model was missing. During the convey and interpretation, the pad foundation was missing which is considered to be a very serious interoperability issue for this simulation model. The scenario of missing pad foundation for all the column indicating the interpreted information is not accurate. During the analysis of model, it has been found that pad foundation interoperability issue was conveyed from Autodesk Revit. Since Autodesk Revit does not have the capability to detect the pad foundation automatically, the interoperability is then repeated in Esteem 9. Figure 9 shows the view of model generated in 3-dimensional view indicating no pad foundation.

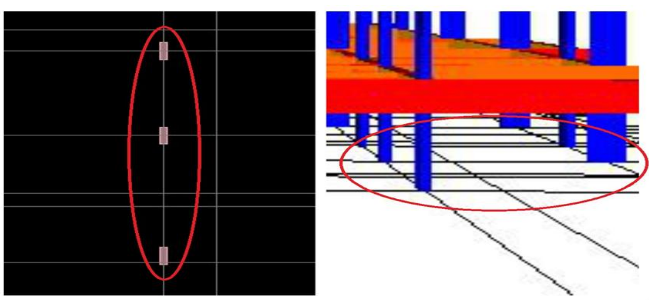

Figure 9. Interoperability Issue for Stage 3 Pad Foundation.

3) Interoperability Issues for Stage 5.

The following interoperability issues are for stage 5 which was raised by Autodesk Revit as a result of conveying information from Esteem 9. The model used for this information convey is based on Esteem 9 model that has been done during stage 4. Table 7 is an attempt to explain the interoperability issues.

Table 7. Summary of Errors Detected for Stage 5.

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	1 Missing
Gridline	126	Nil
Slab	88	Nil
Beam	416	Nil
Column	180	Nil
Masonry Wall	40	40 Missing
Pad Footing	45	45 Missing

a) Floor Level Interoperability Issue for Stage 5.

In stage 5 of the simulation experiment, it has been found that the model has some minor interoperability errors. There is only 1 floor level missing from the generated model of information from Esteem 9 to Autodesk Revit. The floor level height reflects the accurate reading as the input in Esteem 9 which is 4000mm. The height of stump was accurate as input which is 1100mm. This means Autodesk Revit was unable to interpret the foundation floor level which is -1100mm away from Ground Level. After thorough inspection of the model, conclusion was made where ‘Foundation Level’ was not generated due to interoperability issue. Besides that, Autodesk Revit also has interoperability where there is 2 floor marking which reads the same floor level. In the generated model, there is 2 floor marking at height of 4000mm which is floor ‘Level 2’ and ‘1F’. The marking ‘1F’ was the indication of Esteem 9 for first floor. This means, there is minor error of redundancy of reading same elements in 2 different floor markings. Figure 10 illustrates the floor level discrepancy in 3-dimensional view for further understanding.

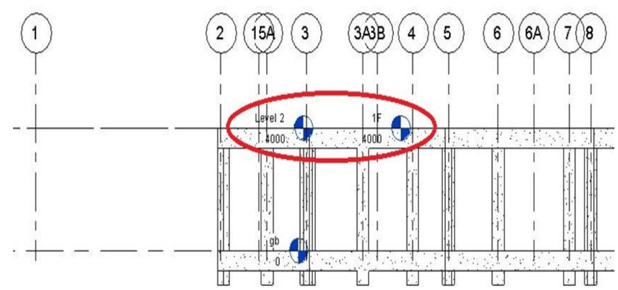

Figure 10. Floor Level Interoperability Issue for Stage 5.

b) Masonry Wall Interoperability Issue for Stage 5.

All the masonry walls in the generated model has interoperability issues. In Esteem 9, option to select a brick wall was found to design the bungalow house where the information was not interpreted by Autodesk Revit due to built-in option. Autodesk Revit was programmed without considering the brick wall. Option ‘Wall’ found in Autodesk Revit is to model a shear wall. The contradictory scenario causes the model to be generated without an external and internal masonry walls. This indicates that, Autodesk Revit has an interoperability issue with masonry wall. Figure 11 shows the view of model generated in 3-dimensional view indicating no masonry wall found.

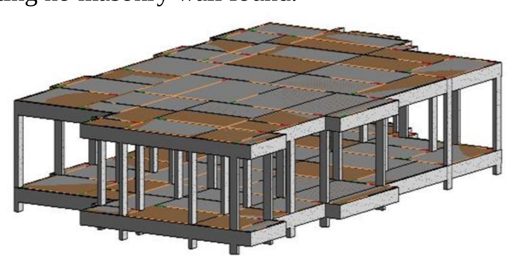

Figure 11. Interoperability Issue for Stage 5 Masonry Walls.

c) Pad Foundation Interoperability Issue for Stage 5.

All the pad foundation in the Autodesk Revit generated model was missing. In Esteem 9, the foundation of the bungalow house was designed to be pad foundation. During the convey and interpretation, the pad foundation was missing which is considered to be a very serious interoperability issue for this simulation model. The scenario of missing pad foundation for all the column indicating the interpreted information is not accurate. During analysis of the model, the missing pad foundations was concluded in result of missing floor level namely ‘Foundation Level’. Based on Autodesk Revit’s behaviour, structural elements cannot be created without reference of floor level at that particular position. This misunderstanding leads the model to be generated without the pad foundation. Figure 12 highlights the missing information of pad foundation in 3-dimensional view.

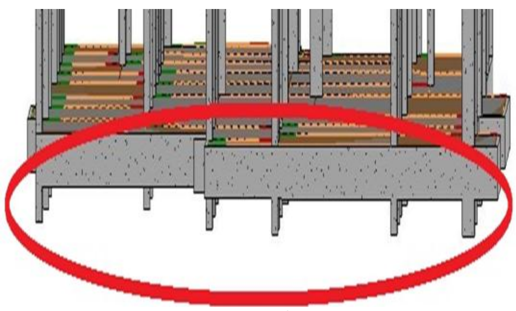

Figure 12. Interoperability Issue for Stage 5 Pad Foundation.

4) Interoperability Issues for Stage 6.

The following interoperability issues are for stage 6 which was raised by Orion 18 as a result of conveying information from Autodesk Revit. The model used for this information convey is based on Esteem 9 model that has been done during stage 4. Table 8 is an attempt to explain the interoperability issues.

Table 8. Summary of Errors Detected for Stage 6.

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	1 Missing
Gridline	126	14 Missing
Slab	88	88 Missing
Beam	416	416 Errors
Column	180	Nil
Masonry Wall	40	40 Missing
Pad Footing	45	45 Missing

a) Floor Level Interoperability Issue for Stage 6.

In stage 6 of the simulation experiment, it has been found that the model has some minor interoperability errors. Foundation floor level was missing from the generated model of information from Autodesk Revit to Orion 18. The floor level height reflects the accurate reading as the input in Esteem 9 which is 4000mm. Unfortunately, there is 2 floor marking indicating the same level. This interoperability error inherited based on Autodesk Revit model that discussed earlier in stage 4. The height of stump was accurate as input which is 1100mm. However, the value for ‘1st storey bottom level’ supposed to 650mm was interpreted wrongly where the model indicates the value as -1100mm. This means Orion 18 was unable to detect the depth of beam at ground floor automatically. After thorough inspection of the model, conclusion was made where ‘Foundation Level’ was not generated due to interoperability issue inherited from Autodesk Revit. Figure 13 illustrates the floor level discrepancy that was obtained from Orion 18 ‘storey information’.

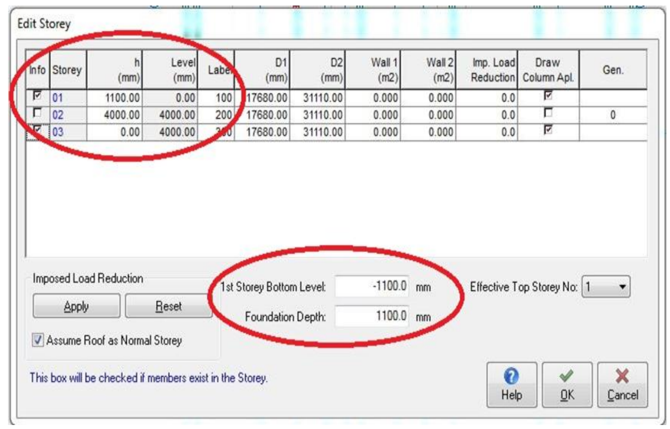

Figure 13. Floor Level Interoperability Issue for Stage 6.

b) Nodal Connectivity Interoperability Issue for Stage 6.

All structural element in the generated model has interoperability issues. In Orion 18, the connectivity of structural element is connected through intersection of gridlines. In contradictory, Autodesk Revit generates its nodal connectivity by combining structural elements. The point of nodal connectivity in Orion 18 is different from Autodesk Revit causes the generated model to have major error. Without the connectivity of nodal at gridline intersection, Orion 18 will not able to design the structural elements. The model considers to be unstable in term of connectivity due to this interoperability. Thus, the rectification of this interoperability is necessary in order to design the model in Orion 18. Figure 14 shows the nodal connectivity error in Orion 18.

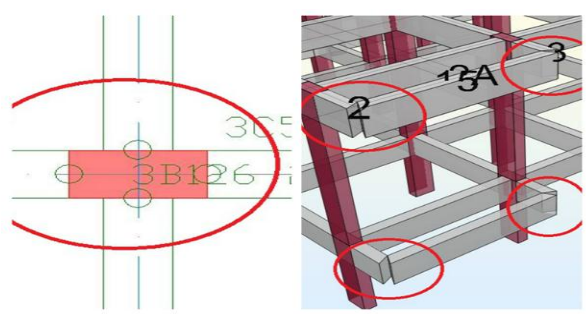

Figure 14. Nodal Connectivity Interoperability Issue for Stage 6.

c) Grid Line Interoperability Issue for Stage 6.

Some of the gridlines in the generated Orion 18 model is not detected. The information conveyed from Autodesk Revit to Orion 18 was not accurate for some gridlines that causes the gridline existence not to be recognised. The exact understanding of this interoperability is yet to be clear. Therefore, the discussion on this interoperability issue is not available at the moment. Figure 15 illustrates the unrecognised gridline for further understanding on this interoperability issue.

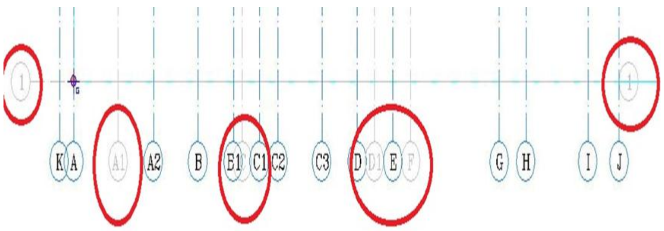

Figure 15. Gridline Interoperability Issue for Stage 6.

d) Grid Line Interoperability Issue for Stage 6.

In the generated model, some of the simply supported beams generated as continuous beams. The interpretation of this information causes interoperability in generating beams of the bungalow project. Mechanism of beam is essential in designing structures for any project. Misleading information in beam mechanism may leads to collapse of structural element without warning. Besides that, the length of the continuous beams identified to be exceeding 11000mm. Orion 18 was programmed to give warning for designers to reduce the length of continuous beam if exceeds 11000mm. Therefore, such misleading information affects the overall progress of designing structural elements in short time. Figure 16 illustrates the beam mechanism interoperability for further understanding.

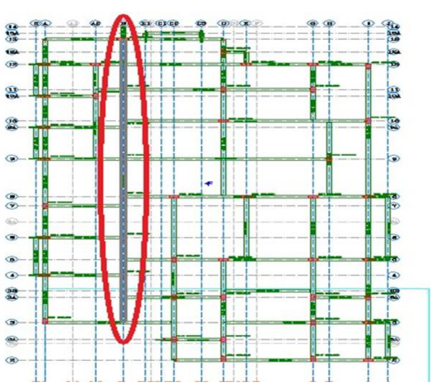

Figure 16. Beam Mechanism Interoperability Issue for Stage 6.

e) Slab Interoperability Issue for Stage 6.

All the slab panels in the generated model has interoperability issues. The information passed from Autodesk was not interpreted properly where there are no slab panels found in the floor level 01 and level 02. Thus, Orion 18 has interoperability issues to interpret the information conveyed by Autodesk Revit. Figure 17 shows the view in 3-dimensional view and floor plan on level 01 for further understanding of the interoperability issue.

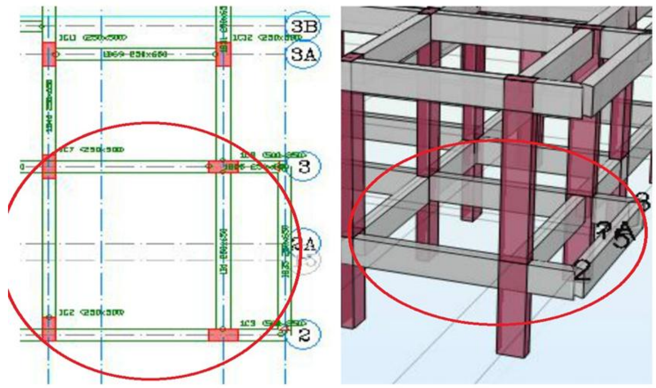

Figure 17. Slab Interoperability Issue for Stage 6.

f) Masonry Wall Interoperability Issue for Stage 6.

All the masonry walls in the generated model has interoperability issues. Orion 18 is capable to design a brick wall with built-in option. Due to misinterpretation from Autodesk Revit, Orion 18 unable to generate the masonry walls both internal and external. This indicates that, information conveyed by Autodesk Revit is not accurate for Orion 18 to generate the masonry wall which considered to be an interoperability issue. Figure 18 shows the view of model generated in 3-dimensional view indicating no masonry wall found.

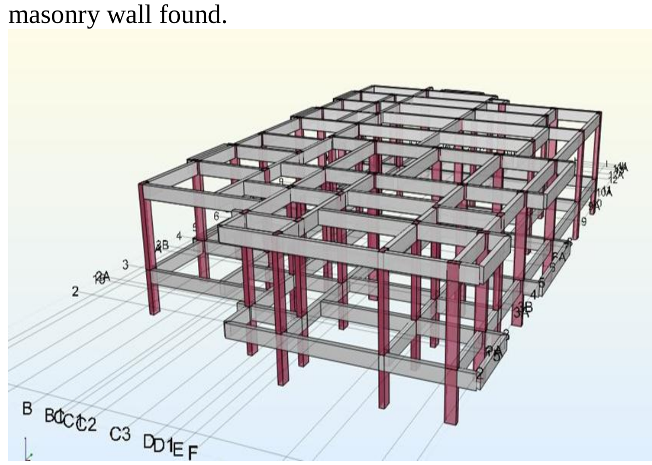

Figure 18. Masonry Wall Interoperability Issue for Stage 6.

g) Pad Foundation Interoperability Issue for Stage 6.

All the pad foundation in the Orion 18 generated model was missing. This interoperability is identified to inherited from Autodesk Revit which causes the Orion 18 model to have the same issue. Figure 19 highlights the missing information of pad foundation in plan view and 3-dimensional view for further understanding.

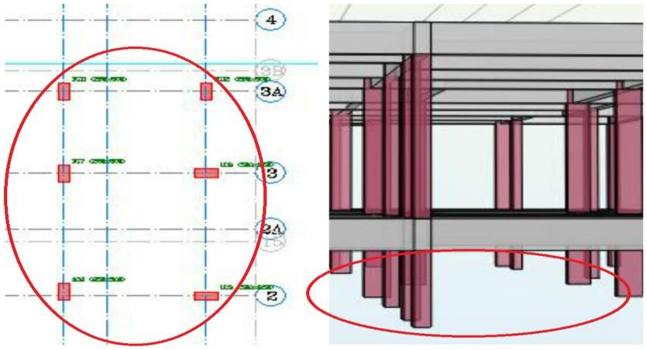

Figure 19. Pad Foundation Interoperability Issue for Stage 6.

5) Interoperability Issues for Stage 8.

The following interoperability issues are for stage 8 which was raised by Esteem 9 as a result of conveying information from Autodesk Revit. The model which was used for this information convey is based on Autodesk Revit model that has been done during stage 7. Table 9 is an attempt to explain the interoperability issues.

Table 9. Summary of Errors Detected for Stage 8

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	Nil
Gridline	126	Nil
Slab	88	Nil
Beam	416	Nil
Column	180	Nil
Masonry Wall	No Input	No Input
Pad Footing	45	45 Missing

a) Pad Foundation Interoperability Issue for Stage 8.

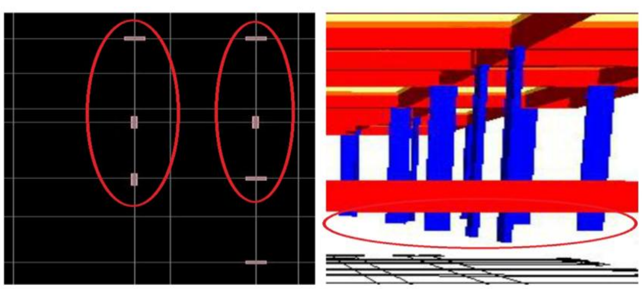
Figure 20. Pad Foundation Interoperability Issue for Stage 8.

All the pad foundation in the Esteem 9 generated model was missing. During design of bungalow house in stage 7, pad foundation was to be designed with a dimension of 1800mm length, 1200mm width and 450mm depth is found to be missing in stage 8. This source of this interoperability issue is identified to be convey of information from Autodesk Revit to Esteem 9. It was concluded that there is an issue with the built-in pad foundation design in Autodesk Revit that causes Esteem 9 not able to interpret the data. During analysis of the model, floor 'Foundation Level' is identified to be exist in Esteem 9 as programmed in Autodesk Revit. Therefore, the stated explanation further evidencing that interoperability is caused by Autodesk Revit. Figure 20 highlights the missing information of pad foundation in plan view and 3-dimensional view.

6) Interoperability Issues for Stage 9.

The following interoperability issues are for stage 9 which was raised by Orion 18 as a result of conveying information from Autodesk Revit. The model used for this information convey is based on Autodesk Revit model that has been done during stage 7. Table 10 is an attempt to explain the interoperability issues.

Table 10. Summary of Errors Detected for Stage 9

Analysis Aspect	Number of Elements	Errors Identified
Floor Levels	3	Nil
Gridline	126	Nil
Slab	88	88 Missing
Beam	416	416 Errors
Column	180	Nil
Masonry Wall	No Input	No Input
Pad Footing	45	45 Missing

a) Stage 9 Nodal Connectivity Interoperability Issue.

All structural element in the generated model has interoperability issues. In Orion 18, the connectivity of structural element is connected through intersection of gridlines. In contradictory, Autodesk Revit generates its nodal connectivity by combining structural elements. The point of nodal connectivity in Orion 18 is different from Autodesk Revit causes the generated model to have major error. Without the connectivity of nodal at gridline intersection, Orion 18 will not able to design the structural elements. The model considers to be unstable in term of connectivity due to this interoperability. Thus, the rectification of this interoperability is necessary in order to design the model in Orion 18. Figure 21 shows the nodal connectivity error in Orion 18.

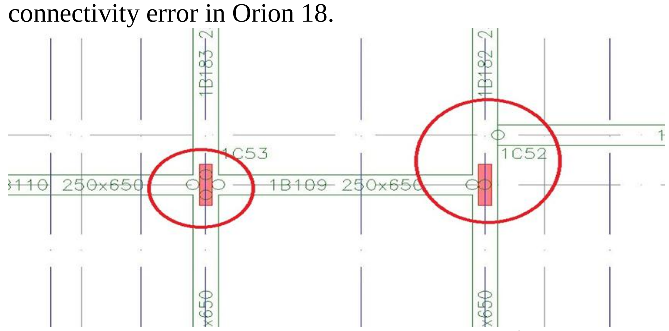

Figure 21. Nodal Connectivity Interoperability Issue for Stage 9.

b) Slab Interoperability Issue for Stage 9.

All the slab panels in the generated model has interoperability issues. The information passed from Autodesk was not interpreted properly where there are no slab panels found in the floor level 01 and level 02. Thus, Orion 18 has interoperability issues to interpret the information conveyed by Autodesk Revit. Figure 22 shows the view in 3-dimensional view and floor plan on level 02 for further understanding of the interoperability issue.

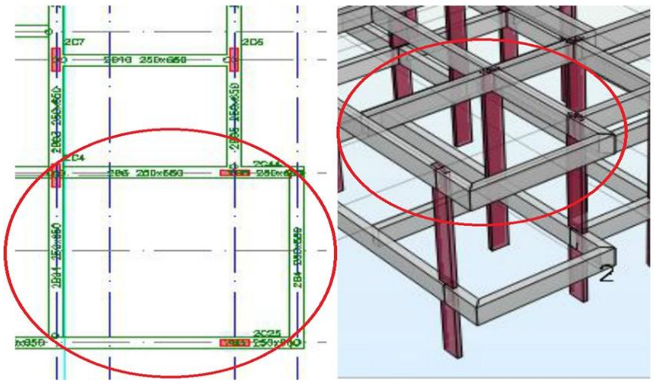

Figure 22. Interoperability Issue for Slab Panels in Stage 9.

c) Pad Foundation Interoperability Issue for Stage 9.

All the pad foundation in the Orion 18 generated model was missing. During design of bungalow house in stage 7, pad foundation was to be designed with a dimension of 1800mm length, 1200mm width and 450mm depth is found to be missing in stage 9. This source of this interoperability issue is identified to be convey of information from Autodesk Revit to Orion 18. It was concluded that there is an issue with the built-in pad foundation design in Autodesk Revit that causes Orion 18 not able to interpret the data. During analysis of the model, floor 'Foundation Level' is identified to be exist in Orion 18 as programmed in Autodesk Revit. Therefore, the stated explanation further evidencing that interoperability is caused by Autodesk Revit. Figure 23 highlights the missing information of pad foundation in plan view and 3-dimensional view.

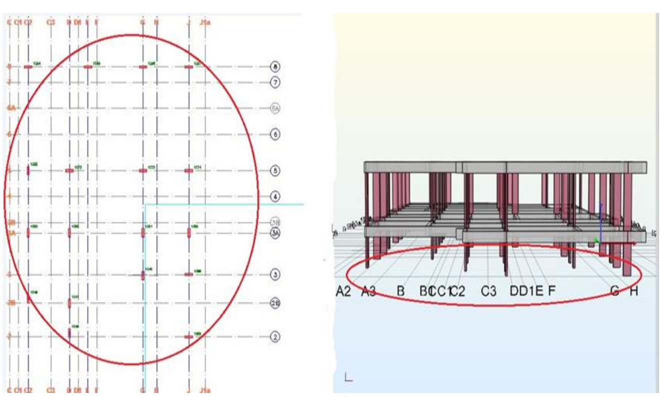

Figure 23. Interoperability Issue for Pad Foundation in Stage 9.

V. Conclusion and Future Scope

A. Conclusion

Building information models plays a significant role in construction industry nowadays in order to get more efficient workflow without clashing of information between other industry stakeholders such as architects, engineers, contractors and owners. The strength lies within BIM is that being multifaceted data which rich with information database. In this aspect, Autodesk Revit performs a well role as a BIM host, that able to support its functions towards completing necessary features of BIM. Once a model in Revit has been made, it can serve various purposes through its family components.

Interoperability of building information models with structural engineering software programmes emerging area, and gaining attention in the building industry. However, most of the engineering consulting firms are reluctant to adopt BIM completely to their projects due to interoperability issues. Interoperability issues often leads to redundant work that needs more time and money to be spend in non-standard solutions that often increases project costs. Even though interoperability and information sharing leads to speed of project design and construction, misleading or lack of information due to interoperability issues often affects the quality of the project.

Given that BIM is a very powerful tool, its key strength lies within interoperability with other programmes. However, at the moment, there is a large gap in promise made by BIM proponents and what it actually being delivered. Until now, there is interoperability issues during the convey and delivery of information. The main role of BIM in acting as platform to exchange information is being staked.

In knowing that there were a lot of interoperability issues between structural engineering programmes and building information modelling programmes, there is little effort that has been taken to study and overcome the respective issues. The integration of structural engineering model into pre-built modelling is a step in this direction and the analysis of the study is extremely crucial in intention for all the structural engineers to adopt BIM completely. However, this is a very beginning step into the right direction as there may be further researches in future.

B. Recommendations

BIM software vendors are recommended to enable direct export and import of structural software model information to facilitate further research in the interoperability issues. During convey of information, software programmes requires 'plug-in' to enable the interoperability between software programmes. Data integrity during the conversion processes is a stake where 'plug-in' may interpret data wrongly that causes interoperability issues. Therefore, recommendation of direct export and import of structural software model information is highly recommended.

To speed up the transition of two-dimensional CAD to three-dimensional BIM, the industry should practice BIM as a mandatory requirement in projects. This further enhances the usage of BIM in industry which will cause the two-dimensional CAD to phase out slowly in industry practise. By practise this regulation, BIM will be a major dominant in industry compare to two-dimensional CAD.

Building Information Modelling vendor should further develop their software to interpret all the information from structural modelling. At present, there is no technology available for transferring information such as reinforcement detailing and masonry wall into BIM. This causes the user to edit the required details manually by adding them into library. This process is not efficient for BIM users because it consumes more time and skill which is not preferred commonly. Therefore, transferring all the necessary database from structural modelling is crucial to ensure the efficiency of BIM.

Apart from technical side, priority should be given to equipping the students and practitioners with BIM skills. In order to meet the short-term requirement, training centres such as Computer Aided Design (CAD) centres could collaborate with experienced BIM practitioners to offer short term BIM training courses for the draftsmen in industry to exposed with BIM. With such practise, the adoption of BIM into industry will be ensured as draftsmen will slow adopt the practise of BIM. Besides that, for long run institutions should include BIM as a mandatory curriculum of undergraduate and diploma programmes where appropriate to adoption of BIM. Students will easily adopt to practise of BIM as they have never exposed to CAD system compare to engineers in industry. With time, the industry will be equipped with practise of BIM that gives more benefits compare to CAD system.

C. Future Works

Interoperability issues between building information modelling and structural engineering software programmes is a vast area of study which can be diverted to many areas. These can include areas in BIM interoperability, interoperable 'plug-in' formats, testing procedures, testing model and testing components.

a) BIM Interoperability.

In future, the study of interoperability issues may use different pre-built modelling software programmes such as Graphisoft AchiCAD, Nemetschek AllPlan and more. Besides that, the study can also further be diversified by using other structural analysis programmes such as STAAD.Pro, PROKON, SCIA Engineer and more.

b) Interoperable 'plug-in' Formats.

A further study in the 'plug-in' is required to test the accuracy of 'plug-in' in interpreting data. This is to reduce the possible number of interoperability issues between structural engineering programmes and pre-built modelling programmes.

c) Testing Procedure.

A further study should be conducted using different method of approach in order to identify more interoperability issues. A different method of approach such as combining two different structural modelling into one project that represents large-scale project is one the example of approaching method.

d) Testing Components.

A further research of using more complex structural components is advised to identify interoperability issues further. Testing of structural components such as cantilever slabs, pre-stressed elements and more are welcomed.

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