



Comparison of Data Integration Methods in BIM Tools for Structural Engineering: An Evaluation through Structural Analysis Tools

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Highlights

- This paper focuses on the bi-directional data exchange methods, IFC and API, within BIM technology.
- A case study is conducted to find a reliable data exchange method for structural engineering.
- The API is better than IFC; however, it isn't extremely smooth to enable bidirectional data flow.

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Abstract

Building Information Modelling (BIM) is a technology that allows data generated by different disciplines using different software to be shared and used in a digital environment. By promising bi-directional data integration between all stakeholders, BIM encourages interoperability in the industry. This study aims to assess the operability and reliability of bidirectional data exchange methods within BIM technology, specifically Industry Foundation Classes (IFC) and Application Programming Interface (API). The study tests these methods between the architecture and structural engineering disciplines using Autodesk Revit along with the structural software packages: ETABS, Robot Structural Analysis, SAP2000, and Tekla Structures. The results show that the IFC file extension causes data losses in information sharing between software, while the API method can provide reliable data integration between different tools. However, the API only works smoothly between the tools developed by the same company. Nevertheless, API may be a promising way to achieve the interoperability goal of BIM technology.

1. INTRODUCTION

Architectural design and structural analysis are two distinct yet interrelated domains within a construction project. Each field follows unique procedures and pursues specific objectives in the building design process. The architectural design focuses on determining the configurations of various architectural elements, including their dimensions and materials, while the structural analysis examines the structural and mechanical properties of building components, such as stress, strain, and stability [1]. Both architectural and structural design are crucial for the successful completion of a building's design [2].

Structural design encompasses several tasks, including defining the structure, conducting structural analyses, and creating drawings and technical documentation. To develop a comprehensive project involving multiple disciplines, a series of phases is undertaken by various technical teams, each employing different tools. The information needed for each stage is primarily derived from technical drawings, which often result in omissions and inaccuracies, leading to inconsistencies in the final product. Throughout these processes, it is crucial to have trust in the data exchanged between the different systems. To ensure this trust and facilitate seamless collaboration, a high level of interoperability is essential [3]. At this point, the Building Information Modelling (BIM) concept is promising to centralize and transfer all the information generated throughout the development of the project. BIM serves as a collaborative working platform that

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embodies the physical, analytical, digital, and functional characteristics of a building. It is a smart, object-oriented, and information-rich digital representation of the project, encompassing all necessary details [4]. The essence of BIM is enabling a database for all disciplines of the project to improve collaboration and communication [5]. Therefore, BIM has been embraced to address issues of fragmented workflow, insufficient communication, and ineffective coordination within the Architecture/Engineering/Construction (AEC) industry [6]. BIM provides synchronized data and interoperability of the project from the beginning of the design phase [7], and so, essential information for design, calculation, simulation, execution, operation, maintenance, renovation, and demolition has been automatically acquired. Thus, the crucial aspect is to possess building models that can be easily accessed, modified, and shared within a unified data environment [8]. According to the BIM's undertaking in the literature, importing and exporting data from one BIM software to another is trustworthily achieved [9]. There are different methods for sharing and transferring data contingent upon the extent of interoperability [10], such as Application Programming Interface (API) supplements [11] and Industry Foundation Classes (IFC) based data [12]. With all promises and advantages, the actual implementation of BIM interoperability is still a challenge [13].

This research examines the interoperability between architectural design and structural analysis. The aim is to investigate the BIM interoperability through data transfer processes among various software platforms using two types of pathways: (i) Application Programming Interface (API) or "immediate connection," which refers to the direct link between software programs from the same provider; and (ii) indirect connection Industry Foundation Classes (IFC), which involves transferring information through third-party software or methods/algorithms. The methodology of the research includes a simple case study involving an analysis of data exchange abilities between common architectural and structural software. The main building model in the case is created in Autodesk Revit. For the structural analysis part, ETABS 21, Autodesk Robot Structural Analysis Professional (RSA), SAP2000, and Tekla Structures tools are chosen as the main authorized tools.

2. INTEROPERABILITY FOR BI-DIRECTIONAL DATA EXCHANGE

In a standard construction project, multiple entities such as architects, engineers, clients, contractors, subcontractors, specialists, etc., are involved. Each stakeholder employs a range of software tools tailored to their specific needs, supporting large and complex projects. When collaborating with other users, ensuring seamless data exchange between these tools becomes a critical issue for interoperability. The direct one-on-one data format transitions between each participant are excessive and not necessary for the actual exchange of data. Moreover, with the growing complexity of projects, the conventional approach scarcely fulfills the escalating demand for sharing and exchanging data [14]. Achieving interoperability among these software packages is a significant challenge, but essential for ensuring seamless sharing of information models. This is where data-sharing techniques come into play, enabling the analysis of data that needs to be shared and determining the data-sharing requirements for improved collaboration. Seamless interoperability can help minimize delays and cost overruns by eliminating the need for re-modeling in construction projects [1]. At this point, BIM technology has been introduced based on the concept of creating, storing, and managing a large amount of information throughout the building life cycle in an integrated way [15].

The central concept of BIM is interoperability, which means that the data contained within the building model should be shared seamlessly and utilized effectively [16]. As per Sacks et al. [17], interoperability denotes the ability to effortlessly share and utilize information generated by various vendors and software within a team, free from any complications. This reduces the risk of errors, delays, and miscommunications, leading to more efficient and effective project delivery. Especially, in complex building projects, owing to multiple stakeholders, data sharing and exchange between different software tools is inevitable so a common data format is necessary for data interoperability [14]. Arayici and colleagues [18] highlighted the significance of interoperability in facilitating an integrated design approach. Effective collaboration, interaction, and information exchange among team members require interoperability through open standards. The use of open standards is crucial for facilitating a smooth interchange of information, irrespective of the nature of the data or the software employed. Laakso and Kiviniemi [19] emphasized that

interoperability relies on open data standards, enabling the development of universally compatible file formats usable across different applications.

Rammant [10] explains that there are different levels of interoperability depending on the data sharing and exchanging requirements. The basic level is the first level, where team members can export and import data from one software to another. This method requires manual intervention to ensure the data's correct coordinates, and it becomes impractical for complex projects due to the need to redo the import/export process for every revision. Moreover, each discipline employs different software applications, which further complicates the process. Rammant [10] also presented the second tier of interoperability, which encompasses an openly accessible standard format enabling users to retrieve all data. The Industry Foundation Classes (IFC) format is a widely accepted schema in the AEC industry at this level. Ultimately, as outlined by Rammant [10], the highest level involves establishing a direct connection between diverse software, linking two distinct application interfaces through the Application Programming Interface (API). Over recent years, the predominant facilitators of project data exchange have been the API [11] and the open format known as IFC [12].

2.1. The Industry Foundation Classes (IFC)

The Architecture, Engineering, Construction & Facility Management (AEC/FM) industry has a need for BIM interoperability, which has led to the development of Industry Foundation Classes (IFC). IFC is a neutral and open standard building data model created and maintained by buildingSMART to facilitate data sharing among all stakeholders throughout the entire lifecycle of a project [20]. In other words, it is an ISO-registered, open, and neutral data exchange standard for BIM [2]. The development of IFC can be traced back to 1994 when Autodesk formed a consortium, the International Alliance for Interoperability (IAI), to promote integrated application development. The IAI was later renamed buildingSMART to reflect its ultimate goal [17]. Sacks et al. [17] described the Industry Foundation Classes (IFC) as an object-oriented data representation schema used for exchanging data between various applications employed by different disciplines. According to buildingSMART International's (2023) data [21], the latest version of IFC is 4.3. ADD 2 specification, but this is under Final Draft International Standard (FDIS) Voting and expected to be published by the International Organization for Standardization (ISO) in early 2024. Therefore, IFC4 and IFC 2x3 versions are available for the exchange file format structure.

The Industry Foundation Classes have two main components: a data schema and an exchange file format structure. The data schema is described using two languages - EXPRESS data specification language and XML Schema definition language (XSD), with the former being the source and the latter being generated from it according to mapping rules defined in ISO 10303-28. To facilitate the exchange and sharing of data, two exchange file formats are specified: a clear text encoding of the exchange structure defined in ISO 10303-21 and Extensible Markup Language (XML) defined in the XML W3C Recommendation. Other exchange file formats may also be used as long as they comply with the data schemas. This IFC release includes both the data schemas (in EXPRESS and XML schema representations) and reference data, which includes definitions of property and quantity names, as well as formal and informative descriptions [21].

According to Khemlani [22], the IFC model covers a wide range of building information, including elements such as walls, columns, and doors, as well as schedule, construction cost, and organization, in the form of data objects throughout all phases of a building's lifecycle, from conceptual planning to occupation and operation. The IFC model is organized around building entities, which makes it an object-based data model. Unlike the conventional geometric data model based on computer-aided design (CAD), a data model provides information that can be shared and utilized for a variety of purposes such as analysis, documentation, visualization, and calculation.

Laakso and Kiviniemi [19] have identified four layers within the architectural IFC data model, which progress from the lowest to the highest. These layers are the resource layer, core layer, interoperability layer, and domain layer. The BIM utilizes the data model to depict geometric data, material properties, and interoperability. Positioned above other layers, the resource layer contains commonly used elements in the AEC industry, categorizing entities based on generic properties like geometry, material, cost, date, and

time. The core layer, the second layer, delineates entities in the upper layers and comprises two schemas: the kernel and extension. The kernel imparts fundamental concepts about elements, relationships, procedures, attributes, and actors, while the extension encompasses control, product, and process extensions. The interoperability layer, the third layer, furnishes a shared platform for the upper domain layer to seamlessly exchange data. Finally, the domain layer, the highest layer in the IFC structure, is tailored to specific AEC domains such as architecture, structural engineering, HVAC, construction management, and others, according to Laakso and Kiviniemi [19]. Official model view definitions (MVDs) are released by buildingSMART International [21] as related specifications. These MVDs are designed to work with IFC 4.3.0 and currently have three levels of implementation: Reference View, Alignment Based Reference View, and Design Transfer view. These levels can be thought of as incremental stages that progressively add more advanced features to the implementations. The data schema architecture of IFC is structured into four conceptual layers, and each schema is allocated to one of these layers.

The IFC model, a versatile compilation of building model data, plays a vital role in facilitating bidirectional data interchange across diverse software platforms. This model incorporates a broad spectrum of entities about building elements (such as windows, doors, and slabs) and business tasks (like construction schedules, costs, and organizational aspects). The organization of objects in the IFC schema is structured according to their relationships, and the IFC "framework model" encompasses various elements like object types, classifications, attributes, materials, geometry, and properties to represent the building model comprehensively. All physical elements are nested within the IFC structure using different entities [19]. The IFC platform encompasses data related to architectural, structural, mechanical, electrical, and plumbing aspects. As a result, the IFC model incorporates multiple dictionaries to facilitate data interpretation. Consequently, when transferring data via an IFC file, the exchanged information needs to be understood in terms of its data category. Subsequently, the model can be converted into compatible data using relevant dictionaries [16].

2.2. Application Programming Interface (API)

Application programming interface (API) is a set of subroutine definitions, protocols, and tools for building application software [2]. In BIM technology API is a file transfer method also known as a direct link or direct native link. This link automatically establishes a connection between two different applications. The link operates in both directions, ensuring the seamless exchange of data without loss, as stated by Fleming [23]. As outlined by Sacks et al. [19], direct connections relying on programming-level interfaces represent the oldest but enduringly vital method for data transfer. These interfaces empower software to construct models and perform actions such as exporting, checking, or deleting data. Application interfaces, on the other hand, facilitate the import and adjustment of data to acquire information from other applications. The establishment of direct links occurs between a minimum of two distinct software programs, aiming to streamline data exchange as companies strive for a compatible interface and enhanced support for data export and import. According to Yousefzadeh et al. [24], direct links are delineated as extensions or additions designed exclusively for a specific software program, in contrast to IFC files which can be used across multiple software programs. Consequently, data interchange through direct links is characterized by superior quality, yielding more satisfactory final results compared to other file transfer methods. Rammant [10] illustrated that the API has the capability to connect Revit Structure software with Computer-Aided Engineering (CAE) software, enabling the seamless transfer of intelligent models to ETABS, RSA, and Scia Engineer, eliminating the necessity for redundant data entry.

To enhance the functionality of BIM platforms, developers create plug-ins that allow the integration of different external applications. Plug-ins play a crucial role in improving the design stage by increasing productivity, performing calculations, running analysis, and enhancing interoperability. In particular, the development of plug-ins is essential for creating reliable solutions for simulations, and the BIM community needs to collaborate to develop these plug-ins. Developing bi-directional plug-ins with the Revit API and framework is crucial for streamlining the design process and mitigating data loss during cross-platform interactions. This approach promotes interoperability through files, as exemplified by the CSiXRevit plug-ins within Revit, facilitating seamless data exchange between Revit and ETABS/SAP2000 [11, 17]. In

conclusion, the advancement of technology in achieving interoperability enhances the maturity of BIM, leading to the optimization of projects, better building performance, and increased focus on sustainability.

API is utilized to create customized software extensions and add-ons that enhance the functionality of BIM methods. As noted by Yousefzadeh et al. [24], the use of API extensions enables the exchange of high-quality data, contributing to a successful and integrated project lifecycle. However, it is important to recognize that direct links are specific to particular target applications, meaning that a developed direct link is designed to operate exclusively with specific software platforms and their corresponding versions. Consequently, extensions serve as limited transitional pathways between specified programs. Software production firms and their partners develop API-based extensions and plug-ins to facilitate information exchange between target applications such as Revit and its designated application [20]. Plug-ins are utilized primarily to streamline the construction process, enhance interoperability, and boost productivity. They enable team members from different disciplines to perform calculations and execute commands within building tasks. BIM users actively encourage the development of plug-ins as they facilitate the sharing of project data, improving synchronization with external applications. Additionally, plug-ins are leveraged in various areas such as cost estimation, project scheduling, energy efficiency, sustainability analysis, and the utilization of diverse computational tools [11]. According to Ignatova, Zotkin, and Zotkina [25], utilizing the API permits internal analysis by extracting data directly from native building information models. This ensures that the results of the analysis stay within the primary building model. Subsequent sections will assess the effectiveness of this method between Revit and different structural analysis tools.

3. CRITICAL REVIEW OF THE LITERATURE

BIM has transformed the construction industry and is increasingly becoming a focal point of discussion in Engineering, Architecture, and Construction firms due to the advantages it offers when implemented [26]. BIM brings various benefits to the industry, such as linking design to detailing, reducing errors, enhancing collaboration, and enhancing structural quality. Construction projects, whether medium or large-scale, involve multiple structural consultants who utilize various structural analysis applications. These technologies and applications suffer from insufficient interoperability, and there remains a lack of research addressing interoperability issues within the field of structural engineering [2].

Despite advancements in the data exchange methods of BIM technology, the literature consistently points to significant challenges in achieving seamless data transfer and interoperability. One major issue is the lack of standardization in data exchange formats, which leads to inconsistencies and loss of information during transfers [27]. Furthermore, the integration of different software platforms often requires extensive manual intervention, which is time-consuming and prone to human error [28], the developments in open data standards such as IFC, practical challenges are due to varying interpretations of these standards by different software platforms, leading to data loss and inconsistencies [27]. The use of APIs and direct links between software from the same provider offers promising solutions for seamless data exchange; however, they are often hindered by the complexity of implementation and the need for extensive customization [29]. Indirect links through third-party tools, while providing broader compatibility, frequently result in data fragmentation and increased error risks [30]. These challenges highlight a critical gap in the standardization and robustness of data exchange formats within the BIM. Furthermore, the disparity in data handling across different BIM tools exacerbates these issues, necessitating manual interventions that are both time-consuming and prone to human error [28]. Addressing these interoperability and data transfer problems is essential for harnessing the full potential of BIM technology in the architecture, engineering, and construction (AEC) industry. For these reasons, this research's case study is selected simply with 3 bays in both directions, including basic structural elements such as concrete columns, beams, shear walls, and slabs. The bi-directional data transfer methods among various software, Revit and RSA, ETABS21, SAP2000, and Tekla Structure, were checked on this simple model.

4. MATERIAL AND METHOD

In this study, the effectiveness and reliability of two data transfer approaches, API and IFC, were evaluated using a simple case study with various BIM tools. A building model was created in Autodesk Revit 2023

and transferred to four different structural analysis tools, ETABS, RSA, SAP2000, and Tekla Structures to assess the validity of these data transfer methods. The goal of the case study was to explore how BIM models from architectural designs can be utilized in structural analysis tools and to determine if the analysis results can be accurately transferred back to the main building model. This bi-directional data transfer was tested using both API and IFC methods to evaluate their effectiveness in preserving data integrity.

Revit was chosen as the authoring tool due to its widely used and its ability to support various data exchange methods, as well as its compatibility with various BIM applications. Revit is extensively employed in information modeling technology due to its provision of functional templates for diverse disciplines and its ability to streamline data interchange among various applications within the BIM framework [25]. Revit offers a comprehensive suite of software applications tailored for the construction industry. Its capabilities include everything from creating 3D animations with an emphasis on visual effects to handling simple CAD drawings. Revit products are specifically designed for BIM projects and play a significant role in the planning stages of construction projects [2]. Revit consists of Revit Structural, Architecture and MEP templates. The key feature that makes Revit Structure easy and flexible to use is also what makes it essential. Autodesk Revit is well-suited for structural design in 3D and supports interoperability. The Revit Structure software combines a physical model made of various materials with a separate analytical model, which can be modified and utilized for efficient structural analysis, design, and description [31].

Robot Structural Analysis Professional is specialized software for analyzing structural loads. Revit and RSA tools are software products developed by the same company, Autodesk. It ensures compliance with building codes and facilitates data exchange with Revit through integrated BIM workflows. Utilizing this software allows for the creation of designs that exhibit resilience and constructability, while also delivering precision, effective coordination, and seamless integration within the BIM environment [32].

ETABS and SAP2000 are software for structural and earthquake engineering developed by Computer & Structures, Inc. (CSI). ETABS and SAP2000 are a widely used industry software for finite element analysis. It offers various capabilities including structure modeling, analysis, design processes, and reporting outputs. With the aim of enhancing productivity in the industry, ETABS and SAP2000 have been positioned as an integrated software package, providing improvements in data exchange with Revit [33].

Tekla Structures is a powerful structural BIM software developed by Trimble. Tekla Structures is a specialized structural engineering software designed for construction industry professionals, especially structural engineers. This software allows users to create information-rich 3D Building Information Modeling (BIM) models, allowing them to design and model structures of varying sizes and complexity. Tekla Structures excels at handling materials such as steel, concrete, brick, timber, aluminum, insulation, and composite structures with exceptional precision and detail [34].

4.1. Aim and Objectives

The main purpose of the study is to examine the availability of exchange methods for bidirectional data exchange. The objectives of the research are (i) to evaluate the shortcomings and capabilities of distinct transfer strategies: API and IFC, (ii) to test and compare data exchange methods for various structural analysis software, and (iii) to assess the level of interoperability. In light of the objectives, four different structural software packages RSA, ETABS, SAP2000, and Tekla Structures are utilized.

As part of the methodology, a building model developed in Autodesk Revit was exported to BIM-compatible structural analysis software. To ensure the accuracy and completeness of data transfer, the imported models were thoroughly examined for any loss of information. This included the verification of structural grids, axes, columns, beams, slabs, their connections, geometrical configurations, cross-sectional and material properties, and dead loads. Upon confirming the integrity of the transferred data, dead load analyses were conducted to complete the process. The results were then integrated back into the original Revit model to facilitate coordinated information sharing among all project stakeholders. The overall workflow of the study is illustrated in Figure 1.

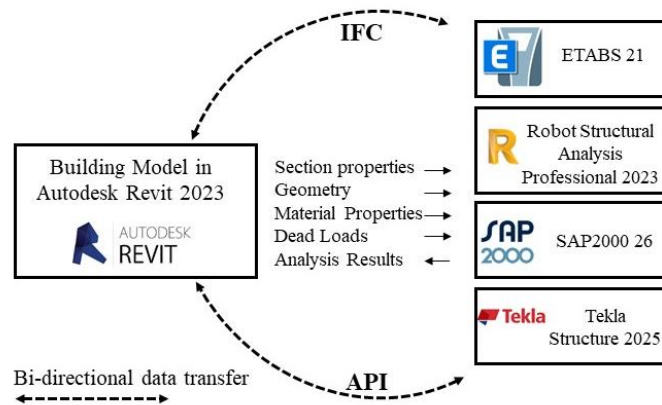


Figure 1. Research process to examine IFC and API methods for bi-directional data exchange among Revit and various structural analysis tools

4.2. Case Study

The concept of BIM allows for the creation of intelligent objects in a building model. These objects contain more than just geometric information like size, volume, and orientation. They encompass non-geometric factors like material, cost, manufacturer, and specification. In an object-oriented model, each element's physical and functional attributes, material properties, and design parameters are precisely outlined. It is imperative to ensure the accurate exchange of all attributes for each element between software systems. Annotation elements like grids and levels are also part of the building model, and it's important to export and import them into target applications as well.

To test the proposed flow work, a case study is performed. The building model utilized is a symmetrical, small office building designed for this research. It has an eight-story with a 4-meter story height and no basement. The building has three bays in each direction and reinforced concrete frame elements in the perimeter, along with shear walls in the core. The case study is a concrete building, with dead loads that are uniformly distributed on the beams. The major structural components include the external columns, beams, shear walls in the core of the buildings [35]. The physical and analytical models developed using the Revit 2023 Structural Template are seen in Figure 2. Only structural elements; columns, beams, slabs, and shear walls are included in this study. Interior walls and other building elements are excluded. Utilizing this template enables the automatic generation of an analytical model that mirrors the physical model. This analytical model simplifies data interchange with other structural analysis tools, allowing for the verification of connections among all Revit elements and nodes before deploying the model in various analysis platforms. Furthermore, the analytical model is adaptable, permitting manual adjustments and edits by overseeing nodes that connect frame and panel elements [33,36].

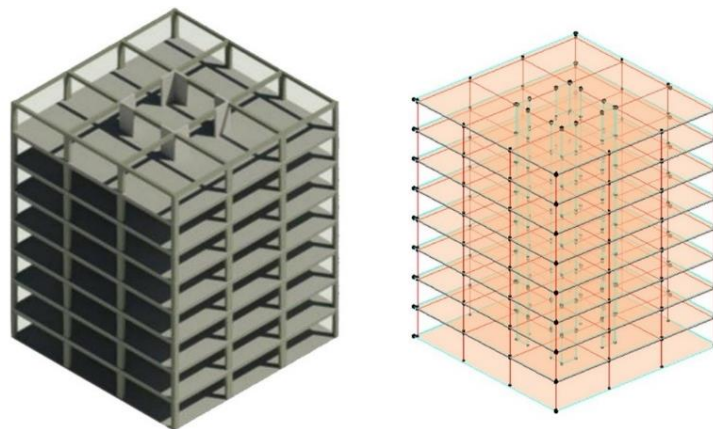


Figure 2. Physical (architectural) and Analytical (structural) models produced in Revit interface [35]

5. THE RESEARCH FINDINGS

In the exchange process between Revit and structural analysis software tools, two main data transfer paths are compared. In the exchange process between Revit and structural analysis software, two main data transfer paths are compared. The building model is first sent to structural analysis tools with an indirect link through IFC. Then, the same model is exported to structural analysis tools via a direct link API method. Afterward, the structural models in the analysis tools are checked in terms of the achievement of the transfer. If structural models are proper for the analysis, a dead load analysis was carried out with the self-weight of the elements. Lastly, the analysis results return to the main building model in Revit. The findings are illustrated in the following section.

During the data transfer process from Revit to structural analysis tools, building objects, their geometric representations such as size, width, height, orientation, volume, and shape, non-geometric attributes like material, cost, manufacturer, specification, and more should be reliably transferred. Additionally, the building model should include annotation elements like grids and levels, which need to be exported and imported into the intended applications.

5.1. Data Exchange with IFC File Format

In this section, the exchange of data between Autodesk Revit and structural analysis tools through the utilization of the IFC file format. The initial step involves exporting the analytical structural model from Revit to an IFC file model, utilizing the IFC 2x3 Coordination View 2.0 version, which represents the most current coordination view. The latest versions of IFC, IFC4x3, and IFC4 structural are also used throughout the trials. However, imported these files into structural analysis tools, many missing structural elements are observed in the analysis tools. Therefore, IFC 2x3 can be accepted as a better data exchange version among IFC versions. In Revit, specific IfcObjects (IfcColumns, IfcBeams, IfcWalls, and IfcSlabs) are selected for export, along with obtaining the quantity, dimensions, and material specification of each type. Then, the IFC extension file is imported into Robot Structural Analysis, ETABS, SAP2000, and Tekla Structures interfaces as seen in Figure 3.

When the IFC file extension is imported to Robot Structural Analysis, no warnings or errors are encountered during the import process. However, it is observed that certain elements are not successfully transferred to the Robot interface. In the imported structural model, some panel elements like the concrete shear walls are transferred deficiently on some floors. Also, some frame elements like beams are missing in the structural model. There is frame instability because of no connection between elements. Therefore, the transferred model cannot be effectively used for analysis purposes. The inability to read elements in the Robot tool may be attributed to issues with the formulation of IFC and the lack of data readability in Robot.

The same IFC file is imported into ETABS. However, upon transferring the model and conducting a thorough examination, several inaccuracies were identified. Some elements lack dimensions and material properties in the structural model, and the connections of frame elements pose issues in the imported model. The unconnected frame elements in the imported structural model show that the existing IFC versions that have been developed and integrated into the current BIM software tools targeted at structural engineers remain highly restrictive. Running analysis through this imported model encounters various warnings like checking the structure carefully for: - inadequate support conditions, or - one or more internal mechanisms, or - zero or negative stiffness properties, or - extremely large stiffness properties, or - buckling due to p-delta or geometric nonlinearity, or - a frequency shift (if any) onto a natural frequency. Likewise, the IFC file is imported into SAP2000, then the software gives a warning. When the imported model is examined, some beam elements are absent. Some elements in the structural model lack dimensions and material attributes, and the imported model has difficulties with frame element connections.

Lastly, IFC file is imported to Tekla Structures. The model is opened in Tekla Structure interface as reference model. Although the imported model arrived in the Tekla interface without errors, the IFC elements are not in a usable version in Tekla. The Convert IFC objects command was used to convert the elements into reusable Tekla objects under the Manage tab in the Tekla interface. However, this processing

did not convert the elements into structural elements such as beams and columns. Therefore, the imported model via IFC in the Tekla interface looks like an image instead of a 3D structural model.

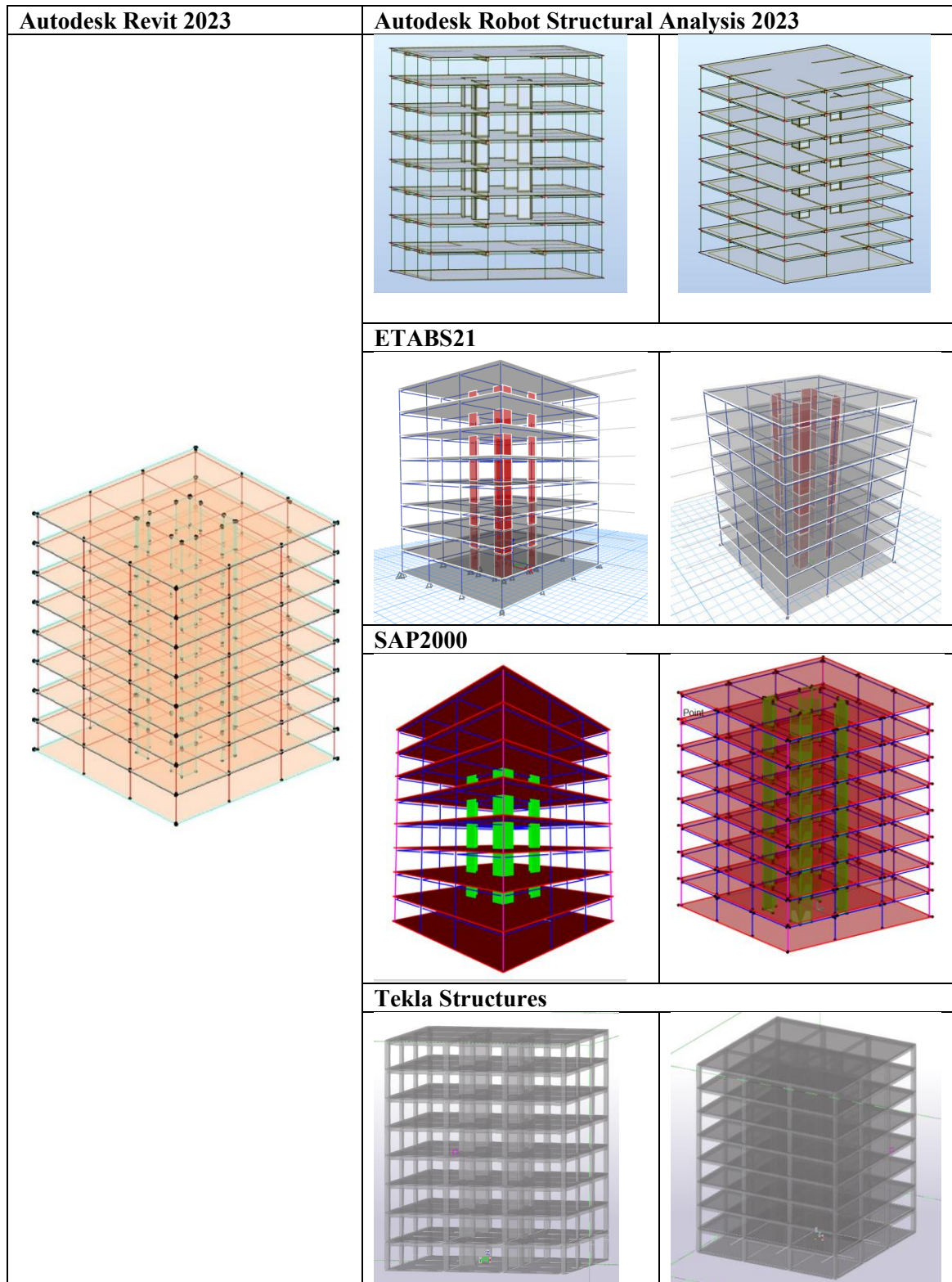


Figure 3. Data transfer testing via *IFC file* between Revit and Structural Analysis tools

5.2. Data Exchange with API Extensions and Supplements

This portion concentrates on the transfer of the model through a direct link native file and API between Revit Structure, Robot Structural Analysis Professional, ETABS, SAP2000, and Tekla Structures. First of all, the data exchange process by API between Revit and Robot Structural Analysis was examined. As both Revit and Robot Structural Analysis software are products of the same developer, Autodesk, they provide a direct connection link for a smooth data transfer. When Robot Structural Analysis software is downloaded, it seamlessly integrates with the Revit platform. The Robot Structural Analysis Professional tool is easily accessible within the Revit structural analysis interface, situated under the 'Analyze' tab. Activation of this tool opens the integration link through the Robot Structural Analysis dialog box. Within this dialog box, the user can opt for the direction of data flow. For the initial data exchange, the "Send model" option is selected to facilitate the transfer of data. Through the direct integration link between Revit and Robot Structural Analysis Professional, data can be transferred rapidly in either direction. Revit generates a structural model that corresponds to the analytical model needed for the analysis process, including all essential properties such as material properties, section profiles, loads, load combinations, and boundary conditions. Once in the Robot Structural Analysis interface, which is a software for finite element analysis, it is important to verify if any data loss has occurred in the model. The architectural model in Revit encompasses components such as grids, levels, structural columns and beams, shear walls, floors, material specifications, designated loads and load cases, and member end releases. Through the direct link integration, all these elements and their characteristics are conveyed to Robot. Within the Robot Structural Analysis platform, the model is capable of receiving additional updates by specifying final load cases and combinations, and by incorporating advanced analysis parameters.

From the ETABS and SAP2000 perspective within the BIM concept, CSI has developed an API, a widely used programming language. In the collaboration between ETABS-SAP2000 and Revit, a plug-in named "CSiXRevit" has been developed. This plug-in facilitates bidirectional data exchange between ETABS-SAP2000 and Autodesk Revit Structure. Throughout the data transition, specific elements such as grid lines, story levels, materials, structural frame elements, walls, and flat or non-sloped floors, along with defined loads and load cases (excluding area loads), are transferred from Revit Structure to ETABS and SAP2000, as detailed in the CSI Documentation [33]. Upon installation, CSiXRevit is incorporated into the Revit interface as an external tool in the Add-ins tab. This tool establishes a shared file format, ".exr," for intermediary data exchange. The resulting .exr file can then be imported into ETABS and SAP2000 for further processing.

For the Tekla Structures interoperability concept, Trimble, the Tekla manufacturer, has created a Trimble connection for the live connectivity between tools to provide smooth data interchange between Revit and Tekla Structures. This is a 'File Uploader' plug-in that works with the Revit interface. The structural model in Revit is uploaded to Trimble Connect using this plugin. The uploaded file is then imported into the Tekla Structures interface via the web browser.

Before conducting the structural analysis, the models sent to the RSA, ETABS, SAP2000, and Tekla Structures platforms, as seen in Figure 4, undergo a thorough verification and approval. This includes the successful data exchange of crucial information such as grids, levels, dimensions, and properties of structural components, including their section properties, nodes, dimensions, and material definitions, and the connectivity of frame elements. Finally, the structural models are subjected to rapid analysis for dead load cases, and if the models are proper for the analysis, as the primary objective of this research is to examine the data exchange capabilities of the API method. Accordingly, the goal of this section is to assess the data exchange functionalities of the API method. Efforts are made to transmit the analysis outputs back to Revit to update the building model following the analysis results. In the study, only the structural model in RSA is ready for the analysis. Therefore, analysis results are obtained from RSA, and then the results are transferred again to the Revit interface. The models in ETABS, SAP2000, and Tekla Structures are not proper for the dead load analysis due to the deficiencies of the data transfer.

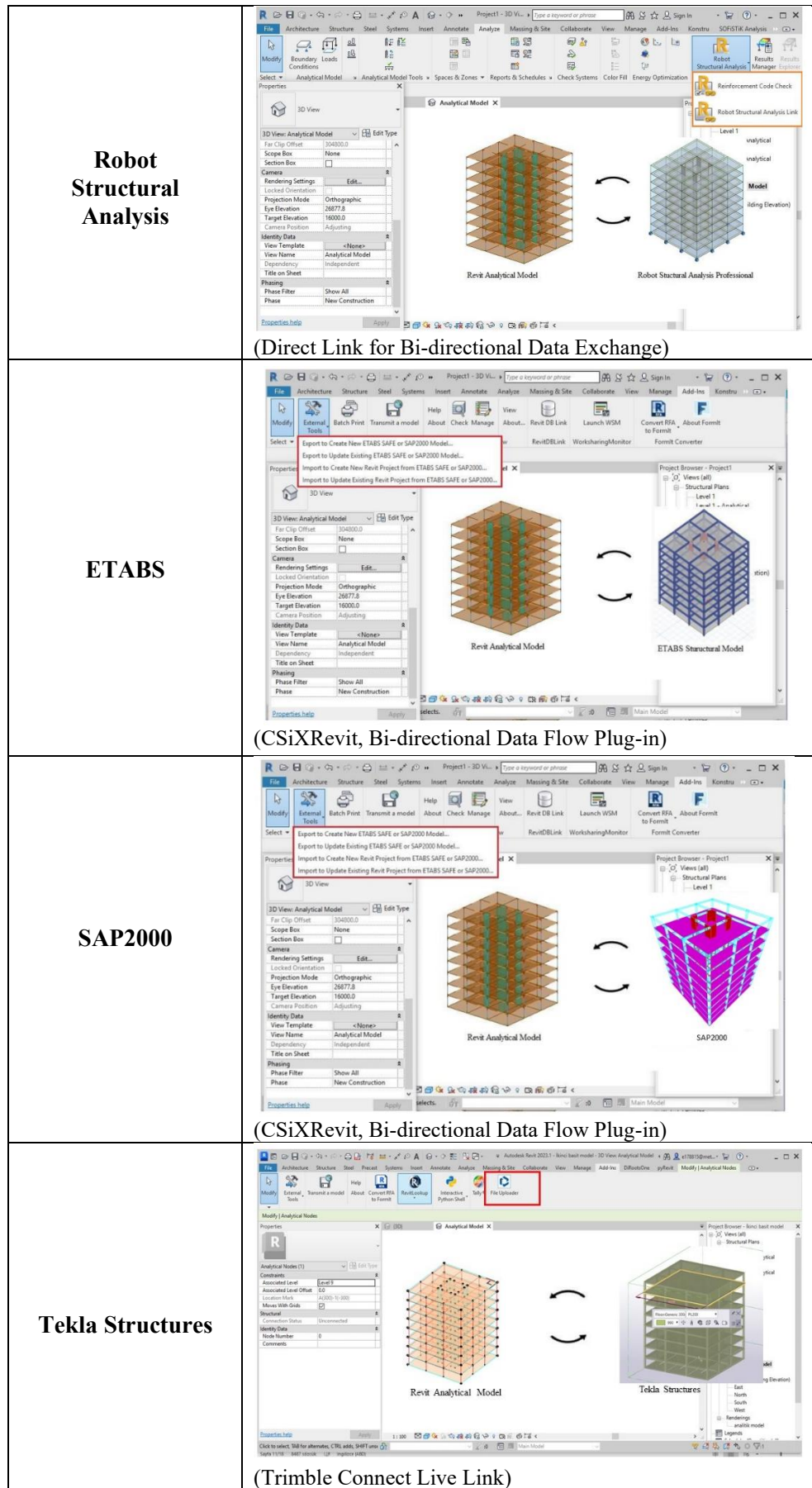


Figure 4. Data transfer testing via **API** between Revit and Structural Analysis tools

Initial findings may seem promising, as the direct link integration between Revit and structural analysis tools is smoother and faster. However, there are still some problems with API method data transfer, such as missing data, unstable links, undefined materials or dimensions, except for Robot Structural Analysis, which is the product of Revit's manufacturer. Therefore, the dead load analysis was carried out only in RSA. In other tools, the imported models were still not proper for any analysis.

Revit and RSA emphasize their support for interoperability and their capacity to consolidate all revised data within a building model. The dead load analysis results are seamlessly transmitted to the Revit interface. Following the analysis in RSA, to update the Revit model, the integration direction needs to be set as “update model and results” in the Revit interface. Consequently, all modifications and results can be incorporated into the Revit building model. In Revit, the 'result manager' and 'result explorer' add-in tools facilitate the preservation of the updating process, allowing the visualization of structural analysis results, as depicted in Figure 5. In this figure, the deformation and displacement results on slabs under the dead load pressure are sent to the Revit interface, and it is still readable and reliable in the Revit interface. A key advantage of this link between Revit and RSA, highlighting the significance of BIM tools in design and analysis, is its bidirectional functionality, allowing the RSA model to also send data back to Revit. This feature is particularly important as structural designers often need to update and modify designs based on structural specifications.

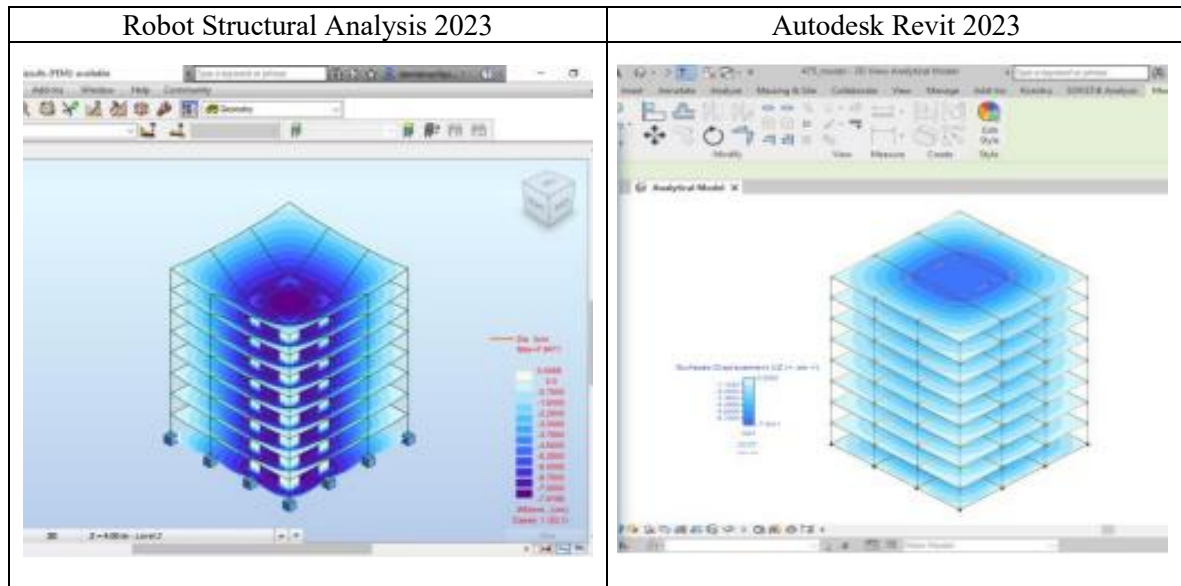


Figure 5. The analysis results are transferred back from Robot Structural Analysis to the Revit interface via API [35]

This bidirectional data compatibility is crucial as structural engineers may need to modify the Revit model based on the structural analysis results of their designs. The information transferred is identical to that in the direct link using the native file. Consequently, the results demonstrated that the design modifications and analysis outcomes for the foundation, frame elements, and surfaces can seamlessly transfer to the Revit interface with the output data. The physical model in Revit was updated based on these design changes and analysis results.

6. CONCLUSION

6.1. Summary of the Research and Discussions

This study focuses on exploring the use of BIM in structural analysis and architectural design by examining interoperability, identifying the more effective data transfer method between architectural and structural software, and determining the viability of these integrated design pathways in structural engineering practice. The research aimed to answer the following questions:

1. How does BIM facilitate interoperability between architectural design and structural analysis?
2. Which data transfer pathway is the most capable among architectural and structural disciplines?
3. What are the outcomes of a bidirectional data transfer process between Autodesk Revit and various structural analysis tools?

At the beginning of the research, the issue of interoperability within the construction sector using BIM technology is reviewed. BIM is a modern approach and process for the AEC industry, which replaces traditional practices with digital construction delivery processes. Establishing two-way data exchange between two separate applications holds great promise for the industry. Thus, this research explores data-sharing methods, namely IFC and API, within BIM technology to evaluate their capabilities and reliability. IFC and API methods are investigated through architecture and structural engineering disciplines. To verify these methods, the five most preferred tools are chosen; Autodesk Revit, Robot Structural Analysis, and ETABS, SAP2000 and Tekla Structures. Then, a case study is carried out.

As a case study, a simple structural system for a building was modeled in Revit. The model consisted of several crucial elements, including axes and concrete frame components such as columns, beams, shear walls, and slabs. Subsequently, the model was exported from Revit to Robot Structural Analysis, ETABS, SAP2000, and Tekla Structures' interfaces to conduct a comprehensive structural analysis using IFC and API methods. Bi-directional data transfer from Revit to structural analysis tools, and vice versa, was tested thoroughly using IFC and API methods. The results of the data transfer were meticulously analyzed, and the findings are presented in Table 1.

Table 1. The summary of bi-directional data transfer results via IFC and API among selected BIM tools

Transferred Data	IFC (indirect link)				API (direct link & native file)			
	Revit RSA	Revit ETABS	Revit SAP2000	Revit Tekla	Revit RSA	Revit ETABS	Revit SAP2000	Revit Tekla
Annotation Elements								
• Grids and Levels	-	-	-	-	+	+	+	-
Section Properties								
• Height and Width	+	+	+	+	+	+	+	+
Geometry								
• Length	+	+	+	+	+	+	+	+
• Analytical Position	+	+	+	+	+	+	+	+
Material Properties								
• Yield stress	-	-	-	-	+	+	-	-
• Modules of elasticity	-	-	-	-	+	+	-	-
• Shear modulus	-	-	-	-	+	+	-	-
• Density	-	-	-	-	+	+	-	-
Loads								
• Self-weight loads	-	-	-	-	-	+	-	-
Analysis Outputs								
• Dead load analysis results	-	-	-	-	+	-	-	-

RSA(Robot Structural Analysis)

(+) The data exchange is achieved.

(-) The data exchange is not achieved.

Studies in this research have indicated that there are challenges in exchanging data between different applications when using the IFC file format. During this research, the IFC 2x3 file version is used. Because the latest versions IFC4x3 and IFC4structural do not work during the data exchange processes. The structural analysis tools give errors when trying to open one of these versions. As reviewed from the literature, when importing and exporting an IFC file across various BIM software, there is a risk of data loss and unintentional modifications due to differences in how each software handles modeling properties [12]. The representation of object geometry, properties, and relationships can vary, resulting in inconsistent models when exchanging data between different tools. Additionally, software tools may struggle to recognize certain objects from other disciplines due to their specialized domains [14]. Likewise, in the course of this investigation, within the Revit interface, the building model was converted to the IFC format and then brought into RSA, ETABS, SAP2000, and Tekla Structures. The imported structural models in the analysis tools, deficiencies of elements, and data were observed, and it was not possible to run the analysis. However, the idea of interoperability, reliable data, open and neutral standards, collaboration, flexibility, and sustainability in the building industry based on the openBIM is defined by buildingSMART International. OpenBIM encompasses the creation and maintenance of open and neutral standards, the high-quality implementation of these standards, and the establishment of recognized independent benchmarks to ensure quality and thoroughness. IFC is one of the neutral and open standard data file formats, and IFC provides a foundation for openBIM data exchanges. Therefore, buildingSMART is responsible for developing IFC schemas [37]. With the improvements in the IFC neutral data exchange format, more straightforward platform-to-platform communication can be achieved without any data loss. Thus, data exchange can be smoothly provided among different software developed by different companies without the need for any plug-in.

Considering the different versions of the tools used in the data exchange process, the API does not work between different versions of the tools. In other words, for a direct connection between Revit and Robot Structural Analysis tools, both Revit and Robot must be the same version. Similarly, for data transfer with the API, Revit, ETABS, SAP2000, and also the CSiXRevit plugin must be the same version. At this point, IFC, which is an open file format, does not require the same version for data exchange between programs. In other words, a model produced in Revit 2023 version can be opened with an IFC file in SAP2000 v26 version. However, the SAP2000 v23 version is required for the link received from the Revit model using the CSiXRevit plugin to work correctly.

Employing the API method for data exchange within the BIM framework allows for bidirectional data flow. This approach functions seamlessly in Revit-Robot Structural Analysis connections. However, the other structural analysis tools have some problems with the data exchange process. The data exchange between Revit and Robot Structural Analysis is more seamless compared to the Revit-ETABS, SAP2000, and Tekla Structures link because both Revit and Robot Structural Analysis tools are developed by the same company. The direct integration between Robot and Revit software promotes coordinated working principles. The utilization of the API method enhances the speed and efficiency of project processes while effectively mitigating errors and issues. Essentially, the sophisticated API functions as a state-of-the-art method for data exchange, facilitating bidirectional data flow and enhancing collaboration between Revit software and Robot Structural Analysis Professional. CSI, the developer of ETABS and SAP2000, has created a well-functioning plug-in, CSiXRevit, to encourage the interoperability between Revit and ETABS- SAP2000. CSiXRevit claims to provide a seamless bi-directional data exchange between Revit and ETABS- SAP2000. Yet, during the exchange process, missing elements, dimensions, and specifications are observed. For the smooth data exchange between Tekla Structures, the producer of Tekla, Trimble has developed a Trimble connection for the live link between tools. This is a type of plug-in, 'File Uploader', that works in the Revit Interface. The structural model in Revit is uploaded to the Trimble Connect by using this plugin. Then, this uploaded file is imported into the Tekla Structures interface from the browser. But the imported model is inapplicable for performing a structural analysis.

Consequently, through the conducted research, it becomes possible to identify the optimal approach for structural engineers to adopt, considering the observed limitations in interoperability. The direct link API seems a highly efficient and user-friendly method for data exchange, only between the products of the same

company. Therefore, it is highly likely that the API method will emerge as the optimal pathway for advancing BIM maturity levels in the foreseeable future.

6.2. Limitations of the Research

The study has some limitations. The following items address them;

- The experiment was limited to a single project model, which, while useful for identifying issues related to missing information, may not accurately reflect scenarios involving different types of structural models.
- The effectiveness of the API method in dealing with complex and large-scale projects,
- The capability of the API method in the curvilinear and sloped elements,
- The measures taken by the API to guarantee data security and integrity are not examined in this study.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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