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ISTANBUL GEDİK NIVERSITY
INSTITUTE OF GRADUATE STUDIES

CONTRIBUTION OF BUILDING INFORMATION MODELLING WORKING TO STRUCTURAL ENGINEERING ANALYSIS

MASTER’S THESIS

Mohamed Nur Ali

Civil Engineering Department

Master in Civil Engineering English Program

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Enstitümüz, Civil Management Department İngilizce Tezli Yüksek Lisans Programı (211291018) numaralı öğrencisi Mohamed Nur ALI'nin "Contribution of Building Information Modelling Working to Structural Engineering Analysis" adlı tez çalışması Enstitümüz Yönetim Kurulunun 09/08/2023 tarihinde oluşturulan jüri tarafından *Oy Birliği* ile Yüksek Lisans tezi olarak *Kabul* edilmiştir.

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DECLARATION

As the sole author of this thesis titled "Contribution of Building Information Modelling Working to Structural Engineering Analysis," I, Mohamed Nur Ali, hereby attest that the work presented herein is entirely my original creation, completed in fulfillment of the requirements for the master's degree in the faculty of Civil Engineering. I further affirm that no portion of this thesis, in part or in whole, has been submitted or presented for consideration in any other university or academic institution as part of any degree or research paper.(09/08/2023)

Mohamed Nur ALI

DEDICATION

I express my heartfelt gratitude to the Almighty, who granted me the strength and guidance to complete this work independently. It is my sincere hope that this endeavor will bring value to the community. Furthermore, I would like to extend my sincere thanks and appreciation to all those who have contributed to this research, whether by providing advice or information. Specifically, I would like to acknowledge the invaluable support and guidance of my thesis advisor, Asst. Prof. Dr. Hasan Bozkurt Nazilli, who worked tirelessly with me throughout the writing process. I am also grateful to my friends and acquaintances, and particularly to my colleague who generously offered their assistance and support. Lastly, I dedicate this work to my beloved mother, whose unwavering support and prayers have been a constant source of strength and encouragement throughout my life.

PREFACE

I would like to thank God to your advice to help me to finish my thesis and to expose me the way to achieve achievement as a research scientist. I would love to specific my particular thank you and heartfelt gratitude to my counselor, Assist. Prof. Dr. Hasan Bozkurt Nailli, that you had been a extraordinary mentor and that your recommendation has helped me. Your extraordinary feedback and hints were precious and will not be ignored both in studies and my profession. I would really like to thank every person who reacted to me through giving me information.

June 2023 Mohamed Nur ALI

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ABBREVIATIONS

AEC : Architecture, Engineering, Construction
BIM : Building Information Modelling BIM
BPS : Building Performance Simulations
DCO : Design, Construction, and Operations
FEM : Finite element method
GbXML : Green Building XML
IFC : Industry Foundation Classes

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BİNA BİLGİ MODELLEME ÇALIŞMASININ YAPISAL MÜHENDİSLİK ANALİZİNE KATKISI

ABSTRACT

Building Information Modelling (BIM) offers significant benefits and potential within the realm of structural engineering as well. These potentials encompass aspects such as enhanced productivity, improved coordination, better visualization, comprehensive documentation, and decreased waste generation. However, realizing these advantages necessitates the establishment of an effective mechanism to facilitate seamless data transfer from the BIM platform to the structural analysis domain. The existence of challenges in data transfer and interoperability stands as a prominent barrier, impeding the full integration of structural engineers into the BIM workflow.

The primary aim of this thesis revolves around exploring the feasibility of transitioning from the Revit BIM platform to structural software. This is achieved by establishing a framework for the exchange of a central Revit model, enriched with pertinent load-bearing data, with two commonly utilized structural software programs: SOFISTIK and ETAB. The initial phase involves an in-depth analysis of BIM's application in structural engineering. This scrutiny emphasizes its influence on structural design and workflow, highlights the key advantages it offers, and identifies challenges encountered during implementation.

The study subsequently defines and delves into three primary levels of interoperability between BIM and structural software: the direct native file exchange (applicable when dealing with the same commercial software providers), the direct link or bidirectional data exchange, and the utilization of the IFC (Industry Foundation Class) standard. The theoretical exploration of these levels furnishes valuable insights into their workings and implications.

To validate the thesis's propositions, two comprehensive case studies are conducted. The first case assesses the potential of direct link interoperability, facilitated by add-ons or plug-ins, between the Revit BIM platform and SOFISTIK. The second case examines the viability of indirect link interoperability between the Revit BIM platform and ETAB through the application of the IFC standard. Notably, the research concludes that data exchange via this interface is both well-coordinated and efficient, underlining its reliability within the structural engineering BIM workflow.

In conclusion, the findings of this thesis contribute pertinent insights into BIM's interoperability within the context of structural engineering. Moreover, the study corroborates prior research by affirming that interoperability, particularly at the direct link level, represents the most efficacious approach to facilitating seamless data communication between the Revit BIM platform and structural engineering software.

Keywords: *Building Information Modelling (BIM), Interoperability, civil engineering, structural analysis, FEM.*

BİNA BİLGİ MODELLEME ÇALIŞMASININ YAPISAL MÜHENDİSLİK ANALİZİNE KATKISI

ÖZET

Bina Bilgi Modellemesi (BIM), yapı mühendisliği alanında da önemli faydalar ve potansiyel sunmaktadır. Bu potansiyeller, geliştirilmiş üretkenlik, gelişmiş koordinasyon, daha iyi görselleştirme, kapsamlı dokümantasyon ve azaltılmış atık üretimi gibi hususları kapsar. Ancak bu avantajların gerçekleştirilmesi, BIM platformundan yapısal analiz alanına kesintisiz veri aktarımını kolaylaştıracak etkili bir mekanizmanın kurulmasını gerektirmektedir. Veri aktarımı ve birlikte çalışabilirlik konusundaki zorlukların varlığı, yapısal mühendislerin BIM iş akışına tam entegrasyonunu engelleyen önemli bir engel olarak duruyor.

Bu tezin birincil amacı, Revit BIM platformundan yapısal yazılıma geçişin fizibilitesini araştırmak etrafında dönüyor. Bu, yaygın olarak kullanılan iki yapısal yazılım programı olan SOFISTIK ve ETAB ile ilgili yük taşıyan verilerle zenginleştirilmiş merkezi bir Revit modelinin değiş tokuşu için bir çerçeve oluşturarak gerçekleştirilir. İlk aşama, BIM'in yapısal mühendislikteki uygulamasının derinlemesine bir analizini içerir. Bu inceleme, yapısal tasarım ve iş akışı üzerindeki etkisini vurgular, sunduğu temel avantajları vurgular ve uygulama sırasında karşılaşılan zorlukları tanımlar.

Çalışma daha sonra BIM ve yapısal yazılım arasındaki üç temel birlikte çalışabilirlik düzeyini tanımlar ve derinlemesine inceler: doğrudan yerel dosya alışverişi (aynı ticari yazılım sağlayıcılarıyla çalışırken uygulanabilir), doğrudan bağlantı veya çift yönlü veri alışverişi ve IFC'nin kullanımı (Industry Foundation Class) standardı. Bu seviyelerin teorik olarak araştırılması, onların işleyişine ve sonuçlarına ilişkin değerli içgörüler sağlar.

Tezin önermelerini doğrulamak için iki kapsamlı vaka çalışması yapılmıştır. İlk vaka, Revit BIM platformu ile SOFISTIK arasında eklentiler veya eklentiler tarafından kolaylaştırılan doğrudan bağlantı birlikte çalışabilirlik potansiyelini değerlendiriyor. İkinci durum, IFC standardının uygulanması yoluyla Revit BIM platformu ile ETAB arasındaki dolaylı bağlantı birlikte çalışabilirliğinin uygulanabilirliğini inceler. Özellikle, araştırma, bu arayüz aracılığıyla veri alışverişinin hem iyi koordine edilmiş hem de verimli olduğu sonucuna vararak, yapısal mühendislik BIM iş akışı içindeki güvenilirliğinin altını çiziyor.

Sonuç olarak, bu tezin bulguları, BIM'in yapısal mühendislik bağlamında birlikte çalışabilirliğine ilişkin uygun görüşlere katkıda bulunur. Ayrıca çalışma, özellikle doğrudan bağlantı düzeyinde birlikte çalışabilirliğin, Revit BIM platformu ile yapısal mühendislik yazılımı arasında kesintisiz veri iletişimini kolaylaştırmak için en etkili yaklaşımı temsil ettiğini doğrulayarak önceki araştırmaları destekler.

Anahtar Kelimeler: *Bina Bilgi Modellemesi (BIM), Birlikte çalışabilirlik, inşaat mühendisliği, yapısal analiz.*

1. INTRODUCTION

1.1 Background

BIM is the most important tool accessible to structural engineers nowadays for maintaining their competitiveness and utilization of modern techniques and software. Engineers are always searching for innovative solutions to advance and keep up with the modern economy, reaching new heights in areas like productivity, coordination, and problem-solving. BIM may be able to assist with these crucial elements. The capacity to intelligently integrate items into the model is its key contribution. These intelligent objects hold all the information about a specific component, including its geometrical details and interactions with other components to create an information enrich model. BIM has several advantages for civil engineers since it updates the model frequently to reflect any changes to the design or general standards, ensuring that all data is as precise as possible.

The utilization of BIM brings about a transformation in how we examine and perceive elements. Its primary impact is on design processes such as conceptual design and structural analysis. BIM plays a crucial role in reducing design errors and enhancing productivity, thereby leading to decreased design costs. Furthermore, it facilitates improved situational analysis. By employing BIM, one gains a holistic perspective, identifies potential design issues, and generates fresh and innovative solutions. This thesis will primarily focus on the contribution of building information modeling and its influence on structural engineering. To comprehensively comprehend the impact of BIM in this field and effectively leverage its advantages, it is imperative to explore its benefits in terms of productivity, coordination, data consistency, visualization, and simulation. The successful implementation of BIM tools for collaborative purposes relies on the efficient sharing and exchange of information among project participants at different stages. This information sharing is vital throughout the entire building lifecycle to ensure the successful and efficient utilization of BIM technology.

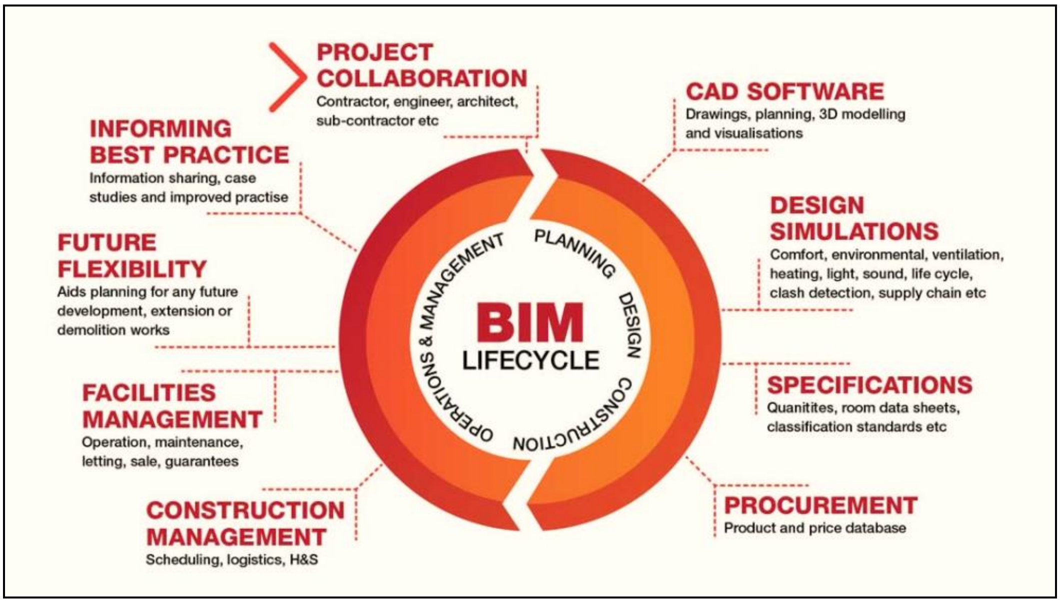

Figure 1.1: Life Cycle of BIM

Source: https://www.pbctoday.co.uk/news/bim-news/what-is-bim/40457

1.2 Problem Statement

The objective of this thesis is to investigate the concept of interoperability in BIM structural engineering. The study aims to address the following inquiries:

1) Investigate methods for structural engineers to improve the exchange of data between BIM and structural software tools, with the goal of enhancing interoperability.
2) Evaluate how the ETAB software interprets a structural model that originates from a BIM tool.
3) Evaluate the efficiency and record-keeping of BIM processes within the realm of structural engineering.
4) Investigate the advantages and obstacles linked to the seamless integration of BIM technology in the field of structural engineering.

By addressing these questions, the thesis seeks to contribute to a better understanding of the practical issues involved in the integration of BIM and structural software tools in structural engineering. It aims to provide insights into the technical and organizational aspects of interoperability and identify potential solutions to the challenges encountered in this context.

1.3 Objectives

The focus of this thesis centers on BIM structural engineering, emphasizing modeling, analysis, design, result documentation, and coordination, all of which contribute to interoperability. For a successful implementation of BIM, data sharing is crucial due to the AEC sector's collaborative nature, involving multiple stakeholders with diverse software and file format needs. Consequently, the thesis aims to accomplish the following objectives:

- Present a comprehensive analysis of BIM's significance within the construction sector, presenting an advanced framework that enhances the operational efficiency of structural engineers.
- Investigate how BIM is employed in the structural engineering process, covering modeling, analysis, design, and documentation.

The main aim of the thesis is to develop a thorough comprehension of how Building Information Modeling (BIM) is utilized in the field of structural engineering. The main focus of the investigation will be to understand the technological hurdles and prospects that emerge while exchanging structural model information among different BIM software and platforms.

1.4 Scope of the Thesis

The objective of this thesis is to investigate and demonstrate the transmission of BIM data in the field of structural engineering using the method of direct link data exchange. The thesis examines the initial phases of BIM data exchange in structural engineering and presents real-life instances through case studies, focusing specifically on data exchange in frame structures. The case studies involve transferring data between a central Revit BIM model and different FEM software programs.

1.5 Methodology of Thesis

To comprehend the theories, principal and concepts arguments pertaining to the thesis subject, a comprehensive review of literature was conducted, followed by an extensive investigation of interoperability with respect to data exchange. To reach the conclusions of the thesis, a methodology was employed that relied on an experiment in data analysis, which included detailed case studies. To achieve this goal, Revit, which is the primary tool for all BIM data, was utilized. The FEM software was used to analyze and clarify the impacts of structural properties in the data transfer process by exchanging the Revit BIM model. The model, which was a reinforced concrete structure, was subjected to various transfer scenarios at the direct link interoperability level, and evaluated for effectiveness, with higher scores indicating better data transfer performance. Additionally, an evaluation of internal forces was conducted, offering further proof of the precision of information transfer from Revit (BIM) to structural programs.

1.6 Layout of the Thesis

Chapter 1: Introduction

In this introductory chapter, the thesis is presented and its main features are outlined. The chapter covers various aspects such as the background, scope, motivation, research objectives, and strategy. Additionally, the thesis problem is introduced and briefly discussed.

Chapter 2: Literature Review

In this section, a review of the literature is presented to highlight the significance of achieving interoperability between structural and architectural engineering. The challenges associated with collaboration between these two disciplines are explored, specifically in relation to the utilization of various software and data standards, including S-BIM and BIM tools.

Chapter 3: BIM Adaptation for Structural

In this chapter, the focus is on the examination of the pathways for analyzing the interoperability between architectural design and structural analysis using BIM. The assessment involved the evaluation of two distinct types of data transfer paths: a direct link utilizing a native file and an indirect link facilitated via IFC. In this chapter, we delve into the topic of interoperability and specifically explore how the IFC file and its data structure can facilitate it. We concentrate on explaining load scenarios and combinations within structural analysis software, aspects that are usually overlooked during data exchange between architectural and structural software.

Chapter 4: Case Studies

In this section, various models are introduced as case studies, each accompanied by a distinct exchange scenario. The focus of the evaluation was on data transfer and interoperability, with a particular emphasis on structural modeling and analysis. The ensuing section provides a detailed discussion of the findings.

Chapter 5: Conclusions and Result

In this chapter, the results of various exchange scenarios are presented, where they have been gathered, condensed, analyzed, and interpreted. The chapter discusses the pros and cons of the different scenarios, draws conclusions based on the findings, outlines the limitations of the study, and suggests areas for future research.

2. LITERATURE REVIEW

This chapter presents a thorough examination of the main subjects associated with construction information modeling during the structural design phase. The initial focus is on various BIM-related topics, including the practical applications of BIM in structural design.

2.1 BIM

Building Information Modeling (BIM) is a rising phenomenon in the Architecture, Engineering, and Construction (AEC) sector, facilitating the merging of various software models, evaluation of results, and collaboration on project materials among different fields and stages. An important advantage of BIM is its capacity to promptly detect and address problems and discrepancies in the pre-construction phase. Additionally, BIM project data can be employed for post-construction activities such as building operation and maintenance. Consequently, the utilization of BIM has garnered significant attention in AEC-related organizations due to its manifold advantages (Hu *et al.*, 2016).

Architectural design and structural analysis are closely linked disciplines within the realm of construction projects, each encompassing distinct methodologies and goals during the building design phase. Structural analysis involves analyzing the mechanical and structural features of building components such as stress, strain, and stability, while architectural design describes the proportions, materials, and configurations of various architectural elements. Both architectural and structural design are essential for the successful design of a building (Chen and Tang, 2019).

Thanks to Building Information Modeling (BIM), designers can possess a comprehensive understanding of the construction process, anticipate upfront decisions, and maintain continuous communication while constructing buildings and other structures. BIM's advantages have transformed engineering, architectural, and construction firms, making it a hotly debated topic (Hu *et al.*, 2016). BIM offers numerous benefits to constructions, such as integrating design and detailing, minimizing errors, promoting teamwork, and facilitating top-notch construction. In medium to large-scale building projects, multiple structural engineers employ a range of structural engineering applications.

The construction sector faces complex information management and cooperation difficulties due to the involvement of multiple disciplines, teams, and technologies, as well as the multi-phase and dynamic nature of projects. The insufficient integration and interoperability are considered significant obstacles to the adoption of innovative systems in the design, construction, and operations (DCO) sector. These economic issues need to be addressed. (Hu *et al.*, 2016). The procedures involved in structural analysis necessitate the sharing of diverse data sets and information models.

(Arayici *et al.*, 2011) have asserted that the absence of integration solutions between various technologies for structural analysis has made the activity exceedingly challenging, time-consuming, and resource-intensive, given the number of personnel required to perform remodeling and resolve discordant and inconsistent issues. However, the adoption of Building Information Modeling (BIM) technologies has been on the rise in the design, construction, and operation industry. BIM provides a digital, parametric, intelligent, and object based representation of a building's physical and functional characteristics, creating a shared database and knowledge resource for project and building information.

According to (Azhar, 2011) BIM's development has resulted in the creation of open and neutral data schemas to facilitate interoperability, which is critical in streamlining information flows between different disciplines. The challenges encountered in interoperability are related to the import and export capabilities of data models among different technologies, which can impede BIM's progress. Although many structural engineers consider BIM to be similar to CAD, it is actually a logical successor to traditional CAD. BIM is a 3D entity that allows for excellent coordination with 2D drawings, cost estimation, and clash detection.

2.2 Main Misconceptions about BIM

Some individuals mistakenly believe that BIM is exclusively intended for building projects due to the inclusion of the term "building" in the acronym.

However, as (Bartley, 2017) points out, BIM can be applied to the design, construction, and facility management of various types of infrastructure. The term "modeling" itself can also cause confusion, with some assuming that BIM is solely focused on creating a 3D model of a building. In reality, BIM goes beyond 3D modeling and has many other applications throughout the project's lifecycle.

(Eastman *et al.*, 2008) explain that BIM integrates parametric design, coordination, communication, and visualization with a 3D model.

Table 1.1: BIM Dimensions

BIM Dimension	Remark
4D BIM	Construction sequencing
	Helps in adding schedule to a 3D model
	Improves planning and controlling of construction
5D BIM	Add cost estimation information to the 4D model
	Managing costs along with procurement
	Assists in keeping the progress of project activities along with the associated costs
6D BIM	works on sustainability
	Information such as energy use, resource efficiency is added to the model
7D BIM	
	Helps in information regarding facility management to the model

2.3 Contribution of BIM

2.3.1 Takes part in terms of collaboration and communication

Throughout the duration of a project's lifespan, various professionals from different fields work in collaboration. Typically, this teamwork involves the exchange of 2-Dimensional drawings and documents, as stated (Singh, Gu and Wang, 2011). Although these professionals may use 3D models in their individual work, their collaborative efforts have predominantly remained based on 2D exchange. The employment of a shared database in BIM facilitates the interaction and exchange of ideas among structural engineers and the rest of the design team (Bartley, 2017). Modifications made by any member of the design team are automatically recorded and updated for the structural engineer and vice versa. Hence, BIM enables the integration of all related areas into a unified digital model(Chen *et al.*, 2005).

2.3.2 Increased efficient in visualization

Structural engineers can effectively communicate their design ideas to non-technical stakeholders by utilizing a range of visualization tools through the use of BIM. These tools include interactive 3D models that provide an accurate representation of the real-world asset, as noted by (Bartley, 2017).

Conducted a case study on a pilot project to demonstrate the potential of BIM workflows. They successfully created a 4D virtual simulation of the project, which allowed professionals involved to gain a better understanding of the design (Chen and Tang, 2019). Recognizes the time-saving benefits of using BIM workflows. The simultaneous generation of analytical and physical models eliminates the need for manually creating structural models from architectural models, saving valuable time. (Hunt, 2013). Furthermore, structural designers can integrate analysis with construction drawing preparation, further increasing efficiency, according to(Bartley, 2017).

2.3.3 Well documented design process

The adoption of BIM offers an added advantage when it comes to documentation. The central model used in BIM gathers all pertinent information about the structure and ensures it is well-documented. This makes it effortless to access information whenever it is needed. As a result, there is a reduction in the repetition of entering information since all the documentation is done in a shared model, as noted by (Nielsen and Madsen, 2010).

2.3.4 Cloud computing

Expanding the potential of BIM can be achieved by integrating it with the internet. By utilizing a device that is connected to the central database, design data can be retrieved from anywhere and at any time, without the requirement of carrying physical drawing papers as stated by(Bartley, 2017).

2.3.5 Better material quantities estimate

BIM workflow generates structural models with rich information, enabling professionals to obtain the most accurate material quantity estimate (Basak Ozturk and Eraslan, 2018). Typically, a human carries out the material quantity estimate, which is susceptible to human error and time-consuming. Although computers are used in the process, most of the responsibility lies with the individual. However, BIM allocates the computing task to computers, as it should be. Consequently, the material quantity estimate is instantaneously and accurately performed with higher quality than traditional methods.

2.4 Clash Detection

Identifying conflicts is an essential step in the design process. Instead of using a single model during design, numerous models are combined to create a comprehensive model of the structure. To create a comprehensive digital model of the building, the players must overlap their individual models they create during the design phase (Sampaio, 2017).

When several elements occupy the same space, a clash might occur. This conflict was described as "physical conflicts" by (Sampaio, 2017). For instance, a water supply line passing through a beam, a window partially buried in a beam, or a door partially buried inside a column are examples of this. Conflicts with rules fall under the heading of Clashes. These are disputes relating to elements and the regulations they failed to satisfy, claims (Sampaio, 2017).

Traditionally, experts have used 2-D drawings to try to detect conflicts (Mr. Swapnesh.P.Raut and Dr.S.S.Valunjkar, 2017). Some confrontations continue to go undiscovered even after laboriously completing this process, only to be discovered later on during building. Costly rework is the result at building sites. The use of BIM, however, enables the automatic detection of all incompatibilities during design, preventing potential disputes during construction activities. This is due to the great degree of detail in BIM models, which improves visualization (Sampaio, 2017). (Berdeja, 2014) carried out a case study to assess BIM's capacity for collision analysis. Revit 2014 was one of the applications used for the investigation. The study showed how BIM may be used to identify and resolve conflicts between design disciplines.

The author emphasized that the adoption of BIM can increase the level of detail of the project at hand, which is necessary for conflict detection and resolution. The researcher agreed that BIM's capacity to bring disparate fields together was essential for collision detection. The author thought that using BIM had an undeniable benefit over conventional techniques for collision identification (Berdeja, 2014).

2.5 Interoperability

BIM still has certain problems in addition to these benefits. One of the biggest dangers of using BIM is interoperability, among other things. There are no established standards for information sharing between these applications because most of the structural analysis software based on FEM already existed before BIM. Interoperability is crucial to the effectiveness of BIM. Therefore, for businesses using a variety of tools and programs, a lack of interoperability is an issue. The flow of information throughout the project lifetime depends on integration using open standards. Industry Foundation Classes (IFC) and green building Extensible Markup Language are the two formats currently utilized for the integration of BIM models (gbXML). IFC details geometrical details, material characteristics, and connections in a BIM model. Building Performance Simulations (BPS) tools and BIM models may communicate data more easily thanks to the gbXML schema. Even though both formats are widely used in the AEC sector, adoption does not guarantee error-free data interchange.

The means in which practitioners produce and distribute information are not covered by the IFC model. Additionally, because gbXML cannot read complex geometry, it can only be used for straightforward design solutions. The client is utilizing the IFC scheme and is probably experiencing the similar issues. With the help of Dynamo, the research team will attempt to address the client's lack of program and tool compatibility. Current challenges with structural design development typically involve a lack of flexibility, tedious or time-consuming labor tasks, and communication breakdowns with various design elements. It has been difficult to find innovative and better design ideas at an early stage. The lack of connectivity between architectural and structural problems is being addressed via BIM-enabled structural analysis. Most structural design components are already included in a BIM model. This suggests that relatively small changes may be required to enable structural analysis using BIM. For instance, during the architectural modeling process, the architect (and/or BIM modeler) may take into account extra variables besides geometrical features.

Implementing structural analysis in BIM provides a number of benefits, including making users more aware of the building's usability (such as safety and functionality) in addition to the structural criteria. Another benefit is that better and more sophisticated design solutions can be produced when stakeholders communicate more effectively. Additionally, structural analysis in BIM enables adjustments throughout the design process and visualization of the effects of various design solutions. On the other side, there are a few drawbacks to BIM. The loss of information during data interchange processes is a significant problem. The advantages of BIM-enabled structural analysis are anticipated to grow even more in the future, which will lead to more functional, sustainable, and safe buildings. It is feasible to facilitate structural analysis based on BIM in a number of ways. The degree of integration of BIM varies between the techniques. Two approaches are explained and reviewed using literature. These strategies are the focus of the next sentences.

2.6 Robot

The Structural Analysis Toolkit can be used to incorporate structural analysis into Revit in addition to interacting with other software packages. Structural engineers may analyze and verify the structure inside the Revit environment thanks to the toolbox, which supports the BIM process. Using Autodesk Robot Structural Analysis Professional, the Revit analytical model can be expanded (Robot). The tool can transfer structural models in both directions between Revit and Robot, update structural models in one program after readjustments have been made in the other program, and transmit static analysis results and reinforcing requirements determined in Robot to the Revit model. His strategy faces the same challenge as IFC, namely the incorrect alignment of structural parts. This problem needs to be resolved in order to use the integration with Robot.

2.7 Information sharing model

Achieving global standardization in Building Information Modeling (BIM) methods and practices relies heavily on the ability to exchange data seamlessly. OpenBIM, an open-source method that employs open standards and workflows, is essential in reaching this goal. The effective communication between project members greatly depends on open data standards, as they facilitate the exchange of relevant information across different software applications. These standards are built upon three fundamental elements: terminology, process, and digital storage.

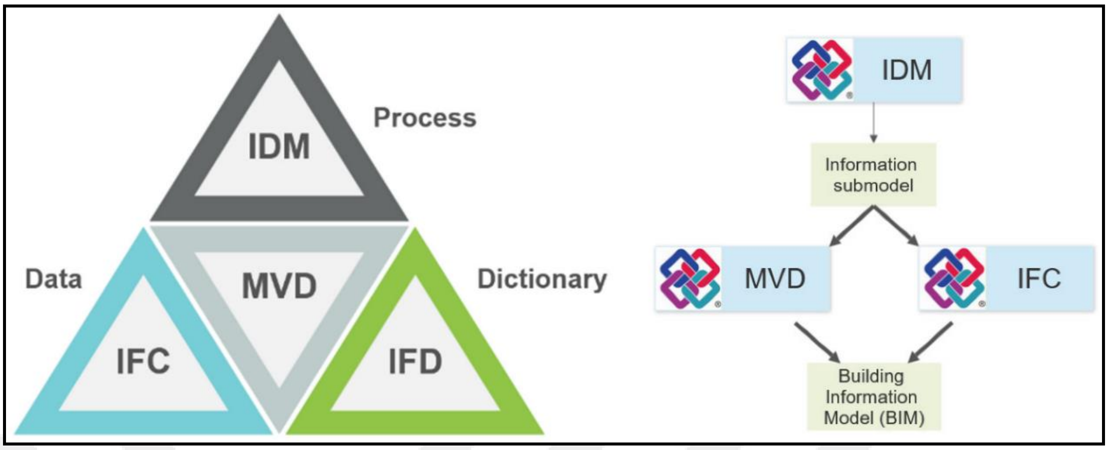

Figure 2.1: Data sharing Model

Source: Armijo, (2021).

SMART Building, a prominent participant in the construction industry, has created a standardized approach to Building Information Modeling (BIM) known as IFC. This standard, officially recognized as ISO 16739, encompasses data models, processes, and terminologies. IFC is supported by various other open standards such as IFD (International Framework for Dictionaries), IDM (Information Delivery Manual), MVD (Model View Definitions), and BCF (BIM Collaboration Framework). IFC provides a consistent digital representation of constructed environments like buildings and civil infrastructure, independent of specific hardware or software platforms. The schema specification outlines the design, construction, and operation of facilities or installations. IFC is capable of describing physical building elements, manufactured goods, mechanical/electrical systems, as well as abstract models for structural and energy analysis, cost estimations, and work schedules. Additionally, IFC can be used to archive project information throughout the design, procurement, and construction phases, or to preserve a collection of "as-built" information for long-term operational purposes.

2.7.1 Structural data in IFC

In this section, the primary objective is to present the necessary details and elements needed to represent structural data in the IFC schema, while also establishing connections between them using relationship entities. To create an open BIM data model for structural engineering, the relevant information has been organized into seven main categories: static analysis, dynamic analysis, probabilistic analysis, finite element analysis, pre-stressed concrete, steel connection design, and reinforcement detailing.

The IFC Structural Analysis Domain is utilized to describe the structural analysis model, integrating the field of structural engineering within the context of static analysis. This involves linking structural assumptions with the definitions of the current building and spatial structure elements to accurately capture structural engineering information, allowing it to be accessed by other relevant domains. However, when it comes to dynamic analysis, probabilistic analysis, finite element analysis, and pre-stressed concrete, the IFC lacks specific entities that describe the parameters for these analysis methods. To address this issue, these parameters can be included in an IFC model through Property Sets, which define attributes that can be expanded dynamically and represent the attributes within a schema. The interpretation of these attributes depends on their names, with the appropriate entity for load effect being the IFC Structural Load.

2.8 Comparison IFC and Robot

A master's thesis examined various structural-BIM technologies. The authors came at the conclusion that the best outcomes came from a direct connection between Revit and Robot. Because the structural engineer can only use one piece of software, they did not advise it. They recommended substituting the integration of IFC Structural Analysis View. This makes it possible to employ several FEM software programs. They were unable to test this at the time since the program they were using did not yet enable IFC Structural Analysis View. Since none of the solutions are ideal, the thesis implies that the problems with interoperability between the many fields have not yet been fully resolved. The above papers discuss how adopting a BIM-based structural analysis presents various difficulties, which prevents businesses from embracing new technology. Working with the structural model in Revit needs to be revised for both the IFC and Robot approaches.

2.9 New Job Descriptions Coming With BIM on A Global Scale

Paradigm change in building and construction industry with Building Information Modeling The transformation, which is also considered as this created a need for new team members to fulfill the duties. Looking at the literature the job descriptions that come with BIM are defined as "BIM Experts" as a whole

Table 2.1: BIM Related Specialization

New job definitions with BIM	
BIM modeler (BIM models)	Modelling specialist
BIM analyst	BIM facilitator
BIM application developer or BIM software developer	BIM specialist

2.9.1 BIM modeler

BIM Modeler, model builder, developer, and 2D models it is the person who provides the data flow between them. BIM Modelers always be CAD experts as it is not compulsory, the experts who use CAD for a long time have shown against BIM. CAD experts are generally not BIM Modelers due to resistance.

2.9.2 BIM analyst

BIM can also work as a Design Consultant in design firms. Analyst; analysis such as building performance analysis, circulation and security analysis, and makes simulations

2.9.3 BIM application and software developer

BIM Application and Software Developers develop software that supports the BIM process. They are experts who develop and customize it. They are working to fix the technical errors of the application. In a nutshell, BIM Application and Software New add-ons whose developers work on the technical capabilities of the program are the developers and are key in solving the technology-induced barriers to BIM transitional re playing a role.

2.9.4 Modeling specialist

Modeling Specialist, familiar with IFC data structure and modeling concepts, coordinates the data flow between models. Also, these experts it is also responsible for mapping and data coordination. Each company shares has a qualified Modeling Specialist to ensure the integrity and security of the data to be is important.

2.9.5 BIM facilitator

Job description of BIM Facilitator, other not yet proficient in BIM operation helping professionals visualize software and model information. BIM Facilitator; facility manager, employer and project managers about the project. It helps them to follow the project by obtaining information, helps BIM users and other It acts as a connector between stakeholders.

2.9.6 BIM consultant

BIM Consultant provides projects to companies that have or will adopt BIM. They are experts who provide guidance as part of a team. Project in preparation and BIM Consultant, who assisted the company and team members during the project process by supporting the three separated into the group. These consultants;

- Strategic Consultant,
- Functional Consultant and
- Counted as Operational Consultant

2.9.7 BIM researcher

BIM Researcher at universities, research institutes and government agencies the employee is an expert on BIM. Research and development on BIM becomes the pioneer of the industry. BIM Researcher; industry, society and environment should act with the vision of creating new knowledge that will benefit.

2.9.8 BIM trainer

Looking at the industry, most of the people who are BIM Researchers are BIM Educators appears to be working as well. BIM Trainer, training on BIM He is the person who fundamentally supports the BIM transformation by providing training to institutions and companies. Students who receive BIM training along with CAD training at school It takes its place in the sector as an accelerator of BIM transformation.

2.9.9 BIM manager

The BIM Manager is responsible for the implementation of the BIM process and the production of the model. Is the person responsible for maintaining its use? BIM The manager is also responsible for the coordination of the team within the company. This persons; by reviewing BIM objectives, project resources, and availability, and develops a plan for their wishes. BIM Manager of various design templates Responsible for preparing and coordinating the model. However, the most important function to guide the team. When we look at the listed work items and job descriptions, especially BIM Consultant and BIM Manager have an important role in the transition to BIM appears to be.

In line with the job descriptions that come with BIM and the needs of BIM experts, team members it is important to clarify its definition and duties. In schools of design and architecture to the curriculum change to close the gap of these business items in the market. It seems important to go. New work items are created by team members not just because of program knowledge, but at different clearly demonstrates the need to acquire competencies. Therefore Evaluation of the current situation of construction and architectural firms in Turkey the situation and qualifications of the specified job descriptions in practice. Examination is important.

2.10 The Situation of Construction Companies in the Transformation with BIM

According to the NIBS, BIM is defined as a collaborative methodology that provides data generation for use at different stages of the lifecycle, such as maintenance and operation of a building. This methodology has been steadily increasing since 2007. Moreno et al. suggest that the desire of architects and employers to use BIM influences project managers and site managers to apply BIM in projects. Therefore, the transition to BIM is influenced by user-driven social factors. However, the attitudes of stakeholders in the project process towards the use of BIM and their individual efforts and competencies for interoperability cannot be ignored. Furthermore, research on the size and type of collaboration in projects has shown that they affect the BIM-based collaboration process (Miettinen and Paavola, 2014).

BIM encourages all participants to make joint efforts and share ideas and information in a more effective and organized way. In this transformation with BIM, construction companies, especially contractors and engineers, play an important role, just like architects. One of the important reasons for this is to avoid problems during the construction phase. With BIM, it is possible to virtually create the structure before it is built, allowing the identification and resolution of problems without driving a single nail on the construction site. In addition, BIM provides realistic results with its quantity and cost analyzes, which minimizes financial losses and encourages early solutions. BIM also provides effective planning of the process during the construction phase, supports the formulation and implementation of plans, and brings process control with its three-dimensional design. Another important factor for civil engineers to prefer BIM is the fabrication of the system off-site after the building components are designed (Eastman *et al.*, 2008).

The use of BIM in harmony with portable technologies such as iPad predicts transformation and solves the problem of serious loss of space when archiving project outputs

2.11 The Situation of Architectural Firms in the Transformation with BIM

BIM helps architects minimize errors and omissions in projects and documents, while also facilitating faster downloads, reducing revisions, and shortening design time. BIM libraries enable architects to create manufacturing details and furnishings, allowing more time to be allocated to the concept design of the building by automating the process and reducing risks through increased efficiency (Moreno, Olbina and Issa, 2019).

One of the most important reasons why architects prefer to use BIM is that, during the analysis phase of building design, BIM provides access to data that supports sustainable design. Additionally, the industry's general perception is that BIM encourages cooperation between parties and is an ideal tool for sustainable design.

BIM tools offer more realistic designs compared to other modeling tools, and their visualization feature simplifies communication among project participants and facilitates cooperation among stakeholders (Arayici *et al.*, 2011). However, despite the recognized advantages of BIM in building design, projects produced with BIM often lack experience due to a lack of supportive education and training in BIM, and the industry's slow adoption of BIM due to barriers such as a lack of software resources.

According to Yan and Damian conducting surveys with BIM users to examine BIM adaptation reveals that architectural firms that use BIM show good project performance as long as it is easy to use and their organization is BIM-ready. It is expected that BIM will improve collaboration, reduce fragmentation in the industry, reduce cost and time, and provide better information access, but it may take time for BIM to be fully adopted by architectural firms.

(ErdiK and Tülübaş Gökuç, 2020). Examined various factors that impact BIM adoption and firm performance in architectural firms. These factors were examined under three models: Design Task and BIM Technology Compliance Model, Institutional Competence and BIM Technology Compliance Model, and Designer Competence and BIM Technology Compliance Model. Tulumba's conducted a statistical study on architectural firms in the USA in line with the given factors and found that project quality and harmony between design tasks and BIM technology can positively affect the cost and duration of the project. The research also showed that 3D visualization, design productivity, and communication were the most important needs met by BIM.

3. BIM ADOPTATION FOR STRUCTURAL DESIGN

3.1 Introduction

Vendors assist in the modeling of BIM software by offering improvised programs for structural design and information modeling, boosting industry cooperation from dispersed design towards integrated project delivery. Applications such as Navisworks, Tekla Structures, and Bexel Manager to name a few, have the capability to pinpoint clashes among different models (Quirk., 2012).

Various software platforms enable the use of structural analysis and design within BIM settings. Autodesk Robot and cloud computing, for instance, can be combined with Revit to create a sophisticated structural modeling, analysis, and design program. SOFiSTiK offers highly interoperable integrated technologies like FEA analysis, design, and Reinforcement Generation, which can be integrated into the Revit platform to provide a comprehensive solution for structural engineering. ProSap Professional, another program for structural engineers, allows for the import and export of IFC formats, ensuring model interchange compatibility. Additionally, Trimble provides Tekla Structural Designer (TSD) and Tekla Structures (TS) for analysis, design, and detailing, which are designed to work together seamlessly to enhance compatibility and efficiency in workflows.

“Research indicates that the utilization of Building Information Modeling (BIM) applications for structural engineering design has shown a substantial increase since 2014. One area that has garnered significant attention is information management. Furthermore, there is a recognized need for improvement in the modeling of structural components, automation for assembly and planning, and optimization. It is worth noting that research on BIM for civil engineering is still in its nascent stages, and the literature only briefly touches upon the current state of the art in BIM applications for structural engineering (Vilutiene *et al.*, 2019).

Source	Review period in years	Number of analyzed articles	Source of articles (databases)	Focus	Key findings
Abdirad [13]	2007–2014	97 (selected out of 322)	ASCE, Elsevier, Taylor & Francis, Emerald, and ITcon	BIM implementation assessment	Developments of BIM implementations; metric-based BIM assessment; gaps and limitations
Bradley et al. [10]	2000–2015	259	Scopus, Engineering Village, ScienceDirect, WoS	BIM for infrastructure	4 research gaps in infrastructure and BIM; an information management framework
Bruno et al. [48]	2007–2017	120, 86 of them with international impact, and 1 project	—	Historic BIM	Gaps in historic BIM; methodology for diagnosis of historic buildings using BIM
Cheng et al. [26]	2002–2014	171 case studies and 62 articles	—	BIM for civil infrastructure	Current practices of BIM adoption in different civil infrastructure facilities; research gaps and recommendations; evaluation framework
Davies et al. [51]	2007–2016	36 articles and BIM guides	—	Roles and responsibilities of BIM specialists	Definition of roles and responsibilities of BIM practitioners
Edirisinghe et al. [52]	1996–2016	46 (selected out of 207)	—	BIM in FM	Conceptualization of a BIM-based FM framework; determining the path of future research
Guo et al. [21]	2000–2015	78	WoS and ASCE Library databases	The use of visualization technology	Usage of visualization technologies in safety management
Kylili and Fokaides [63]	2005–2016	Actual European policies and legislation	European policies and legislation	Existing European policies and legislation for the built environment and the construction materials	Future trends in construction
Laakso and Nyman [54]	1997–2007	The first 11 years of research on standard 938	—	Research and BIM standardization	Classification of data
Li et al. [14]	2004–2015		WoS	BIM knowledge map	60 key research areas 10 key research clusters
Lopez et al. [64]	—	BIM software websites, articles, brochures, and videos	—	The readiness and development of 4D BIM	A BIM knowledge map; a review of different issues concerning the usability of 4D BIM; matrices for decision-making according to investment in BIM software

Figure 3.1: Most review studies in BIM

Source: Vilutiene et al., 2019

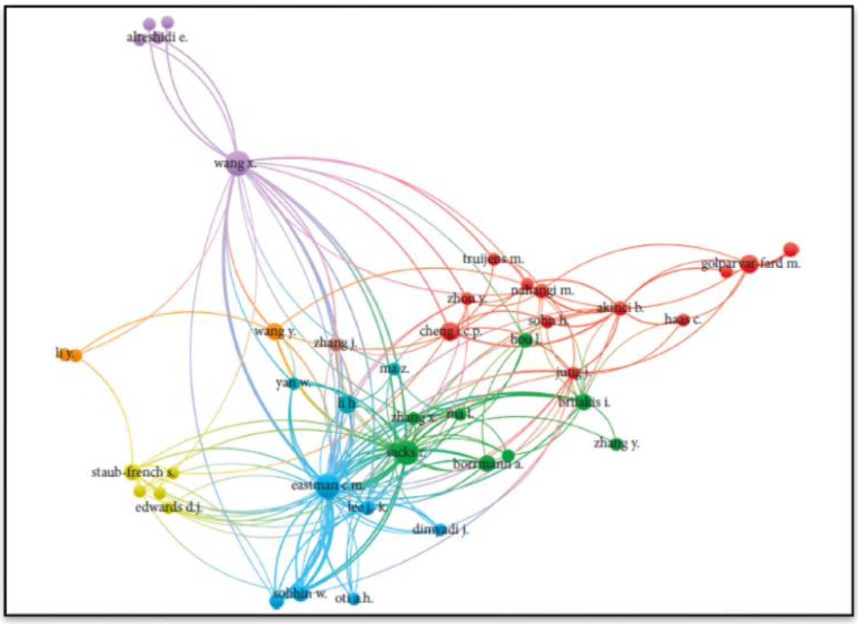

Figure 3.2: Citation network of Authors

Source: Vilutiene et al., 2019

It was determined that BIM has typically focused on finding solutions to operational problems with coordination and management. Its potential for handling complicated issues in specialized fields of structural engineering is still untapped (Vilutiene *et al.*, 2019).

Author	Number of articles	% of articles	Number of citations
C. M. Eastman	**11**	**13.75**	**704**
R. Sacks	**10**	**12.50**	**476**
X. Wang	**10**	**12.50**	**396**
M. Golparvar-Fard	6	7.50	278
A. Borrmann	5	6.25	46
I. Brilakis	5	6.25	172
S. Staub-French	5	6.25	31
B. Akinci	**4**	**5.00**	**318**
K. K. Han	4	5.00	155
L. Hou	4	5.00	93
J.-K. Lee	**4**	**5.00**	**299**
Y.-C. Lee	4	5.00	42
M. Nahangi	4	5.00	105
W. Solihin	4	5.00	33
Total	80	100	

Figure 3.3: Countries with Number of Articles Exceeding 5

Source: Vilutiene et al., 2019

3.2 BIM for Structural Design

The safety of frame structures, whether they are horizontal or vertical, is of utmost importance during construction. To achieve this, it is necessary to have the expertise of a skilled structural engineer involved in the planning, designing, and building of these structures. The structural engineer must ensure that the structures are not only safe but also cost-effective. In the context of the BIM workflow, the structural engineer is responsible for creating a comprehensive and error-free structural BIM model that includes all relevant data for structural design and analysis, such as material properties, loads, section properties, boundary conditions and load combinations. With the ability to manage the cost and order of construction of structural components, the structural engineer has a significant impact on the BIM workflow. This chapter explores the various types of structural BIM models and workflows used in the field of structural engineers, as well as the benefits and challenges associated with using BIM. Additionally, the workflow process of a structural engineering during the design project phase is also presented.

BIM has proven to be immensely advantageous for structural projects that rely heavily on prefabrication and scheduling. By utilizing BIM, material coordination, such as steel and precast concrete, becomes more manageable, leading to better shipping, handling, and installation processes with less need for storage space. A survey indicates that more than half of the design and engineering companies extensively incorporate BIM into their infrastructure projects. Additionally, 42% of owners are closely monitoring the implementation of Structural Information, with 42% opting for a medium implementation. The recent upsurge in BIM adoption within the industry is largely due to the increasing demand from owners and stakeholders for projects to be designed using BIM (Salce, 2012).

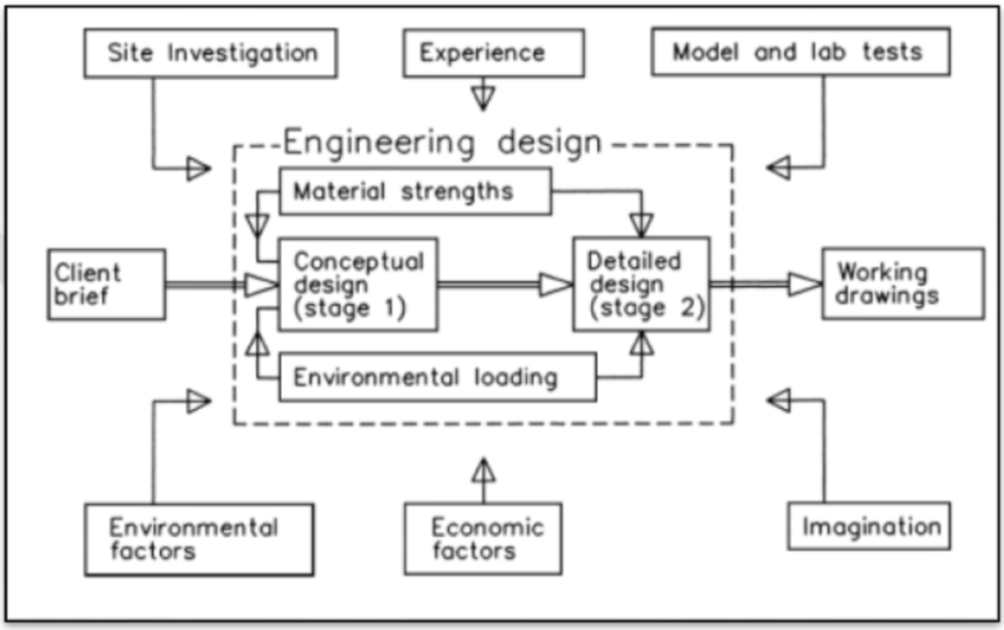

Figure 3.4: Structural Engineering Mind in Design Stage

Source: Salce, 2012

3.3 Structural Information

Element type and element characteristics are two examples of structural data that may be included in a building information model (like area, moment of inertia). With the use of all this data, a structural analysis model that can be loaded into structural analysis software and contains boundary conditions, loads, and other details may be created. The analysis for structural safety may start once the model has been updated with all the element properties, such as type, material, boundary conditions, etc. The layout and construction papers can then be modified with the new information in accordance with the findings.

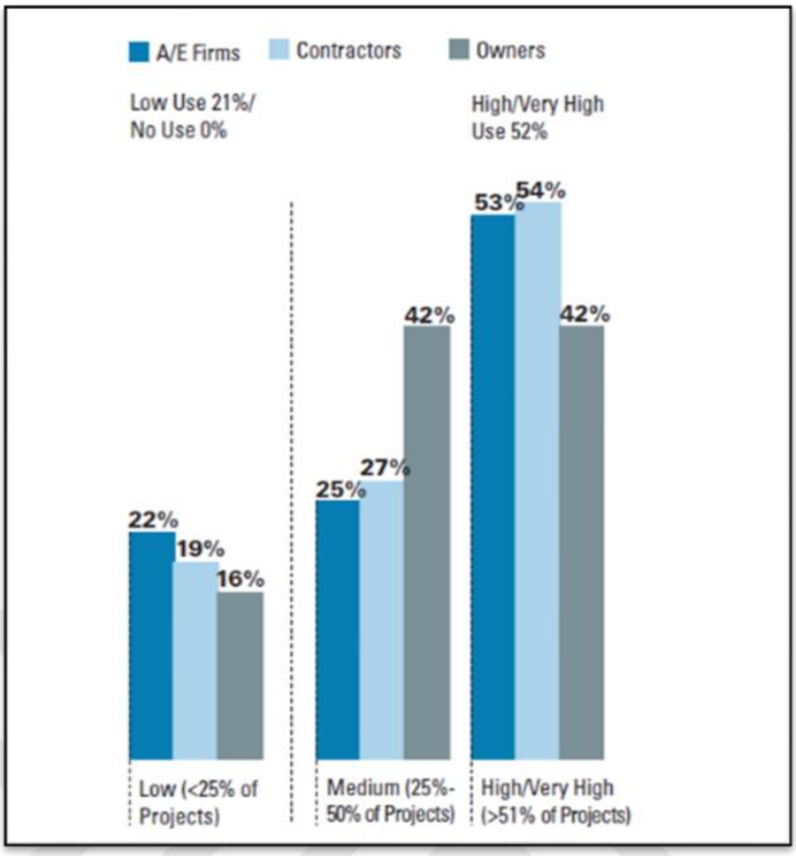

Figure 3.5: Implementation of BIM for Infrastructure 2013

3.4 Structural Design Process

Interpreting the architectural blueprints is the first stage in the structural design process of a project when done the traditional method. This provides the structural engineer with a general idea of the design and lays the groundwork for developing the analytical model that will be used in the structural engineering software to analyze the project in accordance with the specifications, be they related to gravity, seismicity, dynamic behavior, or wind. Drafters often begin the drawing phase at the same time, constructing a representation of the structure and starting the construction documentation. As a result, the identical information was created in many drawings. The fact that several models are being developed for the same project raises the coordination efforts required and increases the possibility of mistakes. The papers get out of sync, compromising the validity of the design, if a change made by the structural engineer to a design element is not updated by the drafter.

3.5 BIM in Structural Use

A study carried out in the United States in 2008 found that the use of BIM in structural engineering was most prominent in interdisciplinary coordination, structural analysis and design project documentation, and. The assessment was conducted to evaluate the extent of BIM adoption in various firms, with specific criteria used to rank the applications. The survey revealed that BIM was highly effective in project documentation, receiving an overall score of 87%, followed by project coordination at 47%, and analysis and design at 25% (Schinler and Nelson, 2008).

The field of structural engineering is witnessing a rapid expansion in the utilization of Building Information Modeling (BIM) techniques, which is increasingly becoming the norm. By employing BIM in a project in a proficient and effective manner, significant time and cost savings can be realized, while also ensuring superior levels of project quality and performance. In the succeeding section, we will examine three commonly acknowledged BIM applications in the domain of structural engineering.

3.6 Inter-Coordination

Coordination plays a crucial role in the widespread adoption of Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) industry. BIM provides a comprehensive prototype model that includes all building components, enabling team members like architects, Mechanical, Electrical, and Plumbing, cost estimators, structural engineers to communicate effectively. With precise 3D geometry and data, stakeholders can seamlessly coordinate and make informed design decisions with confidence. In BIM projects that focus on structural engineering, the coordination view serves as a vital communication tool that promotes effective collaboration between the structural analysis and design team and other project members. However, it's important to note that the coordination view is not suitable for designing or analyzing structures. Instead, it conveys critical information about the building's geometry and other architectural details necessary for design purposes (Ramaji and Memari, 2018).

Efficient collaboration during the construction stage is crucial since it offers contractors significant insights into project scheduling, cost estimation, and sequencing. Moreover, project owners depend on this approach to manage project facilities effectively (Schinler and Nelson, 2008). The coordination view presents a more versatile approach compared to the structural analysis view, allowing for seamless integration across different disciplines using tools like Revit or open file formats such as IFC. This is illustrated in the accompanying diagram where the model is displayed in both coordination and analysis views.

3.7 Documentation

When it comes to the BIM process for structural engineering, creating detailed annotations and schedules for structural parts is usually left until the final stages. Nonetheless, generating 2D rebar drawings and schedules from a 3D model can be a difficult task. Fortunately, SOFISTIK, a German constructability software provider, has developed well-integrated solutions for structural BIM workflows, which are strongly integrated with Revit. These solutions enable the automated production of 3D rebar directly from a FEM model. By automating this process, SOFISTIK provides structural engineering more control over the process of designing and eliminates the need for physically fabricating rebar after FEM analysis, which was previously the norm. This represents a significant shift from traditional practices and is a crucial step in the documentation of structural engineering BIM workflows. Autodesk and SOFISTIK have collaborated to make it possible for engineering to annotate, schedule and detail structural parts from the same analysis and design platform.

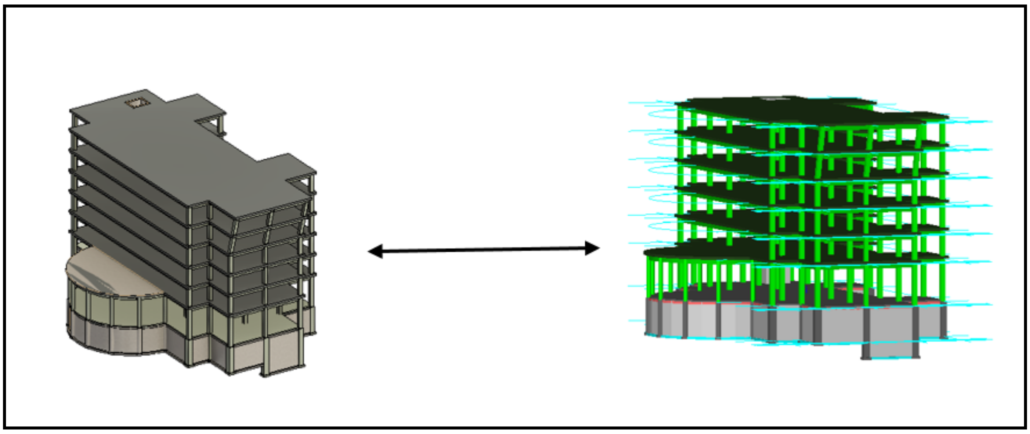

Figure 3.6: Same Model in Different Platforms

3.8 Analysis and Design

The task of analyzing and designing BIM structures is a complex and demanding one that should only be entrusted to a qualified structural engineer or an individual with a deep understanding of structural engineering and static computation. This stage of the structural engineering BIM process involves interpreting numerical data produced by the BIM software, such as the stresses, deformation of structural components, and their behavior within the BIM and FEM environment, which requires specialized expertise in the field. If someone without the necessary skills is tasked with this work, it could result in costly errors that compromise the structure's reliability, safety, and quality. Fortunately, advancements in FEM software, such as SOFISTIK, Dlubal, ETAB Engineer, SAP2000, and others, have significantly enhanced the analysis and design capabilities within the BIM workflow. Previously, transferring quick model data among various BIM systems and analytic tools was challenging, and the exchange of analysis models was restricted to coordination views in the Revit and ARCHICAD BIM platforms. As a result, models transferred using coordination views could not be updated or created in an analytic program. Nowadays, thanks to the introduction of a two-way connection between Autodesk Revit and FEM manufacturers, it has become possible to generate a structural model in Revit, input all the necessary structural information, and seamlessly transfer that model to analysis and design software. This merging of technologies has simplified the BIM process, enabling structural engineers to efficiently analyze and design BIM structures, while also ensuring the safety, reliability, and excellence of the resulting structures.

3.9 BIM Model

The load-bearing elements in a multidisciplinary BIM model are depicted by the structural model. This model incorporates both the physical and analytical models, resulting in a comprehensive structural BIM model. As part of the BIM process, the structural model encompasses all aspects relevant to structural engineers, including vertical and lateral load-bearing components. While analyzing and designing, non-load-bearing components in the model, such as windows, doors, MEP and HVAC installations, floor systems, and ceilings, are deemed less crucial by structural engineers. (Walter Rustler, 2015). A crucial advantage that a structural engineer can derive from utilizing a 3D-BIM model is the central storage of all essential information in a database.

3.10 Physical Model

Within the central of Building Information Modeling (BIM) platform, the physical model geometry refers to a robust representation of the structural components. This physical model is distinct and separable from the main BIM model, devoid of any architectural, mechanical, electrical, or plumbing elements. The BIM modeler has the autonomy to initiate the creation of a physical model, even without the involvement of the architect. By constructing the physical model, the structural template in the Autodesk Revit BIM system automatically generates analytical building components like analytical beams, braces, columns, floors, and walls. The analytical and physical models are presented in Figure.

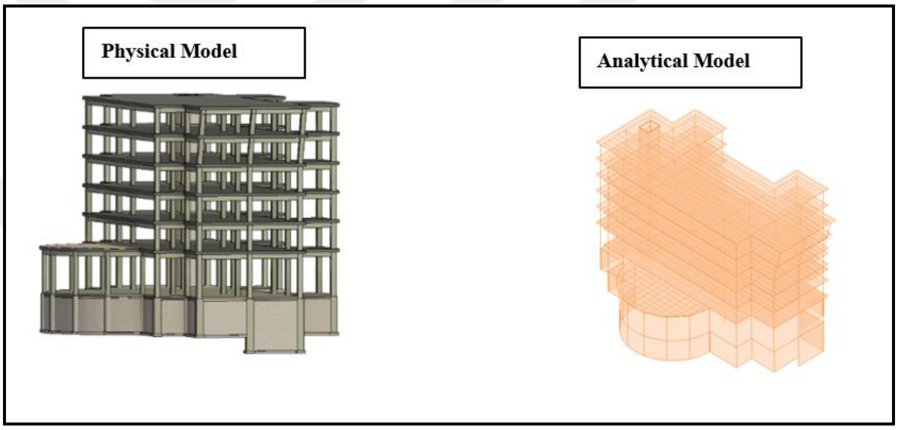

Figure 3.7: Structural Template in Autodesk Revit BIM System

3.11 Analytical Model

As previously mentioned, there is a close relationship between the physical and analytical models. The latter relies heavily on the former for important data, such as material properties, cross-sectional attributes, and overall shape. In Revit, the analytical model is automatically created alongside the physical model, representing frame elements like columns and slabs as lines or surfaces. This simplifies the structural computation, analysis, and design process. Without an analytical model, interoperability between BIM and FEM software can be difficult, and performing finite element analysis becomes more complicated. Depending on the intended purpose or analytical interest, the analytical model in Revit can be turned on or off during the physical model's construction. Relevant structural loads and boundary conditions are only applied to the analytical model. The diagram depicts a classical analytical model that possesses essential structural characteristics, such as loads and boundary conditions. The analytical model plays a significant role in performing structural analysis by establishing interconnected connections between Revit and FEM software applications.

3.12 Structural Template

The BIM model creation process commences with the use of templates, which provide a solid foundation. Revit software suite comes equipped with a diverse range of templates that are tailored to meet the unique requirements of various specialized fields in the AEC industry. A wide range of templates is available, covering different areas such as architecture, structural engineering, construction, and MEP (mechanical, electrical, and plumbing). These templates include specialized families, libraries, and views that are tailored to meet the specific needs of each discipline. For instance, in the structural discipline, non-load-bearing elements like walls, windows, and insulation panels are concealed from view. Additionally, the templates associated with each discipline are identified by the RTE file extension.

3.13 Structural BIM Workflow

Through a thorough examination of literature and industry standards, we demonstrate how BIM has revolutionized the design process and greatly improved the efficiency of structural engineers. This segment showcases the practical implementation of BIM in the field of structural engineering, while the following section offers a concrete illustration of how a single, central BIM model can seamlessly traverse various disciplines in the structural design lifecycle.

3.14 Central Model

The structural BIM process is exemplified in the figure below, which outlines the steps involved in developing a BIM model. Beginning with the creation of a BIM model in Revit, structural parameters, attributes, and metadata are added to the model, as depicted in the accompanying figures. Revit serves as a central platform for producing, managing, and updating BIM model data, allowing for efficient collaboration among project team members. Depending on the project scope, the architect or a designated BIM modeler may initiate, create, or begin the structural BIM model. It's important to note that architects and structural engineers may have differing perspectives on geometry, member size, and material characteristics, necessitating careful consideration during the structural model development process. Architectural and structural levels, same settings and templates, may also differ. In some cases, visual scripting environments like Dynamo or Grasshopper may be employed to parametrically generate models, reducing redundancy and enabling easy modifications. While there's no single, definitive BIM process for structural engineering, it's advisable for project teams to develop a streamlined, tailored workflow that meets their specific design requirements. This workflow must easy to follow, and audit for maximum efficiency and accuracy.

3.15 Finite Element Model Method

The majority of structural engineering software relies on the Finite Element Method, or FEM. To effectively use these tools, it's crucial to understand the concepts, mathematics, and physics that underpin the governing equations and internal force calculations. Without a solid grasp of these fundamental ideas, computed findings may be unreliable and lead to dangerous design decisions. Structural engineers use various techniques for static analysis, such as the force, reduction, and displacement methods, to examine internal forces, moments, and deformation capacity. The displacement method is often favored due to its efficient computing power in modern FEM software.

The computational procedure for Finite Element Method (FEM) utilizing the numerical approximation technique entails dividing a structural component into finite elements using a mesh. Subsequently, the stiffness matrix is computed for each element, and nodal loads or load vectors are generated. The cumulative stiffness matrix is then calculated, along with a vector representing the total load for the system. Afterward, the combined stiffness matrix and load vector are taken into account for support and restraint conditions. Finally, the internal forces and displacements at each node are determined by employing the principle of virtual work.

To analyze and design an analytical model in Revit, it's necessary to transmit it to a FEM program linked to Revit. In a SOFISTIK environment, a Finite Element Model can be visualized, and ribbons can link a Revit to a SOFISTIK FME software environment. It's also possible to create subsystems for different analysis in SOFISTIK, such as a slab of a certain level, or a frame section.

3.16 Reinforcement Detailing

The implementation of BIM technology has revolutionized the field of structural engineering, offering a multitude of benefits such as the ability to visualize the arrangement, placement, and spacing of reinforcement, as well as quickly identifying potential issues. By harnessing the full potential of BIM, structural engineers can now significantly enhance their design capabilities, while also saving valuable time and minimizing mistakes and rework. Furthermore, the reinforcement model can be conveniently accessed and customized by engineers according to the required additions and existing reinforcement. To illustrate, software such as SOFISTIK can be utilized to generate a 3D rebar model and subsequently transform it into a 2D reinforcing plan based on design and analysis outcomes. A real-life example which displays a 3D rebar model that was created for a slab in a case study. This 3D model was then used to obtain a 2D reinforcement plan. Furthermore, the SOFISTIK window, which is used to make necessary reinforcement adjustments.

3.17 Documentation

In the BIM process, structural engineers are responsible for the detailed scheduling and design of structural components after thorough analysis. The Revit-SOFISTIK environment offers greater control to structural engineers during the design process, which is a departure from traditional methods of describing and generating quantity or material schedules. One of the major achievements of BIM documentation is the ability to annotate and describe structural components within the same analysis and design platform. There are several options available to users for reporting and documenting reinforcing schedules, such as SOFISTIK's OpenXML (.docx), or Revit schedule, document, report browser (plb) and quantity toolbar. It's important to recognize that the structural discipline is not isolated and must consider interconnectivity with other fields during the design process. The design process depends on software and work processes, and many suppliers are continually updating their solutions to enhance BIM applications. BIM adoption has been identified in several case studies, including a comparison between conventional design methodologies and collaborative SAP2000 and Revit integrated in Robot and Revit (Sampaio and Azevedo, 2018).

The goal of (Hamidavi, Abrishami and Hosseini, 2020) is to advance BIM to level 3 by integrating optimization into Robot and Dynamo. The purpose of the thesis go through two possible scenarios that can be utilized. The first scenario is the conventional one, while the second one involves the utilization of IFC exchange that employs interoperable procedures. The third scenario, known as integrated modeling, requires all stakeholders to work within the same environment. Each scenario is closely tied to a specific BIM level framework, such as the UK BIM Framework or Succar's BIM Framework.

Different software may be employed depending on the workflow. In the traditional design approach, the processes are unable to communicate with one another, which results in independent coordination of the structural model from the other disciplines. Compatibility and clash detection are performed manually instead of using BIM coordination tools. Sharing information on paper, performing numerous manual tasks, and avoiding automation are necessary when following the conventional method.

On the contrary, the IFC interchange approach requires the utilization of an openBIM tool in the latter scenario. Various software applications, such as ProSap Professional, Autodesk Revit/Robot, Tekla Structural Designer (TSD), and Tekla Structures, offer interoperable modeling format exchange (TS). It is crucial to ensure that the IFC import/export operations comply with the standards to ensure accurate architectural, MEP, and structural modeling. A high level of software interoperability is desirable to minimize information loss and errors throughout the process. Starting with the structural model, the architectural model can be developed, and federated models can be utilized to identify conflicts among different models. TSD/TS and Revit/Robot are capable of producing comprehensive 3D models, and issues are detected and monitored during the process. In the third scenario, a collaborative approach to modeling is required, involving idea sharing and information exchange among all participants through a Common Data Environment (CDE). Autodesk Revit

2021 can be used to model for architectural, structural, and MEP disciplines within the BIM 360 CDE. Similarly, in the Trimble Connect CDE, TSD and TS may collaborate on integrated project workflows. For those seeking a comprehensive environment that supports numerous native formats and includes IFC format, as well as model verification, and advanced information management and project collaboration, Oracle Aconex is a possible provider to consider.

3.18 Workflow's Description

As we progress from one scenario to another, we can witness the evolution of the three processes, which transition from pre-BIM situations to integrated modeling. The BIM levels that were initially described in the UK Framework the ISO19650-0 from 2019, and the BIM Stages presented by (Succar, 2010) may all be compared.

3.19 Traditional Design Workflow

Collaboration among professionals remains an essential factor in some nations. One effective approach to enhancing designs and processes is to implement Business Process Reengineering (BPR), which can facilitate the transition from BIM level 0 to level 1. Typically, the conventional design process involves the transfer of files in formats such as .dwg and .pdf, with 3D modeling primarily employed for architectural visualization and rendering purposes. However, owing to the absence of interoperable interchange protocols that allow for seamless collaboration, this technique often lacks cross-disciplinary compatibility, leading to redundant designs.

3.20 IFC Exchange Improvement

This method prioritizes collaboration and leverages compatible formats, with automated model inspection and the creation of new roles such as the BIM Manager Coordinator. It represents a step forward in the adoption of BIM-enabled processes, facilitated by the utilization of interoperable exchange formats like the (IFC) and the relevant modification of the (CDE). When a Structural Design is part of the workflow, the process involves generating and distributing a Structural Information Model. The benefits include increased compatibility, the identification of conflicts through BIM Coordination tools, enhanced collaboration, and greater cost savings.

3.21 CDE's Integrated Modeling

The aim of this methodology is to go beyond the Level 2 BIM norms (ISO19650-0, 2019) by promoting interdisciplinary cooperation across several domains. Due to the interdependent nature of design operations for architecture, structural, and MEP, it may be challenging to differentiate between process components. As a result of this repetitive process, model detailing is constantly refined. A rudimentary model with a LOD 200 definition is created in the first iteration, which is then followed by three subsequent iterations for LOD 300, 350, and 400, respectively. This approach is employed to eliminate the need for rework while the detailed process continues in a sequential manner.

To guarantee the quality of every stage, the consent of the BIM Manager, Coordinator, and Supervisor is indispensable for the subsequent phases.

- The initial phase, Phase 0, encompasses basic models for architecture, structure, and MEP with a Level of Development (LOD) of 200.
- Moving forward, Phase 1 involves preliminary models with an LOD of 300 for the aforementioned aspects.
- In Phase 2, the focus shifts towards more intricate modeling, with detailed models for architecture, structure, and MEP at LOD 350.
- Finally, in Phase 3, the models become even more comprehensive, with detailed models at LOD 400 for all three components.

3.22 Processes for Structural Design, Analysis and Detailing In the BIM

Currently, numerous software applications employ BIM methodology to perform modeling, analysis, design, and detailing tasks. To outline the steps involved in structural analysis, design, and detailing, a straightforward approach can be adopted. The process commences with the creation of a physical model, which is subsequently integrated with other disciplines. Next, an analytical model is developed based on the software used, and then structural analysis is conducted, either within the same software or in conjunction with the mapping of elements, loads, boundaries, and other variables. Once the code is validated, the detailed process is initiated.

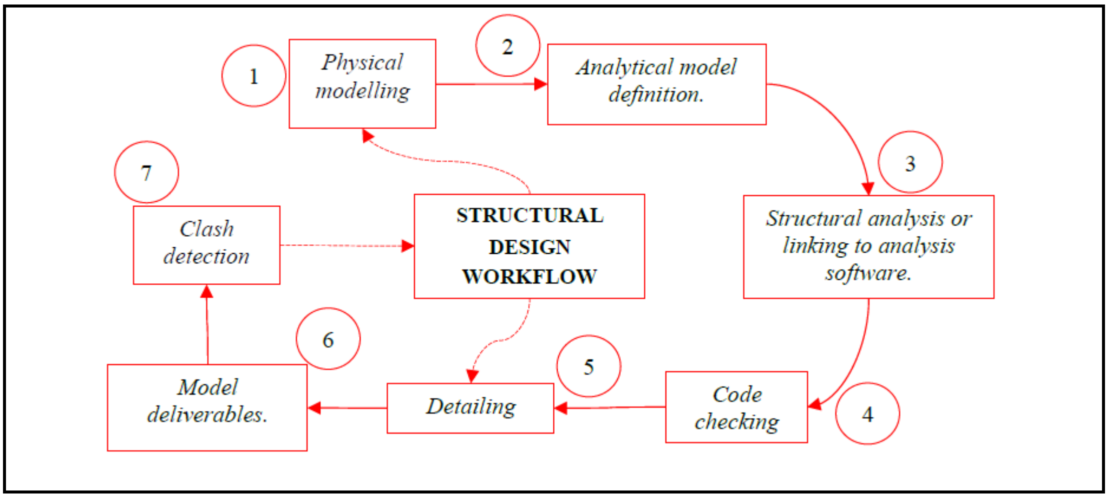

Figure 3.8: Structural Design Workflow

4. CASE STUDY OF INTEROPERABILITY OF BIM

4.1 Introduction

The thesis provides evidence to support its conclusion through a case studies. The first case study examines the exchange capabilities between Revit and selected FEM software through a direct link. The second case study examines the exchange capabilities between Revit and ETAB through indirect link. The first case study outlines various scenarios for direct data exchange between Revit's BIM platform and FME tools, such as SOFISTIK. Second case study, on the other hand, focuses on indirect data exchange scenarios between the Revit BIM platform and the ETAB program. Through this case study, we can understand how BIM benefits structural engineers.

It is essential to note that numerous BIM software options are available in the market, and some of the most popular ones include:

Table 4.1: Various Software's For Structural Engineering

Autodesk Revit	Trimble SketchUp
ArchiCAD	Graphisoft MEP Modeler
Bentley AECOsim	Nemetschek Allplan
Vectorworks	Autodesk Navisworks
Tekla Structures	Rhino BIM

4.1.1 Project definition

Table 4.2: Project Detail Elements

Utility of building	Residential complex
No of stories	G+5
Type of construction	R.C.C framed structure
Types of walls	brick wall
Ground floor	2.9 m
Floor to floor height	2.9 m
Column sizes	230x600 mm
Beam Sizes	230x600 mm
Slab thickness	125 mm
Wall thickness	150 mm

4.2 Material properties

Concrete grade= M30

According to IS code the following material parameters are considered:

Compressive strength f_{ck} = 30 MPa

Tensile strength f_{etm} = 2.9 MPa

Modulus of Elasticity E_{com} = 32.8 GPa

Weight (reinforced concrete) = 25 kN/m^3

Partial safety factor y_e = 1.50

Design strength f_{ed} = 20 MPa = 2.0 kN/cm^2

Reinforcing steel

Steel grade F_e 415 grade in accordance with IS code is chosen for all reinforcing steel.

Yield strength f_{yk} = 415 MPa

Partial safety factor y_s = 1.15

Design strength f_{yd} =391 MPa 39.1 kN/cm^2

4.3 Model preparation

To start using BIM, a central model needs to be created that will act as a shared database for design data from different fields. In this particular case, the BIM platform being used is Autodesk's Revit, and the structural model is being created using Revit Structure. The goal is for Revit to act as the integration platform. Autodesk also offers Robot structural analysis software for building analysis and design, but the authors found that it has a steep learning curve and lacks some necessary capabilities. Many structural engineers are more familiar with traditional software like ETAB and SAFE from CSI, so using those packages alongside BIM could help with adoption. Therefore, for the superstructure, ETAB was chosen for this study.

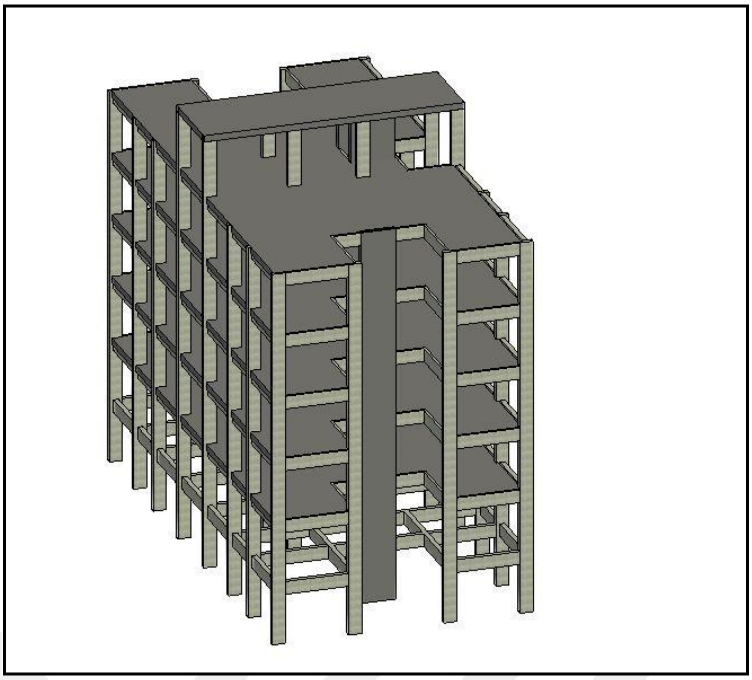

Figure 4.1: Structural Model of the Thesis

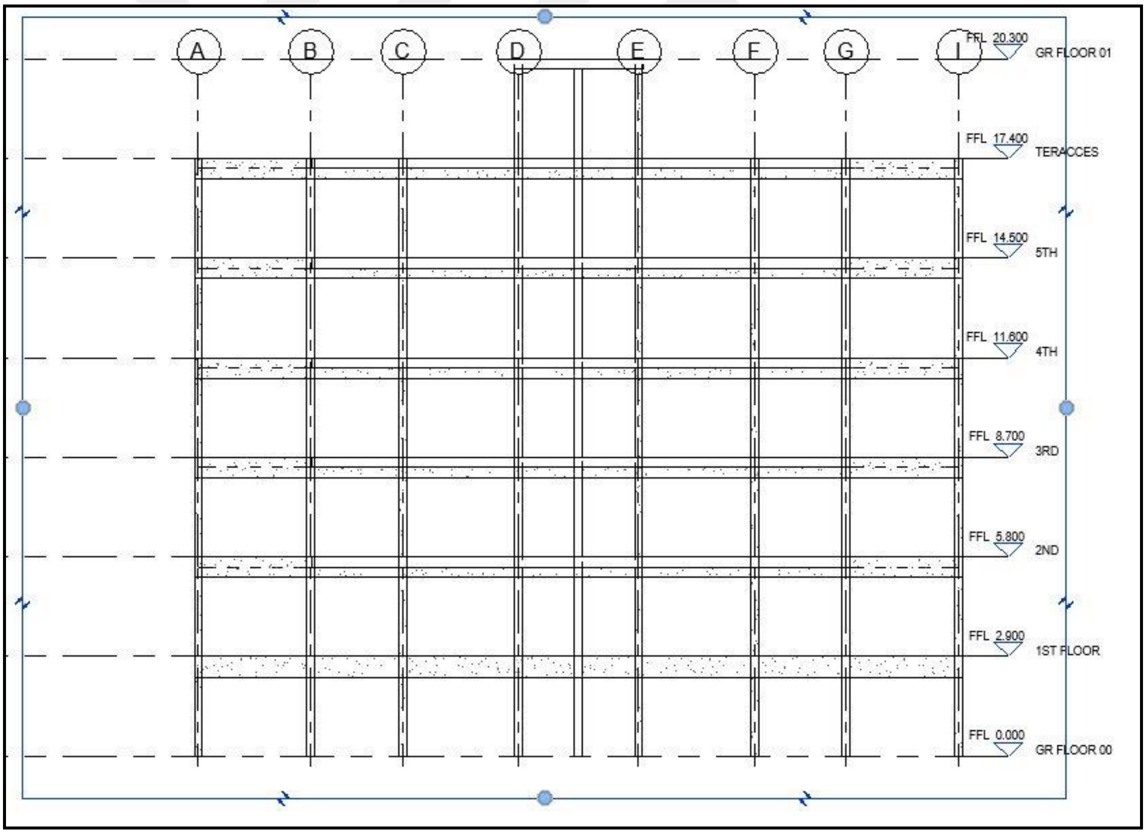

Figure 4.2: First Floor Elevation

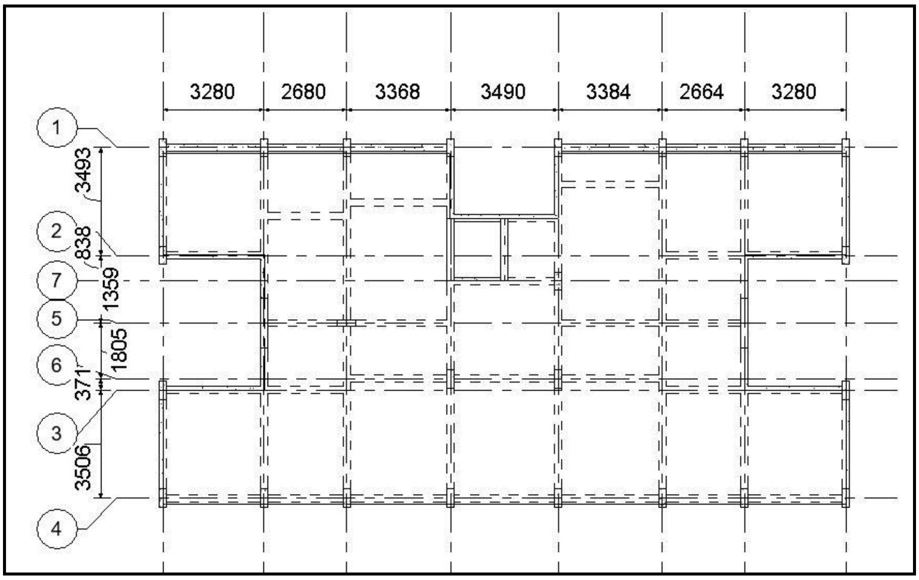

Figure 4.3: Structural Plan View

4.4 Creating the Analytical Model

When using a BIM workflow, the creation of an architectural model results in the simultaneous creation of a corresponding structural model. This approach reduces the modeling workload of the structural engineer. The figure below shows the central model of the building being studied, which includes both physical and structural components. Analytical models play a crucial role in structural engineering as they provide engineers with a means to analyze and design complex structures efficiently and accurately. Some of the key benefits of using analytical models in structural engineering include:

Understanding the behavior of structures: Analytical models enable engineers to understand how structures behave under different loads and conditions. This understanding is critical for designing safe and efficient structures. Design optimization: Analytical models provide engineers with the ability to optimize the design of structures to meet specific requirements, such as minimizing weight or reducing cost. By using analytical models, engineers can simulate the performance of various design alternatives and select the most effective one.

Prediction of failure: Analytical models can predict the behavior of structures in extreme conditions, such as earthquakes or high winds. This information is critical for designing structures that can withstand these events and minimize the risk of failure.

Time and cost savings: Analytical models can save time and reduce costs by allowing engineers to simulate the behavior of structures before they are constructed. This can help identify potential problems and design solutions before construction begins, reducing the need for costly changes during construction. Verification of experimental results: Analytical models can be used to verify experimental results, allowing engineers to validate their designs and ensure they meet the required standards.

4.5 Physical to Analytical Automation

Utilize the physical model as a reference point to automate the generation, linking of elements, and maintenance of the analytical model. To implement automation from physical to analytical methods:

To access the Structural Analytical Model panel in the Analyze tab, click on (Analytical Automation). From there, utilize the physical model to create analytical elements and establish connections between them. This will result in the construction of an analytical model that can be modified as necessary to reflect changes made to the physical model.

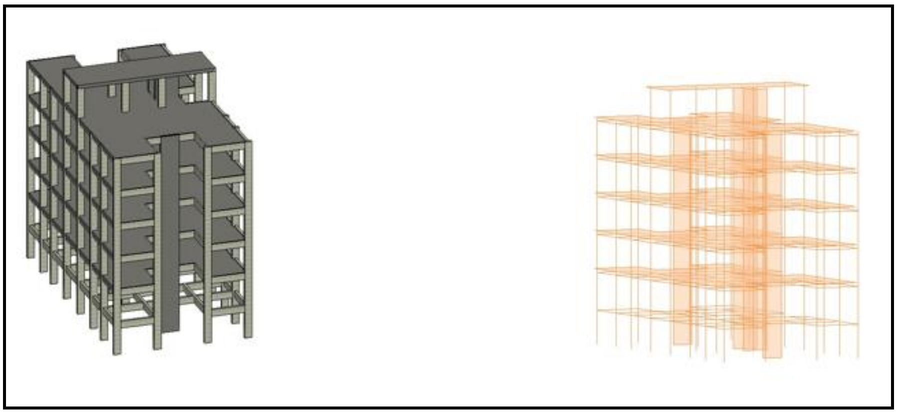

Figure 4.4: Physical to Analytical Geometry

4.6 Clash Detection

The primary requirement for any composite design in a multidisciplinary project is clash detection. Clash detection involves inspecting 3D models created using various modern software tools such as Revit Architectural, Revit Structural and Revit MEP to identify interferences that frequently occur during the coordination process. In Building Information Modeling (BIM) 3D models are created for different types of structures, including Structural, Civil, Architectural and MEP (Mechanical, Electrical, and Plumbing). When these different models are combined to create a complete BIM model clashes between elements can occur.

Clash detection tests are conducted to identify conflicts between different elements within the 3D Building Information Model before the construction begins. This helps optimize the construction schedule reduce costs and minimize change orders. The use of clash detection applications in the AEC industry enhances the productivity of design and construction projects.

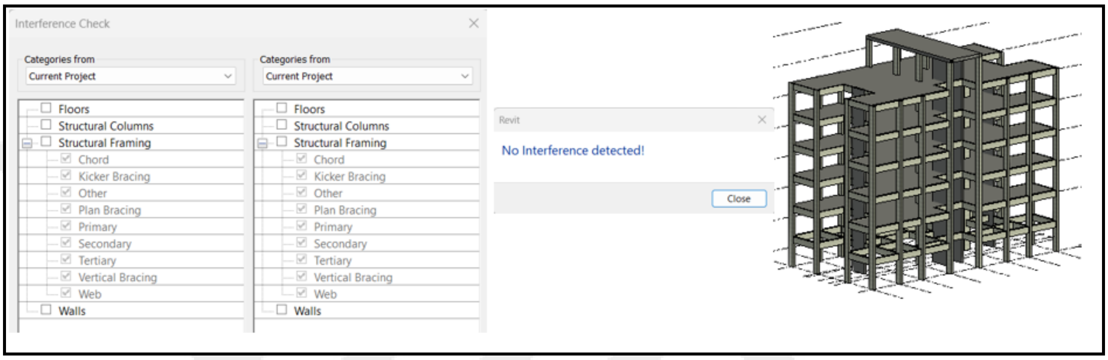

Figure 4.5: Checking interference in Revit

4.7 Exporting Analytical Model Using IFC

Revit provides tailored options for IFC export setup. Export parameters for IFC export are depicted in Figure, which Revit uses to export the modeled data to an IFC file. These export parameters are categorized into different sections, which include: General, Additional content, and Property sets, Level of detail and Advanced

4.8 Verification (FZKViewer)

Once the model was successfully exported from Revit to IFC format, it underwent a check in model viewers to identify any modelling errors. The entities and relations that were exported into the IFC file format are summarized in Figure which indicates the presence of 264 beams, 24 columns, and 6 slabs. The FZK model viewer interpreted the model, as shown in Figure.

Entity	Amount
Entities	**326**
IfcBeam	264
IfcBuilding	1
IfcBuildingStorey	8
IfcColumn	24
IfcGrid	7
IfcOpeningElement	10
IfcProject	1
IfcSite	1
IfcSlab[Floor]	6
IfcWallStandardCase	4
Relations	**1354**
IfcRelAggregates	3
IfcRelAssociatesMaterial	43
IfcRelContainedInSpatialStructure	8
IfcRelDefinesByProperties	1234
IfcRelDefinesByType	56
IfcRelVoidsElement	10
EntityTypes	**4**
IfcBeamType	25
IfcColumnType	24
IfcSlabType	6
IfcWallType	1

OK

Figure 4.6: FZK Viewer Result

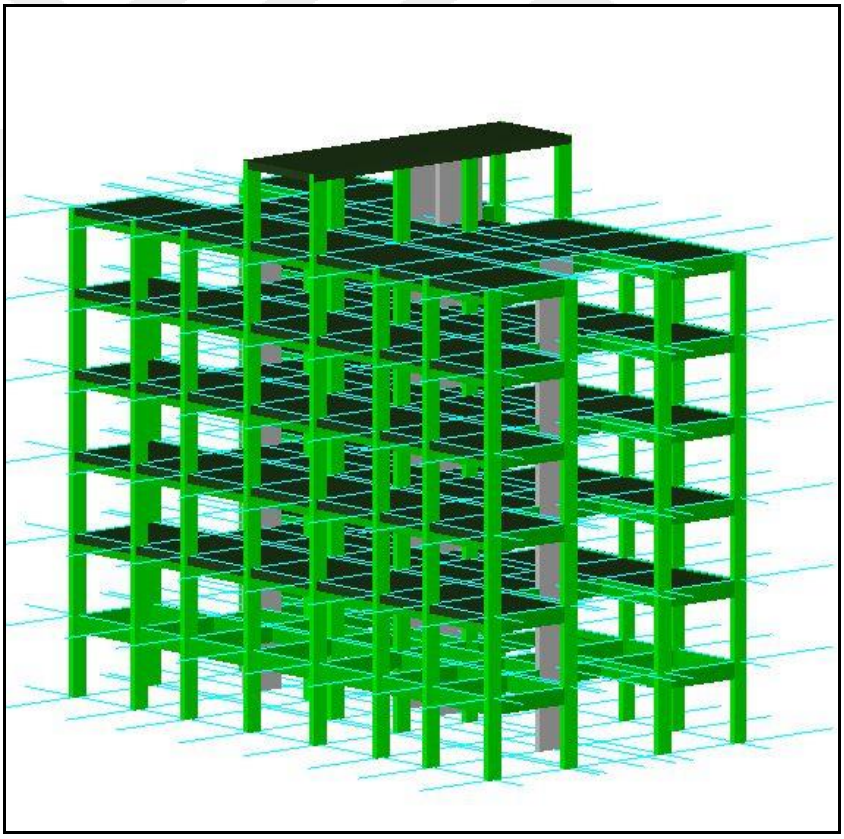

Figure 4.7: FZK Model Viewer

4.9 Case 1: Revit-SOFISTIK Direct Link Interface

The Revit-SOFISTIK interface enables seamless transmission of modeling, analysis, and design data. The integration is highly precise and facilitates direct transfer of critical structural information, including material properties, load cases and combinations, and boundary conditions.

Afterward, the Revit structural model (analytical) is modified and shared with SOFISTIK (FEM) via bi-directional links. The image illustrates all the structural data and attributes necessary for structural analysis by SOFISTIK.

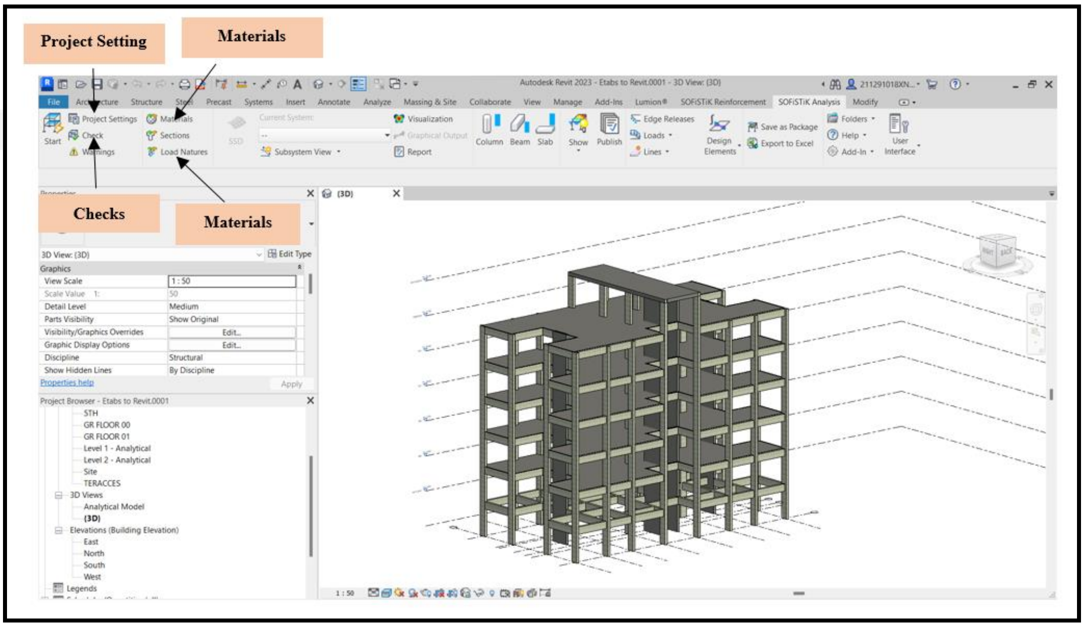

Figure 4.8: SOFISTIK User Interface

Upon completion of the BIM model preparation, a green add-on link becomes available, giving user's access to a range of commands. Upon clicking the link, a ribbon with various options is revealed, as illustrated in Figure above. The following is a summary of each command:

a) Analysis settings - This command allows users to adjust various project settings, including file titles, project design code, language, FEM model type and more.

b) Analytical check - Prior to calculation, this command scrutinizes the Revit analytical structural model for inconsistencies such as , support, misalignment of structural elements, mapping failure, overlap and properties.

c) Materials - Users can use this command to compare SOFISTIK material and Revit material in a table for reference.
d) Section - This command displays a mapping table for Revit against SOFISTIK cross-sections and cross-section parameters.
e) Load Nature - With the Load Nature command, you can compare the load nature specified in the SOFISTIK Revit Load Natures mapping table to the one defined in the Revit Load Natures mapping table.
f) Analyze - Use this command to export the analytical data of your Revit model to the SOFISTIK (FEM) platform. This feature allows you to review and analyze the model, export it, load it, and generate a mesh.

4.10 Workflow

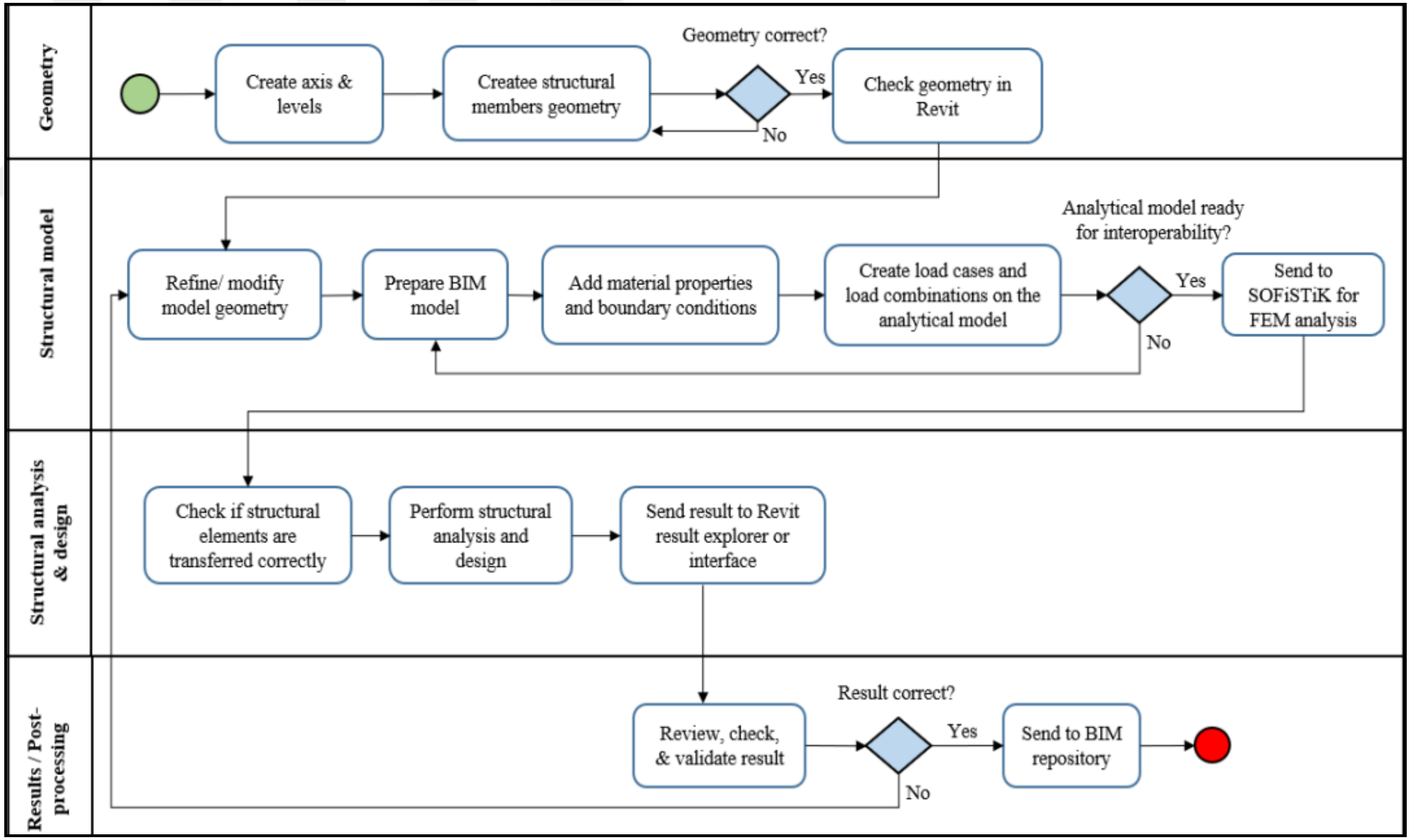

Figure 4.9: Workflow for Revit Structure -SOFISTIK

Results

The Revit-SOFISTIK exchange scenario results are presented in the following table.

	Legend
✓	BIM transfers structural properties to FEM tool accurately
× ✓	Slight adjustments may be needed in FEM tool to ensure accurate transfer of properties
×	Inability to transfer properties is not an option

Table 4.3: Result SOFISTIK

Structural Data	**Revit of SOFISTIK**
Geometry	
Overall model	✓
Floor plan (axis)	✓
Beam (cross sections, b)	✓
Slab	✓
Column (cross sections, c)	✓
Column (Length)	✓
Beam (Length)	✓
Material Properties	
Material type (concrete)	✓
Material Strength	✓
Material type (reinforcing steel)	✓
Material Strength	✓
Boundary Condition	
Fix support	✓
Load	
Live load(LL)	✓
Dead load(DL)	✓
Wind load(WL)	✓
Snow load(SL)	✓
Load Combination	
All combinations	✓
Result Exploration	
Calculated results back to Revit	✓

4.11 Case 2: Revit-ETAB indirect Link Interface

In this case study, the operational process of indirect link exchange between Revit and ETAB software is depicted in the diagram below. The diagram provides all the relevant data points. To enable the seamless transfer of data between the Revit-ETAB Engineer, an IFC link is employed. The Revit-ETAB exchange scenario has been summarized in the following table.

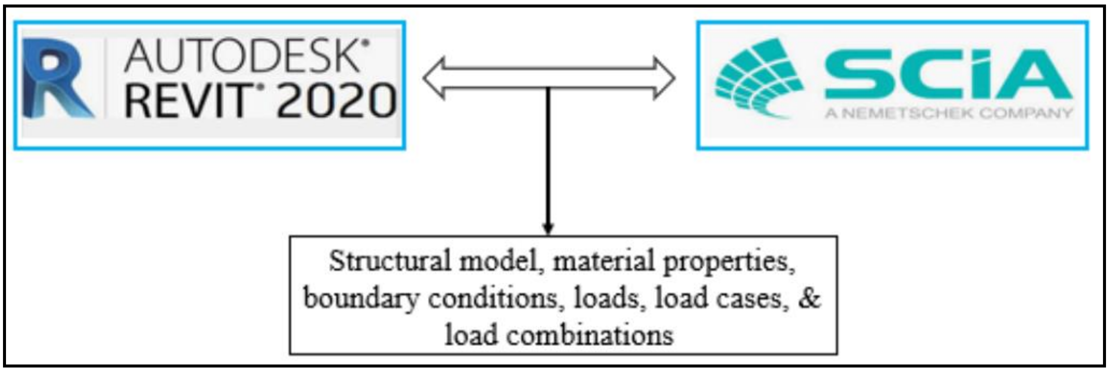

Figure 4.10: Revit to ETAB

Workflow

In the diagram below, you can observe the process map that illustrates the workflow between Revit and ETAB Engineer. The sequence of steps involved in this workflow is quite similar to that of the Revit-SOFISTIK workflow.

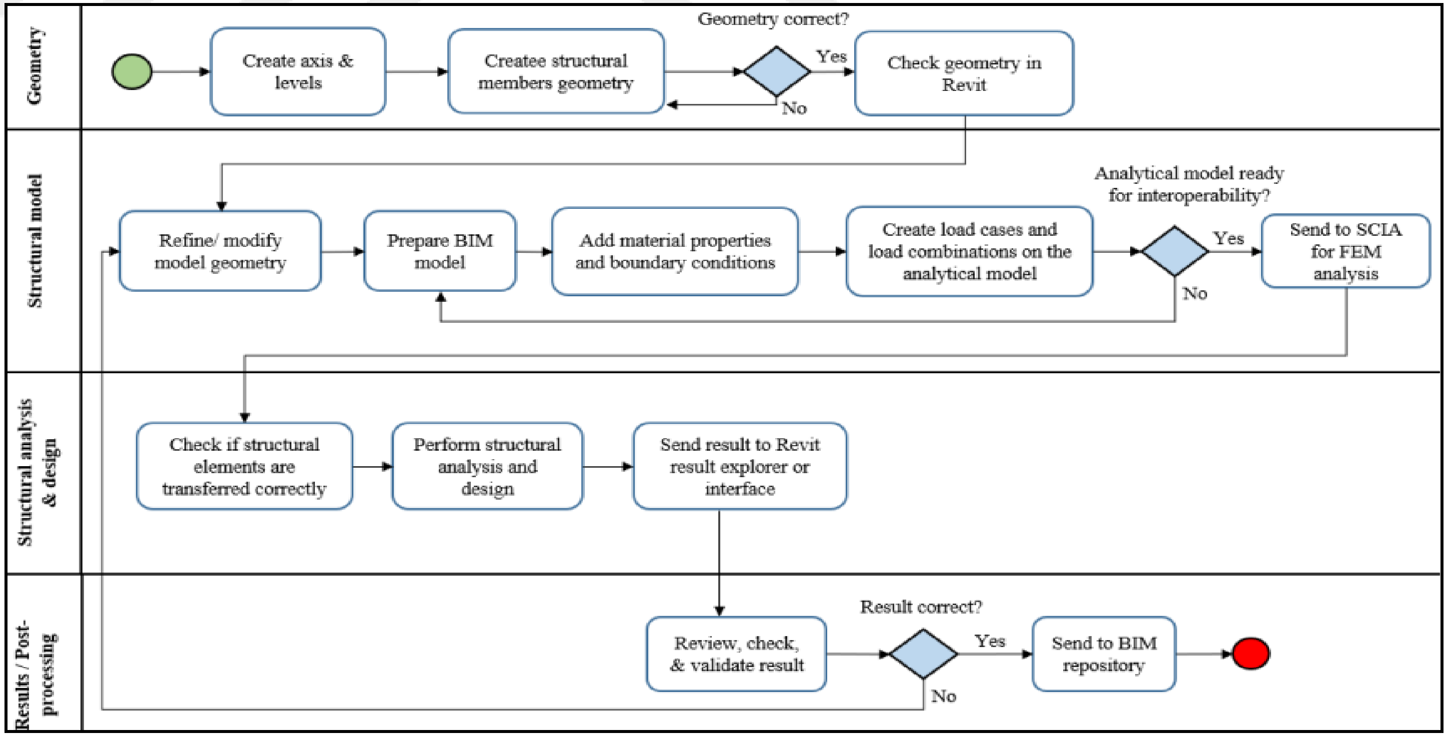

Figure 4.11: Workflow for Revit Structure to ETAB

4.12 Import to ETAB

The input data quality was verified using the Model Viewer tool before transferring it to ETAB Engineer. The following section evaluates ETAB ability to import data from IFC and the quality of the imported data. ETAB provides import statistics for every successfully imported IFC file.

The analytical model is utilized for conducting structural analysis in E-tabs. The imported model, as depicted in Figure exemplifies the conversion of the model into an analytical one, with visible disjointed nodes.

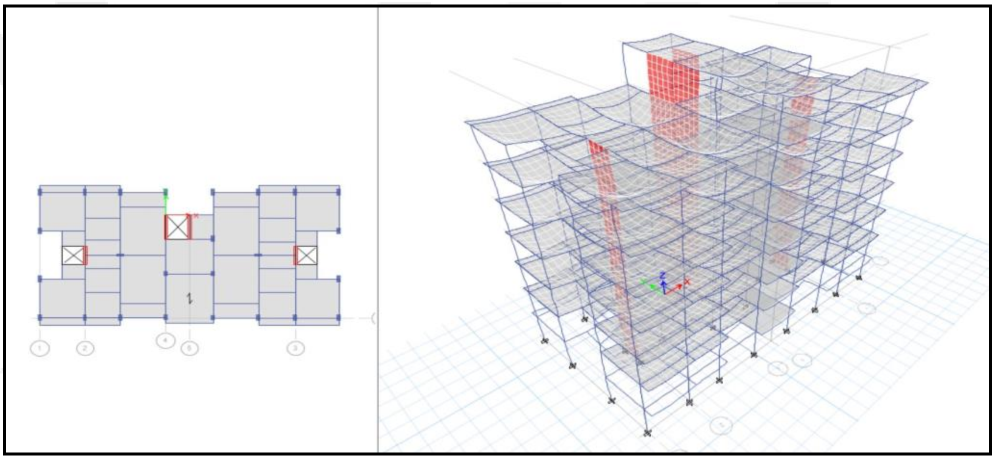

Figure 4.12: 3D View in ETAB

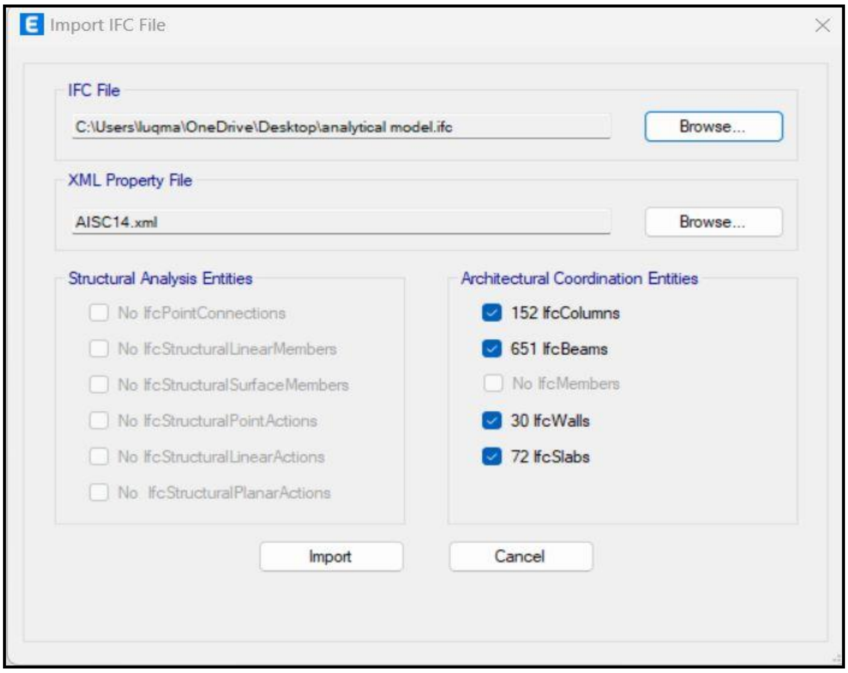

Figure 4.13: Dial Box of ETAB

Results

The data from the Revit-ETAB exchange scenario has been consolidated and presented in the form of a table, as shown below:

	Legend
✓	BIM transfers structural properties to FEM tool accurately
× ✓	Slight adjustments may be needed in FEM tool to ensure accurate transfer of properties
×	Inability to transfer properties is not an option

Table 4.4: Result Revit to ETAB

Structural Data	**Revit ETAB**
Geometry	
Overall model	✓
Floor plan (axis)	✓
Beam (cross sections, b)	✓
Slab	✓
Column (cross sections, c)	✓
Column (Length)	✓
Beam (Length)	✓
Material Properties	
Material type (concrete)	✓
Material Strength	× ✓
Material type (reinforcing steel)	×
Material Strength	×
Boundary Condition	
Fix support	✓
Load	
Live load(LL)	✓
Dead load(DL)	✓
Wind load(WL)	✓
Snow load(SL)	✓
Load Combination	
All combinations	✓
Result Exploration	
Calculated results back to Revit	✓

5. DISCUSSION AND RESULT

This section of the thesis provides a brief analysis and discussion of the key findings. Some exchange scenarios have been assessed and compared, revealing significant outcomes. Furthermore, a comprehensive table has been created to demonstrate the transfer of structural parameters and data via a scoring system.

5.1 Revit –ETAB Software

The objective of this dissertation is to explore the reliability and coherence of data transmission from Revit to FEM software, specifically ETAB and SOFISTIK tools. The study's outcomes are highlighted as a consequence of this inquiry. The table presents the exchange scenarios for Case Study 2, and a brief overview of the findings from Case Study 2 is provided.

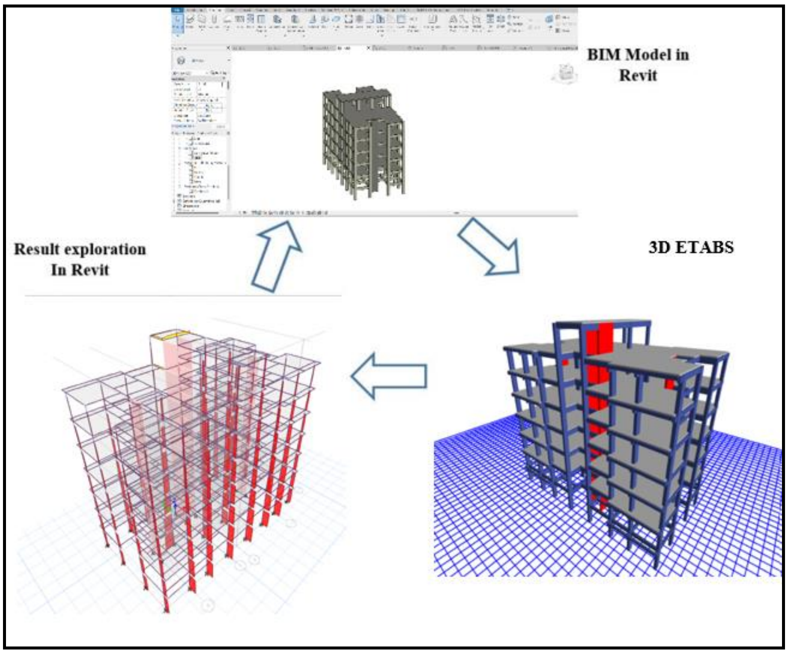

Figure 5.1: Revit to ETAB link

The Figure provides a visual illustration of the round-tripping process in Indirect Link Interoperability. This approach enables the utilization of a single interface for analyses. The workflow commences with the creation of the BIM model using Rivet, which is subsequently transferred to ETAB for conducting Structural Analysis. Ultimately, the analyzed or designed model is sent back to Revit for result exploration, elaboration, and more comprehensive examination.

5.1.1 Geometry

The method used to create the model's geometry closely mirrors that of the preceding section. The software programs used to construct the model allowed for seamless exchange of all its components, including beams, columns, and slabs. It's recommended to choose a suitable building code or standard to use in ETAB Engineer before exporting the BIM model. This step helps ensure the model is processed smoothly and created without any issues in ETAB Engineer.

5.1.2 Materials

In terms of material properties, the manner in which concrete material is linked between ETAB and Revit software can be likened to that of SOFISTIK. Nonetheless, dissimilarities in naming conventions exist in the libraries of both software programs. In order to ensure a seamless transfer of the case study model to Revit, I had to manually align the Revit material families with those of ETAB Engineer materials/sections.

5.1.3 Boundary condition

Regarding the Boundary Conditions, there were no obstacles or complications encountered during the transfer of data between the ETAB and Revit software programs.

5.1.4 Load cases

Regarding Loads and Load Cases, the transfer process to ETAB was not without difficulties. The issue stemmed from the CAD program utilized by ETAB for bi-directional exchange, which is outsourced to a vendor using a different software platform. Exporting the load and its corresponding load cases presented several challenges. Nonetheless, despite these difficulties, the load export was largely successful, akin to previous instances of data exchange.

5.1.5 Load combination

Finally, successful transfer of load combination can be observed in Figure, indicating that ETAB and Revit software are compatible with each other.

5.1.6 Comparison of results

The table below provides a comparison of exchange scenarios utilized in a case study, and their corresponding scores or grades. The grading system was based on the percentage of accurately transferred structural elements and properties. This was computed by dividing the number of correctly transferred elements by the total number of elements in each category, then multiplying the result by 100%. Each transferred element was assigned a score between 0 and 1, based on specific grading criteria. A fully transferred element or property from BIM to FEM was awarded a score of 1, while a score of 0.5 was given when minor adjustments were required before correct transfer. A score of 0 was assigned when no transfer was possible. After analyzing all the data exchanges, the Revit-SOFISTIK link had a perfect score of 100% transfer fidelity, while the Revit-ETAB Engineer link had a score of 86%.

	Legend
✓	The successful transfer of structural parameters from BIM to FEM earns 1 point.
×✓	For accurate transfer, minor adjustments may be required in the FEM tool, worth 0.5 points.
×	If transfer is not feasible, no points are awarded.

Table 5.1: Comparison Result

Structural Data	**Revit-SOFISTIK**	**Revit-ETAB**
Geometry		
Overall model	✓	✓
Floor plan (axis)	✓	✓
Beam (cross sections, b)	✓	✓
Slab	✓	✓
Column (cross sections, c)	✓	✓
Column (Length)	✓	✓
Beam (Length)	✓	✓

Table 5.1: (Cont.) Comparison Result

Structural Data	**Revit-SOFISTIK**	**Revit-ETAB**
Material Properties		
Material type (concrete)	✓	✓
Material Strength	✓	×✓
Material type (reinforcing steel)	✓	×
Material Strength	✓	×
Boundary Condition		
Fix support	✓	✓
Load		
Live load LL	✓	✓
Dead load DL	✓	✓
Wind load WL	✓	✓
Snow load SL	✓	✓
Load Combination		
All combinations	✓	✓
Result Exploration		
Calculated results back to Revit	✓	✓

5.2 Conclusion

The aim of this study was to evaluate the interoperability potential of Revit Building Information Modelling (BIM) software with two structural engineering software's, namely SOFISTIK and ETAB. The study found that the direct link interoperability approach was often used by structural engineers as it allowed for smooth and bi-directional data transfer within the BIM environment. The first case study examined the direct connection capabilities between the Revit BIM platform and the SOFISTIK program, and the second case study demonstrated the indirect connection between Revit BIM and ETABS via IFC. The study used a percentage score between 0 and 1 to evaluate the accuracy and quality of data exchange, with the Revit-SOFISTIK link achieving a perfect score of 100% data transfer accuracy and the Revit-ETAB link scoring 86%. This suggests that the Revit-SOFISTIK link is a reliable method for transmitting structural information between BIM platforms and structural engineering software.

It is important to note that the evaluations and rankings were determined through the company's own expertise and familiarity, and the research was conducted utilizing the latest versions of BIM and Structural software as of 2023. Additionally, certain software companies have introduced innovative tools and neutral file sharing formats, such as ETAB Auto Converter and SAFE, which have the potential to enhance interoperability via Open BIM initiatives.

To ensure a reliable and precise structural model in BIM-based structural engineering design workflows, it is essential to have a solid understanding of structural engineering. The thesis contributes to the worldwide conversation on intelligent data-driven 3D construction methods by discussing the advantages and challenges of using BIM in structural engineering. The study recommends a modified BIM organizational structure for structural engineering firms that prioritizes the involvement and collaboration of project team members and stakeholders.

Overall, the study presents significant findings that can benefit structural engineers and companies looking to integrate BIM into their workflow. It includes customized case studies that address essential queries about the adoption of smart-3D modeling techniques and offers guidelines on connecting FEM models with a BIM platform. This research lays the groundwork for the usage of BIM in structural engineering and contributes to the continuous development of the intelligent data-driven 3D construction methodology.

5.3 Recommendation and Limitation

Hence, it is strongly advised that developers of BIM software prioritize the integration of comprehensive IFC support within their platforms. This integration will facilitate the utilization of an indirect link, enabling seamless import and export of complete information. Furthermore, it is recommended that future efforts focus on investigating the underlying causes of missing information and developing effective methods to address this issue. Successfully resolving the problem of missing information represents a crucial initial stride towards overcoming all interoperability hurdles.

The study acknowledges one significant limitation it was conducted on only two project models. While this approach was sufficient to identify missing information problems, it may not reflect the scenario when different types of structural models are utilized. Therefore, further testing using diverse types of structural models is necessary to validate the findings presented in this thesis. In future research, it is recommended to replicate the experiment on a broader range of structures, including composite structures, timber structures, etc., encompassing varying levels of complexity. Additionally, it is important to investigate the causes of the information missing problem and devise methods or algorithms to mitigate this issue.

The thesis incorporates case studies to examine different aspects of using BIM as a structural tool. It aims to compare popular software options to enhance their usability in construction at the structural level and assess their respective advantages, disadvantages, strengths, and weaknesses.

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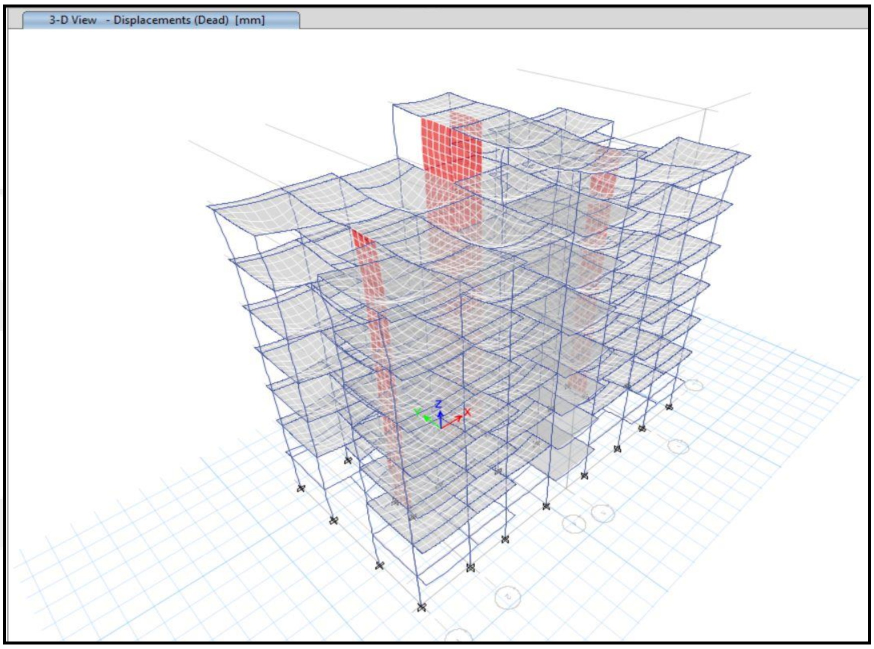
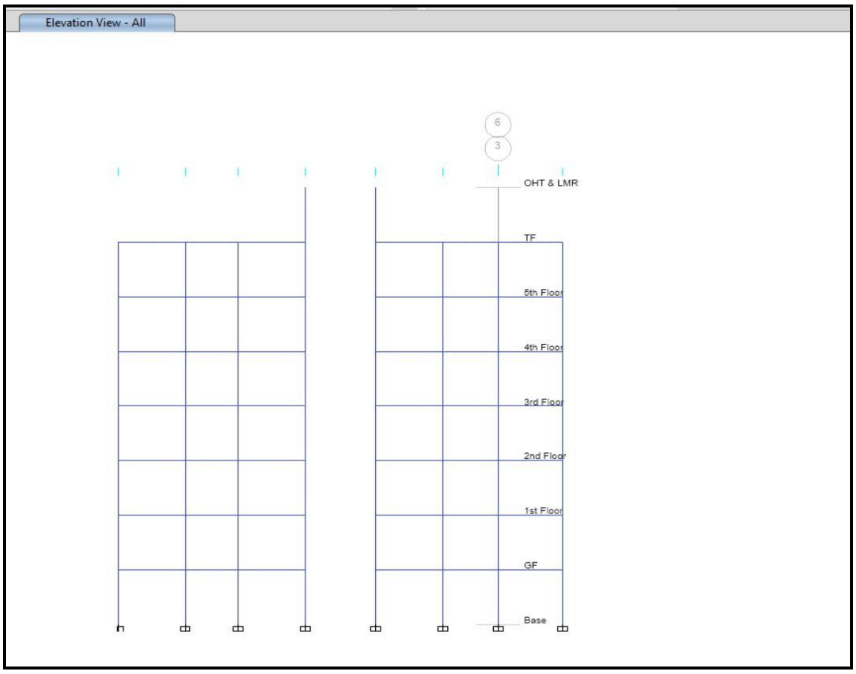
APPENDIX

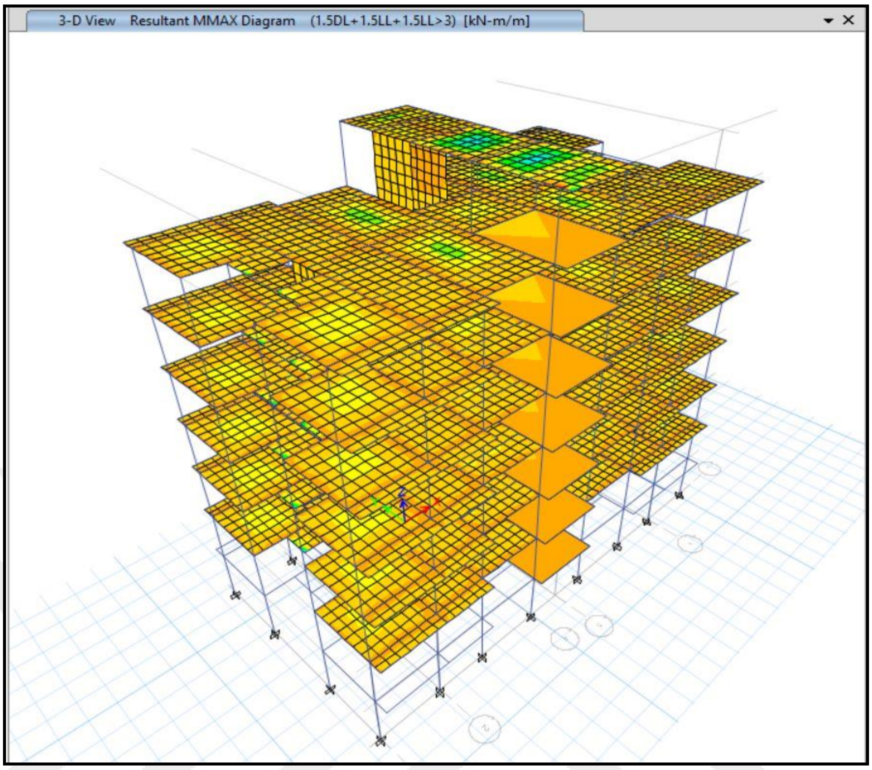
Displacements



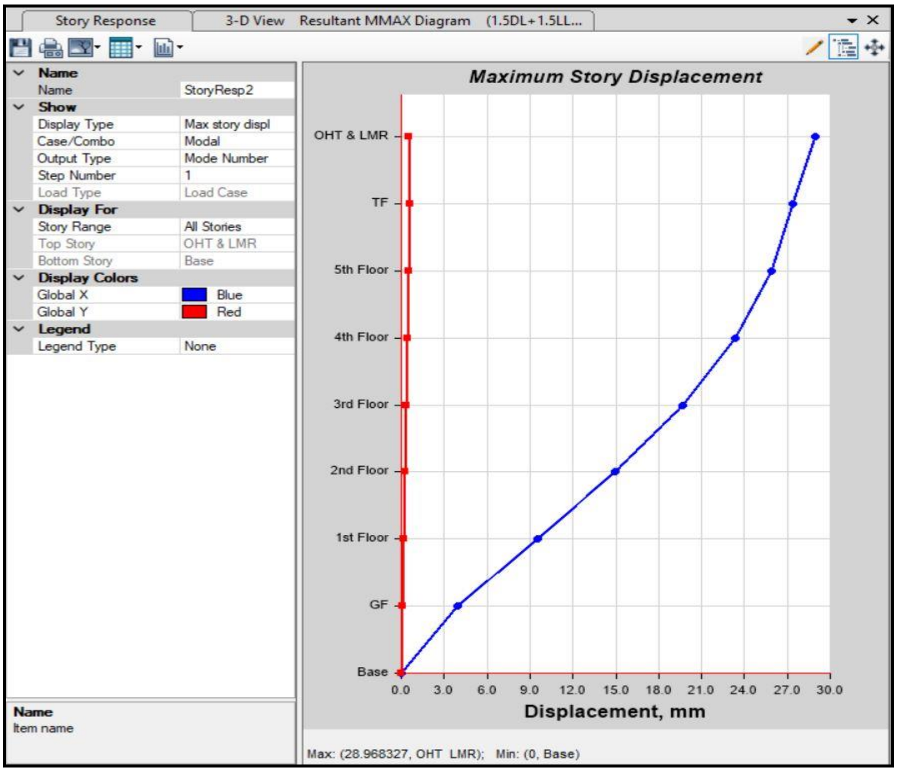
Elevation



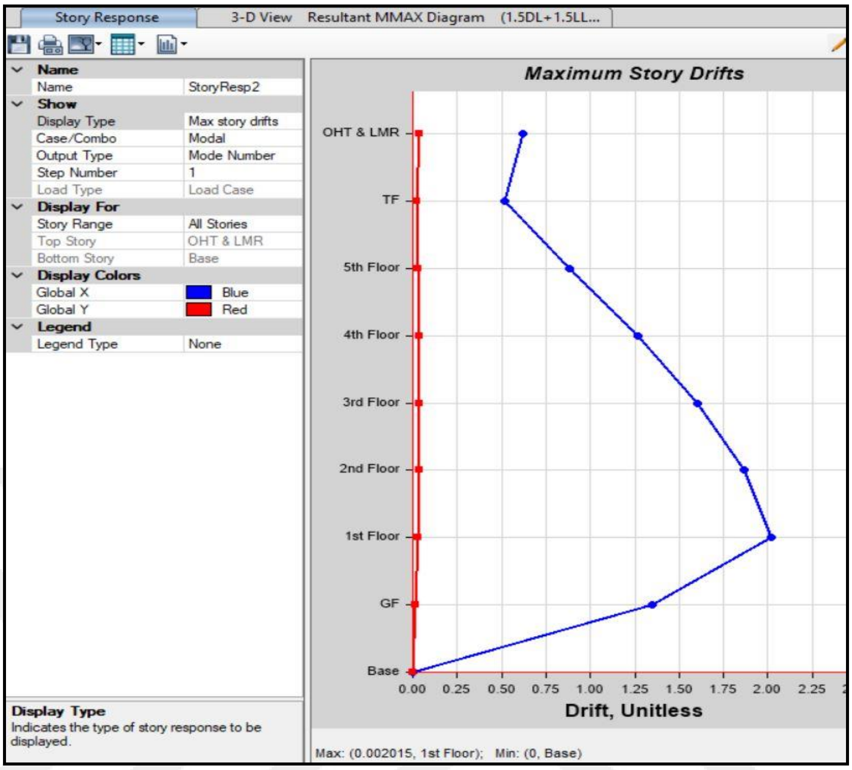
Maximum Moment



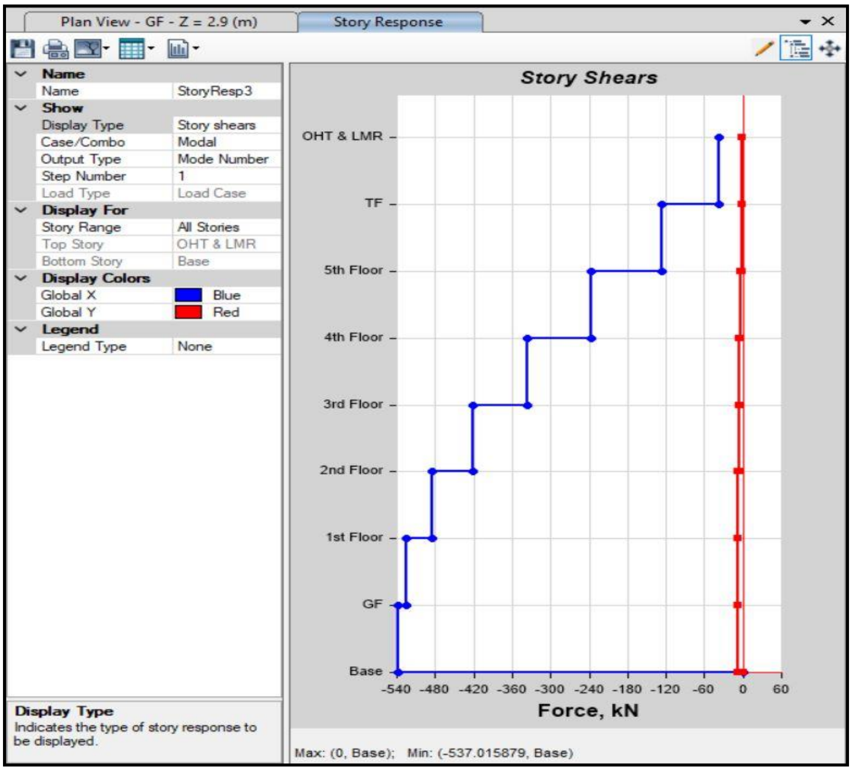
Maximum story displacement



Maximum story drift



Story shear



RESUME

Mohamed Nur Ali

Discipline: Bachelor of Engineering

Branch: Civil and Infrastructure Engineering

Collage: Adani Institute of Infrastructure Engineering

About Me

Interested in understanding the connections and interdependence between innovation, culture, people, and the future; not to mention, the constant seeking of experiences bumping me with new people and new stories, because in the end, we are all a sum of the experiences we have lived!

Educational Qualifications

Class	Board/University	Institution	Year	Percentage/Grade/CGPA
Bachelor of Engineering	Gujarat Technological University	Adani Institute of Infrastructure Engineering	2021	9.37 (CGPA)
XII	Schools Association for Formal Education	Ablaal School	2016	0.924
X	Kenya National Examinations Council	Umul-Qura School	2012	71%

Internship and Training

1. Organization: Shreenathji Infra Space LLP

Project: G+14 luxurious hotel and commercial

Duration: 6th June 2019 to 27th June 2019

Description: G+14 luxurious hotel and commercial owned by Time Square Grand. I learnt how to make Bill of Quantity (BOQ) of Civil & flooring work, Furniture work, false ceiling work, Paint work, etc. And also, I learn about the various material specification used based on purpose of building and tendering work.

2. Organization: CADD Centre

Duration: 13th December 2018 to 31st December 2019. Description: In that period, I learnt Revit Architecture and AutoCAD. I confidently can make Level and grids, create floors and roofs documentation and schedule, visualization, link projects and collaboration and etc.

3. Organization: Hi Tech Project Pvt. Ltd.

Project: Arvind Aavishkar, Ahmedabad, a residential tower of 14 habitable floors.

Duration: 8th December 2019 to 10th January 2020

Description: The Inspire central business hub has total 12 builds among 9 are having G+5 with 2 level basement floors and Other 3 are having above G+8 floors. I learnt about construction of activities like Formwork, Reinforcement work, Concrete work, Construction of Flat Slab & Post tensioning Slab and various other construction.

4. Organization: Adani Institute of Infrastructure Engineering (AIIE)

Duration: February-March 2018 (40 hours)

Description: I successfully completed Fundamentals of Information Technology

5. Organization: Adani Electricity Mumbai Ltd, Dahanu.

Duration: 26th August 2019- 31st August 2019

Description: One week of hand on training of power plant familiarization

Computer Skills

• Professional in AutoCAD 2D and Revit architecture

• Intermediate in Designing & Analysis tool STAAD Pro and ETAB

• Intermediate in Primavera

• Professional in Microsoft office

• Intermediate in sketch up software

Technical Workshops

• 2 Days workshop on Digital Marketing organized by Technospecies Global Solution.

• 2 Month workshop on Fundamentals of Information Technology organized at Adani Institute of Infrastructure Engineering (AIIE).

• 1 week of Hands-on Training for Power Plant Familiarization organize by Adani Electricity Mumbai Ltd, Dahanu.

Achievement and Extra-Curricular Activities

• Fully Funded Indian Government Scholarship (ICCR Scholarship) Government of India [15/07/2017]

• We have done Traffic Survey at Vaishnodevi Circle on 2nd of February 2019.

• We have 2nd runner Football game in our college level sports fest in 2019.

• I have participated in many other Technical fests and sports fests held in various colleges across Gujarat at Zonal, State as well as National Level.

Strengths

A self-Motivating Person and Active listener

Team player & team leader and Time management abilities

Personal Details

Address	Warshadaha Street, Odweyne Degmada Deynille.
Nationality	Somali.
Date of Birth	01-Jan-95.
Hobbies	Travelling, Football, Cricket.
Marital Status	Single.
Languages Known	Somali, English, Hindi, Arabic and Swahili.