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BIM IN STRUCTURAL ENGINEERING: A STUDY OF INTEROPERABILITY BETWEEN BIM AND FEM FOR IMPROVED STRUCTURAL ANALYSIS AND DESIGN – AN OVERVIEW

(PHASE I)

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ABSTRACT:

Building Information Modelling (BIM) has the potential to significantly improve productivity, coordination, visualization, documentation, and waste reduction in the field of structural engineering. However, achieving these benefits requires smooth data transfer from the BIM platform to structural analysis or Finite Element Modelling (FEM) software, which can be hindered by challenges in interoperability. This thesis aims to examine the possibilities of converting from the Tekla Structures BIM platform to commonly used FEM programs, including Staad.Pro, Etabs, SAP2000, SOFiSTiK, Dlubal (RFEM), SCIA (SCIA Engineer), and Robot (Autodesk), for improved structural analysis and design. The study includes two case studies, one in concrete structures and the other in steel structures, where load-bearing data is added to the central Tekla models to enable interoperability. We first review the use of BIM in structural engineering, including the impacts on structural design and workflow, key benefits, and challenges during use. We then define and theoretically research the three main levels of interoperability between BIM and FEM software: direct native file exchange, direct link or bi-directional data exchange, and IFC (Industry Foundation Class). Our case studies demonstrate the benefits of using BIM and FEM interoperability for improved structural analysis and design, including the early detection and correction of design errors, and improved collaboration between architects, engineers, and contractors. Overall, this thesis contributes to the field of structural engineering by providing practical guidance on the use of BIM and FEM interoperability for improved structural analysis and design.

KEYWORDS: Building Information Modelling, BIM, interoperability, Tekla Structures, FEM, structural analysis, Staad.Pro, Etabs, SAP2000, SOFiSTiK, Dlubal (RFEM), SCIA (SCIA Engineer), Robot (Autodesk), concrete structures, steel structures, productivity, coordination, visualization, documentation, waste reduction, early detection, design errors, collaboration, architects, engineers, contractors, Industry Foundation Class, IFC.

1. INTRODUCTION

Interoperability between Building Information Modeling (BIM) and Finite Element Method (FEM) software is becoming increasingly important in the architecture, engineering, and construction (AEC) industry. BIM software is used to create 3D models of building designs, while FEM software is used to simulate and analyze structural behavior and performance.

Interoperability refers to the ability of these software tools to exchange data and work together seamlessly. This can involve transferring 3D models between software tools, sharing data about materials and components, or using data from one tool to inform analysis and modeling in the other.

By improving interoperability between BIM and FEM software, designers and engineers can create more accurate models, simulate and analyze structural behavior more effectively, and reduce errors and rework in the design and construction process. This can ultimately result in more efficient, cost-effective, and sustainable building designs.

Key Points about Interoperability between BIM and FEM Software in Building Design and Construction:

1. BIM-FEM interoperability enables better collaboration and communication between different stakeholders in the building design and construction process. For example, architects, engineers, and contractors can work together more efficiently, sharing data and insights to improve the design and construction of the building.
2. BIM-FEM interoperability can help to identify potential design flaws and errors before construction begins. By simulating and analyzing the behavior of the building in a virtual environment, designers and engineers can detect issues early on and make necessary adjustments to the design to avoid costly rework during construction.
3. BIM-FEM interoperability is particularly important in the context of sustainable building design. By using FEM software to simulate and analyze the energy performance of a building, designers and engineers can optimize the design for energy efficiency and reduce the building's environmental impact.
4. BIM-FEM interoperability is not just limited to structural analysis and simulation. It can also be used for other types of analysis, such as lighting analysis, acoustics analysis, and fire safety analysis. This allows designers and engineers to create more comprehensive and accurate building designs that take into account a range of different factors.
5. BIM-FEM interoperability can also be used to improve the maintenance and management of buildings after construction. By using BIM models and FEM simulations, building owners and facility managers can monitor the performance of the building over time and identify potential issues before they become major problems.

2. SCOPE OF THIS THESIS

This thesis aims to explore the possibilities of converting from the Revit and Tekla Structures BIM platform to commonly used FEM programs, such as Staad.Pro, Etabs, SAP2000, SOFiSTiK, Dlubal (RFEM), SCIA (SCIA Engineer), and Robot (Autodesk), for improved structural analysis and design. In order to achieve the benefits of Building Information Modelling (BIM) in structural engineering, it is important to have smooth data transfer from the BIM platform to structural analysis or Finite Element Modelling (FEM) software. This can be hindered by challenges in interoperability between the different software tools. The study includes two case studies, one in concrete structures and the other in steel structures, where load-bearing data is added to the central Tekla models to enable interoperability. The research begins with a review of the use of BIM in structural engineering, including the impacts on structural design and workflow, key benefits, and challenges during use. The three main levels of interoperability between BIM and FEM software are then defined and theoretically researched: direct native file exchange, direct link or bi-directional data exchange, and IFC (Industry Foundation Class). The case studies demonstrate the benefits of using BIM and FEM interoperability for improved structural analysis and design, including the early detection and correction of design errors, and improved collaboration between architects, engineers, and contractors. Overall, this thesis provides practical guidance on the use of BIM and FEM interoperability for improved structural analysis and design, contributing to the field of structural engineering.

3. EVOLUTION OF CAD - BIM – FEM

1. The evolution of Computer-Aided Design (CAD) to Building Information Modelling (BIM) to Finite Element Modelling (FEM) has transformed the way construction projects are designed, planned, and executed. CAD software enabled designers to create two-dimensional drawings on a computer, allowing for more precise and efficient drafting than traditional manual methods. However, CAD had limitations in terms of collaboration and data management.
2. BIM emerged as a more advanced form of CAD, incorporating three-dimensional modelling and a comprehensive database of project information. BIM software enabled designers, architects, engineers, and contractors to collaborate more effectively, share information in real-time, and manage complex projects more efficiently. BIM also allowed for the simulation and analysis of various aspects of a building project, such as energy efficiency and structural integrity.
3. The integration of BIM and FEM software has enabled even more advanced analysis and simulation of building designs. FEM software uses complex mathematical models to simulate the behaviour of structures under different conditions, such as stress and load. By combining BIM and FEM software, it is possible to optimize building designs for a range of factors, such as structural performance, energy efficiency, and occupant comfort.
4. Overall, the evolution of CAD to BIM to FEM has led to a more streamlined and efficient building design and construction process, with greater collaboration and communication between project stakeholders. As technology continues to evolve, it is likely that these software tools will continue to advance, enabling even greater levels of precision, efficiency, and innovation in the construction industry.

4. CONNECTION BETWEEN CAD, BIM AND FEM

1. The connection between Computer-Aided Design (CAD), Building Information Modelling (BIM), and Finite Element Modelling (FEM) lies in their shared goal of improving the design and construction process of building projects. CAD software allowed designers to create two-dimensional drawings on a computer, which was a significant advancement over traditional manual methods. However, CAD had limitations in terms of collaboration and data management.
2. BIM emerged as an evolution of CAD, incorporating three-dimensional modelling and a comprehensive database of project information. BIM software enabled designers, architects, engineers, and contractors to collaborate more effectively, share information in real-time, and manage complex projects more efficiently. BIM also allowed for the simulation and analysis of various aspects of a building project, such as energy efficiency and structural integrity.
3. The integration of BIM and FEM software takes this collaboration and analysis even further, enabling more advanced simulation and analysis of building designs. FEM software uses complex mathematical models to simulate the behaviour of structures under different conditions, such as stress and load. By combining BIM and FEM software, it is possible to optimize building designs for a range of factors, such as structural performance, energy efficiency, and occupant comfort.
4. In summary, CAD, BIM, and FEM are interconnected through their shared goal of improving the design and construction process of building projects. CAD was the first step towards digital design, BIM evolved the process by adding data and

collaboration, and FEM allows for advanced simulation and analysis to optimize building designs.

5. METHODOLOGY

An extensive literature review was conducted to understand the theories, concepts and main arguments of the thesis subject, followed by a detailed study of the interoperability from data exchange perspectives. The method employed to arrive at the conclusions of this thesis is based on a data analysis experiment. Tekla structures was used as a central platform for all BIM data. The Tekla structures BIM model was exchanged (see Figure 1) with FEM software to examine and describe what happens to structural parameters in the data exchange process. The model are reinforced concrete structure and Steel structures, and the tests are based on direct link interoperability level.

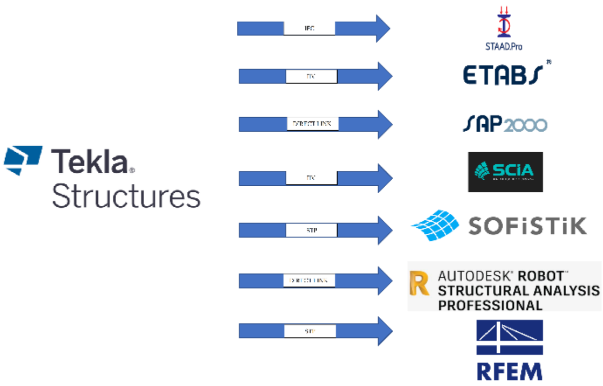

Figure 1: Exchange scenarios implemented in the case studies: Tekla structures vs. FEM software

The transfer scenarios investigated and assigned score marks. The highest scores achieved much more data transfer efficacy than the lowest. A comparison of internal forces is presented, further demonstrating the fidelity of data transfer from Tekla structures to FEM programs.

6. BIM OVERVIEW

BIM stands for Building Information Modelling, which is a process for creating and managing digital information about a building or infrastructure project. BIM is used in the architecture, engineering, and construction (AEC) industries to improve project efficiency, reduce errors, and facilitate collaboration among different stakeholders. BIM involves creating a virtual model of a building or infrastructure project that includes all relevant information about the project, such as geometry, materials, specifications, and schedules. This model is used throughout the project lifecycle, from design and construction to operation and maintenance. BIM software allows users to visualize the building or infrastructure project in 3D, as well as simulate various aspects of the project, such as lighting, acoustics, and energy consumption. BIM also facilitates collaboration among different stakeholders, such as architects, engineers, contractors, and owners, who can work together in a common digital environment to share information and make decisions. BIM is becoming increasingly important in the AEC industry, as it can help reduce costs and improve project outcomes. It is also being used to develop smart buildings and infrastructure, which can optimize energy efficiency, reduce waste, and improve occupant comfort and safety.

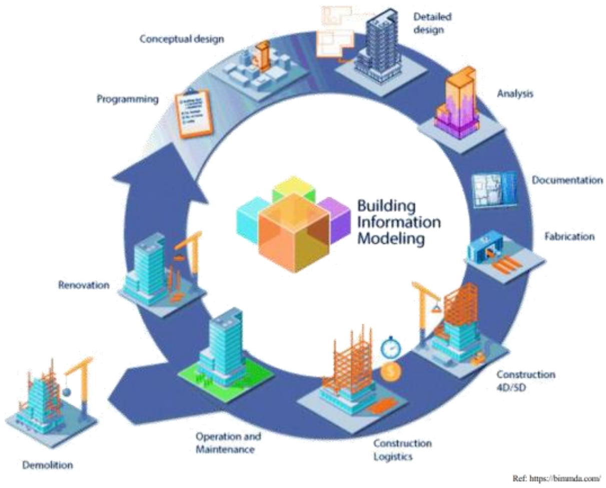

Figure 2: BIM defined graphically

The 3D modelling approach gradually being adopted in structural design companies improves decision supports and coordination. In most developing countries, where the construction industry is seen as one of the major sources of graft and theft, the application of the real-time 3D modelling approach has the potential to improve planning processes and communications. This promises a significant contribution to the fight against waste, corruption, and abuse of meagre public resources.

The building lifecycle has three major phases: design, construction, and Management. Outlined below is how BIM provides critical information to each phase in the building lifecycle

1. Design phase - provides data on analysis and design model, project schedule, and cost.
2. Construction phase - provides data on construction sequence/schedules, cost, and quality.
3. Management phase -provides data on facility management, utilities, finance, performance, and utilization.

7. BIM Maturity Level

BIM Maturity Levels, also known as BIM Levels of Development (LOD), are a way of measuring the extent to which BIM is used in a particular project. There are generally four levels of BIM maturity, each with increasing levels of detail and accuracy:

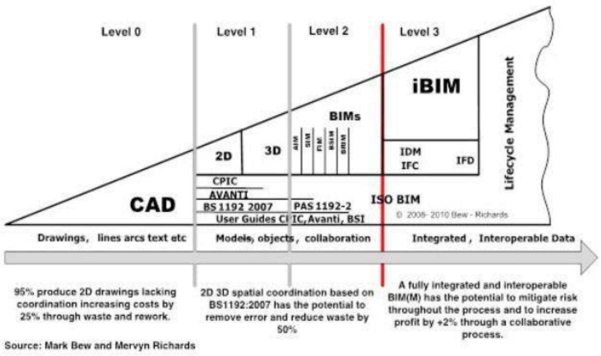

Figure 3: BIM Maturity mode

1. Level 0: This is the lowest level of BIM maturity, where there is no use of BIM. Drawings and specifications are created in 2D format, with no digital model or data available.
2. Level 1: At this level, 3D models are created, but the data included is limited. The models are often used for visualization purposes and are not yet used for construction documentation.
3. Level 2: This level is where BIM really begins to make an impact. The 3D model becomes the focus of the project, and it is used for both design and construction documentation. The model contains a higher level of detail, and information is shared between project teams using a common data environment (CDE).
4. Level 3: This is the highest level of BIM maturity, where the model is used for the entire lifecycle of the project, from design and construction to operation and maintenance. The model is highly detailed, and data is shared in real-time between all project stakeholders using a cloud-based platform.

Each BIM maturity level has its own benefits and challenges, and the level used in a particular project will depend on factors such as project complexity, client requirements, and team capabilities. However, moving towards higher levels of BIM maturity can lead to improved project outcomes, including increased efficiency, reduced risk, and better collaboration.

8. Level of Development in BIM

Level of Development (LOD) in BIM refers to the degree of completeness or accuracy of a BIM element at a specific stage of a project. LOD is a measure of how much information has been incorporated into the digital model and how reliable that information is. The higher the LOD, the more detailed and accurate the digital model is.

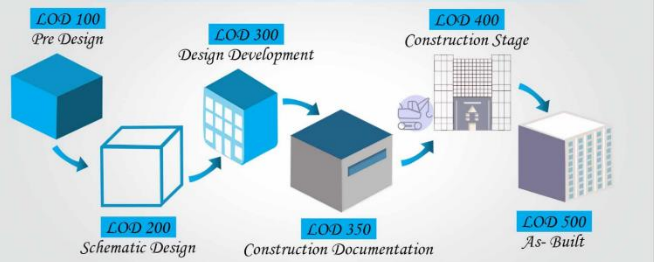

Figure 4: Level of Development

There are typically five levels of development in BIM:

1. LOD 100: Conceptual Model: This is the most basic level of development where a BIM element is represented by a simple geometric shape or a placeholder, and is used to convey the basic concept or location of the element.
2. LOD 200: Schematic Design: At this level, the BIM element is represented by a more accurate geometric shape and basic properties, including size, shape, orientation, and location, are defined.
3. LOD 300: Detailed Design: In this level, the BIM element is fully defined in terms of its size, shape, and location, and additional details such as material type, connections, and performance data are added.
4. LOD 400: Fabrication & Assembly: At this level, the BIM element is detailed to the extent that it can be used for fabrication and assembly. Additional information such as specific product data and fabrication, installation, and assembly details are included.
5. LOD 500: As-Built: This level is reached when the construction of the element is complete, and the element has been installed and verified in the field. The BIM element reflects the actual conditions of the constructed element.

The selection of an appropriate LOD for a project depends on project requirements, available resources, and the stage of the project. A higher LOD requires more time and resources to develop but provides a more accurate and detailed model, which can reduce errors and rework during construction and operations.

9. BIM EXECUTION PLAN (BEP)

1. A BIM Execution Plan (BEP) is a document that outlines the processes, procedures, and requirements for creating and managing a BIM project. It is a critical component of any BIM project, as it provides a roadmap for how BIM will be implemented, managed, and used throughout the project lifecycle.
2. The BEP is typically created at the beginning of a BIM project, and it includes information about the project goals and objectives, the roles and responsibilities of team members, the BIM standards and protocols to be followed, the BIM software and hardware to be used, the level of detail required at different stages of the project, and the procedures for sharing and exchanging BIM data among team members.
3. The BEP helps ensure that all project team members have a clear understanding of the project requirements, responsibilities, and expectations related to BIM, which can help reduce errors, delays, and conflicts during the project. It also helps ensure that BIM data is consistent, accurate, and usable across all stages of the project.
4. The BEP should be reviewed and updated regularly to reflect changes in the project scope, requirements, or team composition. It should also be communicated to all project stakeholders to ensure that everyone is aligned and working towards the same goals.

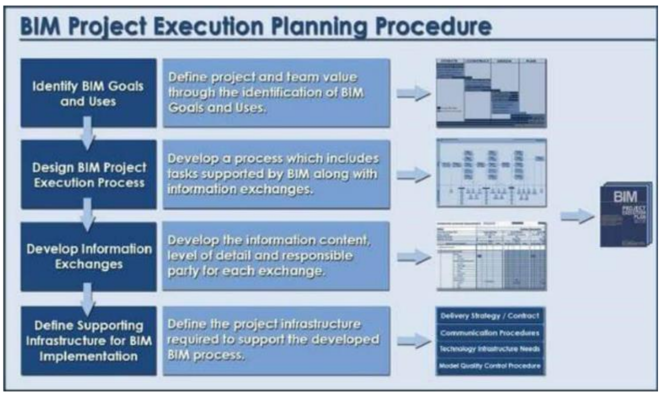

Figure 5: A template of BIM Project Execution Planning Procedure

10. FINITE ELEMENT MODEL (FEM) – OVERVIEW

A Finite Element Model (FEM) is a computer-based mathematical model used to simulate the behavior of complex engineering systems, structures or components. FEM models are created by dividing the structure into smaller, simpler parts called elements, and then solving a set of mathematical equations to determine the behavior of each element. The results of these equations are then combined to predict the overall behavior of the structure under various loading and environmental conditions.

The FEM modeling process involves several steps, including:

1. Pre-processing: This involves creating a 3D model of the structure or component, defining the material properties and boundary conditions, and dividing the model into smaller elements.
2. Analysis: This involves solving a set of mathematical equations to determine the behavior of each element under various loading and environmental conditions.
3. Post-processing: This involves visualizing and interpreting the results of the analysis, such as stress and strain distributions, deformation, and displacement.

FEM models can be used to analyze a wide range of engineering problems, including static and dynamic structural analysis, thermal analysis, fluid dynamics, and electromagnetic analysis. FEM modeling is particularly useful for solving problems that cannot be solved analytically or through experimental methods.

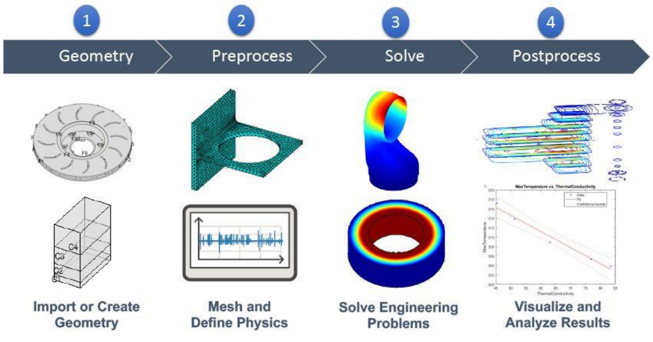

Figure 6: Workflow of Finite Element Model (FEM)

Most structural engineering software is based on the principles of the Finite Element Method or FEM. As a user of these software tools, it is very fundamental to understand the underlining principles, mathematics, and mechanics behind the governing equations and how internal forces are computed. Hence, without a deeper understanding of the basic principles behind the computational method of these analysis tools, a critical assessment of computed results is not possible, which might otherwise lead to an unreliable and unsafe design.

In static analysis, the force method, reduction method, and displacement method are the three methods widely employed by structural engineers to investigate internal forces, moments and assess the deformation capacity of structures. FEM software often uses the displacement or deformation method due to its effective computational power in modern computer programs. By utilizing numerical approximation technique, the FEM performance the calculation as follows:

1. Mesh or divide a structure member into several finite elements.

2. Compute stiffness matrix for each element.

3. The loads acting on each finite element is transformed into nodal loads or load vector.

4. Summation of the element stiffness matrix

5. The loads at each node are summed to form a vector of total load for the entire system

6. Support and restraint conditions are then considered in both the total stiffness matrix and total load vector

7. The displacement vectors and internal forces at each node are then determined based on the results of previous steps

When the analytical model is properly cross-checked and ready in Tekla structures, it is then exported to a FEM software connected to Tekla structures for analysis and design purposes.

11. COORDINATION AND CONSISTENCY OF DATA

BIM adoption in the industry is encouraged by several key factors, with coordination being one of the most important ones. Coordination helps project team members, such as architects, cost estimators, structural and MEP engineers, to share project data by utilizing a single prototype model that includes all aspects of the building. This allows project stakeholders to effectively coordinate and make reliable design decisions, facilitated by accurate 3D geometries and data.

Coordination provides a range of benefits in BIM, especially during conception design, where it enables the project team to examine alternative design solutions, review costs, and explore optimized solutions. Additionally, it is helpful when communicating the intent of the structural engineers to the fabrication and construction team. In a BIM environment, lack of coordination renders BIM adoption irrelevant.

The mainstream BIM platforms, such as Bentley, Revit, and Tekla, have improved their platforms to handle project modeling, coordination, and documentation of results obtained through FEM analysis programs. Figure 7 illustrates the data exchange challenges and coordination issues between a structural engineer and an architect in the absence of a robust digital model workflow, while Figure 8 demonstrates how a structural BIM workflow is optimized by reducing cumbersome repetitions and enabling smooth flow of information.

Such seamless exchange of data is achieved through the concept of interoperability, which is one of the main topics of this thesis. Therefore, coordination plays a crucial role in BIM adoption, enabling the project team to collaborate efficiently and effectively, resulting in better design decisions and optimized solutions.

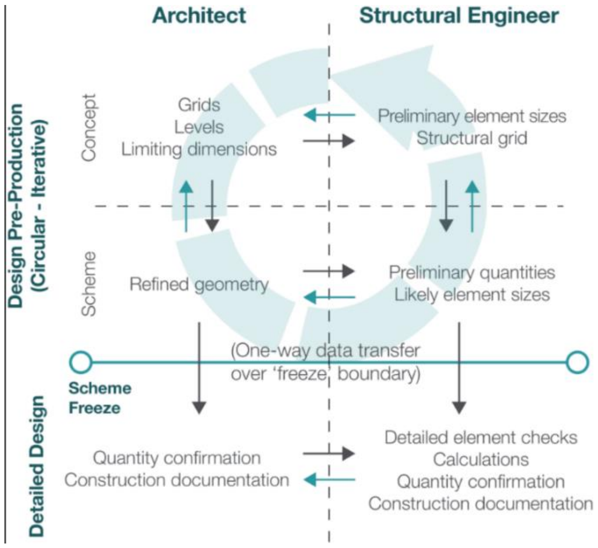

Figure 7: Example of a workflow between a Structural engineer and an architect without a robust workflow

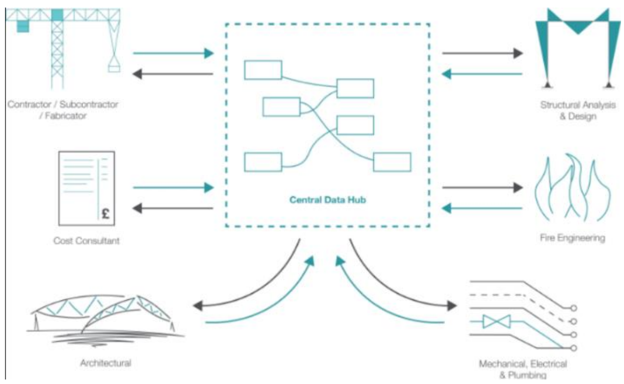

Figure 8: Example of a robust data enabled in a multi-disciplinary project team

12. INTEROPERABILITY

BIM's potential benefits are achieved only if appropriate data transfer mechanism between platforms and tools are put in place. The process ensuring that this takes place is called interoperability. Interoperability, as the central theme of this thesis, is examined in detail. In this chapter, a detailed discussion on the three levels of interoperability in BIM structural engineering is presented; the level mostly applicable in structural engineering explained. These interoperability levels are direct native file exchange (exchange between the same commercial software providers), direct link or bi-directional data exchange, and IFC (Industry Foundation Class). Factors contributing to data exchange in structural BIM workflow is provided, and some benefits and challenges of interoperability discussed. Figure 9 graphically defined interoperability, where one system exchanged data with another system and then re-use the exchanged information. Figure 10 illustrates how interoperability supports robust multi-disciplinary by reducing cumbersome repetitions and enabling integration and seamless flow of information.

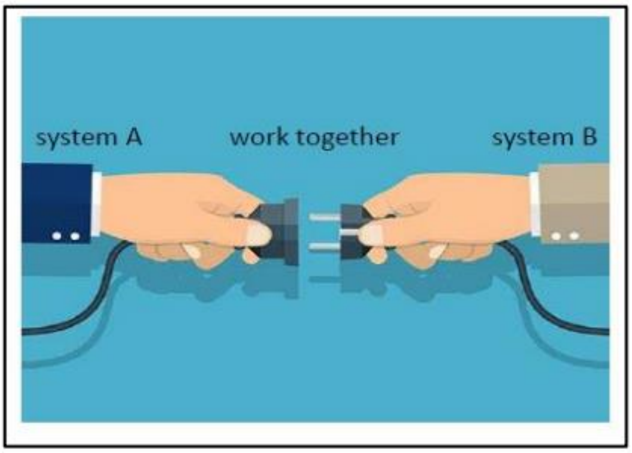

Figure 9: A Graphical representation of Interoperability

Due to the high necessity for interoperability in engineering practice in recent times, many structural engineering software solution providers are directing their research in developing strong interoperability links with BIM platforms. Figure 10 illustrates the current existing level of interoperability between some analysis and design software and BIM platforms, where BIM platforms (Tekla Structures, Bentley Structures, and Autodesk Revit Structure) exchange model information with analysis software (in light grey colours) and vice versa.

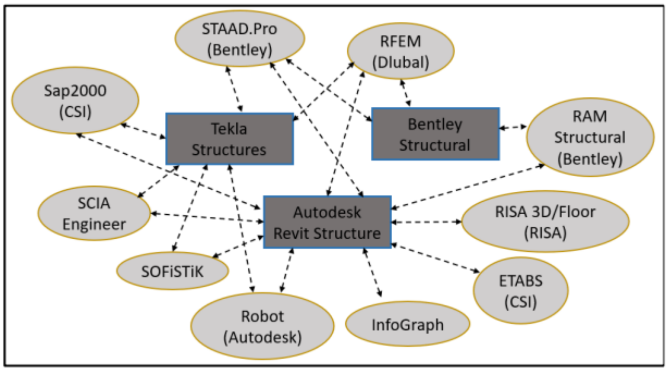

Figure 10: Some currently available interoperability between BIM platforms and analysis and design software

13. TYPES/LEVEL OF INTEROPERABILITY IN BIM STRUCTURAL ENGINEERING

Interoperability between software tools is achieved through several means or level. In this section, a detailed discussion aimed at answering one of the key questions of this thesis—the Interoperability of data in BIM structural engineering (domain-specific) is presented. The three levels that are most common in structural engineering practice are elaborated. These interoperability levels are direct native file exchange, direct link data exchange, and IFC. These levels address how data exchange scenarios between mainstream BIM platforms and FEM tools are made possible.

Interoperability between BIM and FEM can be achieved in several ways:

Direct Native File Exchange

1. Direct Native File Exchange is a method of interoperability between different software packages where the software packages use the same file format to exchange data directly. This method is often used when both the software packages involved in the data exchange support a common file format.
2. For example, if a BIM software package uses the .ifc file format to represent a 3D model of a building, and an FEM software package also supports the .ifc file format, then data can be exchanged between the two packages directly without the need for file conversion or data translation.

3. This method has the advantage of preserving data fidelity, as there is no need to convert data to a different format, which can result in data loss or corruption. Direct Native File Exchange also saves time and eliminates the need for manual data transfer or import/export processes.
4. However, one disadvantage of this method is that it requires both software packages to support the same file format. If the software packages do not support the same file format, then other methods of interoperability, such as direct link data exchange or IFC, may need to be used.

Direct Link Data Exchange

1. Direct Link Data Exchange is a method of interoperability between different software packages where the software packages are linked through an API (Application Programming Interface) or a plugin. This method allows data to be exchanged directly between the two software packages without the need for file conversion or data translation.
2. For example, if a BIM software package and an FEM software package are linked through an API or a plugin, the 3D model data can be exchanged directly between the two packages without the need to save the data to a file first. This method has the advantage of being faster and more efficient than other methods of interoperability, such as file conversion or manual data transfer.
3. Another advantage of Direct Link Data Exchange is that it allows the two software packages to work together seamlessly, with changes made in one software package being reflected in the other package in real-time. This can save time and reduce errors in the design and analysis process.
4. However, one disadvantage of this method is that it requires the software packages to have a compatible API or plugin, which may not be available for all software packages. Additionally, changes made in one software package may not be compatible with the other software package, resulting in errors or data loss. Therefore, careful attention must be paid to data compatibility and version control when using Direct Link Data Exchange.

IFC (Industry Foundation Classes)

1. IFC (Industry Foundation Classes) is a file format developed specifically for the exchange of building information modeling (BIM) data between different software packages. IFC is an open and neutral file format, which means it is not owned by any particular software vendor, and it can be used by any software package that supports it.
2. IFC is designed to represent a complete and accurate description of a building or structure, including its geometry, spatial relationships, properties, and other relevant information. IFC files can contain information about different elements of a building, such as walls, floors, doors, windows, and other objects.
3. One of the advantages of IFC is that it provides a high level of interoperability between different software packages, allowing users to exchange data between different software tools without the need for file conversion or data translation. IFC can be used to exchange data between BIM software packages, as well as with other software packages, such as FEM software, energy analysis software, and cost estimating software.
4. Another advantage of IFC is that it supports the exchange of data at different levels of detail (LOD), ranging from conceptual design to detailed construction documentation. This allows users to exchange data at different stages of the building design and construction process, and to collaborate more effectively across different disciplines and software packages.
5. However, one disadvantage of IFC is that it can be complex to use and require a higher level of expertise compared to other methods of interoperability. Additionally, some software packages may not support the full range of IFC data or may interpret IFC data differently, which can lead to data loss or inconsistencies. Therefore, careful attention must be paid to data compatibility and version control when using IFC.

14. FEM SOFTWARES

1. Staad.Pro: Bentley Systems Structural Analysis and Design Program.
2. SAP2000: Structural Analysis Program 2000 by Computers and Structures, Inc.
3. SOFiSTiK: Structural engineering software by SOFiSTiK AG.
4. Dlubal (RFEM): Finite Element Analysis Software by Dlubal Software GmbH.
5. SCIA (SCIA Engineer): Structural engineering software by SCIA Group.
6. Robot (Autodesk): Robot Structural Analysis by Autodesk.
7. Etabs: Extended Three-dimensional Analysis of Building Systems by Computers and Structures, Inc.

These software programs which are commonly used for structural analysis and design, will be examined in phase 2 of the study for their interoperability with Tekla Structures BIM platform.

15. DATA TRANSFER METHODS

There are several methods to convert Tekla models to other structural analysis and design software, such as Staad.Pro, Etabs, SAP2000, SOFiSTiK, Dlubal (RFEM), SCIA (SCIA Engineer), and Robot (Autodesk). Some of these methods include:

1. Exporting to IFC format: Tekla Structures supports the Industry Foundation Classes (IFC) format, which is a standard data format used to exchange information between different BIM software applications. By exporting the Tekla model to IFC format, it can be imported into other software applications that support IFC, such as Etabs, SAP2000, and SCIA Engineer.
2. Direct interface: Some software applications, such as SOFiSTiK and Robot, have a direct interface with Tekla Structures, which allows the Tekla model to be directly imported into the software without the need for file conversion.
3. Exporting to compatible file formats: Tekla Structures can export models to several file formats, such as CIS/2, SDNF, and STP, which can be imported into other structural analysis and design software, such as Staad.Pro, Dlubal RFEM, and SCIA Engineer.
4. Third-party software: There are several third-party software applications available that can convert Tekla models to other software formats. For example, the Tekla to Robot Link is a software application that can be used to transfer models from Tekla Structures to Robot Structural Analysis Professional.

It is important to note that the accuracy of the converted model depends on several factors, including the compatibility of the software applications, the level of detail and complexity of the model, and the quality of the data exchange. Therefore, it is recommended to test and verify the accuracy of the converted model before using it for analysis and design purposes.

16. CONCLUSION

1. This journal aims to examine the possibilities of converting BIM data from Tekla Structures to commonly used FEM programs, for improved structural analysis and design. The study includes two case studies, one in concrete structures and the other in steel structures, where load-bearing data is added to the central Tekla models to enable interoperability.
2. In phase 1, the study reviewed the use of BIM in structural engineering, including its impacts on structural design and workflow, key benefits, and challenges during use. The three main levels of interoperability between BIM and FEM software were also defined and theoretically researched, including direct native file exchange, direct link or bi-directional data exchange, and IFC.
3. In phase 2, two case studies, one in concrete structures and the other in steel structures, where load-bearing data is added to the central Tekla models to enable interoperability. The case studies will demonstrate the benefits of using BIM and FEM interoperability for improved structural analysis and design, including the early detection and correction of design errors, and improved collaboration

between architects, engineers, and contractors. The thesis will conclude by providing practical guidance on the use of BIM and FEM interoperability for improved structural analysis and design, thus contributing to the field of structural engineering.

4. Overall, the journal provides valuable insights into the challenges and benefits of achieving interoperability between BIM and FEM software in the field of structural engineering. The case studies demonstrate the potential of using BIM and FEM interoperability for improved collaboration and early error detection, which can significantly enhance productivity, coordination, visualization, documentation, and waste reduction. The thesis also provides practical guidance on the use of different interoperability methods, thus contributing to the advancement of the field.

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