Jurnal Kejuruteraan 36(1) 2024: 211-221
https://doi.org/10.17576/jkukm-2024-36(1)-20

Structural Design of RCC Building Using Integrated BIM-Based Design Workflow and Analysis Result Comparison between ETABS and RSAP

Muhammad Yousaf [a*], Mohammad Sohail [a], Muhammad Tayyab [a], Muhammad Javedan [a] & Muhammad Habib [b]

[a]*Department of Civil Engineering, Faculty of Engineering & Architecture, Balochistan University of Information Technology, Engineering and Management Sciences (BUITEMS), Quetta, Balochistan, Pakistan*

[b]*Department of Civil Engineering Technology, National Skills University Islamabad, Pakistan*

[*]*Corresponding author: khan978yousaf@gmail.com*

Received 29 October 2023, Received in revised form 30 November 2023
Accepted 30 December 2023, Available online 30 January 2024

ABSTRACT

Rapid computerization and stakeholder integration in the construction industry stressed the need for a new design methodology that was only possible through BIM. To address the inefficiency and limitations of conventional design flow that lead to design clashes, information loss, delays, and poor stakeholders' coordination throughout the design phase, as well as the designer's reluctance to use BIM-integrated software for design. This study aims to develop an integrated design flow using the Autodesk system followed by structural design through the developed flow. Further, the study also aims to identify and resolve design clashes between architectural and structural models and incorporate analysis results comparison of RSAP and ETABS. The results of the study revealed that BIM design flow provided better coordination between stakeholders, speedy clash detection, and resolved bi-directional interoperability issues using an extension (structural analysis toolkit). Furthermore, design through BIM provided better visualization i.e., both 2D and 3D, and final documentation in the shape of structural detailing of designed elements. Navisworks successfully identified coordinate and element clashes between architectural and structural models and provided a virtual 3D representation of the facility before the construction phase. The analysis results of RSAP and ETABS revealed that RSAP gives higher analysis results than ETABS due to the different analysis procedures of the two software packages thus yielding safer design.

Keywords: Building Information Modelling (BIM); Robot Structural Analysis Professional (RSAP); Structural analysis toolkit; Interoperability issues; Federated model; Parametric model; Clash detection

INTRODUCTION

Every construction project comprises a variety of individuals from many disciplines who collaborate to accomplish the project's intended and desired aim from the design through the construction phases. Construction projects used to be designed manually, which required a lot of time and effort and increased the risk of human mistakes. Then, as computerization in the sector of construction advanced, software was used to design projects, and specialists created a traditional workflow to facilitate communication and coordination of the information needed to meet project objectives (Hassan et al. 2020). In the traditional workflow, experts from different disciplines work separately and typically communicate through 2D drawings, which leads to information loss, design clashes, and limited visualization. Therefore, the construction industry has been implementing a cutting-edge concept over the past few decades called Building Information Modelling (BIM) to address all these problems (Habte & Guyo 2021).

Every stakeholder involved in a building process can use the Building Information Model created by the BIM process as a common platform. Engineers, architects, contractors, builders, government agencies, and users are a few of the prominent stakeholders (Nielsen & Madsen 2010). BIM also produces a framework that permits cross-discipline collaboration among various industry professionals to put their work on a shared database known as the federated model (Habte & Guyo 2021; Hassan et al. 2020).

BIM offers a data-rich parametric model with both geometric and non-geometric data, early clash identification, and improved coordination and communication between key stakeholders (Akhmetzhanova et al. 2022; Habte & Guyo 2021; Lin & Huang 2019; Nielsen & Madsen 2010; Sampaio 2017). Even though BIM has many benefits, it is not without facing challenges. These include interoperability issues at all four levels of business, process, service, and data, as well as a lack of professionals, clients, and contractors having BIM expertise (Habte & Guyo 2021; Muller et al. 2017).

According to (Wasim 2018) inaccurate cost estimate, inaccurate scheduling, and delay in design phase are amongst top ten causes of project failure in Pakistan. Due to insufficient coordination and communication between the structural engineer, architect, and draftsman during the design phase several issues emerge during the construction phase that ultimately lead to project failure. Thus, by creating a virtual prototype of the building with accurate architectural, structural, mechanical, electrical, and plumbing details before the construction phase, BIM can address all these flaws in the conventional workflow. Additionally, BIM enables the team to work together and make more effective design choices based on an actual accurate 3D model. This 3D model can also be utilized by Contractors for quantity estimation, scheduling, and phasing (Akponeware & Adamu 2017; Kermanshahi et al. 2020; Schinler & Nelson 2008).

The conventional workflow for design has failed to address the current needs (information sharing, coordination, speedy clash detection) of construction projects therefore construction industry is gradually shifting from traditional design workflow to integrated BIM-based design. On the other hand, lack of information, resources, guidelines, and standards for BIM application are some challenges to adopting BIM instead of the traditional design workflow. Furthermore, out of numerous design tools widely used, it becomes necessary to check BIM-integrated design tool RSAP results with them to ease designers' concerns about utilizing RSAP for design activities. Therefore, a research study is necessary to address the aforementioned issues.

To overcome the data interoperability problems that are related to the software integrity and information sharing between different software packages, this study aims to develop a BIM-based design workflow for the AEC (Architecture, Engineering, and Construction) building industry covering structural design and clash detection. Additionally, this study will evaluate the effectiveness of BIM-integrated software by comparing it with commonly used software, which will help professionals adopt BIM more readily.

LITERATURE REVIEW

As per the definition proposed by (Charrel et al. 2007) a project is the effort taken in from designing to building. To accomplish the project's overall purpose, these efforts are made by numerous project stakeholders from the concerned discipline. As a result, better coordination and communication between the project's various phases and the associated stakeholders must be guaranteed for the project's goals to be met.

In the construction industry, it is customary to adopt tried-and-true procedures and techniques in projects to meet the intended objectives. These procedures and techniques frequently undergo slow changes (Nielsen & Madsen 2010). The phases of the traditional construction process are fairly distinct from one another, and each step comprises a large number of individuals that work independently, as indicated in Figure 1. Because of this, the conventional flow, particularly if the process is iterative, takes considerable time and becomes inefficient (Nielsen & Madsen 2010; Pruskova & Kaiser 2019). As demonstrated in Figure 2, the BIM, on the other hand, improves the integration of the phases to facilitate a smoother construction process.

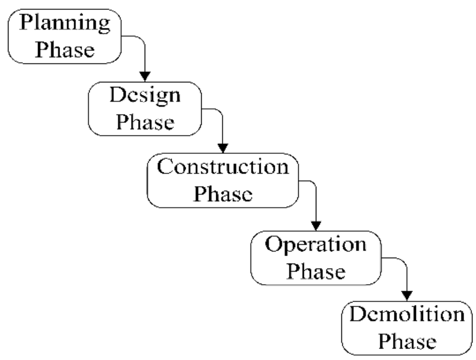

FIGURE 1. Phases in Conventional Building Process
Source: Nielsen & Madsen (2010)

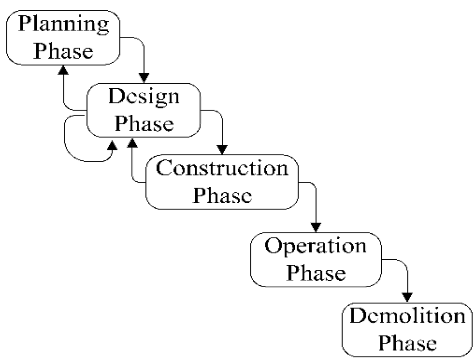

FIGURE 2. Phases of Integrated Building Process
Source: Nielsen & Madsen (2010)

This integrated building process offers better coordination between participants in each phase as well as greater integration between phases. A shared model that can only be developed through the BIM process may be used to achieve this integrated building process.

As the primary participants in designing a building project are architects, engineers, and draftsmen, these participants tried various techniques and workflows from time to time depending on the ease of applicability and considering their benefits. These techniques and workflow are broadly classified into three categories: the classical method, the traditional method, and the BIM-based design method.

CLASSICAL DESIGN METHOD

The classical approach of design was used by architects and engineers for the design of building projects for many centuries up until the second half of the 20th century. In the traditional approach, each participant uses a separate drawing sheet and a set of instruments, such as tracing paper for conflict detection, papyrus and ink for drawing, and a basic abacus for computation, to complete their task. The project was solely the responsibility of the architect under the traditional technique (Czmoch & Pękala 2014).

TRADITIONAL DESIGN METHOD

The employment of classical methods, techniques, and tools by architects and engineers was replaced in the latter half of the 20th century by computer-aided design (CAD). PRONTO and SKETCHPAD were the first two CAD programs. CAD/CAE systems are currently the most popular and well-recognized systems. Any software that engineers utilize for analysis and design is referred to as Computer-Aided Engineering (Czmoch & Pękala, 2014).

The collaboration among participants and the flow of information through 2D drawings in the design phase is depicted in Figure 3. The three key participants in the design phase the architect, engineer, and draftsman work in segregation. Firstly, architectural drawings are created by the architect, followed by structural engineering analysis and design, and then the final draft, or the highly detailed technical drawings, created by the draftsman. Usually, in the traditional method, Autodesk AutoCAD is used for creating architectural drawings by architects and draftsmen for detailed drawings and widely used structural analysis and design tool ETABS by engineers for designing (Pruskova & Kaiser 2019).

Using distinct layers in the CAD program by various professionals, the CAD system has modernized the workflow and improved the process of clash detection; however, the conventional workflow is time-consuming and is not usually successful in terms of clash detection before the construction phase. The traditional workflow also lacks a degree of collaboration amongst the design team members. As each participant creates their model using different software and communicates information with each other through 2D drawings that leads to information loss, misunderstandings, and poor visualization (Sampaio, 2017). According to (Akponeware & Adamu, 2017) isolated working as practiced in the classical and traditional work methods was found to be the prime cause of high occurrences of clashes linked to mechanical, electrical, and plumbing (MEP) 3D BIM systems. Therefore, to overcome and tackle the issues with the conventional workflow the construction industry started to adopt the integrated BIM workflow in the last two decades.

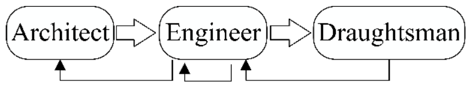

FIGURE 3. Collaboration between Participants in the Design Phase
Source: Nielsen & Madsen (2010)

BIM-BASED DESIGN

The transition from paper design to computer-aided design demonstrates that there is always room for innovation and strategies to improve the building process and engineering solutions in the construction industry. BIM is one of those breakthroughs and approaches that will replace traditional design methods and workflows in the construction industry to efficiently integrate building operations and stages. A Central-BIM model is used by each participant involved in BIM-based design to coordinate, communicate, and share information. Furthermore, each participant can retrieve the required data from and update back to the central BIM model and finally create a data-rich model known as the parametric model as shown in Figure 4 (Pruskova & Kaiser 2019; Sampaio 2017).

Even though each of the participants engaged in the design phase of the building uses a separate BIM-integrated tool for their work, they all collaborate on the same BIM model. After completing their work, each participant adds it to the central BIM model so that the other participants can utilize it for their work.

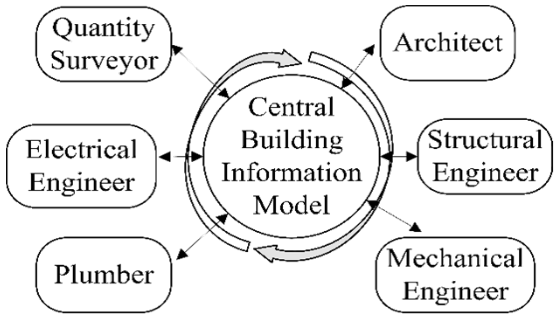

FIGURE 4. Central Building Information Model and Design Participants of the Building Process

BUILDING INFORMATION MODELLING (BIM)

Table 1 lists the definitions of BIM stated by various writers and in various research articles.

TABLE 1. Definitions of BIM

No.	Reference	Year	Definition
1	(Coenders, 2010)	2010	“BIM as a vision and BIM as a software technology”.
2	(Nielsen & Madsen, 2010)	2010	“BIM can create such a model which contains all of the information needed about a structure, to optimize the building process”.
3	(buildingSMART, 2017)	2017	“A new approach to being able to describe and display the information required for the design, construction, and operation of constructed facilities”.
4	(Sacks et al. 2018)	2018	“A modeling technology and associated set of processes to produce, communicate and analyze building models”.
5	(Habte & Guyo, 2021)	2021	“Building Information Modelling (BIM) – a technology that transforms the entire design process”.

According to the above-proposed definitions, BIM has diverse meanings for various building industry specialists. For some professionals, it’s a software technology, while for others, it’s a method for sharing and documenting project information throughout its various stages. In addition, some people have the misconception that BIM is solely utilized for building projects and is a 3D representation of architectural design (Kjartansdóttir et al. 2017; Nielsen & Madsen, 2010). Additionally, the definition of “BIM as a vision” put forth by (Coenders, 2010) and evaluated by (Heinfelt, 2007) concludes that the current BIM software have much room for improvement in terms of data interoperability between various software packages. Therefore, interoperability needs to be improved in terms of precision and easement for “BIM as a vision” to be true.

BIM can be summed up as a vision, a method, and a modelling technology that enhances collaboration, information flow, documentation, and visualization of a project between different project phases and stakeholders in each phase to create a data-rich parametric model that is a digital simulation of the actual project facility to be built.

Using a shared database known as a federated model, BIM offers clash detection of all three types, including heavy, light, and technological clashes (Czmoch & Pękala 2014; Habte & Guyo 2021; Kermanshahi et al. 2020). Moreover, the clashes have been categorized in literature in different ways as shown in Table 2.

Clash detection has become one of the main functions of BIM in recent years. Many BIM tools offer clash detection, Autodesk Navisworks Manage is a powerful tool that allows the user to set the rules, determine clashes, generate Reports, Trace Clashes, Status Clashes, Manage Clashes, Custom Clash tests, Clearance tests, time-based clashes in a smooth flow (Kermanshahi et al. 2020). Navisworks manages the information through its three different file formats that are Navisworks cache file containing geometry and properties for a converted model, Navisworks federated file containing many cache and delivery files, and Navisworks delivery file used for delivering generated views, annotations, and comments (Molinos, 2016). Clash detection becomes necessary because building projects contain the work of different professionals. In BIM each participant works on a common model that in the end contains several models (structural, architectural, MEP, etc.). All these models must be then checked for clashes and their mitigation before the construction phase which when discovered on site would take valuable working hours and ultimately, increases the overall cost of the project. Moreover, Navisworks and other BIM tools detect a huge number of clashes both relevant and irrelevant making the clash-resolving process as time-consuming as a manual process (Akhmetzhanova et al. 2022; Lin & Huang 2019). Therefore, only relevant clashes that are harmful to the building and its construction are then filtrated and resolved. This study only focuses on clash detection between architectural and structural models and resolving them through Navisworks in the design phase.

BIM provides more than just a 3D model of an architectural design; it augments the 3D model with additional data, such as time and cost information, transforming it into a 4D and a 5D model, respectively. The BIM 6D model is focused on sustainability, the 7D model is focused on facilities management, and the 'nD' model is focused on model-based analysis that aids in early decision-making. Consequently, the result of BIM is a virtual, intelligent, data-rich model known as a parametric model that tends to adopt modifications readily and swiftly to the 3D model (Azhar 2011; Czmoch & Pękala 2014; Habte & Guyo 2021; Moreno et al. 2019; Nielsen & Madsen 2010; Othman et al. 2020; Sampaio 2017).

Although BIM offers many advantages, it also faces challenges like lack of professionals, clients, and contractors having BIM knowledge, lack of information, resources, guidelines, and standards on BIM application, and interoperability issues of all four levels of business, process, service, and data (Habte & Guyo 2021). Therefore, this study is focused on developing a BIM-based integrated design workflow for building projects to overcome the data interoperability issues that are related to software integrity and information sharing between different software packages.

TABLE 2. Classification of Clashes

No.	Classification	Definition
1	Soft Hard	Clashes associated with clearance violation between design element and access space. Clashes associated with components that physically interfere with one another. (Akhmetzhanova et al. 2022)
2	Heavy Light Technological	Clashes such as two different elements occupying the same space. Free space (clearance or tolerance) needed for assembly of installations. Clashes associated with delivery schedule and assembly sequence. (Czmoch & Pękala, 2014)
3	Relevant Irrelevant	Clashes that are harmful to the project and need to be resolved. Repeated or intentionally created clashes that don't need resolution. (Lin & Huang, 2019)

STRUCTURAL DESIGN TOOLS

Different software packages are available for the structural design of a building. Each of these software packages has a different specialty. For the structural design of building CSI ETABS developed by Computers and Structures Inc. is world widely used as it enables rapid modelling of complicated frame structures. Contrary to this, RSAP developed by Autodesk is a BIM integrated (integrated with Revit and other BIM tools) analysis and design software. RSAP enables wind simulation, a variety of analyses i.e. linear static, seismic, non-linear, and time history, and more Design options with Dynamo for the creation of complex and resilient structures (Habte, 2021). In addition to these promising features of ETABS and RSAP, a structural engineer needs to know the analysis result comparison of them as both adopt different design philosophies. Additionally, the comparison will also develop the structural engineer's trust and reduce reluctance in using BIM-integrated design software in the design phase.

METHODOLOGY

BIM completely incorporates all design and construction processes from initial planning through demolition which increases the product's efficiency and economics. Although BIM encompasses all stages of construction, this study mainly centers on the analysis, design, and design coordination (clash detection) of an RCC building using a BIM design workflow and comparing it to a conventional workflow.

The process of BIM was implemented using the Autodesk software (Revit, Navisworks Manage, and RSAP), while the conventional design approach was carried out using CSI software products (SAFE, ETABS, and CSI Detailing).

Initially, Revit was used to create structural and architectural models. Regarding coordinates and floor levels, the structural model must be in agreement with the architectural model.

Following that, the structural model was transferred from Revit to RSAP using the 'Structural Analysis Toolkit', a tool that connects Revit and RSAP and enables model transfer in both directions. Interoperability issues may occur at this point, however, the likelihood of these problems here is lower because they are least likely to occur when moving forward. These interoperability issues need to be fixed to transfer the model completely without any missing information or element.

After the model was successfully transferred to RSAP, loads were defined and applied to the structural components following ACI Code. The load combination was established, and the preferred slab sizes were achieved by meshing. After that, the model was run to perform analysis. The structural elements' required and provided reinforcements were then designed. The structural drawings for each member can be produced at this stage.

After the structural design was finished, the model was updated back in Revit using the 'Structural Analysis Toolkit' which transfers all the results of analysis and design from RSAP to Revit. Due to the model being transferred in the opposite direction in this case, the interoperability issues may be more severe. There could be one or more missing members or information about them such as reactions, stresses, etc.

Ensuring that there are no interoperability issues at this stage, later the foundation was modelled in Revit according to the RSAP design, and the reinforcement bars were made visible in the structural components of the building. 'Autodesk Extensions' or the 'Navigate Rebar Extension' is an extra toolkit that was added in Revit specifically for this use. This toolkit makes it possible to see how components of the structural model have been reinforced.

To check the design coordination, i.e., to verify that all the architectural and structural members are in their required positions and that they don't collide with one another, an automatic clash detection test was performed using Navisworks Manage. This BIM-integrated software package serves as a platform for integrating cross-disciplinary engineering models into one system to create an interactive and comprehensive 3D model. By merging all the models virtually, Navisworks allows us to identify and resolve clashes before construction starts.

To run a clash detection test, the structural and architectural models were first exported from Revit in NWC format and merged in Navisworks Manage in NWF

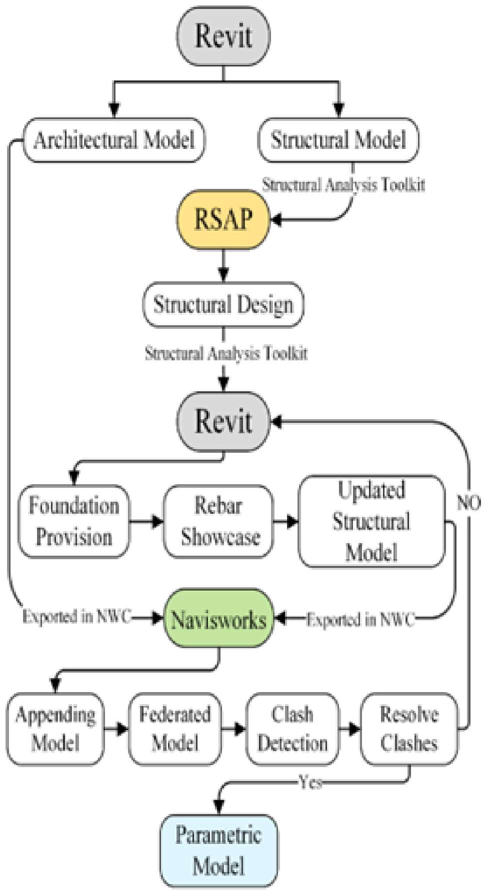

FIGURE 5. Integrated BIM Design Workflow

format. The incorporation of these independent models of different disciplines led to the formation of a federated model which was further used to inspect the clashes resulting due to integration of the models. The NWF format combines the two models into one large file with a functional and editable interface, in contrast to the comparable NWD format which is not editable. Afterward, the test was run to detect the clashes between different elements of the two models. The clashes can be detected either for the entire composite model or any user-defined subsets of the elements. To determine the number of clashes and their location in the Cartesian coordinate system, a detailed clash report was generated by Navisworks. These clashes were later resolved in Revit by adjusting the elements of integrated models without compromising the intended design to establish the final Parametric Model. The entire approach for BIM design is shown in Figure 5.

The BIM design process was completed here, and the analytical results were compared to the conventional design workflow. ETABS and CSI Detailing software programs were utilized in the conventional design approach. The structural model was created and analyzed in ETABS using the identical loads and load combinations as in RSAP.

RESULTS AND DISCUSSION

DEVELOPMENT OF BIM-BASED DESIGN WORKFLOW FOR BUILDING

An integrated BIM-based design workflow was established after extensive research into a variety of software tools for clash detection, structural design, and architectural design. The Autodesk system was chosen for this study because it offers educational licenses and delivers higher interoperability compared to other systems.

This research utilized the Autodesk software programs in a specific order to establish a BIM-based design flow. The design flow is described in the methodology section and is shown in Figure 5. The information exchange between the structural and architectural design was better coordinated through BIM-based design flow. In terms of interoperability, the design flow provided a significant advance. The flow effectively communicated structural and architectural data from Revit to RSAP and vice versa, resolving the problem of bi-directional interoperability. With the help of Navisworks Manage, clashes between structural and architectural models were successfully detected and subsequently resolved in Revit, leading to the creation of a parametric model with no clashes. This parametric model may also be used for several BIM dimensional analyses including scheduling (4D), Cost analysis (5D), and 'nD' analysis. The models in Figure 6 were created in Revit and then structural model was exported to RSAP as shown in Figure 7. Figure 8 displays the model that was updated back in Revit once the structural design was finished.

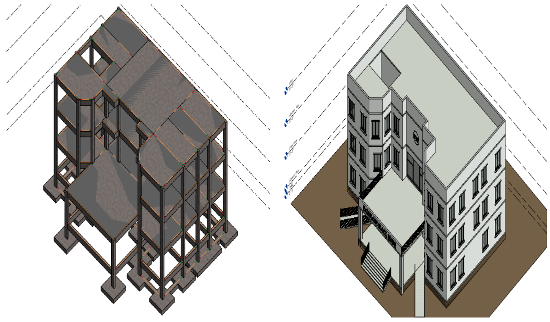

FIGURE 6. Structural & Architectural Model Created in Revit

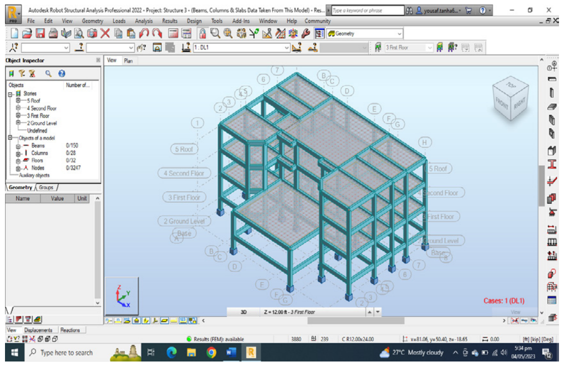

FIGURE 7. Structural Model Exported and Designed in RSAP

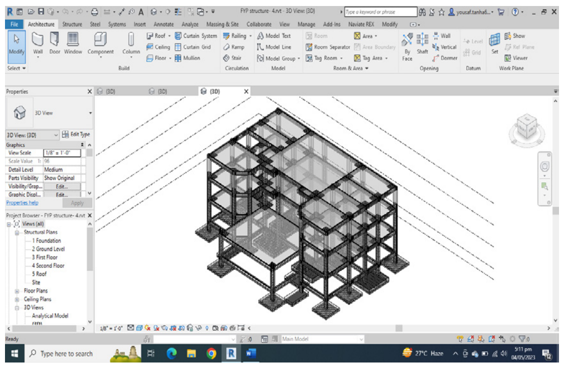

FIGURE 8. Model Updated in Revit after Structural Design

CLASH DETECTION BY NAVISWORKS MANAGE

The Revit-updated structural model together with the architectural model was exported to Navisworks. By merging these models in Navisworks, a 3D federated model was produced, and cross-discipline clashes that arose as a result of the model integration were detected. The inaccurate coordinates of the separate models were the initial cause of the clashes. The models were offset in the horizontal plane, but they were positioned with respect to the vertical plane, i.e., they had the same floor levels. The clashes caused by coordinates can be observed in Figure 9.

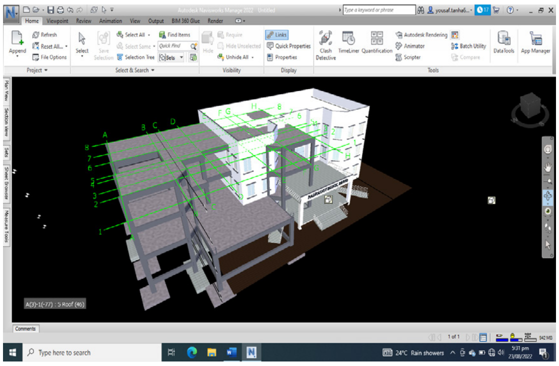

FIGURE 9. Clash Appeared due to Inaccurate Coordinates

The coordinates problem was fixed in Revit by repositioning the structural and architectural models in the Cartesian coordinate system, however, there still existed some clashes between components of the models. To detect, locate and quantify clashes a detailed clash report was produced. Figure 10 displays the clashes between the elements. Later, the structural and non-structural elements were adjusted to eliminate these design clashes without compromising the original design. A parametric model, shown in Figure 12, with no clashes, was eventually obtained after the elements were adjusted and all the clashes were resolved. Additionally, a zero-clash report was generated, as shown in Figure 11.

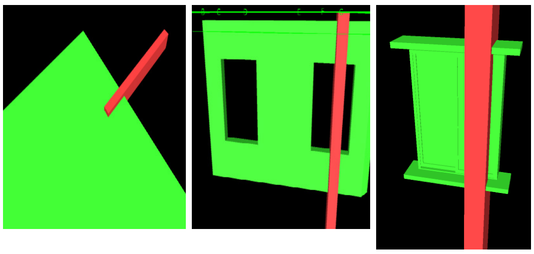

FIGURE 10. Design Clashes Due to the Integration of Structural and Architectural Models

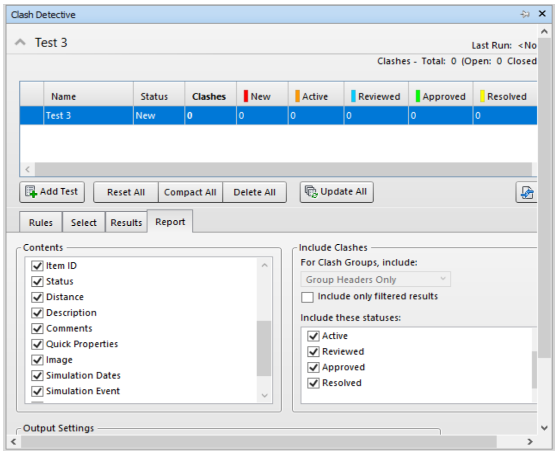

FIGURE 11. Zero Clash Report

FIGURE 12. Parametric Model in Navisworks Manage

ANALYTICAL COMPARISON BETWEEN RSAP AND ETABS

RSAP, a BIM-integrated software, and ETABS, a conventionally used software, were both utilized in this research to design the same structure with same gravity loads and its combination.

ABSOLUTE MAXIMUM NODAL DISPLACEMENT AND BASE REACTION

From the comparison of nodal displacement results in Figure 13, ETABS produces displacement values that are higher than RSAP in the x and y directions but lesser in the z-direction, with 1.36 inches for ETABS and 1.777 inches for RSAP, a difference of 0.41 inches (30.14%). Similar results were seen in the base reaction comparison, where ETABS produced higher reaction values in the x and y directions but lesser values in the z-direction, with 297.53 Kips for ETABS and 338.95 Kips for RSAP, a difference of 41.42 Kips (13.9%) as shown in Figure 14.

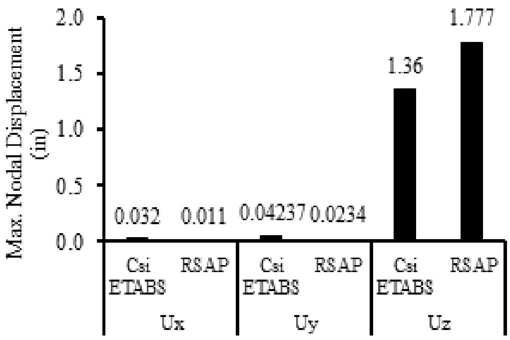

FIGURE 13. Absolute Maximum Nodal Displacement

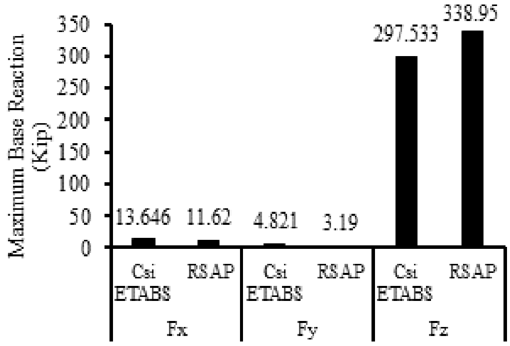

FIGURE 14. Maximum Base Reaction

COMPARATIVE ANALYSIS OF SPANDREL BEAM

A top spandrel beam of 85' comprising 5 spans is taken as a reference for comparison of shear force and bending moment results from ETABS and RSAP along the length of the beam. This beam was subjected to a uniformly distributed load of 0.36 kips along with the loads from the slab supported by the beam. The shear force diagram and bending moment diagram are illustrated in Figure 15 and Figure 16 along with maximum positive and maximum negative shear and bending moment values along the length of the beam.

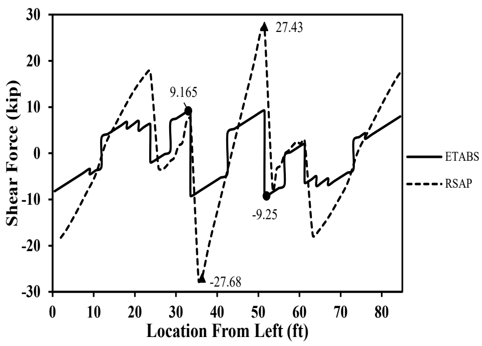

FIGURE 15. Shear Force Diagram

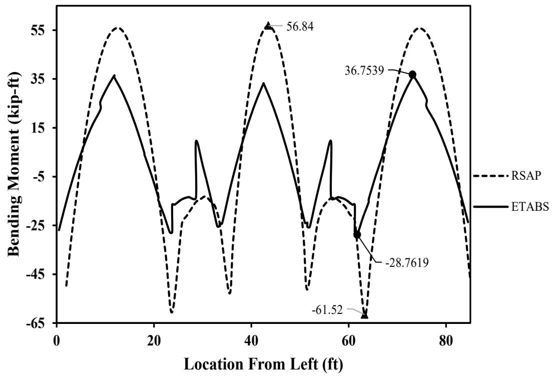

FIGURE 16. Bending Moment Diagram

Despite the same loading condition and load combination, the shear force and bending moment diagrams of the 85' long spandrel beam represent that RSAP yielded greater shear and bending values than ETABS along the length of the spandrel beam. The main cause of the result's variation is that the beam is treated differently by RSAP and ETABS, with RSAP considering it as a shell and a mesh object with more nodes and ETABS considering it as a bar element with two nodes.

As the beam is designed for shear force and bending moment values, therefore, RSAP yields a bigger design section and higher reinforcement quantity than ETABS.

COMPARATIVE ANALYSIS OF COLUMN

The maximum axial forces and maximum moments from ETABS and RSAP for a particular column were compared and assessed in this study for comparative analysis. Table 3 contains a comparison of the analytical results of the column.

TABLE 3. Comparative Results of Maximum Axial Force and Maximum Moment for Column

	ETABS	RSAP	Difference (%)
Max. Axial Force (kip)	190.36	277.3	45.6
Max. Moment (kip-ft)	31.81	90.3	64.7

From Table 3, the analysis results revealed that the ETABS maximum axial force is 45.6% less than the RSAP despite of same loading conditions. Similarly, for the maximum moment, ETABS results are 64.7% less than RSAP. Also, it is found that ETABS designs a column based on the axial force value at the base of the column for each storey while RSAP designs a column for the maximum value of axial force at the base of the column at the foundation level. Since design is carried out based on analysis results. Therefore, RSAP produces bigger column cross sections and reinforcement quantity than ETABS, and hence, found that RSAP column design is safer but uneconomical than ETABS.

COMPARATIVE ANALYSIS OF SLAB

From the analysis results, the maximum slab deflection was compared between the two software for the same load combination throughout the structure. The maximum slab deflection from both software along with the percentage difference in result is shown in Table 4.

TABLE 4. Comparative Result of Maximum Slab Deflection from ETABS and RSAP

Direction	Maximum Deflection (Inches)		Difference (%)
	ETABS	RSAP	
Uz	1.894	1.777	6.17

Since stiffness factors that are modulus of elasticity and planner moment of inertia are inversely proportional to deflection. Therefore, the ETABS result is 6.17% more than RSAP because ETABS models the slabs as a diaphragm and does not consider the relative stiffness of the structural elements while RSAP models the slab as shell elements and considers its relative stiffness.

CONCLUSION

It was found that the integrated BIM-based design workflow developed in this study was an effective design approach in terms of information sharing, stakeholder coordination, clash detection, and clash resolution. Additionally, the bi-directional interoperability problem was successfully resolved by the developed design workflow using the Autodesk system with an extension called the Structural Analysis Toolkit.

Further, a parametric model was created with no clashes after Navisworks Manage successfully found and fixed clashes (coordinates and element clashes) between architectural and structural models. Therefore, BIM effectively locates, examines, and reports clashes as well as mistakes in a design project that would typically be observed on-site. The BIM clash detection process is also quicker and easier to use than the traditional process.

The comparative findings demonstrate that despite having the same inputs (loads and load combinations), RSAP's analysis outputs (base reactions and nodal displacement, shear forces and bending moments for beams, and axial forces and moments at the base of columns) are generally larger than ETABS's due to the two software programs' different analysis procedures. Contrary to this, RSAP yields smaller deflection values for the slab than ETABS because the slab is modelled as a diaphragm without taking its relative stiffness by ETABS and a meshed shell object considering its out-of-plane stiffness by RSAP.

In addition to this, RSAP perceives the beam as a shell and mesh object, ETABS perceives it as a bar element and lastly, because of the different mesh options in both software, the results may also vary.

One of the key benefits of RSAP over ETABS from the perspective of the BIM workflow is that it is integrated with other BIM software and enables the transfer of data without any interoperability problems. When it comes to structural detailing, RSAP is much more effective than ETABS and doesn't need any additional software. Compared to ETABS, its structural detailing, and visualization of designed features are clearer and easier to comprehend.

ACKNOWLEDGMENT

The ability to complete this work was made possible by our entire team, for which the authors are grateful. The technical support provided by Engr. Asmatullah and CAMEOS Consultants have been much appreciated by the writers. Finally, writers express their gratitude to the Almighty Allah, who has always shown us mercy.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Akhmetzhanova, B., Nadeem, A., Hossain, M. A. & Kim, J. R. 2022. Clash detection using building information modeling (BIM) technology in the Republic of Kazakhstan. *Buildings* 12 (2): 102.

Akponeware, A. & Adamu, Z. 2017. Clash detection or clash avoidance? an investigation into coordination problems in 3D BIM. *Buildings* 7 (4): 75.

Azhar, S. 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. *Leadership and Management in Engineering* 11 (3): 241-252.

buildingSMART. 2010. "BuildingSMART international." https://www.buildingsmart.org/.

Charrel, P.-J., Galarreta, D. & Charrel, P. 2007. Project management and risk management in complex projects. Springer.

Coenders, J. L. 2010. Parametric and associative design as a strategy for conceptual design and delivery to BIM. Symposium of the International Association for Shell and Spatial Structures (50th. 2009. Valencia). Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures: Proceedings.

Czmoch, I. & Pękala, A. 2014. Traditional design versus BIM based design. *Procedia Engineering* 91: 210-215.

Habte, B. & Guyo, E. 2021. Application of BIM for structural engineering: a case study using Revit and customary structural analysis and design software. *Journal of Information Technology in Construction* 26: 1009-1022. https://doi.org/10.36680/j.itcon.2021.053.

Habte, D. 2021. Structural analysis of high-rise building using ETABS and RSA software. *Строительная механика инженерных конструкций и сооружений* 17 (2): 133-139.

Hassan, M. S., Williams, G., Przybylski, K., Budzisz, L. & Maguire, F. 2020. Structural Modelling, Analysis and Design of Composite Steel Frame Building Using an Integrated Design Approach.

Heinfelt, T. 2007. The use of 3D and BIM technology for structural analysis and design. Master's Thesis, Department of Civil Engineering, Technical University of Denmark.

Kermanshahi, E. K., Tahir, M. B. M., Lim, N. H. A. S., Balasbaneh, A. T. & Roshanghalb, S. 2020. Implementation of building information modeling for construction clash detection process in the design stage: a case study of Malaysian police headquarter building. IOP Conference Series: Earth and Environmental Science.

Kjartansdóttir, I. B., Mordue, S., Nowak, P., Philp, D. & Snæbjörnsson, J. T. 2017. Building information modelling-BIM. Civil Engineering Faculty of Warsaw University of Technology Warsaw, Poland.

Lin, W. Y. & Huang, Y.-H. 2019. Filtering of irrelevant clashes detected by BIM software using a hybrid method of rule-based reasoning and supervised machine learning. *Applied Sciences* 9 (24): 5324.

Molinos, R. 2016. Navisworks – File types and Revit Model Conversion. https://gamma.modelical.com/en/gdocs/navisworks/.

Moreno, C., Olbina, S. & Issa, R. R. 2019. BIM use by architecture, engineering, and construction (AEC) industry in educational facility projects. *Advances in Civil Engineering* 2019.

Muller, M. F., Garbers, A., Esmanioto, F., Huber, N., Loures, E. R. & Canciglieri, O. 2017. Data interoperability assessment though IFC for BIM in structural design–a five-year gap analysis. *Journal of Civil Engineering and Management* 23 (7): 943-954.

Nielsen, A. K. & Madsen, S. 2010. Structural modelling and analysis using BIM tools. Aalborg University, Sohngaardsholmsvej.

Othman, I., Alashmori, Y., Rahmawati, Y., Amran, M. & Al-Bared, M. 2020. The level of Building Information Modelling (BIM) Implementation in Malaysia. *Ain Shams Engineering Journal* 12. https://doi.org/10.1016/j.asej.2020.04.007.

Pruskova, K. & Kaiser, J. 2019. Implementation of BIM Technology into the design process using the scheme of BIM Execution Plan. IOP Conference Series: Materials Science and Engineering.

Sacks, R., Eastman, C., Lee, G. & Teicholz, P. 2018. *BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers*. John Wiley & Sons.

Sampaio, A. Z. 2017. BIM as a computer-aided design methodology in civil engineering. *Journal of Software Engineering and Applications* 10 (2): 194-210.

Schinler, D. & Nelson, E. 2008. BIM and the structural engineering community. *Struct. Mag* 10: 10-12.

Wasim, S. S. 2018. Causes of construction project failures in Pakistan. *International Journal for Innovative Research in Multidisciplinary Field* 4 (8): 157-163.