DEVELOPMENT OF FRAMEWORK FOR COMPLETE SUCCESSFUL IMPORT FROM REVIT TO ARSAP

By

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Project Supervisor: Engr. Prof. Dr. Majid Ali

BS CIVIL ENGINEERING

JULY, 2023

DEPARTMENT OF CIVIL ENGINEERING

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CERTIFICATE OF APPROVAL

(DEVELOPMENT OF FRAMEWORK FOR COMPLETE SUCCESSFUL IMPORT FROM REVIT TO ARSAP)

by

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PROJECT EXAMINING COMMITTEE

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This is to verify that **Iftikhar Ahmed Baig, Muhammad Umar Farooq** and **Muhammad Wajahat Abbasi** have integrated all comments, suggestions and observations made by the evaluator and project supervisor. Their project title is "**DEVELOPMENT OF FRAMEWORK FOR COMPLETE SUCCESSFUL IMPORT FROM REVIT TO ARSAP".**

Forwarded for necessary action.

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Engr. Prof. Dr. Majid Ali
(Project Supervisor)

Date: July, 2023

DEDICATION

This effort is devoted to our respected and beloved **Parents**, who helped us through each troublesome of our life and yielded every one of the comforts of their lives for our brilliant future. This is likewise a tribute to our **Honorable teachers** who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

Iftikhar Ahmed Baig	(BCE193061)
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Date: July, 2023

DECLARATION

This report is a presentation of our assigned project work. Wherever commitments of others are included, each exertion is made to demonstrate this obviously, with due reference to the writing, and affirmation of communitarian project and exchanges. The work is carried out under the supervision of Engr. Prof. Dr. Majid Ali, at the Capital University of Science and Technology, Islamabad, Pakistan.

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- We need to express our sincere thanks to **Engr. Prof. Dr. Majid Ali** under whose direction the project was led. His direction was precious at each progression ofthis work. His outstanding showing aptitudes helped us get a handle on the topic rapidly. His collaboration at every single phase of our basic choices at Capital University has been significant.
- We thankfully recognize the affection and financial support received from **our parents** for BS studies.
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AMV	=	Analytical Model View
ARSAP	=	Autodesk Robot Structural Analysis Professional
AEC	=	Architecture, Engineering, and Construction
BIM	=	Building Information Modelling
BEM	=	Boundary Element Method
FEM	=	Finite Element Method
IFC	=	Inter Foundation Classes
NA	=	Not Transferred
RCC	=	Reinforced Cement Concrete
RSA	=	Robot Structure Analysis
VPL	=	Visual Programming Language
Y/N	=	Yes/No
>		Transferred in One Direction Only
< >		Transferred in Both Directions

LIST OF INTENDED PUBLICATIONS

Refereed Conference Articles

- Baig, I, A. and Ali, M. (2023). A critique on non-automation of import from REVITt to ARSAP. **(CONFERENCE DECIDED TO BE SOON)**
- Kiani, U., F. and Ali, M. (2023). A review on need for automatic import of area elements in BIM tools in REVIT to ARSAP. **(CONFERENCE DECIDED TO BE SOON)**
- Abbasi, W. and, Ali, M. (2023). A review on need for automatic import of line elements in BIM tools from REVIT to ARSAP. **(CONFERENCE DECIDED TO BE SOON)**

ABSTRACT

By employing BIM in place of the traditional approach, these coordination challenges may be overcome. BIM can automate a number of analysis procedures. The BIM process includes architectural models along with structural framing; free body diagram, FEM model, analysis, design, detailing, sketching, and finally construction. The problem comes in the free body diagram of REVIT because a few elements are missing in the FE model of ARSAP (elements like slabs, beams, and columns) after importing. The main objective of the design project is to give the best solution possible in order to advance in BIM and to reduce the human interaction. In this project, the RCC members of the area and line components of buildings with multi-story frame structures will be taken into consideration. Identifying how human effort is being minimized by automate regaining loss of structural elements for advancing BIM interpolation in ARSAP. It is essential for the project's importance and improvement in complete success import From REVIT to ARSAP of the project is being to promote further BIM in the AEC industry.

To perform this study different literature reviews were reviewed and discussed the ability of BIM tools in AEC sectors along with the discussion with practicing designers, conducted some computer-aided program training and software learning., design project of Group 11 - Batch 2018 and design project of Group 18- Batch 2017 are studied in order to effectively highlight and correlate the stated problem in a systematic method. Structure model are modelled in REVIT and then transfer to ARSAP and identified the problem during import. A creative solution, such as a framework for the complete successful import from REVIT to ARSAP after automatic regaining loss of structural elements for precise modelling of RCC model, must be developed after the issue has been identified.

Bidirectional integration in REVIT automates model issues using structural analytical automation. Flow chart resolves line element issues, ensuring proper import. For area elements, REVIT should have its own library of stairs or model stairs as slabs for automatic import. BIM as an integrated process enhances AEC construction with advancements in tools and automation. REVIT 2023 revolutionizes structural analytical modeling for efficient coordination. The integration between REVIT Structure and Robot Structural Analysis translates certain elements, retaining important parameters.

CHAPTER 1

INTRODUCTION

1.1 Prologue

In any structural design software for RCC building structure design, structural design engineers go through the modelling of a RCC structure, then the following basic procedures, such as the initial framing of the structure while keeping the 3D modeling, which includes free body diagrams, analysis, and determining the influential forces; considering the software area of steel; manual selection of steel rebars; and final detailing. So, structural design engineers use software like ETABs, SAP, or StaadPro, as well as SAFE and AutoCAD. This approach is also called the conventional approach. Architects and structural design engineers are seen as two distinct specialties in conventional approach (Leite, 2019).Afterwards, human participation is required with the expertise of design and construction while interchanging in software.

Building Information Modelling (BIM) was first developed for the AEC industry to include all building design, construction, and operation-related aspects. BIM is a modern way to keep building design and project data in digital form over through the duration of a building's life cycle that enables information sharing and interoperability among the stakeholders. Building information modelling (BIM) has experienced fast growth and adoption in recent years. The breakthroughs of BIM for the architecture, engineering, and construction (AEC) industry has made it easier to predict accurately structures, improve 2D drawings to 3D models, and significantly shorten the building design life cycle, particularly in the phases of drawing, modelling, analyzing, designing, and detailing. Through classes of objects that contain their 3D geometry and other features, BIM models comprehensively describe buildings (Eastman, 2012).

Adopting object-based modelling of structures in computer-integrated construction results in an increase in the construction quality, collaboration and coordination between various engineering disciplines (Jung & Joo, 2010). Through integrations, techniques between a BIM platform and a structural analysis tool have been viable. It enhances efficiency and productivity, assesses the cost and time involved in redesigns, and eliminates conflicts in des-ign. Several operations in the study, design and construction of civil structure are claimed automated by a set of tools known as BIM. But on the other hand problems need to be fixed, including the automatic regaining loss of structural elements in FE model of ARSAP while importing from REVIT which requires human participation. The main goal of this effort is to enhance BIM tools that could minimize human participation when automatic regaining loss of structural elements in FE model of ARSAP while importing from REVIT for precise modelling of RCC members when specifying RCC members for seismic structural integrity.

1.2 Project motivation and problem statement

By employing BIM in place of the traditional approach, these coordination challenges may be overcome. BIM is a set of technologies that automate a number of analysis procedures. The BIM process includes architectural models along with structural framing; free body diagram, FEM model, analysis, design, detailing, sketching, and finally construction. The problem comes in the free body diagram of REVIT because a few elements are missing in the FE model of ARSAP (elements like slabs, beams, and columns) after importing. Moreover, the coordination issues between the two specialties were improved in a construction that is efficiently and promptly constructed in a structure that is created quickly and efficiently. But there are certain shortcomings, one of which is the loss of structural elements in the FE model of ARSAP while importing from REVIT for precise modelling of RCC members, which might have been accomplished by enhancing BIM tools. Therefore, the issue is as follows:

For complete successful import from REVIT to ARSAP and the regaining loss of structural elements in the FE model of ARSAP after importing from REVIT which requires human involvement and is frequently time-consuming, prone to error, and occasionally unfeasible. BIM tool improvements might decrease to prevent mistakes and interaction of structural designers.

1.2.1 Project questions

There are a few questions that may emerge concerning this project. Some of the questions are the following:

- What make the loss of structural elements while importing from REVIT to ARSAP?
- How the loss of line element be corrected?
- How the loss of area element be corrected?

1.3 Overall goal of the project program and specific objectives of this BS design project

The main objective of the design project is to give the best solution possible in order to advance in BIM. And in the process of achieving this objective we have to provide the missing tools for e.g without any loss while importing from REVIT to ARSAP) for precise modelling of RCC members etc.

The main aim of this design project is to create a framework to reduce the human interaction for an automatic regaining loss of structural elements in FE model of ARSAP while importing from REVIT. Because in order to reduce structural engineers work duration and give effective results. In order to advance BIM tools and give effective design output following things are need to be considered:

i. To identity loss of structural elements in FE model of ARSAP after importing from REVIT and exploring their reasons.

ii. To propose guidelines for successful import of area elements from Revit to ARSAP.

iii. To propose guidelines for successful import of line elements from Revit to ARSAP.

1.4 Scope of work and study limitations

By suggesting changes to BIM tools, the proposed approach would automate the regaining loss of structural elements of chosen RCC building after importing from REVIT to ARSAP for both area and line elements.

In this project, the RCC members of the area and line components of buildings with multi-story frame structures will be taken into consideration, RCC members of both area and line elements of multi-story frame structure building will be considered in this project.

i. Line Elements
ii. Area Elements

1.4.1 Rationales behind the variables selections

The main justification for the choice is to minimize the need for human interaction during the regaining loss of structural elements in FE model of Autodesk robot structural analysis software (ARSAP) after importing from REVIT, to improve the coordination of Structural design engineer in the Architecture, Engineering, and Construction (AEC) industry.

1.5 Brief methodology

The initiative uses a strategy to cut down on the time that people spend on regaining loss of structural elements for precise modelling of RCC members. Before beginning any more work that might be used in the final year project, conduct some computer-aided program training and software learning. Following that investigation, various academic works will be examined, together with interviews with working engineers, for the design project of Group 11 - Batch 2018 and Group 18- Batch 173 are studied in order to effectively highlight and correlate the stated problem in a systematic method. A creative solution, such as a framework for the complete successful import from REVIT to ARSAP after automatic regaining loss of structural elements for precise modelling of RCC model, must be developed after the issue has been identified.

1.5 Project uniqueness, project significance, and practical implementation

In an effort to accelerate up the development of BIM interpolation in ARSAP, framework for complete successful import from REVIT to ARSAP is being used to automate regaining loss of structural elements of RC model.

Identifying how human effort is being minimized by automate regaining loss of structural elements for advancing BIM interpolation in ARSAP. It is essential for the project's importance.

Improvement in complete success import From REVIT to ARSAP of the project is being to promote further BIM in the AEC industry.

1.6 Design project report layout

This report consists of four chapters on the whole with reference. Their brief important details are explained below:

Chapter 1 includes the introductory background of the design project. Project motivation, problem statement along overall and specific goals are discussed.

Chapter 2 includes the literature review which consists of three aspects of critique on critique on non-automation of import from Revit to ARSAP. Second aspect is the automatic import of line elements in BIM tools from Revit to ARSAP. The third aspect is an automatic import of area elements in BIM tools from Revit to ARSAP.

Chapter 3 is the project methodology. Firstly, the background is discussed. Then the detailed discussion of design project of batch 173 and batch 183 and also the particular area is explained. Flow chart is developed automatic import of both lines and area elements to develop an appropriate flow chart for the automation of import from REVIT to ARSAP.

Chapter 4 is the results and analysis. Appropriate flow charts are developed to automate the import from REVIT to ARSAP. And also develop the workflows for design engineers to analyze and design building using BIM tools.

Chapter 5 consists of a discussion regarding the lesson learned from the current DP and the structural analytical automation in REVIT 2023 and other elements or parameters that are transfer from REVIT to ARSAP.

Chapter 6 is recommendations and a conclusion. The conclusion is based on the flow charts. Recommendations are made on the bases of interviews with practicing engineers and design outcomes. All references are listed after chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

The seismic analysis and design of the RCC frame structures are done using different approaches such as the conventional approach and the BIM approach. In the conventional approach, the structural designer takes the area of steel and then details with the help of different software such as ETABs or StaadPro along with AutoCad. During switching between software, human involvement with analysis, and design and construction knowledge is needed.Building Information Modelling (BIM) consists of a variety of tools that have claimed the automation of many processes involved in the analysis, design, and execution of civil structures. However, various steps for analysis and design among them is complete successful import from REVIT to ARSAP is the particular step which lacks in the BIM approach. This chapter covers the critical review on the non-automation import from REVIT to ARSAP in BIM tools and the detailed discussion of these aspects given below in this chapter.

2.2 A critique on non-automation import from Revit to ARSAP

Building information modelling (BIM) has undergone substantial growth and application in recent years due to the standard structured model. Building Information Modeling (BIM), which enables a coordinated workflow throughout the project's many stages, including planning, design, construction, operation, and destruction, is one of the most promising technologies. Buildings are richly described in BIM models by classes of objects that contain their 3D geometry and other attributes. Collaboration between many engineering disciplines and construction quality have both increased as a result of computer-integrated construction adopting object-based modelling of buildings. Follow specific interoperability is an efficient technique to raise the quality of the construction process. When both domains use BIM authoring software tools, digital data transmission between architectural design and structural analysis is nevertheless affected by a number of challenges, most notably semantic issues and particularly severe geometric interpretation issues.

Building Information Modelling (BIM) greatly reduces the need to reenter or copy information and ensures that it is used in the correct context. In recent years, it has become possible to represent most of the required resources in the form of different models (e.g., information models, computational models, and ground models) that have been created and prepared by different project participants. As a result these models carry a significant amount of information and also influence each other considerably. For this reason, the ability to achieve interoperability between multiple models has always been a key issue in the AEC/O industry and is becoming more and more challenging with the development of various industry specific tools .The success of the project depends on the effective exchange and reliable translation of data in various shapes and formats to be used as input, parameters, factors, and constraints which have a decisive influence on design and construction

BIM is regarded as a joint digital knowledge base supporting the activities of all stakeholders in AEC. It is based on various data sets, including geometrical and/or non-geometrical information; allowing data generation, exchange and processing within the life cycle of built structures. The full realization of BIM includes domain-specific modeling during the design phase as well as model-based information exchange which, when used together, demonstrate the full potential of BIM.

Within the domain of Architecture, Engineering and Construction (AEC), the digital method of Building Information Modelling (BIM) advances the collaboration between stakeholders and reduces information loss during data exchange. AEC industry stakeholder's benefit in various ways from BIM workflows. The McGraw Hill Survey identifies the reduction of errors and omissions as the most common benefit of BIM workflow, resulting in reductions of costs, duration and the amount of rework. Identified that the main benefit of using BIM models in the design phase is the earlier collaboration of multiple domains, leading to a reduction of errors and omissions, and shortening the design cycle, resulting in a more cost-effective design, there is a bulk of research involving technical improvements or testing of data exchange between architectural design and structural analysis. Research dealing with the data-exchange analysis on inter-organizational level addresses general processes rather than solutions for a particular domain-specific data exchange. The IFC-based data exchange between architectural design and structural analysis is examined on an inter-organizational level within the AEC ecosystem

The architectural design and structural analysis domains require two types of building models: physical model for architectural design and discretized model for further numerical simulation. Data exchange has traditionally been conducted by redefining information provided by the architects in a structural analysis domain-specific software tool. The more advanced model-based data exchange practices use digitally transferred building models. However, due to lacking interoperability or coordinated modelling conventions, a model-based data transfer leads to significant remodeling efforts, prone to errors and misinterpretations.

Integration approaches between a BIM platform and a structural analysis program has been made possible through integrations, e.g. Autodesk Robot – Revit, and other commercial programs connected to Revit via the application programming interface (API) links. Most of current structural analysis programs are based on the finite element method (FEM). This is the primary reason why Analytical Model Views (AMV) of the structure (also termed as Structural Analysis View), such as in Revit, are made to best suit the current trend in structural analysis software i.e. wireframe/centerline representations as shown in figure 2.2.1. The emphasis on centerline representation causes the loss of some vital geometrical data and may lead to inaccurate structural analysis results. Vertical and beam elements are categorized as linear elements, whereas slabs and rafts are categorized as planar elements. A designer using building information models usually tunes the analytical model to best present the most accurate representation of the structure, rather than start a geometrically accurate model from scratch. This is because FEM based software programs require the fine tuning in terms of numerical analysis to produce acceptable, yet not entirely geometrically accurate results.

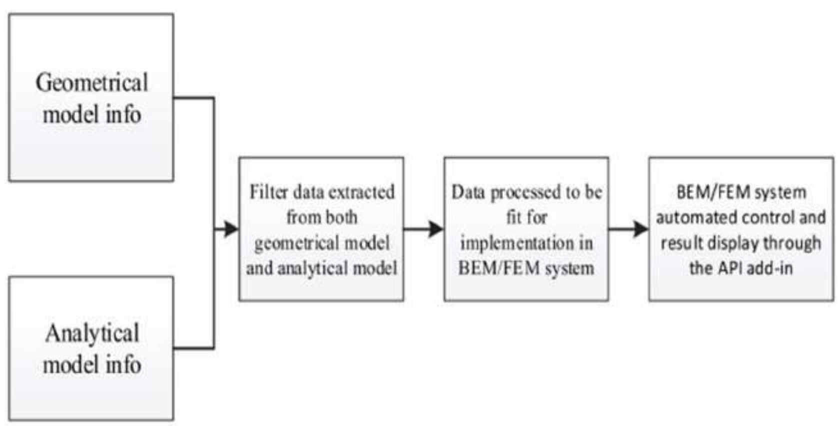


Figure 2.1: The API work flow

Recently, Ramaji and Memari presented a method for interpretation of structural models from the BIM models to facilitate implementation of structural analysis using FEM commercial software. The additional tool they developed automated the transformation, modification, and addition operations, during information exchanges process, from an industrial BIM authoring tool. However, the reduced dimensionality of structural elements in FEM software causes confusion on where particularly reinforced concrete elements are in contact with each other especially at connections. Other successful enhancement attempts are presented by (Belsky et al.), where they proposed composing an additional Industry Foundation Classes (IFC) exchange file that included more semantically useful concepts inferred from the building information model. The prototype software they produced was tested on precast concrete building models to demonstrate the semantic enrichment, which improved the slab's connection concepts with other elements. (Sacks et al.), also developed their semantic enrichment tool in SeeBIM, to be able to interpret geometrically complex structures such as real-world concrete girder highway bridges. Despite the previous attempts, current BIM enrichments contain insufficient semantic definition to allow for hybrid boundary element-finite element numerical modeling of the whole building structure. The boundary elements method (BEM) is a numerical method that does not heavily rely on wireframe presentation of structural elements. The method is standardized for the analysis and design of tall reinforced concrete buildings, as developed by (Mobasher et al.), and (Mohareb et al.) The work showcased the possibility for an accurate representation of structural elements and further development of the IFC standard to fit the modeling for high-rise buildings and compatibility with BIM software. The authors discussed the effect on the design of structural floors and its components using BEM with different design codes, and explained the different approaches and outputs achieved from such an analysis system.

The authors developed a new tool with C#, incorporated in it the application programming interface for Revit (Revit API) to test the proposed BIM-centered system, and to work as a guide for the proposed analytical model when problems in integrating the new AMV arise. The concept design for the application was laid out in three major steps. The first is the extraction of data from an existing BIM application. The second is to process the data extracted from BIM to be presented to the analysis scheme in the correct format that the hybrid system requires. The third step is to automate the commands for initializing and running the structural analysis solver without the need for another independent process.

In reality, the process of automatic conversion of information model into a computational model is difficult. However, in some specific, simpler cases, BIM tools are able to achieve this. Special plug-ins for BIM modelers are also available on the market to facilitate the process of conversion between the information model and the computational model. One such example is the link between Autodesk Revit and Robot structural analysis, but this is mainly due to the use of a proprietary data format and the limited scope of analysis. FEM analysis experts generally prefer specialized programs because they offer more specific analysis and several different models of material behavior. The analysis parameters are also more controlled, and the accuracy of the results is better in such specialized software, but the data transfer from BIM model is more difficult.

2.2.1 From Structural Framing to FBD to 3D FE model

(Hasan et al., 2019) explains deficiencies in the current analytical model view are presented for various structural element geometries and their influence on the analysis and behavior of structural members and whole structure. The deficiencies are in the following members/connections: 1). Beam-column connections. 2). Inclined column contact with slab. 3). Pile and corresponding supporting soil. 4). Cores and wall assemblies' cross-sections. Figure 2.2 explains how the geometry of structural member changes.

Once the model is developed in REVIT, the structural analysis is performed using the RSA. RSA is Autodesk's FEM structural analysis program that has the capability to analyses complex models with the FE auto-meshing modeling algorithms. The designed Revit model is exported to RSA perform analysis. The nonlinear static analysis through RSAVR considers the second-order effects, due to change in stiffness and moments generated due to the applied vertical forces at nodes(Boddupalli et al., 2019).

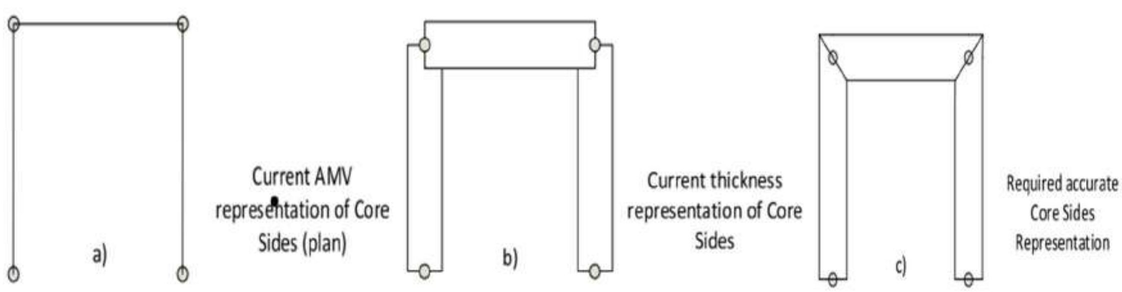


Figure 2.2: Change in the geometry from geometrical model into analytical model

2.2.2 Raised issues

Building design success is strongly reliant on efficient collaboration among all stakeholders (Hauashdh et al., 2022), (Palomar et al., 2020), (Mehrbod et al., 2019). The increasing complexity of modern architecture adds to the difficulties of collaboration between architects and engineers. Architects and engineers are traditionally considered as separate distinct specialties in the conventional design approach, with only minimum integration occurring during the early phases (Liu et al., 2017). Architects start with a conceptual design and then create the shape and arrangement of the structure to suit aesthetic objectives while the structural engineers design the building's structural systems and skeleton to fulfill safety, structural performance, and cost objectives. During architectural design, structural design needs are frequently ignored, i.e., the implications of architectural design on structural performance. (1) Information loss, (2) Contradiction, (3) Duplication of data, (3) Inaccuracy, (4) Productivity loss, (5) Time-delays, (6) Cost overruns, (7) Increased disputes, and (8) Unacceptable output quality is all consequences of this disjointed system (Hamidavi et al., 2020). Figure 2.1 shows the effects of construction delays in AEC sectors.

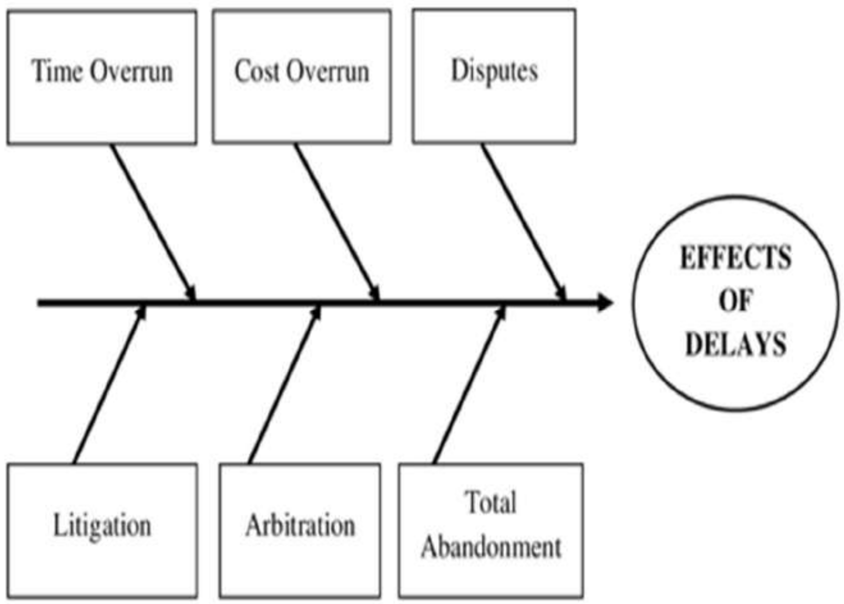


Figure 2.3: Fish-Bone diagram of effects of construction delays (Rocha et al., 2014)

When manually creating and optimizing conceptual designs, structural engineers depend primarily on intuitive knowledge and experience. This is a time-consuming iterative procedure in which engineers can only explore a few options. By using the benefits of automation, the current accessible approaches such as BIM have the potential to enhance the structural design process (Liu et al., 2017). Through an automated and parametric approach, BIM may enable designers to develop and optimize various structural models (Banihashemi et al., 2018). Despite these advantages, adopting BIM to facilitate structural design is still a work in progress. On projects, there is no automated structural design update in response to architectural design changes. Furthermore, BIM federated models lack an intelligent structural optimization feature (Darko et al., 2020). Table 2.1 shows the BIM- based project collaboration issues in the AEC industry.

Table 2.1: BIM-based project collaboration issues [(Alreshidi et al., 2017), (Banihashemi et al., 2018), (Scianna et al., 2022), (Durdyev et al., 2022)]

Theme / Category	**Drafted results**
People	• Team trust
	• Collaboration issues • People's behavior
	• BIM maturity and understanding
Process	• Lack of agreed objectives • No clear procedure for BIM
	• Information delivery process-related issues • Sharing issues in a collaborative process
	• BIM different team skills
Data	• Data loss • Intellectual Property (IP)
	• Copyrights
	• Data compatibility • Big data volumes
	• Interoperability among BIM software is still a challenge • Data transportation
	• Data inconsistency
	• Data storage • Data Ownership

2.2.3 Possible improvement

To avoid such problems, architects and engineers need a collaborative method of work that automatically generates optimized design alternatives that satisfy both architects' aesthetic standards and structural engineer's considerations. This necessitates a dynamic technique that allows the two teams – architects and engineers – to collaborate throughout the whole design process, including the early phases (Ciribini et al., 2016). Commercial BIM servers, such as the Onuma system, RevitServer, ProjectWise, Graphisoft BIM Server, and, more recently, Autodesk BIM 360, can help in collaboration, as can open-source systems like BIMServer and EDMmodelServer. BIM servers, on the other hand, are often owned by their creators, employ proprietary administration data models, and rely on central or local servers for data administration and storage (Alreshidi et al., 2017).

Figure 2.2 shows the BIM governance components. From a governance perspective, there are a few other requirements for overcoming the barriers to BIM adoption and team collaboration: (i) procedure development, (ii) defining responsibilities across disciplines, (iii) Sharing a common model that can be stored centrally or hosted by distributed environments, and (iv) improved specialized communication and negotiation techniques. Furthermore, comprehensive training should be offered, as well as an explanation of stakeholders' official obligations, across fields and at various phases of the building lifespan, to promote awareness. In developing a Cloud-based BIM governance system, numerous factors must be considered: (i) BIM data management procedures, (ii) project lifecycle, (iii) supply-chain complexity, (iv) BIM, team members' rights and duties, (v) codes and guidelines, and (vi) the underlying technology (Alreshidi et al., 2017), (Khattra et al., Towards Automated Structural Stability Design of Buildings-A BIM-Based Solution, 2022).

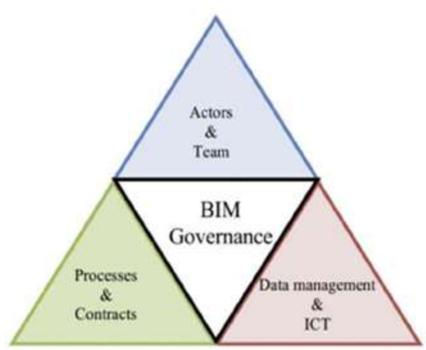


Figure 2.4: BIM governance components. (Alreshidi et al., 2017)

2.3 An overview on need for automatic import of line elements in BIM tools from Revit to ARSAP

The term "Building Information Modelling" (BIM) refers to a group of tools that promise to automate numerous analysis-related tasks. But certain tools are missing. Saving money on materials or speeding up the construction process can both improve economy. Construction can be completed more quickly and with less waste thanks to BIM tools, which ultimately benefits the economy and the environment. The AEC sector uses a wide range of optimization strategies to achieve economy. This research provides a critical analysis of the necessity for automation in BIM tools for recovering loss of beam and column. When converting the Revit architecture model into Autodesk Robot Structural Analysis Professional (ARSAP), line components that require human involvement are missing. To eliminate human involvement, we require automatic recovery of line element loss; particular BIM tools are required for successful import of line elements from REVIT to ARSAP.

2.3.1 FBD of beams and columns required for analysis

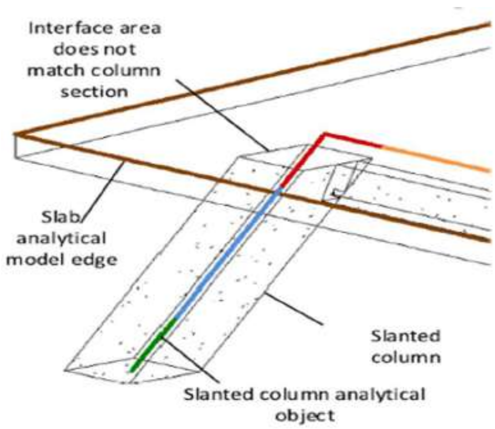
The free body diagram is one of the most effective tools for solving structural analysis problems (FBD). A free body diagram is a graphic, digital form, symbolic representation of the body (structure, element, or fragment of an element) that has had all connecting "parts" removed. A FBD is a convenient way to simulate the structure, structural element, or segment under consideration. It is a method of visualizing the structure and its component pieces in order to begin an investigation.

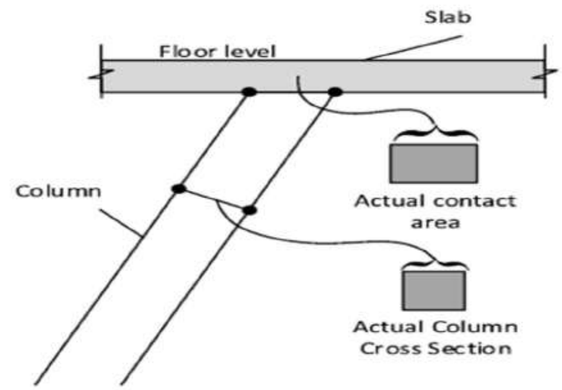
2.3.2 FE modelling of line elements

The finite element method essentially means that a large structural member can be more properly examined if it is divided into smaller discrete or finite elements. The finite element method (FEM) is used by the majority of structural analysis tools nowadays. Linear elements include vertical and beam components, whereas planar elements include slabs and rafts. Instead of starting from the beginning with a geometrically precise model, a designer employing building information models absolutely fine the analytical model to better present the most realistic picture of the structure.

A hybrid BEM-FEM system, which couples the finite element method and boundary element method, is used in this analysis. This approach gains the advantages of both BEM with slabs and rafts and FEM with vertical or linear elements when FEM is used to represent vertical elements and beams.When a beam's centerline does not coincide with the center of a vertical part, such as a column, an inadequate connection results. This most frequently happens when the column is not straight or circular in shape. As in the case of the circular column the AMV has a tendency to forcefully alter the centerline of the beam to achieve connectivity with the centerline of the column, which incorrectly defines connectivity overall. As a result, the eccentric beam-column connection is represented by the AMV. This section briefly introduces the hybrid BEM-

FEM analysis system and the model information required from the BIM authoring tool.





(a) (b)

Figure 2.5: (a), (b) Intersection between vertical inclined columns and slab element

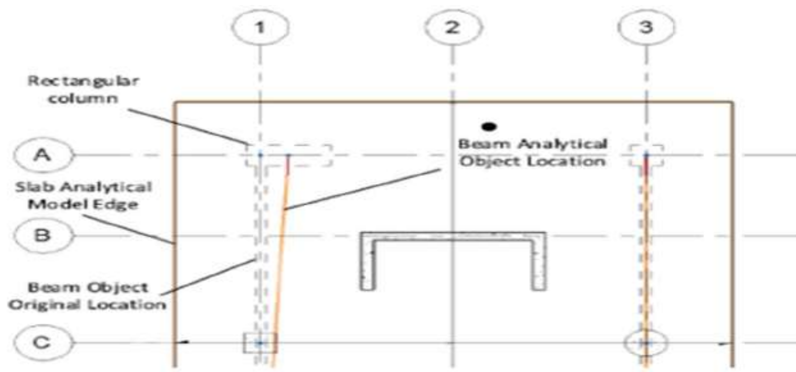


Figure 2.6: Analytical Model View beam does not align with the corresponding beam

2.3.3 Need for automation of BIM tools for import of line elements from REVIT to ARSAP

BIM software is a powerful tool for designing cost-effective steel reinforcement for complicated structures. BIM is a cutting-edge technology that offers a fresh perspective to the architectural, engineering, and construction (AEC) industries and has several advantages.

Researchers have been more interested in automated structural optimization using BIM models. However, several tools are missing when we export the Revit architectural model into Autodesk Robot Structural Analysis Professional (ARSAP), and numerous line components are lost. As a result, skilled people are necessary for restoring line element loss while exporting from Revit to ARSAP. Research on this issue has not yet been considered. For Automatic successful import of line element from Revit to ARSAP will reduce the time and cost also reduce the human involvement

2.4 An overview on need for automatic import of area elements in BIM tools in Revit to ARSAP

Automating processes aids in their optimization by getting rid of wasteful tasks and boosting performance. Process automation will make the project much more profitable, but it also requires an investment of time and money. For instance, searching for project folders is a daily task that typically takes 2 minutes to complete because there is not always an order standard. However, automating the task could cut that time down to 15 seconds by creating an order standard that makes it possible to find the folder much more quickly. We need to develop a solution that will help to automatically import area elements successfully from Revit to ARSAP. The word "automatically" is used because we already can successfully import the elements when they are lost, but by the means of experts. Which is time consuming. Also when importing model from Revit to ARSAP, there is loss of stair element which is explained further below. There are number of ways to regain the loss area elements like IFC 2x4, the transfer of construction elements such as walls or slabs became possible through IFC modeled reinforcement.

2.4.1 FBD of slabs

In Revit, a free body diagram (FBD) is basically analytical model in Revit which will show deflection under various loads. Under which SFD and BMD can be measured. To create a free body diagram of slabs in Revit, you can use the "Analyze" tool and "Structural Loads" option. This will allow you to see the forces acting on the slab and help you understand how the structure will behave under different loads. Additionally, you can add loads such as dead load, live load, wind load, and seismic load to understand the behavior of the slab under various conditions. The FBD can also be used to analyze and design reinforcing elements, such as steel beams or concrete columns, to ensure the stability of the slab.

A free body diagram (FBD) of a slab provides information about the forces acting on the slab, which can be used to automate the transfer of area elements from Revit to ARSAP. By extracting the information contained in the FBD, you can transfer important data about the slab, such as its dimensions, material properties, and loads. It is important to note that the exact process of automating the transfer of area elements from Revit to ARSAP using a free body diagram of a slab will depend on the specific tools and capabilities of the two programs. Before proceeding with the automation, it is recommended to thoroughly review the documentation and resources available for both Revit and ARSAP.

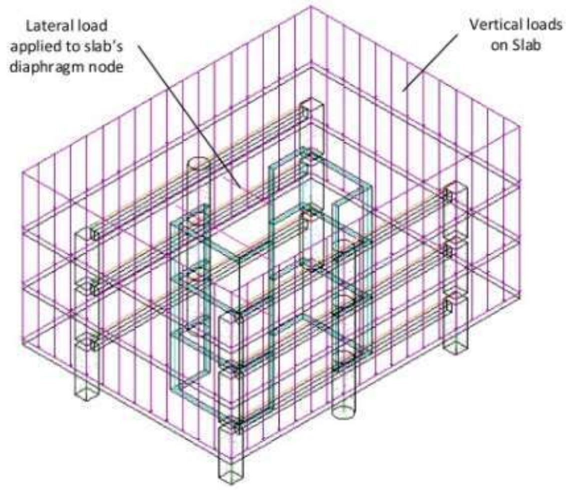


Figure 2.7: FBD of slab

A case study at one of the buildings in Universiti Tun Hussein Onn Malaysia (UTHM). The As-Built Plan of the existing building in UTHM will be obtained for integrated modelling, design, analysis and detailing of reinforced concrete structure by using Tekla Structural Designer software. Figure 2.6 showed the maximum deflection of slab occurred on slab. The maximum value of deflection was 31.6mm. The slab was located at First Floor Level. This happened because slab was the large area in the building that was 32m². So, in order to reduce the deflection, increased the slab thickness or placed the secondary beam on it.

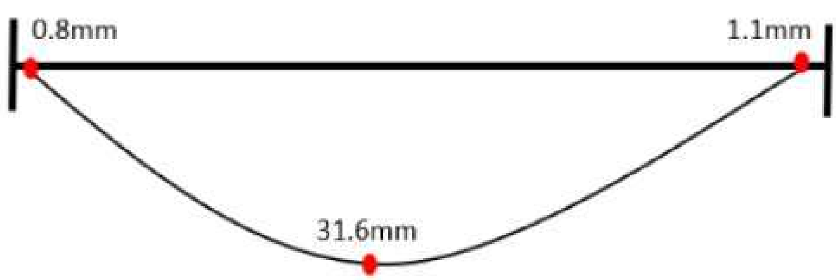
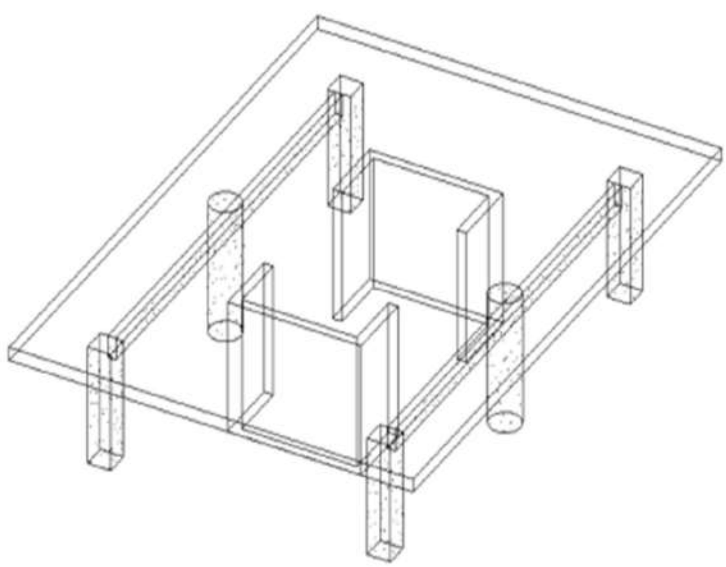


Figure 2.8: Maximum deflection on slab

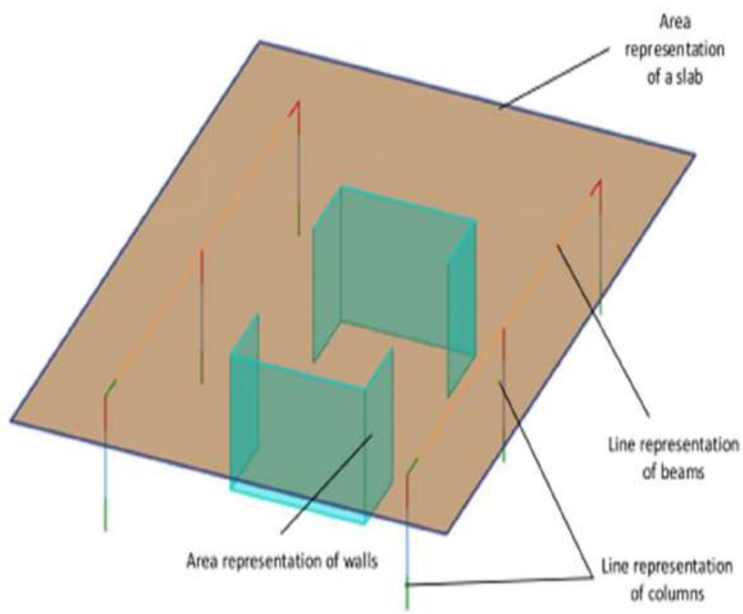
2.4.2 FE modelling of area elements

The finite element method simply refers to the fact that a big structural member is more accurately analyzed if it is broken down into smaller discrete or finite elements. Most of the software used for structural analysis today use the finite element method (FEM) . Robot uses a three dimensional, Finite Element Method-based approach to give structural analysis that is linear, static nonlinear, and dynamic (FEM). The focus on centerline representation results in the loss of some important geometrical information. And due to the loss of geometrical information, the loss of structural detailing results. Vertical and beam elements are considered as linear elements, whereas slabs and rafts are considered as planar elements. The designers using Building Information Models do not focus on geometrical accurate model, their main focus is on accurate representation of the structure. This is due to the fact that FEM-based software need to be accurate in terms of numerical analysis to give results that are acceptable but not totally exact in terms of geometry.

Ramaji and Memari have developed a method for producing structural models from BIM models to simplify the use of commercially available FEM software for structural analysis. The additional tool they created automates the actions of transformation, modification, and addition during the process of exchanging information from an industrial BIM authoring tool. A case study showed that a car park structure in pipers row, wolver Hampton had been collapsed due to the local punching shear resulted through slab load over the columns that punched through the footing. The thickness of footing should be enough to handle punching shear.



a).Wireframe view



b). Analytical model view

Figure 2.9: Actual structural members in: a) coordination view and b) their equivalent AMV elements

Industry standards have shown that, when compared to conventional methods, the finite element analysis method is the most powerful tool for doing a full shear, moment, and displacement analysis. The finite element method's meshing process gives better accuracy for both statics and dynamics, allowing the resulting forces to be adjusted in the codes. To verify its practicality, the authors create a general add-in software that is successfully integrated into a BIM authoring tool. This software serves as a conduit for data exchange between the hybrid Tall Building Package's BEM-FEM system and Revit's geometrical and structural data, such as (materials properties, elements). During the process of developing the generic software, problems were faced since the current AMV lacks enough information for the hybrid BEM-FEM system. The problems related to AMV are, when a column is inclined, the contact between the slab and column changes due to the angle of the column. The connection area of these columns is not taken into account in the present AMV, which leads to an error in the slab analysis. Walls and cores are modelled as area elements in the current AMV, and their connection to the slab is shown as a single line in the plan direction. The AMV's representation of the shape of cores as a geometric entity is shown in Figure 2.7. While in coordination view, Revit perfectly describes the intersection of a slab element and any supporting walls or cores. The analytical model for walls does not incorporate this intersection data, leaving the definition of cores to the single point connection between its wall's starting and ending lines, as shown in Figure 2.8. The area form of the intersection between walls is not known, despite the fact that the AMV's wall elements provide thickness values.

2.4.3 Need for automation of BIM tools for import of area elements from Revit to ARSAP

The model created in Revit is transferred to the Robot software, and the quality of the transferred data is analyzed. The geometry and physical properties of most structure elements have been correctly recognized by the calculation system. However, over the model it was necessary to make some adjustments; the stair elements were not recognized by the system and then sloped slabs were modelled instead as shown in figure 5. That is why there is the need for automation to successfully import the area elements from Revit to ARSAP.

To proceed with the analyses, each slab is divided in finite element mesh surfaces and after calculation, the system automatically set the value of the reinforcement required for each finite element based on the materials.

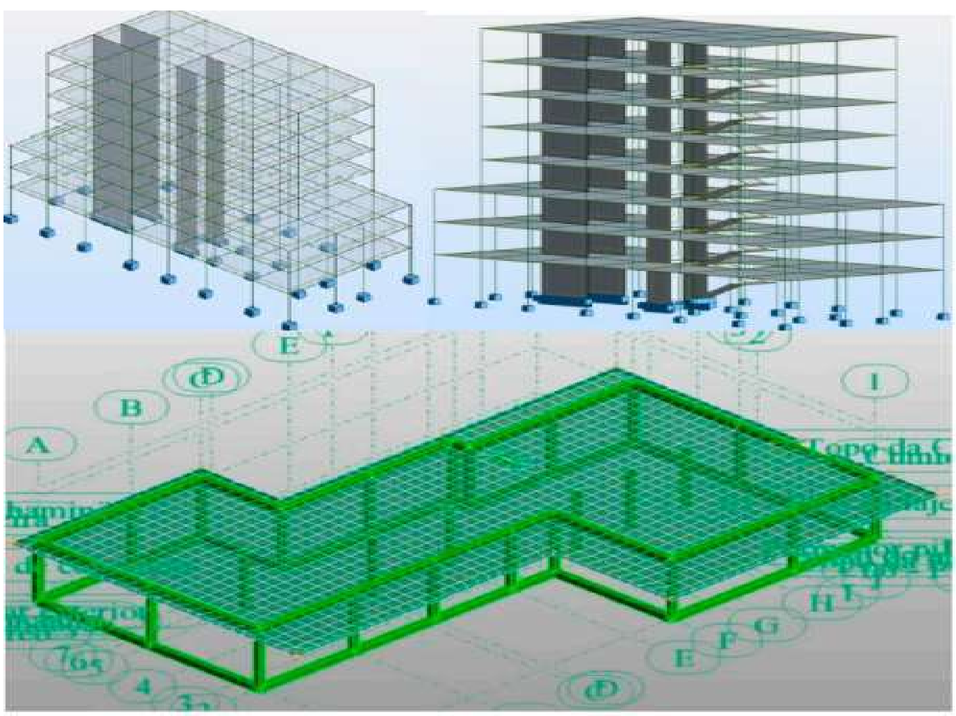


Figure 2.8: Structural models transferred from Revit to ARSA

2.5 Summary

This chapter concludes the literature review part of this project program. It covers the three main aspects of this BS design project which are a critique on non-automation import from REVIT to ARSAP, Philosophy of line elements, and Philosophy of Area elements. These main aspects are further divided into three parts. This covers why the automated import from REVIT to ARSAP is needed to reduce human efforts, reduce chances of error in the analysis. In this chapter, it is described that how these issues can besolved by using a better approach. Different BIM tools possess the ability to automate the import from REVIT to ARSAP.

CHAPTER 3

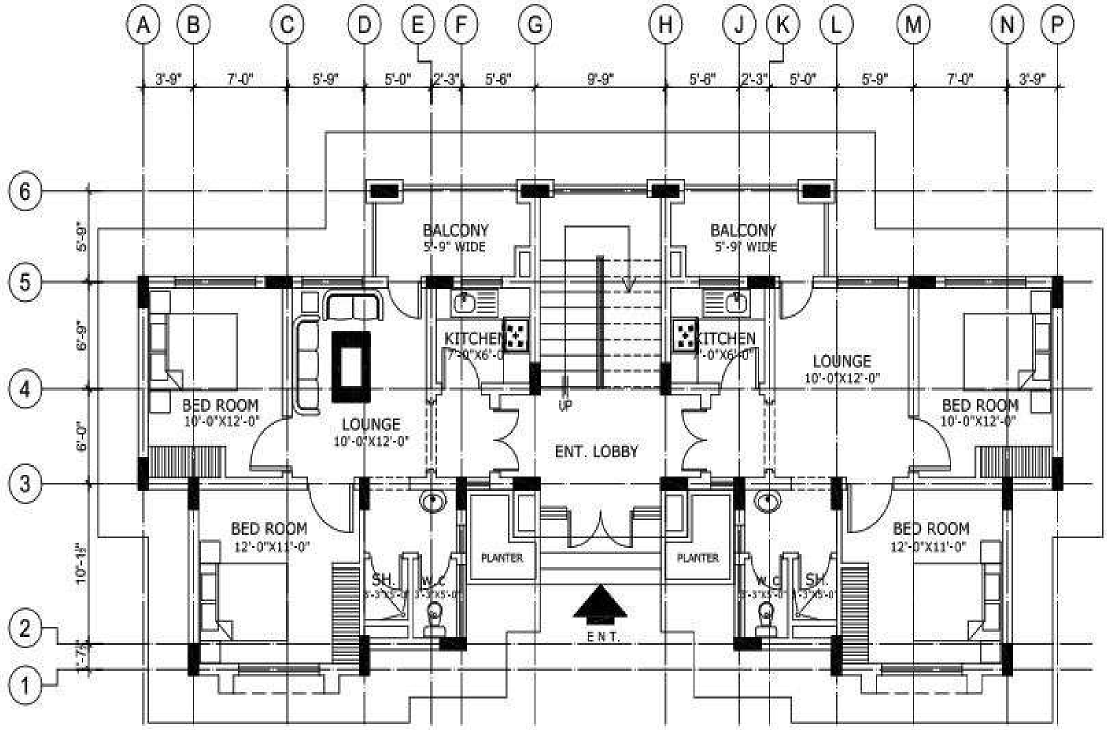
METHODOLOGY

3.1 Background

For the modelling, analysis, and design of a Reinforced Cement Concrete (RCC) frame construction, many software packages is being used nowadays. Another option for modelling, analysis, and designing an RCC frame structure is to use Autodesk Revit architecture to construct all of the architectural drawings, which is easier and provides a better understanding. When compared to prior tools, this program allows you to create model quickly. During the construction of an RCC frame building, these model help to comprehend the process. For the site engineer as well as for the structural engineer's better comprehension, the cross-sections and details of the structure are highly clear and easy to grasp. After finishing the architectural designs, give them over to the structural engineer, who will model them in a structural design program called Autodesk Robot Structural Analysis Professionals (ARSAP). ARSAP is used to evaluate the model, and Autodesk Revit is used to create structural drawings. ARSAP is a Building Information Modelling (BIM) - Integrated software that has been used for the design of different kinds of structures. BIM tools have proved their significance in the AEC industry. Despite these advantages, the BIM tools lack automated updates of structural design in response to architecture design changes. The chapter further deals with the selection of appropriate flow charts for automated import from REVIT to ARSAP of RCC members for both line and area elements.

3.1.1 Description of design project of Batch 173

Design project of Group 18 – Batch 2017, Comparative Seismic Analysis and Design of an RCC Building Using Conventional and BIM approaches. A four-story residential RCC frame building in case of being used for living purposes in the future in Pakistan's capital, Islamabad, has been selected. All elements of the structure must be constructed in concrete armed, with distinct acting loads determined by the construction's BOP-2007 and UBC-97,as required for modeling, strength, balance, and reliability. The soil type "Sc" in which our example is found is granular soil with a high percentage of clays and gravel sand. The structure is in a type 2b seismic zone, which poses a moderate seismic threat and has a seismic zoning value (Z) of 0.20. In this project design of architectural drawings and structural framing are done by using AUTOCAD, analysis and design were done by using ETAB’s and this approach is called the conventional approach. While on the other hand structural framing done by using REVIT and then REVIT model send to ARSAP via direct integration.



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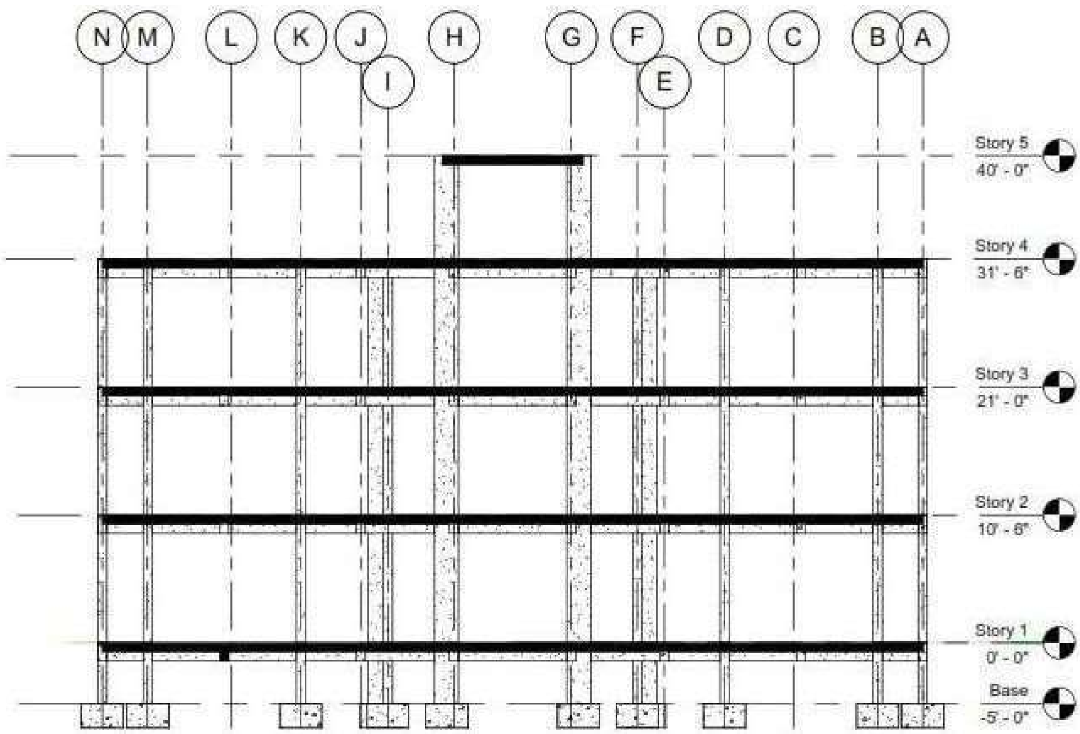

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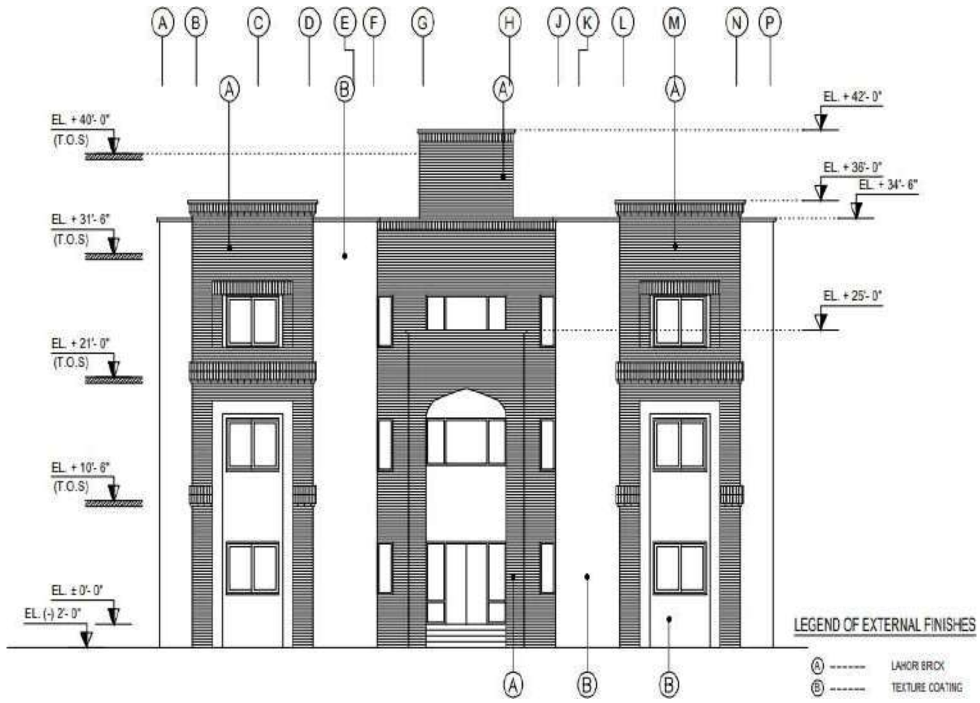


c)

Figure 3.1: a) Ground floor plan of an RCC frame building for this project, b) section of RCC frame building for this project, c) Elevation of an RCC frame building for this project

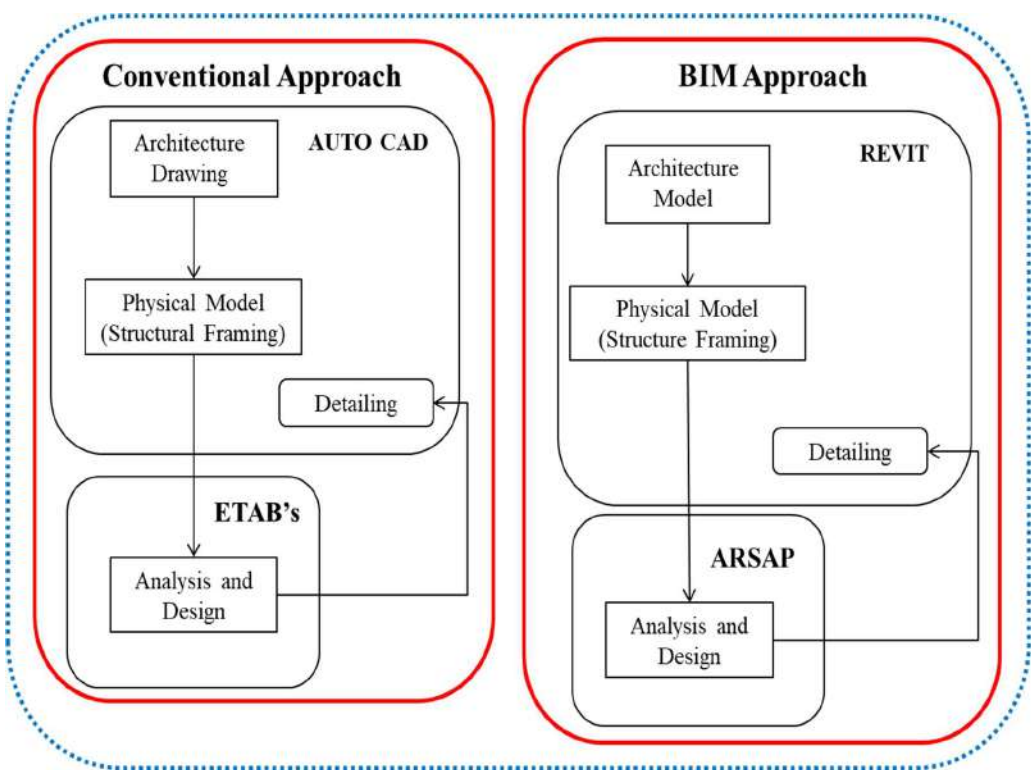
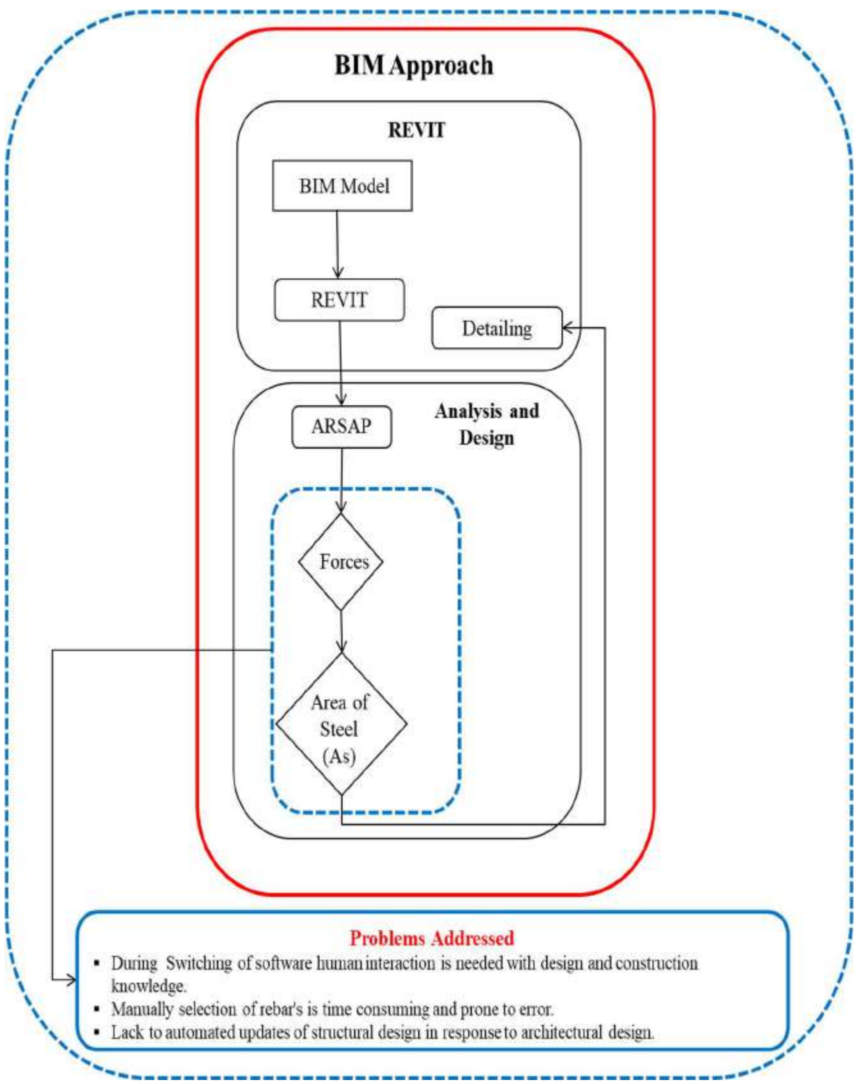


Figure 3.2: Design project of batch 173

3.1.2 Description of design project of Batch 183

Design project of Group 11 – Batch 2018, Prospects of reducing human interaction for seismic structural detailing of RCC members- An advancement in BIM tools. In this design same building is considered as design project of batch 2017 with same specifications. In this design project human interaction involvement is identified after the analysis and design for structural detailing in BIM (during switching of software human interaction is needed with design and construction knowledge, manually selection of rebar's is time consuming and prone to error. lack to automated updates of structural design in response to architectural design) and this project successfully solved those problems. This project also identified that the initial loss of some elements during the transition of data from REVIT to ARSAP for the structural analysis should further be researched for BIM tools enhancement.



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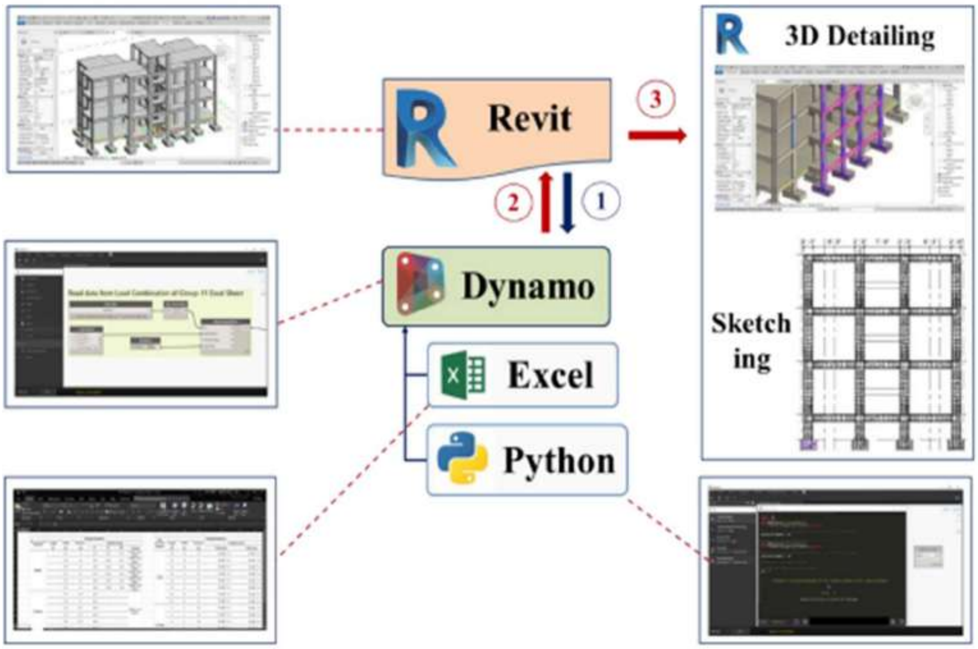

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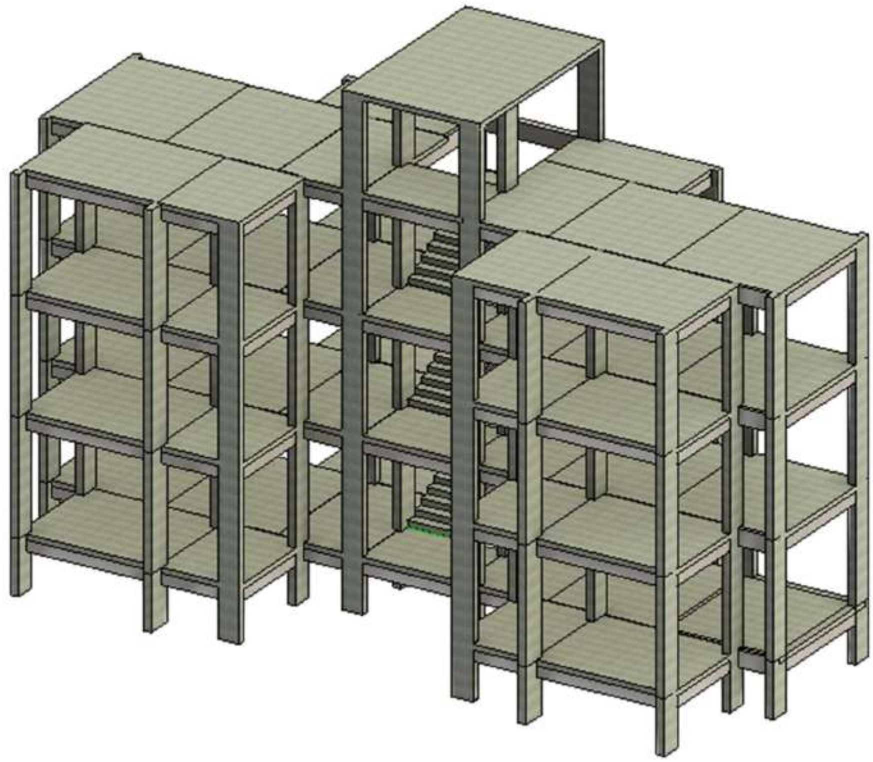
Figure 3.3: a) Design project of batch 183, b) Output of design project of batch 183 (Ali, A., Iqbal, A. and Shah, A,)

3.2 Procedure to develop an appropriate flow chart for automatic import from REVIT to ARSAP

Conducting some computer-aided training on BIM software such as Revit and ARSAP and also reviewing the different literature reviews along with interviews of structural engineers who import the model from REVIT to ARSAP. The survey/interview related to the non-automation of BIM tools in the AEC industry and it was concluded that BIM tools are not fully automated in the AEC industry. The structure is made in REVIT software as shown in Figure 3.7 and then for analysis of the structure the BIM integrated software such as ARSAP is used. From ARSAP software, model is imported from REVIT easily but there are some geometrical issues like loss of architectural stair, connection in between linear elements and alignment of line alignment with slabs, so we need human thinking is needed with modelling and analysis knowledge which is time- consuming and prone to error and also lacks automated structural analysis updates in response to architectural design changes. After identifying the problems, different experimentation on REVIT model (column, beams and slabs) are done to develop an appropriate flowchart for the automated import from REVIT to ARSAP in BIM tools. With the help of a flowchart and software engineers the BIM-based plug-in-tools tool to be developed to automatically solve alignment and nodes connection issues.



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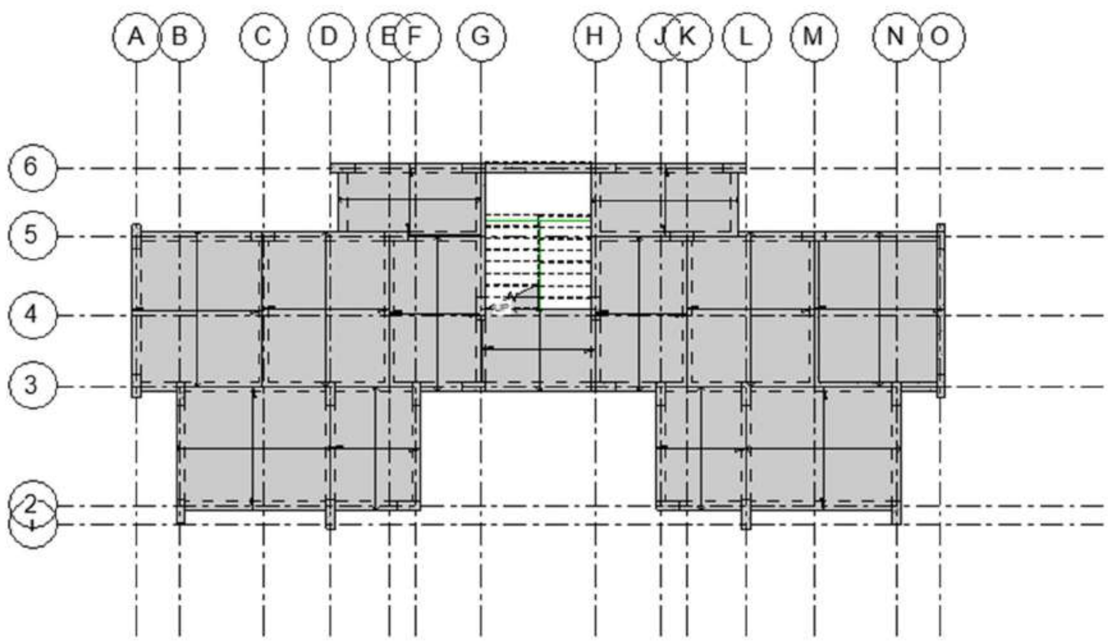

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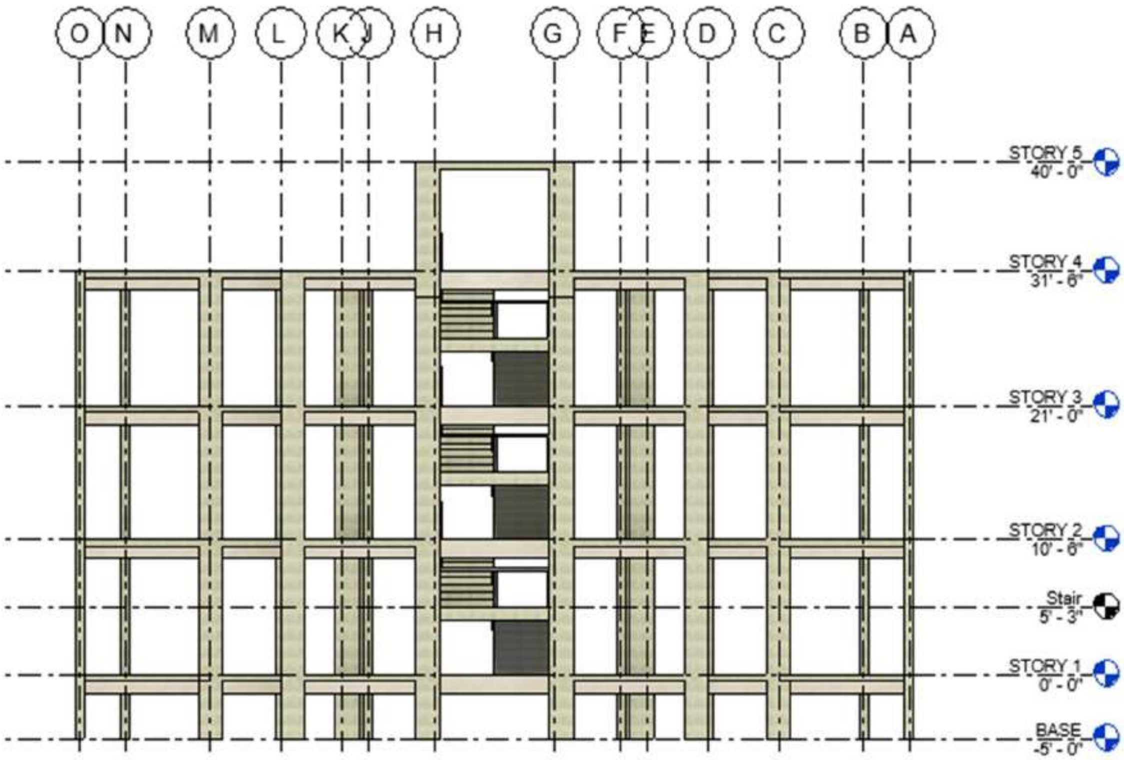

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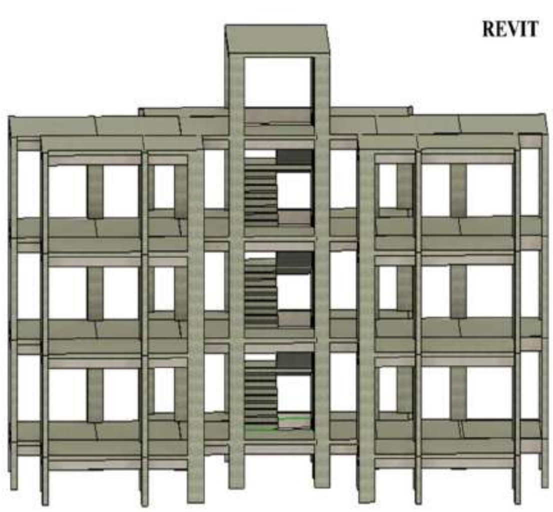
Figure 3.4: a) 3D model in REVIT, b) Plan in REVIT, and c) Elevation in REVIT



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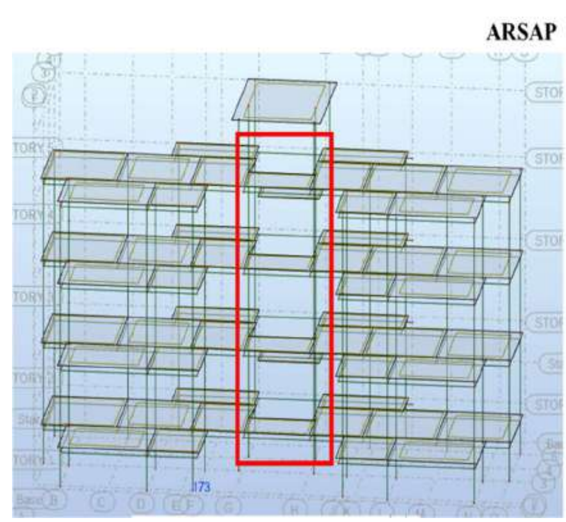

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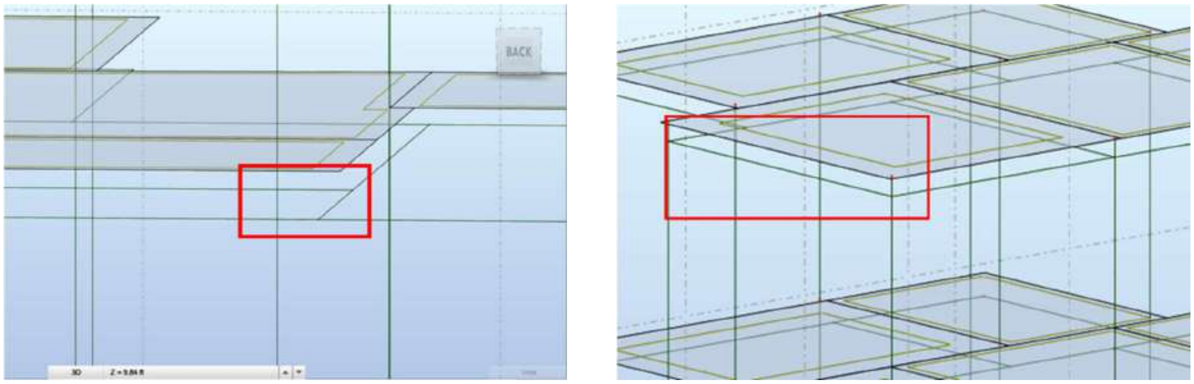


c) d)

Figure 3.5: a) Structure model in REVIT, b) Loss of architectural stairs c) Connectivity issue between beam and column, d) Alignment issues between beam and slab

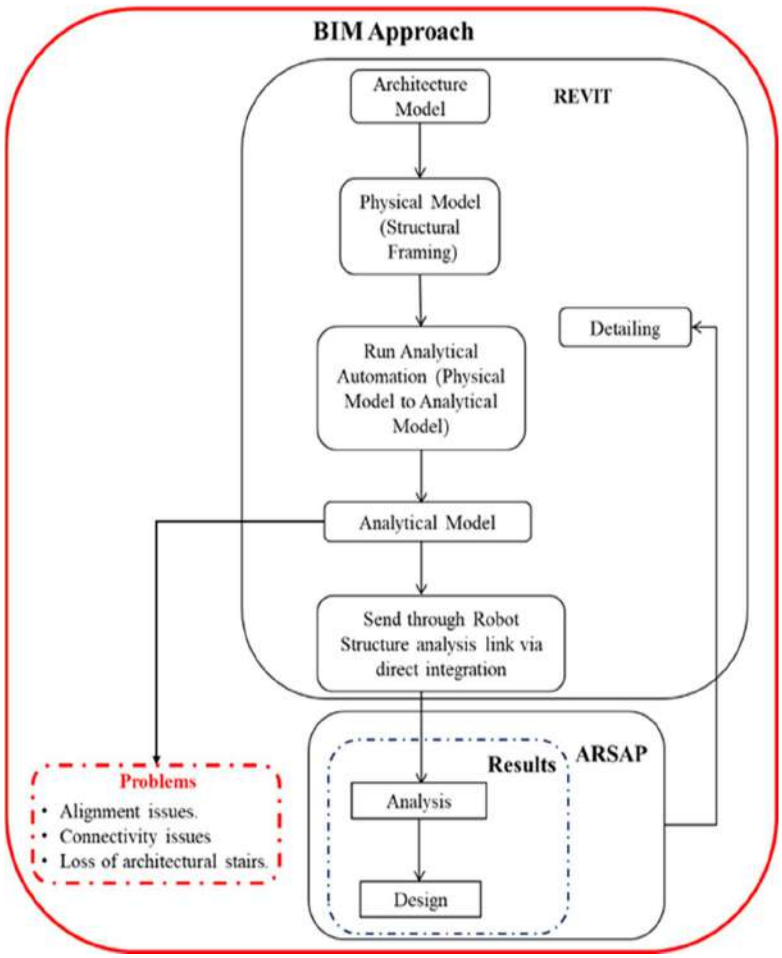


Figure 3.6: Hindrance for automatic import from REVIT to ARSAP

3.3 Procedure for automatic import of beams and columns from REVIT to ARSAP

Structural columns, framing elements, and braces modeled in Revit software are transferred to Robot as bar elements-Columns, Beams, and Simple Bars, respectively. Revit parameters such as Analyze As (for instance, lateral, gravity) and Framing Type (girder, joist) have no bearing on the Robot element. Revit elements such as structural columns spanning multiple levels are transferred intact to Robot as physical members. During analysis, these physical members are split into finite elements at intersecting framing nodes. Beam systems and trusses are container objects in Revit software. The individual framing elements contained in beam systems and trusses are transferred to Robot as beams or bars while the beam systems and trusses container objects are not. The individual framing members hosted by beam system and trusses are editable in Robot and updated accordingly in Revit.

3.4 Procedure for automatic import of RCC slabs from Revit to ARSAP

In the transfer from Revit Structure to Robot Structural Analysis, area boundary conditions are converted into planar supports. Both pinned and user-defined supports are successfully transferred. However, planar supports in Robot Structural Analysis are not transferred back to Revit Structure or preserved there. Structural floors and walls in Revit Structure are transformed into floor and wall panel elements in Robot Structural Analysis, allowing for finite element analysis and design. Roofs in Revit Structure, considered non-structural, are not transferred to Robot Structural Analysis. If steel roof decking is required for analysis and design, it should be modeled as a structural floor in Revit Structure. When foundation slabs are transferred to Robot Structural Analysis, they return as structural floors in Revit Structure. The concrete floors maintain identical cross-sectional and material properties between the two programs. For floors with corrugated steel decking, their section and material properties are appropriately transformed during the transfer. Curved walls modeled in Revit Structure are transferred as curved walls in Robot Structural Analysis. Similar to curved beams, these curved walls are then transferred back to Revit Structure and preserved as hidden data.

3.5 Summary

This chapter concludes the methodology of this project program. It covers the procedure for developing appropriate flow charts for the automated import of linear and planar elements of the RCC frame Building which is selected for the project. Which is modeled, designed, and detailed by group 11 of batch 2018. Its architectural plans are shown in this chapter. The procedure for flow chart is described above for the automation of BIM tools. The procedure for different RCC members is described separately.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Background

Different BIM tools are used in this project. Autodesk Robot Structural Analysis Professional (ARSAP) is used for the structural analysis of RCC frame building and the REVIT is used for architectural design and structural engineering for analysis and design. When physical model is created and then sends to the ARSAP through Robot structural analysis link via direct integration. However REVIT sends analytical model of physical model, so there are issues occur when converting physical model into analytical model such as connection between beam and column are not properly joined, column to column are not properly joined and beam alignment and also architectural stair are missing while converting into analytical planar element. In this chapter, solution to these problems are discussed to reduce human interaction while reworking on these issues.

4.2 Flow chart for automatic import from REVIT to ARSAP

When Robot Structural Analysis Professional is installed on the same computer as the Revit software, new commands are added to the Revit user interface that provide a link between the two products. This link enables the Revit user to send a Revit model to Robot Structural Analysis Professional for analysis and design, and update the Revit model based on the results of the analyses. All analyses and design is performed in Robot Structural Analysis Professional, except for composite steel framing. The Composite Design Extension is used to analyze and design composite steel framing directly in Revit software. Figure 4.1(a) shows the robot structure analysis link in REVIT.

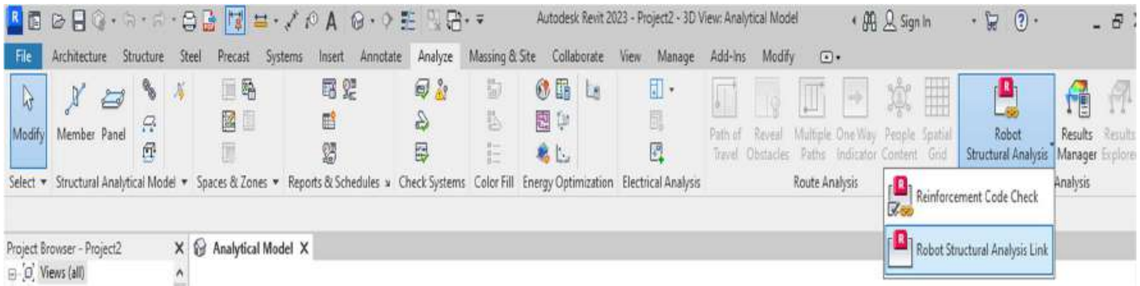
Integrating models from Autodesk Revit to Autodesk Robot Structural Analysis Professional (ARSAP) involves the use of bi-directional links that allow you to pass a model back and forth between the two software systems as shown in Figure 4.1(b).

- **Send model:** Allows sending a Robot model to Revit.
- **Send model and results:** Allows sending a Robot model with associated results to Revit.
- **Update model:** Allows updating a Robot model after making changes in Revit (after changes in the structure geometry).

Revit provides two types of integration with Robot structure analysis professional as shown in Figure 4.1(c).

- **Direct integration:** Allows sending a Robot model directly to Revit.

- **Send to the intermediate file (.smxx):** Allows sending a Robot model to the intermediate file (SMXX). Open the saved file in Robot or in Revit. In addition, use the SMXX file to exchange data between programs on different computers.



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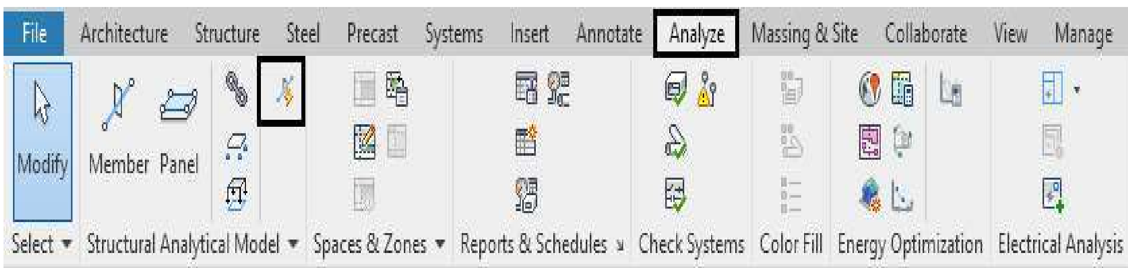

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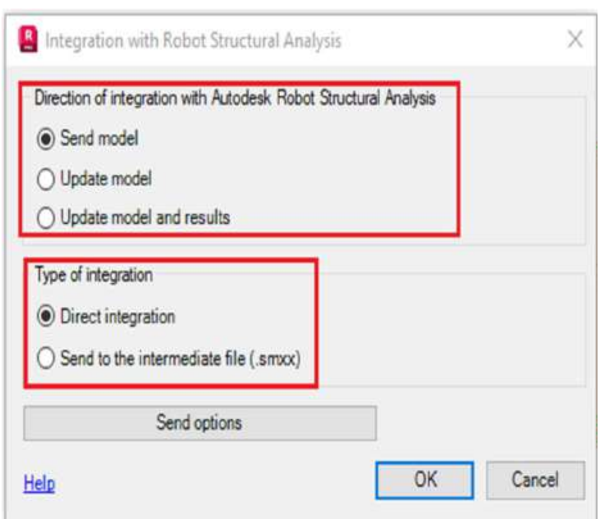
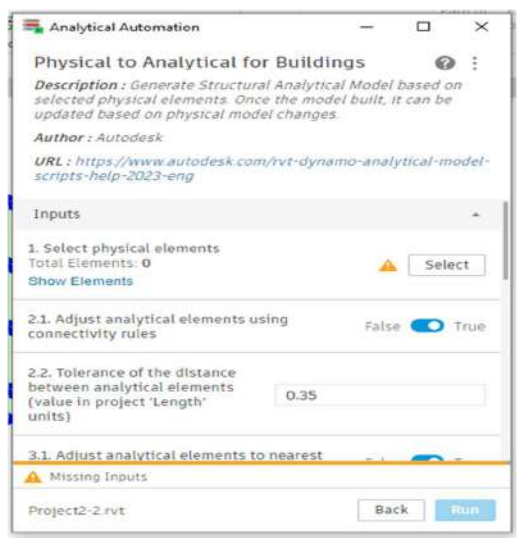


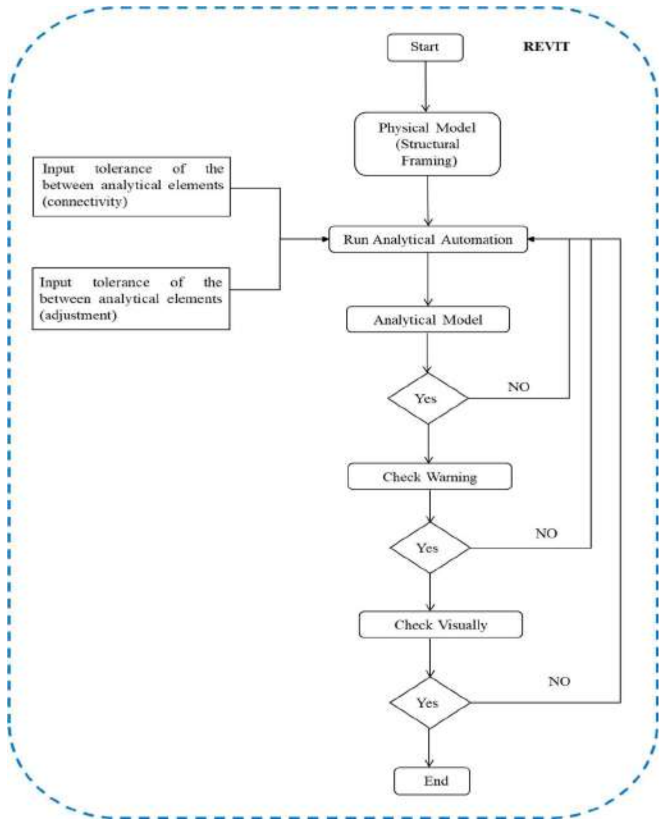


c) d)

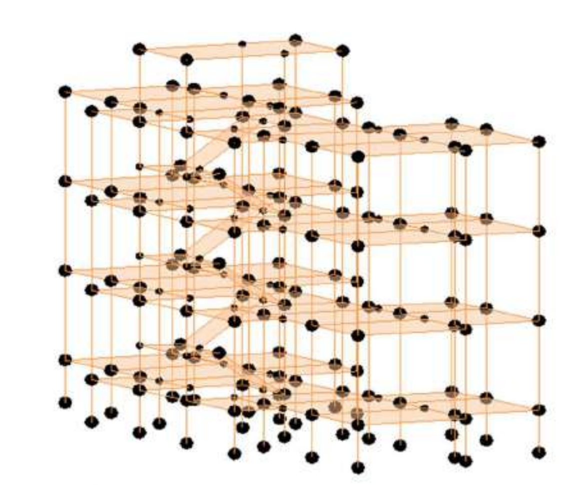
Figure 4.1: a) Robot structure analysis link in REVIT Integration, b) Types of integration in REVIT with ARSAP, c) & d) REVIT 2023 analytical automation in analyze tab

In REVIT when architectural model and structural framing model is done then structural framing model is converted into analytical model before sending to Robot Structure Analysis Professional (ARSAP). In REVIT 2022 manual conversion is done to convert physical model (structural framing) into analytical model. After converting the model, analytical model have errors which are not present in physical model such as loss of architectural stairs, beam-column connection, column-column connection, and beam alignment. In REVIT 2023, Autodesk provides the physical to analytical automation to overcome those errors which are mention above. To use analytical automation, click on the analyze tab and go to the structure analytical model panel and click on the analytical automation option as shown in Figure 4.1(b). After this another dialog box is open as shown in Figure 4.1(d), then click on the run button then dialog box will change and it require input parameters for adjustment and connectivity of model which is called tolerance factor.

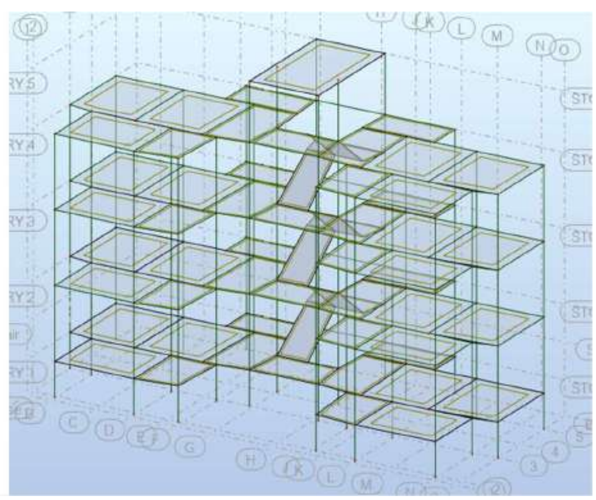
In REVIT 2023, Physical model is created using REVIT built in library and then it is converted through analytical model through analytical automation (Physical to analytical model).In analytical inputs the tolerance factor for model adjustments and connectivity to resolve the alignment and connectivity issues between the element as shown in Figure 5.2. Once the input parameters are done then click and then select all elements of physical model and then run so the analytical model will be created. After that check the model consistency error and then check the nodes visually. However if these above checks are “ok” then send the model to ARSAP for analysis. If these checks are “not ok” then again go to the analytical automation to change the input parameters for tolerance for model adjustment and connectivity. These tolerance factors does not affect the actual geometry of physical model. But it is hit and trial rule to solve these issues. These tolerance factors vary for different model but not a same factors used for every model. It is very tedious way to check the analytical model for different tolerance factors to get the desired results for large geometrical model where a large number of beams-column connections and column to column connections are involved. Flow chart were drawn manually to indicate the automate process to resolve model connectivity and alignment issues of RCC members. Flow charts is created based on manual operation which is done to resolve model issues as shown in Figure 4.2, and also this flow chart needs to integrate into the Dynamo python engine script with the help of software engineers for the advancement of BIM tools.



a) Flow chart to resolve model issues



b)

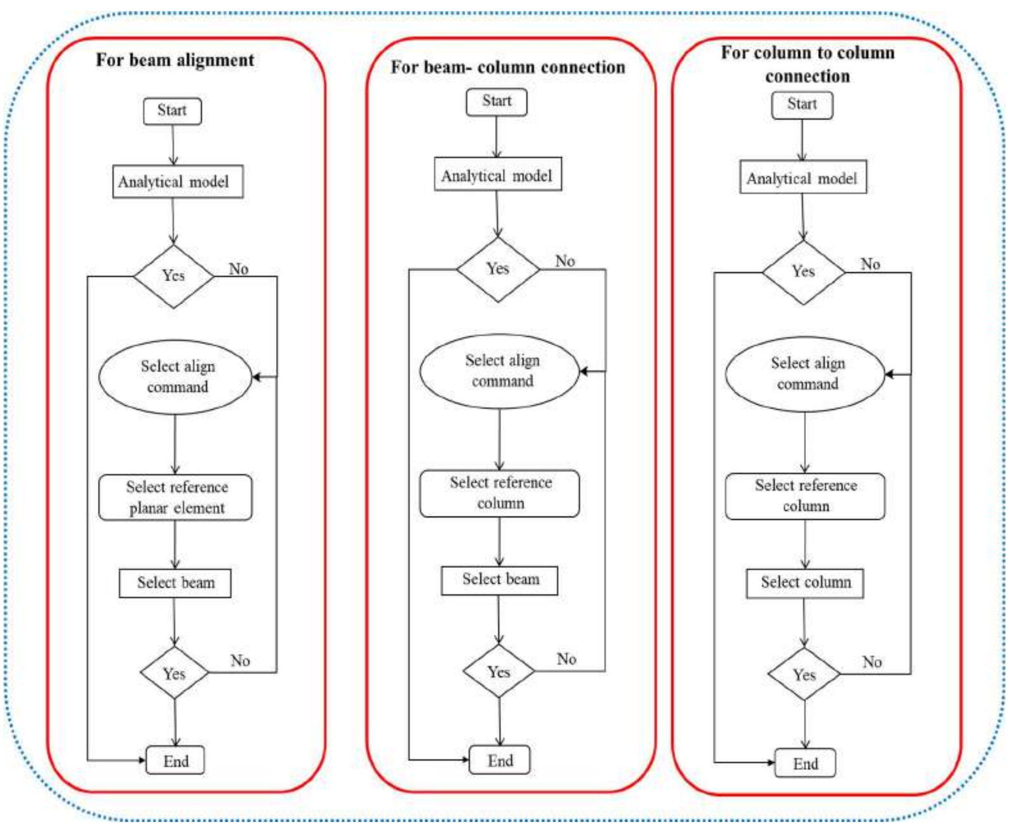


c)

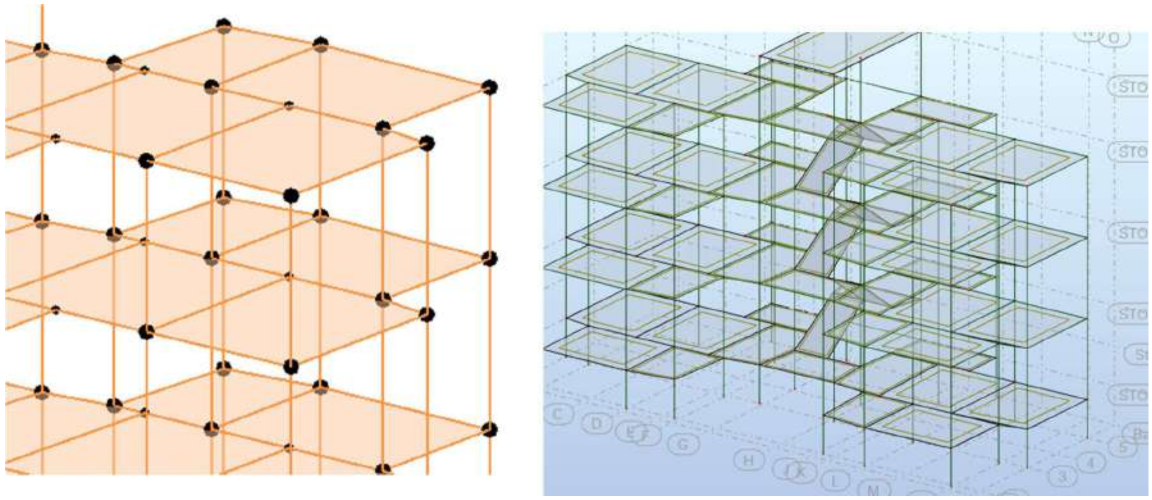
Figure 4.2: Proposed solution and its implementation, a) Flow chart to resolve model issues, b) After resolving issues in analytical model in REVT, c) Model in ARSAP

4.3 Flow chart for automatic import of line elements from REVIT to ARSAP

Autodesk Robot Structure is FEM (Finite Element Method) based computes application used for analysis and design of structures. In FEM process of matrix analysis or stiffness matrix is used and stiffness matrix depends on the nodes. So the issues like beam-column connections, beam to beam connections, alignment issues results in inaccurate formations of nodes. However these issues influences the analysis and design. In REVIT for beam alignment, select the reference planar element which is in correct position, then select align command and then select the beam which is not aligned. For beam-column connection, select the reference column which is in correct position, then select align command and then select the beam which is not connect to a reference column. For column-column connection, select the reference column which is in correct position, then select align command and then select the column which is not connect to a reference column. Flow chart is drawn manually to indicate the automate process to resolve line element connectivity and alignment issues of RCC members. Flow charts is created based on manual operation which is done to resolve line element issues as shown in Figure 4.3 and also this flow chart needs to integrate into the Dynamo python engine script with the help of software engineers for the advancement of BIM tools.



a)



b) c)

Figure 4.3: a) Flow chart to resolve line element issues, b) Solve line element issues in analytical model in REVIT, c) Line elements in ARSAP

Model elements in Revit Structure and Robot Structural Analysis are transferred between the applications. The tables indicate whether an element is transferred in both directions (< >), in one direction only (> or <), is not transferred (NA), or is not eligible for transfer but preserved during iterative round-trip processes (P). Any limitations related to the transfer of an element are noted as well.

Structural Columns, Beams, and Braces modeled in Revit Structure are transferred to Robot Structural Analysis as bar elements: Columns, Beams, and Simple Bars, respectively. Revit Structure parameters such as Analyze As (e.g. Lateral, Gravity) and Framing Type (e.g. Girder, Joist) have no bearing on the Robot Structural Analysis element. Revit Structure elements such as Structural Columns spanning multiple levels are transferred intact to Robot Structural Analysis as "physical" members. During analysis these "physical" members are split into finite elements at intersecting framing nodes. Wall Foundations and Line Boundary Conditions modeled in Revit Structure are transferred to Robot Structural Analysis as Linear Supports. The mode of transfer between Revit Structure and Robot Structural Analysis is the same as that of Nodal Supports. Curved Beams modeled in Revit Structure are transferred to Robot Structural Analysis as discretized linear Beams. Robot Structural Analysis will by default provide a fine discretization unless the discretization parameters (Approximate Curve) are defined for the element in Revit Structure. When updating the Revit Structure model from Robot Structural Analysis, Robot Structural Analysis will preserve the discretized beam segment information in

Revit Structure as new hidden data rather than creating a new—or updating an existing—single curved beam. Beam Systems and Trusses are container objects in Revit Structure.

Table 4.1: Line elements to be taken care of for automatic import

REVIT Structure		Robot Structure Analysis Professional
Line Boundary Condition	>	Linear Support
Wall Foundation	< >	Linear Support
Structural Column	< >	Column
Beam	< >	Beam
Brace	< >	Bar
Curved Beam	P>	Discretized Mesh
Beam System	NA	
Truss	NA	

Table 4.2: Line elements parameters to be taken care of for automatic import

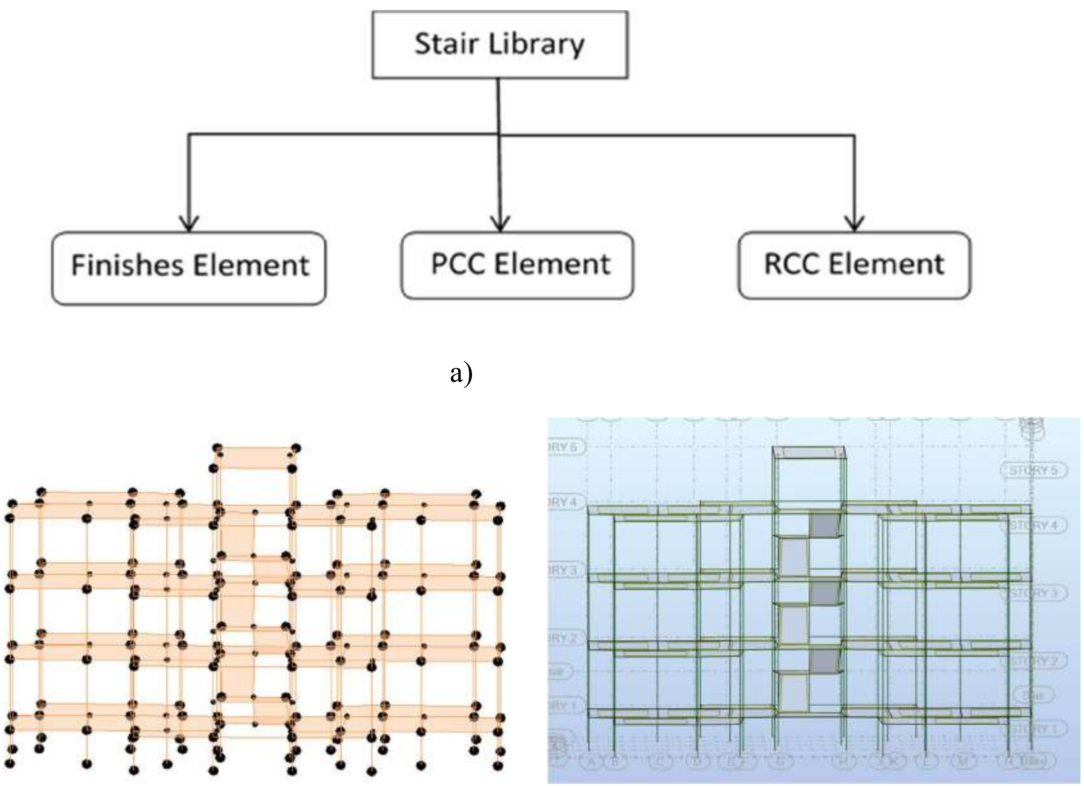
REVIT Structure		Robot Structure Analysis Professional
Offset	>	Offset
Rigid Link	< >	Rigid Link
Cross-Section Rotation	< >	Gamma Angle
	P	Cable
	P	Elastic Ground
	P	Geometric Imperfection
	P	Non-linear Hinge
End Release	< >	End Release
	P	Member Type
	P	Inactive Status
	P	Shear Force respect in deformation
	P	Tension/ Compression member
	P	Axial Forces only

The individual framing elements contained in Beam Systems and Trusses are transferred to Robot Structural Analysis as Beams Bars or while the Beam System and Truss container objects are not. The individual framing members hosted by Beam Systems and Trusses are editable in Robot Structural Analysis and updated accordingly in Revit Structure. However, the best practice is that modification of the member layout be performed in Revit Structure rather than Robot Structural Analysis. Also, note that the Beam System Tag will not update since this is a function of the Beam Type Parameter of the Beam System in Revit Structure. Several of the Element Parameters in Revit Structure are transferred bi-directionally with Robot Structural

Analysis. Other Robot Structural Analysis design parameters such as slenderness and buckling coefficients are preserved in the Revit Structure model.

4.4 Flow chart for automatic import of area element from REVIT to ARSAP

In REVIT there is no loss of area elements and no connectivity issues are occur but the loss of architectural stairs are occurs because REVIT does not consider the architectural stairs are part of structure element so these are missing in the analytical model. From survey about stairs analysis and design form structural design engineers shows that some engineers are considered stairs as structure element so they analyze and design as part of RCC structure, some design engineers are not considered stair as structure element, and some design engineers treat stairs separately for analysis and design. To solve the stair issues this design project propose two solution. REVIT should provide three libraries for structure such as finishes, for PCC (riser and threads) and for RCC (structural element) as shown in Figure 4.5, and stair is modelled as slab in REVIT which is not missing analytical model after physical model conversion.



a)

b) c)

Figure 4.4: a) Suggested solution for stair in REVIT, b) Resolve area elements issues in analytical model in REVIT, c) Area elements in ARSAP

Area Boundary Conditions modeled in Revit Structure are transferred to Robot Structural Analysis as Planar Supports. Both Pinned and User-defined supports are transferred. Planar Supports in Robot Structural Analysis are not transferred to or preserved in Revit Structure. Structural Floors and Structural Walls modeled in Revit Structure are transferred to Robot Structural Analysis as Floor and Wall panel elements, which can be meshed into finite elements for analysis and design. Revit Structure roofs are considered non-structural and are not transferred to Robot Structural Analysis. If steel roof decking is needed in Robot Structural Analysis for analysis and design, it should be modeled in Revit Structure as a Structural Floor.

Table 4.3: Planar element to be taken care of for automatic import

REVIT Structure		Robot Structural Analysis Professional
Area Boundary Condition	>	Planar Support
Foundation Slab	>	Floor
Structural Floor	< >	Floor
Structural Wall	< >	Wall
Structural Curtain Walls	>	Cladding
Curved Structural Wall	P, >	Wall
Wall Opening and Window	P, >	Opening
Door	P, >	Opening
Vertical or Shaft Opening	P, >	Opening
Slab Edge	NA	

Foundation Slabs are transferred to Robot Structural Analysis as Floors and will return to Revit Structure as a Structural Floor instead of a Foundation Slab. Concrete floors in Robot Structural Analysis have the same cross-sectional and material properties as those in Revit Structure. Floors with corrugated steel decking are transferred to Robot Structural Analysis with transformed section and material properties. Curved Structural Walls modeled in Revit Structure are transferred to Robot Structural Analysis as curved Walls. Similar to curved beams, curved Walls in Robot Structural Analysis are transferred to Revit Structure and preserved there as hidden data.

Wall, Vertical, and Shaft openings, Windows, and openings created by Editing Profile modeled in Revit Structure are transferred to Robot Structural Analysis as Openings. The perimeter shape of a Floor, Wall, and Slab including arcs are transferred as the contour shape of the panel in Robot Structural Analysis. Doors modeled in Revit Structure are transferred to Robot Structural Analysis as part of the perimeter panel definition rather than openings. No relationship is maintained between the Revit Structure openings and the Robot Structural Analysis openings. So any modifications made to openings in Robot Structural Analysis and new openings are not updated in Revit Structure.

Finite element auto-meshing of the transferred Floor and Wall panels is not done automatically during the transfer, and must be completed by the engineer in Robot Structural Analysis. The auto-meshing and other planar parameters are preserved as hidden data in Revit Structure during subsequent transfers. However, the auto-mesh should be reviewed after significant revision to the Floor layout.

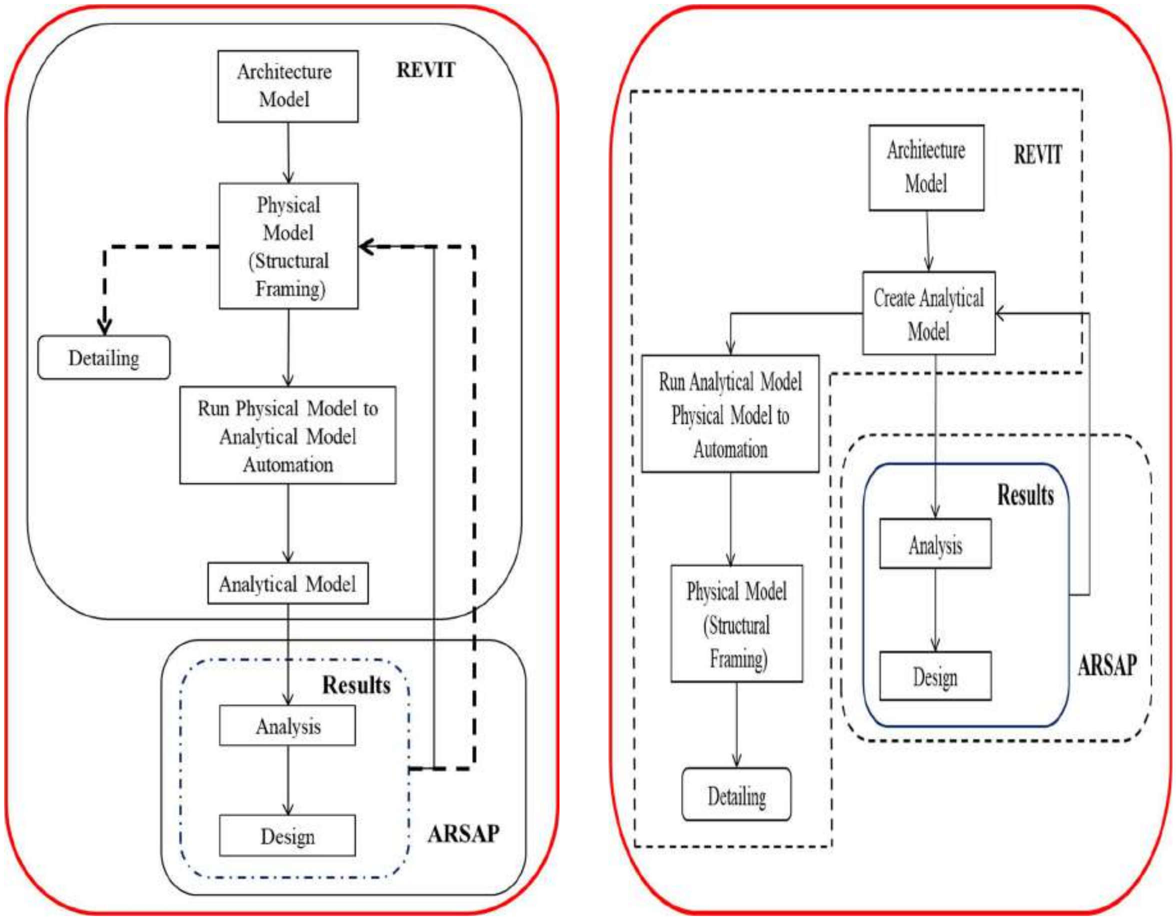
Table 4.4: Planar element parameters to be taken care for automatic import

REVIT Structure	**Robot Structural Analysis Professional**
P	Load Distribution
P	Reinforcement Design Parameters
P	Calculation Model
P	Meshing Parameters
NA	Emitters

4.5 Propose frame work for structural engineers using BIM tools

As more and more structural engineers embrace Building Information Modeling (BIM) workflows, demand is increasing for analytical collaboration in BIM. The development of a structural analytical model is an essential step in a structural engineer's BIM process. This model is often used in collaborative workflows across engineering teams. For many years now, Autodesk Revit has offered features for structural analytical modeling. However, those features did not provide structural engineers with enough flexibility and control in the modeling process, especially for non-standard and complex structures.

For example, an engineer might want to modify the position of a physical model easily without changing the geometry and position of the associated analytical model, but these were directly linked in the past. At the same time, we know that engineers want to ensure that their physical and analytical models remain well coordinated throughout the design process. To that end, Revit 2023 has introduced a completely new approach to structural analytical modeling. The workflow has been totally reimagined to help engineers use Revit to coordinate across structural physical and analytical models and drive BIM-centric analysis workflows.



a) b)

Figure 4.5: Suggested option (a) which is available in old versions of REVIT for structural engineers, Explored option (b) available for precise import in version of REVIT 2023

As before, you can leverage existing physical geometry in 2D and 3D views as context for the analytical model. The analytical model remains associated to physical geometry but is now independent, providing you with the benefits of speed and accuracy in model creation while protecting the analytical model from unexpected changes. This new approach to structural analytical modeling enables you to create representations for any type of structure buildings, frames, pavilions, bridges, stairs and more. You can create consistent analytical models that align with your preferred engineering approach.

Two approaches or workflow are proposed in this design project and both approaches are good enough for structural engineers for analysis and design of a building. Adoption of approach depend upon the familiarity of process. 1) Physical to analytical automation, this script automates the creation of analytical elements and updates the analytical model using the physical model as context. 2) Analytical to physical automation, this script performs the opposite action; the script automates the creation of physical elements and updates the physical model using the analytical model as context. The analytical model in REVIT introduces not only more flexibility and control over the analytical model, but giving workflows to structural engineers the ability to choose their preferred approach to structural design and analysis.

In first workflow, architectural model is created then structural engineer creates physical model (structural framing) then it creates analytical model through physical to analytical automation then it send to ARSAP for analysis and design and at last detailing in REVIT. And in second workflow architectural model is created on REVIT then structural engineer create analytical model not the physical model then this analytical model send to ARSAP for analysis and design and then analytical model in REVIT and it is converted to physical model through analytical to physical automation and at last detailing. Moreover, you can choose to start your modeling process in Robot Structural Analysis Professional, developing your structural geometry (analytical model) from scratch and then send the model to Revit.

4.6 Summary

This chapter concludes the result and analysis of this project program. It covers the propose workflow for structural engineers and also appropriate flow charts for the process of complete successful import from REVIT to ARSAP and also develop flow charts to resolve model alignment and connectivity issues. The flow chart procedure is as described in the proposed automation of BIM tools. The procedure of flow charts for different for model to resolve adjustment issues is described separately. Revit 2023 addresses the previous limitations by offering enhanced capabilities for structural analytical modeling, providing structural engineers with greater flexibility, control, and coordination between physical and analytical models. These improvements enable engineers to effectively design and analyze non-standard and complex structures while ensuring accurate and synchronized models throughout the BIM process.

CHAPTER 5

DISCUSSION

5.1 Background

Building Information Model (BIM) in the civil engineering field is introduced in the past few decades, but with the massive pressure from the stakeholders (Client, contractor) for economical construction, one can assume its massive use. On construction sites, it helps the site engineers to manage all the construction phases easily, and in the future in extensive construction projects, it will not be possible to manage without BIM tools. Technological advancement in BIM tools offers new approaches in construction, which will improve the process of safety, quality, and efficiency. Currently, the major barrier to such technologies is the lack of knowledge and awareness about such tools in theAEC industry. It is essential to be aware of the stakeholder in civil engineering about BIMtools. The essence of improving this situation is not to implement the subject called BIM but to teach people and aware them of BIM across all related disciplines. BIM is a powerfultool, and engineers are modifying its tools regularly after certain essential tools are still missing and need advancement in BIM tools.

5.2 Lessons learned from current DP

Today, in certain areas BIM is considered only software but BIM is not software- only, it is an integrated process as shown in Figure 5.1. On the other hand, without advancements in information technology, including software and hardware, the utilization of the concepts ofthe building information modeling principle in construction practice would not accomplish such development. The 3D model of the structure is sometimes mistakenly thought of as building information modeling. BIM is an integrated tool, which includes relevant information throughout the lifecycle of a project or building, from architectural and structural analysis, execution, building management, and makeovers to its demolition. The3D model is a one-dimensional interpreting method of this information. 3D modeling is un-doubtfully an important function of architects, but other participants in the construction process may be interested in different information. For instance, in addition to the building'saesthetic, an investor can be concerned about the project's economic execution, schedule,and resource use. Additionally, a structural engineer requires the information required for static calculations.

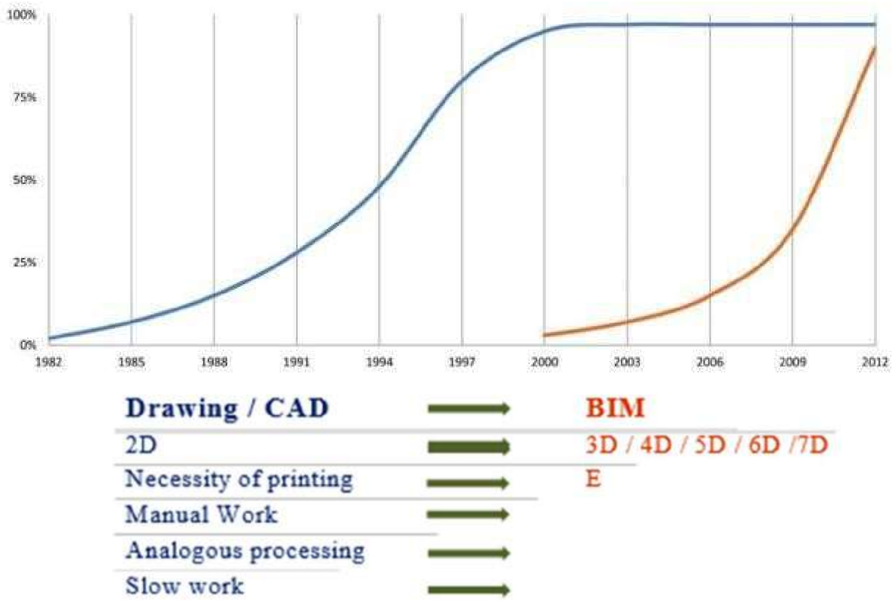


Figure 5.1: BIM versus CAD implementation at different stages

Figure 5.1 shows BIM implementation is twice that of CAD in AEC sectors. It is because that BIM is a powerful tool and most importantly it can update the tools from timeto time. As mentioned earlier that BIM has many tools which advance construction to newheights. BIM modified many tools from CAD, but still, certain tools are missing. Advancing this tool is the necessity of time and industry. For example, clash remover, model import from REVIT ARSAP or any other structure analysis software without any information loss. Such advancements can optimize construction in the AEC industry and ultimately save time and cost. Although several such tools are available still they have several issues, including a need for human involvement in all stages, which increases the chances of error, and some of the tools are not user-friendly, sometimes their results became impractical and not possible for execution. Similarly, there is some plugin available for importing the model from REVIT to ARSAP without any information loss. One of the issues with this plugin is that it is limited to same models. Another approach for automation is the in-built visual programming option in BIM Software. BIM software offersvisual programming for the user to develop their custom commands.

5.3 Structural analytical model automation

Structural engineers rely on a robust structural analytical model as a crucial component of their Building Information Modeling (BIM) process. This model facilitates collaborative workflows among engineering teams. However, previous versions of Autodesk Revit, a popular software for structural engineering, lacked the necessary flexibility and control for non-standard and complex structures. This limitation particularly affected the ability to modify the position of a physical model without altering the geometry and position of the associated analytical model, as the two were directly linked. Recognizing the need for improved coordination between physical and analytical models throughout the design process, Revit 2023 has introduced a revolutionary approach to structural analytical modeling. This update completely reimagines the workflow, empowering engineers to effectively coordinate between structural physical and analytical models and facilitate analysis workflows that are centered on BIM.

The Physical to Analytical Automation meet specific needs in structural engineering. These options include the ability to prioritize adjustments to analytical elements based on their structural category and define connectivity tolerances. By designating a first, second, and third priority element hierarchy, the script allows for a systematic approach to the modeling process. For instance, if column locations take precedence over beam locations, the first priority elements represent the main elements, to which second and third priority elements will snap. This ensures proper alignment and coordination between the different elements.

Moreover, specifying a tolerance for the distance between analytical elements, ensuring that they are accurately positioned. This feature also enables the creation of associations between newly generated analytical elements and their corresponding physical counterparts. Additionally, engineers have the option to inherit properties from associated physical elements, such as material, section type, and cross-section rotation. This streamlines the modeling process by automatically transferring relevant properties, eliminating the need for manual input and reducing potential errors.

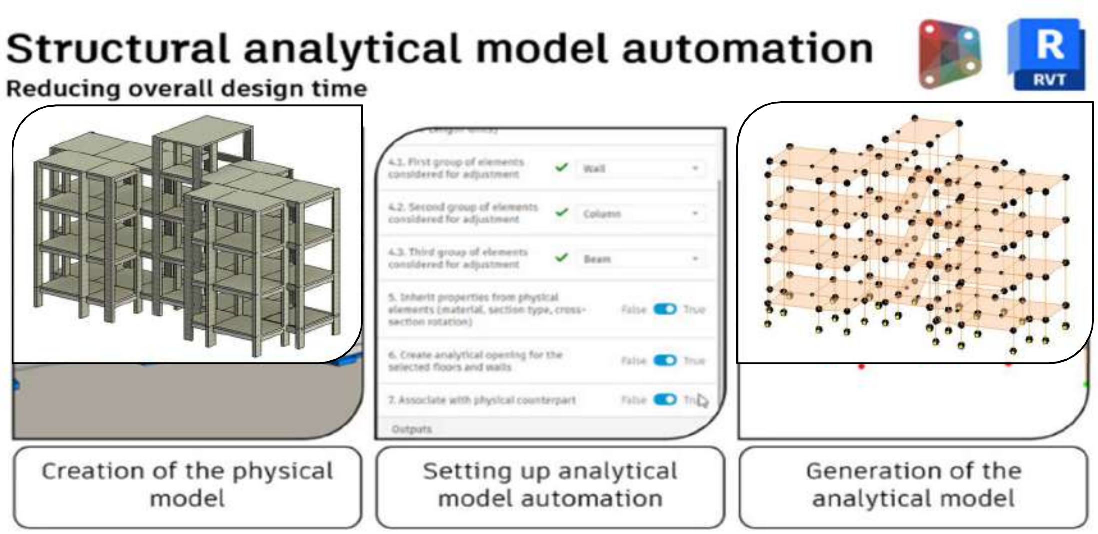


Figure 5.2: Hierarchy of physical to analytical automation

After completing the structural analysis and design in Robot software, the information can be seamlessly transferred to Revit to update the model and related documentation. The updated analytical model in Revit retains its association with the physical geometry but gains full independence, acquiring its own set of properties including section type, material, and more. However, it's important to note that when updating the Revit model after the design process in Robot, any changes to cross-sections might not automatically reflect in the physical section types within the Revit model. This discrepancy is not a concern since the physical and analytical models remain associated with each other. To address this situation, Analytical to Physical Automation, comes into play. The purpose of updating the physical model while using the analytical model as a reference or context. The physical model can be synchronized with the changes made in the analytical model, ensuring consistency between the two.

One of the most ground breaking advancements in Autodesk's BIM-centric workflows for structural analysis is the ability to start projects directly from the analytical representation of the model. This feature allows users to initiate structural analysis workflows in REVIT without relying on any physical context, providing a revolutionary capability. With the analytical model now operating independently, structural engineers have the option to begin the modeling process with analytical intent.

However, manually creating physical elements based on this analytical model can be a time-consuming task if not automated. To address this, Revit offers functionality that automates the creation of associated physical model geometry from the structural analytical model, utilizing configurable rules that can be applied on demand. This automation significantly speeds up the modeling process, ensuring efficiency and accuracy.

By starting the modeling process in Robot Structural Analysis Professional and developing the structural geometry (analytical model) from scratch, engineers can then seamlessly transfer the model to Revit. The new analytical model in Revit not only provides enhanced flexibility and control over the analytical representation but also introduces new workflows. This empowers structural engineers to choose their preferred approach to structural design and analysis, tailoring the process to their specific needs and preferences.

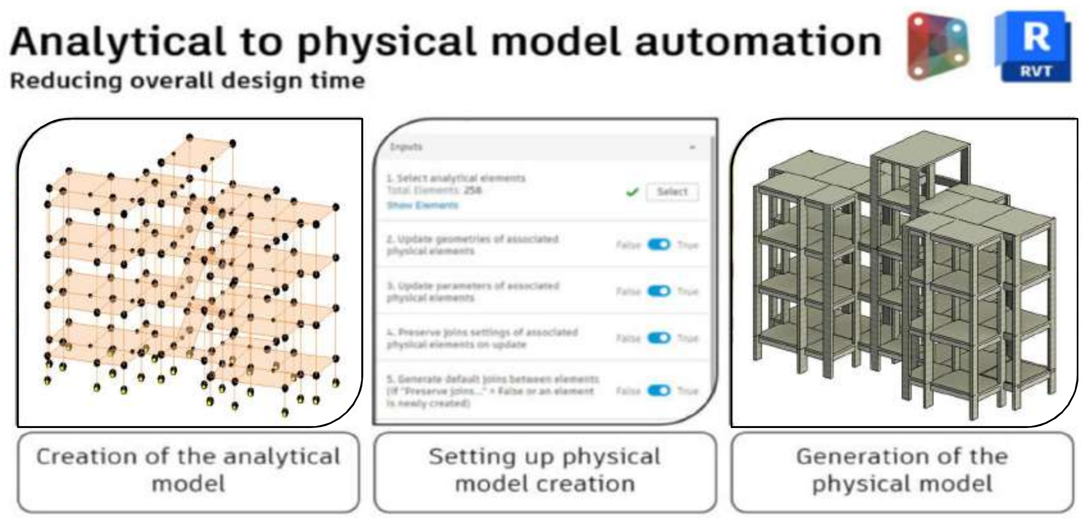


Figure 5.3: Hierarchy of analytical to physical automation

5.4 Guidelines for practicing designer

Before transferring the model, ensure that it is properly prepared in Revit. This includes creating accurate and detailed 3D geometry, organizing the model using appropriate levels, grids, and annotations, and ensuring that all required elements and information are included .Export the model in a format compatible with ARSAP. Typically, ARSAP supports file formats like IFC (Industry Foundation Classes).Consult the documentation or support resources for ARSAP to determine the supported file formats. Once the model is imported into ARSAP, carefully review it to ensure that all the elements, dimensions, and details are accurately transferred. Validate the model's integrity by comparing it with the original Revit model to ensure it's faithfully represented in ARSAP. Structural column should be place before placing structural beams after creating the grid. Structural beams should be place at the exterior face of the column and must be along the centerline of grid. Slabs should be place on grids. Choose the correct families and types for structural elements such as columns, beams, walls, and foundations. Use families with appropriate parameters and properties. Design engineer should know about the transfer of families and structural elements from REVIT to ARSAP. Maintain proper connectivity between structural elements. Use appropriate joins, connections, and constraints to ensure accurate representations of the building's structure.

5.5 Other elements and other parameters transfer from REVIT to ARSAP

In the integration between Revit Structure and Robot Structural Analysis, certain elements modeled in Revit, such as Materials, Grids, and Levels, are translated into corresponding entities in Robot Structural Analysis, namely Materials, Structural Axes, and Stories. However, it's important to note that the directionality of these elements is limited in

Robot Structural Analysis. Therefore, it is advised that users create and fine-tune these elements within Revit Structure to ensure proper alignment and orientation.

On the other hand, various project-wide and structural analysis parameters in Robot Structural Analysis are sent to Revit Structure and retained during the integration process. This means that important data related to the structural analysis, such as load cases, load combinations, boundary conditions, and other analysis-specific parameters, are preserved with in Revit Structure.

Table 5.1: Other element and other parameters to be taken care of for automatic import

Revit Structure		**Robot Structural Analysis Professional**
Material	>	Material
Grid	>	Structural Axis
Level	< >	Story
	P	Global Mesh Parameters
	P	Active Section Databases
	P	Units
	P	Analysis Parameters
	P	Model Generation Parameters

5.6 Summary

Revit 2023 addresses the previous limitations by offering enhanced capabilities for structural analytical modeling, providing structural engineers with greater flexibility, control, and coordination between physical and analytical models. These improvements enable engineers to effectively design and analyze non-standard and complex structures while ensuring accurate and synchronized models throughout the BIM process. The Physical to Analytical Automation Dynamo script provides a versatile toolset for structural engineers, enabling customization and control over analytical adjustments, element hierarchies, connectivity tolerances, property inheritance, and analytical openings. These features enhance the efficiency and accuracy of the structural modeling process within the BIM workflow. The Analytical to Physical Automation Dynamo script offers a solution to update the physical model in Revit using the analytical model as a reference. This helps maintain the connection and consistency between the physical and analytical representations of the structure, facilitating accurate documentation and an integrated BIM workflow. The ability to start projects from the analytical model in Revit, along with the automation of creating physical model geometry based on the analytical model, offers increased efficiency and flexibility in structural design and analysis workflows. This capability revolutionizes the BIM-centric approach, empowering engineers to work with greater control and customization throughout the modeling process.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Building Information Modelling (BIM) is a collection of tools that claim to automate numerous processes in the study, design, and construction of civil projects. The automated complete successful import from REVIT to ARSAP one such issue. The following conclusions are made from this Design Project (DP):

- REVIT provide the bidirectional integration with Revit. To automate the overall model issues, structural analytical automation is used.
- For line element issues, flow chart is developed to resolve. Line element and parameter to be taken care of for automatic import.
- For area elements, REVIT should have own library of stairs for automatic import or stairs can be modelled as slab for automatic import. Planar element and parameter to be taken care of for automatic import.
- BIM is an integrated process, not just software, crucial for construction development. Advancements in BIM tools optimize AEC construction, saving time and cost. However, some tools still require improvement, as they may lack user-friendliness and may need human involvement for execution. Automation options like visual programming show promise for developing custom commands in BIM software. Continued advancements are essential to enhance construction workflows and achieve optimal results.
- REVIT 2023 revolutionizes structural analytical modeling, enabling efficient coordination between physical and analytical models. Automation streamlines workflows, providing flexibility and control.
- Proper preparation in Revit is crucial before transferring the model to ARSAP. Ensure accurate 3D geometry, organized elements, and compatible file formats. Validate and review the imported model in ARSAP against the original. Maintain connectivity and use appropriate elements for accurate representation in both software.
- The integration between Revit Structure and Robot Structural Analysis enables the translation of certain elements, but their directionality in Robot Structural Analysis is limited. To ensure proper alignment, users should create and fine-tune elements in Revit Structure. However, important project-wide and analysis parameters are successfully

sent to and retained in Revit, providing valuable information for users during their work.

6.2 Recommendations

The following recommendations are made from this Design Project (DP):

- It has been analyzed from the study that BIM tool require further refinement and up gradation to complete transfer of model and information from RVIT to ARSAP
- Static analysis and design of regular high-rise building using BIM tools-Solving hindering issues for automation.
- Dynamic analysis and design of irregular high-rise building using BIM tools-Solving hindering issues for automation.

REFERENCES

A. Ejaz and M. Ali, "Limitations of Autodesk Robot Structural Analysis Professional for Structural Design Output: A Review of Frame Building." [Online]. Available: https://help.bricsys.com/hc/en_EU/articles/360007744834

Autodesk, Revit - robot integration, AutoDesk (17 June 2016) [Online]. Available https://knowledge.autodesk.com/support/robot-structural-analysis-products/learn-explo re/caas/ Cloud Help cloud help/2017/ENU/RSAPRO-Users Guide/files/ GUID-B850E0C3-2314-4FEC-B5D1-A7C0CBDF290F-htm. html , Accessed date: 4 March 2018.

Autodesk.com, Revit platform technologies | Autodesk developer network | Revit developer center, [online] Available at https://www.autodesk.com/developernetwork/platform-technologies/revit,

Boddupalli, C., Sadhu, A., Rezazadeh Azar, E., & Pattyson, S. (2019). Improved visualization of infrastructure monitoring data using building information modeling. *Structure and Infrastructure Engineering*, *15*(9), 1247-1263. https:// doi.org/1 0.1080/1573 2479 .2019 .1602150

Cao, D.; Wang, G.; Li, H.; Skitmore, M.; Huang, T.; Zhang, W. Practices and effectiveness of building information modelling in construction projects in China. *Autom.Constr.* **2015**, *49*, 113–122.

C.M. Eastman, BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors, (2012), 9780470541371 https:// doi.org/10.5130/ajceb.v12i3.2749

C. Eastman, P. Teicholz, R. Sacks, K. Liston, BIM Handbook – A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors, John Wiley & Sons, Inc., 2008.

D. Holzer, The BIM Manager's Handbook : Guidance for Professionals in Architecture, Engineering, and Construction, Wiley, Chichester, England, 2016, ISBN 1-118-982401.

E. N. Shaqour, "The role of implementing BIM applications in enhancing project managem ent knowledge areas in Egypt," *Ain Shams Engineering Journal*, vol. 13, no. 1, p. 101509, Jan. 2022, doi: 10.1016/J.ASEJ.2021.05.023.

E. Kfouri, Structural analysis links to Revit structure, [Online]. Available http:// bimapps.typepad.com/bim-apps/2011/02/structural-analysis-links-to-revit structure-1.html, (28 February 2011) , Accessed date: 3 March 2018.

E. Kfouri, Structural analysis links to Revit structure, [Online]. Available http://bim apps. type pad.com/bim-apps/2011/02/structural-analysis-links-to-revitstructure-1.html, (28 February 2011) , Accessed date: 3 March.

G. Aksenova, A. Kiviniemi, T. Kocaturk, A. Lejeune, From Finnish AEC knowledge ecosystem to business ecosystem: lessons learned from the national deployment of BIM, Construct. Manag. Econ. 37 (6) (2018) 317–335, https://doi.org/10.1080/ 01446193.2018.1481985.

Hasan, A. M. M., Torky, A. A., & Rashed, Y. F. (2019). Geometrically accurate structural analysis models in BIM-centered software. *Automation in Construction*, *104*, 299-321. https://doi.org/10.1016/j.autcon.2019.04.022

Hindawi Journal of Advanced Transportation Volume 2021, Article ID 8843277, 18 pages https://doi.org/10.1155/2021/8843277 solutions,

I.J. Ramaji, A.M. Memari, Interpretation of structural analytical models from the coordina tion view in building information models, Autom. ConStruct. 90 (2018) 117–133, https://doi. org/ 10.1016/j.autcon.2018.02.025.

J. Ramaji, A.M. Memari, Interpretation of structural analytical models from the coordination view in building information models, Autom. Constr. 90 (2018), https: //doi.org /10.1016/j. autcon.2018.02.025.

L. Pulka, M. Ristim¨ aki, K. Rajakallio, S. Junnila, Applicability and benefits of the ecosystem concept in the construction industry, Construct. Manag. Econ. 34 (2) (2016) 129–144, https://doi.org/10.1080/01446193.2016.1179773.

M. Aldegeily, J. Zhang, From architectural design to structural analysis: a data driven approach to study building information modeling (BIM) interoperability, in: T. Sulbaran (Ed.), Proc., 54th ASC Annual International Conference, ASC Associated Schools of Construction, Fort Collings, Colorado, 2018, pp. 537–545. http://ascp ro.org//cd///CPRT152002018.pdf. (Accessed 2 October 2019).

M. Belsky, R. Sacks, Semantic enrichment for building information modeling, Comput-Aid ed Civ. Inf. Eng. 31 (2016) 261–274, https://doi.org/10.1111/mice. 12128

M.E. Mobasher, Y.F. Rashed, W. ElHaddad, BIM standards for automated BEM structural analysis and design of RC plates, J. Comput. Civ. Eng. 30 (4) (2015), https: //doi. org/10.1061/ (asce)cp.1943-5487.0000531.

M. Laakso, A. Kiviniemi, The IFC standard - a review of history, development, and standardization, J. Inf. Technol. Construct. 17 (2012) 134–161. http://www.itcon. org/2012/9. (Accessed 30 September 2019).

Oh, M. Lee, J. Wan Hong, S. Jeong, Y. (2015). Integrated system for BIM-based collaborative design, Autom. Construct. 58 196–206, 10.1016/.autcon

Proko, I. (2023). Using Programmatic Methods to Enhance the Interoperability of Architectural and Structural Models (Doctoral dissertation, The Cooper Union for the Advancement of Science and Art).

R. Sacks, L. Ma, R. Yosef, A. Borrmann, S. Daum, U. Kattel, Semantic enrichment for building information modeling: procedure for compiling inference rules and operators for complex geometry, J. Comput. Civ. Eng. 31 (6) (2017) 1–12, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000705.

R.W. Mohareb, Y.F. Rashed, M. Wagdy, M.E. Mobasher, Structural analysis of multistory building using coupled bem-stiffness matrix, 4thECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Kos Island, Greece, 2013, https://doi.org/10.7712/120113.4788. c1646.

V. Bazijanac, D. Crawley, The implementation of industry foundation classes in simulation tools for the building industry,[Online]. Availablehttp://ww w.inive.org/members _area/me dias/p df/ Inive/IBPS A/UFSC585.pdf, (1997) , Accessed date: 27 December 2017.

Y. Jung, M. Joo, Building information modelling (BIM) framework for practical implementation, Autom. Constr. 20 (2011), https://doi.org/10.1016/j.autcon. 2010.09.010.