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An Insight into Advanced Perspectives (Functions) of BIM Tools for Structural Analysis and Design of High-rise Irregular Buildings

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Abstract

The increasing complexity of modern era high-rise buildings, particularly irregular in any aspect either vertical irregularities or plan structural irregularities, demands user friendly commands in softwares for their efficient structural analysis and design. The latest version of commercially available software (like ETABS, SAP, STAAD- PRO, RSAP, TEKLA etc.) have advanced functions to cater various unattended issues like meshing options, modelling of irregular shapes, diaphragm and floor rigidity, wind load simulation, dynamic analysis etc., But still, there are issues which needs to be addressed for quick and precise analysis and design like integration of detailing tools with analysis and design, complex design and analysis process for managing large scale projects. The purpose of this review is to explore the effectiveness of BIM tools (e.g., Revit, RSAP) compared to other frequently used softwares in industry through having insight to advanced functions and automation innovations via programming languages (Dynamo, Python) developed in streamlining workflows, optimizing design, and facilitating collaboration. It involves a rigorous review of high-quality research articles (published in reputed journals within the last three years or having high citations). Insights are drawn to identify the potential of automation, particularly in analysis and design of irregular high-rise buildings. The programming can be integrated with BIM Tools to automate and make process quick and error free. The studies reveal that Dynamo-Revit used in rebar optimization and modelling stairs. Furthermore, new automation tools are necessary for making BIM Tools more efficient and easier to use for analysis and design of high-rise irregular building.

Keywords: BIM Tools; High-rise irregular building; High-quality research articles; Structural analysis softwares.

1. Introduction

Structural analysis and design play a pivotal role in ensuring the stability, safety, and longevity of buildings and infrastructure. Traditionally, this process relied on time-intensive manual calculations, which could take several months and were prone to errors. However, with the advent of specialized software tools, structural analysis has become faster and more accurate. Software like ETABS, STAAD.Pro, Tekla Structures and RSAP make models easier and offer strong analytical tools to help the engineers in better visualizing and analyzing diverse designs. These tools enable engineers to automate calculations and acquire accurate results which in the long run assist engineers in providing economical and sustainable solutions.

Some of the recent advancements in the construction industry include tools such as Building Information Modeling (BIM) including tools like RSA (Robot Structural Analysis) and Revit Structures. These tools are targeting the modern projects that entail a higher level of complication and expansion by increasing the level of accuracy, enhancing team work and shortening the time taken.

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In this regard, BIM promotes the idea of having design, analysis, and documentation in the same platform as the structural engineering process. The use of BIM based software enhances the flow of processes and minimizes mistakes, hence the importance of BIM in development of efficient, sustainable structures. Also, the constant development of BIM tools has led to enhancement in more functionality like the automation functionality. Although contemporary BIM systems have limited automation capabilities with add-ons, or requiring scripting, the inclusion of programming languages such as Dynamo and Python offers customized automation of tasks. This advancement helps the engineers to analyze and design with more efficiency. Other tools that have also enable iterative design include the parametric modeling and VP tools like the Dynamo Visual Programming (VP) especially in high rise and seismic design to generate and adjust design options.

This paper aims to explore commercially available software and BIM tools used in structural engineering for analysis and design particularly of high-rise irregular building, emphasizing how recent advancements have simplified complex tasks. We will explore specific features and capabilities of BIM tools, as well as automation techniques that can improve efficiency and precision in structural analysis and design. By analyzing practical applications of these functions, this paper highlights how automation workflows and BIM integrations make structural analysis more accessible, accurate, and collaborative, providing valuable insights into future developments in the field.

2. Commercially available softwares for structural analysis and design of high-rise irregular building

The This study explores commercially available structural analysis and design software in 4 aspects. First the need for developing software will be assessed. Then the available softwares assessed. Then assess the best considered software among available softwares and finally conclude that how available software contributing in design and analysis. Structural analysis and design plays an important role for ensuring the safety and durability of buildings and infrastructure and structures. Understanding how connected buildings behave during earthquakes is important for keeping people safe, reducing damage, and helping with better city planning and building design[15]. It is the use of scientific principles to assess the performance of a structure under different loads and stresses. In this way, engineers can determine the possible vulnerabilities and enhance the design to withstand the risks. Most importantly, manual calculations take lots of time where it normally takes 5 to 6 months and contains errors. To overcome these challenges, software tools have been designed to do work within a shorter duration [18].These software applications are capable of performing rigorous mathematics and computing, deriving precise solutions and useful information on the structural response of a design.

Structural engineers use computer programs to develop numerous designs, determine the best use of materials, and, in general, rely on software such as ETABS, STAAD.Pro, Tekla Structures, and RSAP to make design easier. These tools are best suited for modeling, performing accurate analysis, and creating more detailed drawings. Each one has its own advantages; for example, ETABS & STAAD.Pro are known for their powerful analysis capabilities, Tekla excels in BIM compatibility, and RSAP specializes in detailed analysis (refer to Table 1). These software advancements allow engineers to optimize designs efficiently, saving time and resources. Additionally, they enhance collaboration between project stakeholders by providing accurate data and seamless integration with other design tools. Such advancements contribute to the provision of efficient and effective structures at lower costs and with better sustainability.

RSA is an effective tool in structural design and analysis, especially where the project is complex or large. In particular, RSA and Tekla have significant benefits to design and structure analysis. RSA has a strong FEA which can deal with various load conditions and is compatible with Autodesk's Revit in the context of BIM and can give more accurate values [6]. Tekla has unique features in producing accurate, constructible and constructible 3D models, especially in steel and concrete structure and facilities enhanced rebar detailing and clash detection capabilities [2]. Altogether, RSA offers strong analysis tools and Tekla has comprehensive design tools that focus on efficiency and precision in the structural engineering project.

Computer programs for structural analysis and design enhance efficiency and reliability of results and have solved the disadvantage of time-consuming manual computations. Software such as

ETABS, STAAD.Pro, Tekla, and RSAP simplify demanding modeling exercises and improve design versatility. RSAP and Tekla also continue to enable large projects requiring more complex FEA and BIM integration for accurate and coordinated processes. In general, this progress allows for safer, sustainable, and cheaper solutions in structural engineering. As Tekla is widely used in the market due to its user friendly interface, there is also a need to consider RSAP due to its ability to handle large projects due to its interoperability and the accurate results for forces, moments can be obtained from RSAP [21]. The integration of these software solutions promotes collaboration among different engineering disciplines and supports the seamless execution of complex projects.

Table 1. Features and Limitations of Commercially available softwares.

Softwares	**Features**	**Limitations**	**References**
STAAD.Pro	Finite element analysis, linear and nonlinear analysis, steel, concrete, and timber design, dynamic analysis, seismic analysis	-Limited to simple structures, lacks material quantity details, and requires skilled labor. -Inefficient for complex geometries like curves and parabolas -Not ideal for large-scale projects, as it can increase costs and risks	[13]
ETABS	Nonlinear static and dynamic analysis, seismic analysis, concrete and steel design, pushover analysis	-ETABS does not offers post tension modelling -Detailing is not much accurately done in ETABS. -It cannot be used in design of foundation.	[14]
Tekla structural designer	3D modeling, detailing, fabrication, and construction management for steel, concrete, and timber structures	-Not ideal for detailed work. -Cannot export results directly to AutoCAD. -Requires specific skills for standard design tasks. -Not suitable for designing foundations and floor slabs.	[2]
Sap 2000	Finite element analysis, nonlinear static and dynamic analysis, steel and concrete design, seismic analysis	-It is not suitable for detailing cannot export its output to AutoCAD -SAP2000 lacks features for designing continuum elements like slabs, shells, and shear walls	[13]
Autodesk Robot structural analysis professional	Finite element analysis, linear and nonlinear analysis, steel and concrete design, seismic analysis, BIM integration. accurate results in forces, moments and reinforcement.	-Limitations in modeling complex geometries as it is time consuming. -Need of automation in design and analysis. -It take more time to import IFC files.	[16,20]

3. Emergence of BIM Tools for structural analysis and design

This study will assess emergence of BIM Tools in which the available BIM Tools softwares explored. Then assess the RSAP and Revit importance in modern era. Then explores how parametric modelling is helpful in BIM Tools and finally conclude to what extent BIM Tools are beneficial. RSA and Revit Structures, powerful BIM tools, emerged as a response to the growing complexity and demands of the construction industry. Building Information Modeling (BIM) has revolutionized the way structures are designed, analyzed, and constructed [7]. BIM tools, such as Revit, Tekla, Robot Structural Analysis Pro, STAAD Pro, andSAP2000, have become indispensable for structural engineers. It has been assessed that the to and fro Transfer of Models within software was effortless in RSA on the other side it is more complex process in STAAD Pro [10]. These tools particularly Revit and RSA provide great platform for modeling, analysis, design and due to its interoperability, it helps in reducing the design cycle time and also improves the project results.

In the increasing complexity of modern construction projects, the adoption of BIM tools like RSA and Revit is crucial. These tools offer numerous benefits, including improved design accuracy, enhanced collaboration, faster construction, reduced costs, and sustainable design practices [21]. Using cloud computing engineers are able to take this to another level and enhance the efficiency of work flow and availability of powerful computational tools. Adoption of these technologies, therefore, becomes crucial for the organization to remain relevant and provide efficient, effective and sustainable construction of buildings and structures.

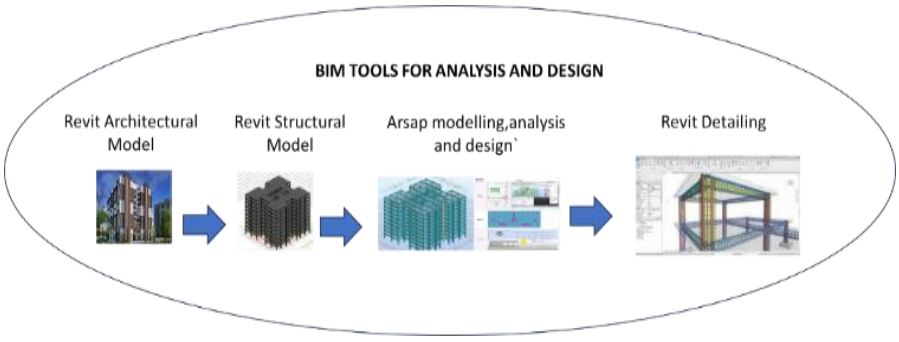


Figure 1.BIM Tools for Analysis and Design

Parametric modelling raises the usability of BIM tools such as RSAP and Revit even further. By utilizing programming environments, designers are able to create new extensions for automating processes, which would allow them to work with big and complex models without disruptions. This integration of programming and BIM improves efficiency, increases productivity and innovation in construction industries [20].

The above studies reveal that structural design has been revolutionized by BIM tools such as RSA and Revit through accuracy, collaboration and efficiency. Such tools facilitate speed of construction, reduction of cost and incorporation of sustainable building designs and interoperability of both software make them stand out among other softwares. Moreover, programming integration can further improve work flow and management as well as design and analysis can be made more easy process.

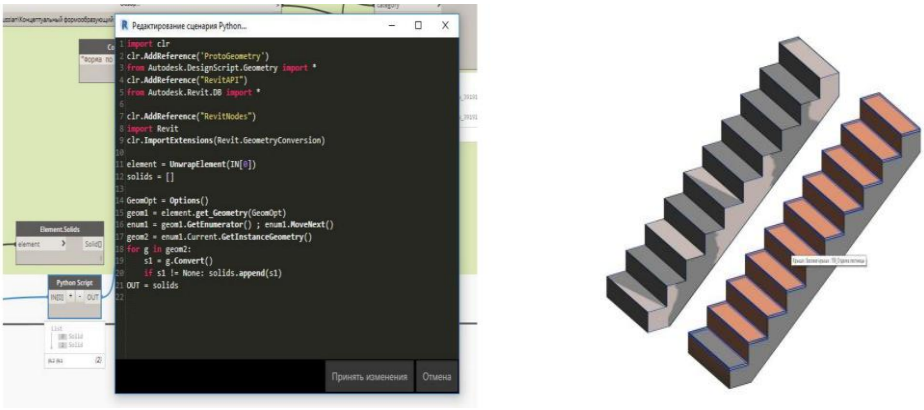
4. Advanced functions of BIM tools

This study will assess current BIM Tools limitations, then advanced functions of BIM Tools particularly Revit and RSAP will be assessed and firstly it assesses RSAP in term of conventional tool used in market i.e. ETABS. Then it assesses Revit advanced functions. Lastly it assesses which areas can be more advanced in BIM Tools to make it more effective. ETABS transfers area loads on membrane elements entirely to support elements without considering relative stiffness. On the other hand, RSAP represents the slab using shell elements that include out-of-plane stiffness, allowing it to distribute loads according to the relative stiffness of the structural components through slab bending. ETABS automatically meshes shell objects for analysis, while RSA offers various meshing options. ETABS auto-generates wind loads based on design codes, whereas RSA simulates wind flow around the structure to generate loads automatically. In ETABS the link-beam is

considered as a bar element with two nodes, but in RSA it is considered as a meshed shell element with more than two nodes [6].

Revit has the ability to produce detailed 3D models that include elevations, detailed drawings, and schedules for each structural component. Its integration with V-ray rendering software enhances the visualization, offering a realistic and efficient view of the project. Revit Architecture gathers detailed information for every structural element, such as material type, thickness, and height. This level of detail helps the project team to clearly visualize the building and detect any design or construction issues early, reducing the chance of expensive changes later on [1]. Each model can be viewed from both vertical and horizontal angles, allowing users to see above, below, and from the sides without needing additional tools. In addition, Revit allows users to take virtual walkthroughs of the structure, providing views of both the interior and exterior from multiple perspectives before construction begins [9]. Revit also supports numerical simulations of wind loads on tall buildings [12].

Dynamo is also used alongside Revit to design objects with complex shapes, such as non-linear, curved, or geometrically dynamic forms. When working with such complex geometry, Autodesk Revit tools like masses and Model In-Place elements (which act as replacements for system families), combined with automation tools like Dynamo, introduce a new method for modeling non-standard designs. This technique combines accurate geometry with detailed information. By clearly outlining the structure of the project and the modeling logic for each geometric part, and by using automation processes, designers can effectively create complex shapes. This method reduces the time needed for edits and adjustments, helping to streamline the entire modeling process for intricate forms.



a) b)

Figure 2. Dynamo-Revit Automation: a) Dynamo-Python script b) Stairs Modelled in Revit [5].

Moreover, Dynamo is used with Revit, RSA and Navisworks in rebar layout optimization The proposed methodology integrates Dynamo for rebar layout optimization with Navisworks for automatic clash detection, enhancing BIM model creation. Validation on continuous-column rebar showed significant reductions in working hours and high modeling accuracy compared to traditional manual methods [19]. As the BIM Tools have advanced functions, their handling is quite difficult in managing high-rise building particularly having irregular geometries. The importance of integrating automation into BIM tools is highlighted in above literatures to streamline complex design and analysis processes. By using programming languages like Dynamo and Python, engineers can automate repetitive tasks, optimize designs, and enhance precision in structural detailing. So, this integration fosters collaboration, improves efficiency, and ensures more accurate, resilient designs, especially in seismic and high-rise irregular building projects as it is a complex task.

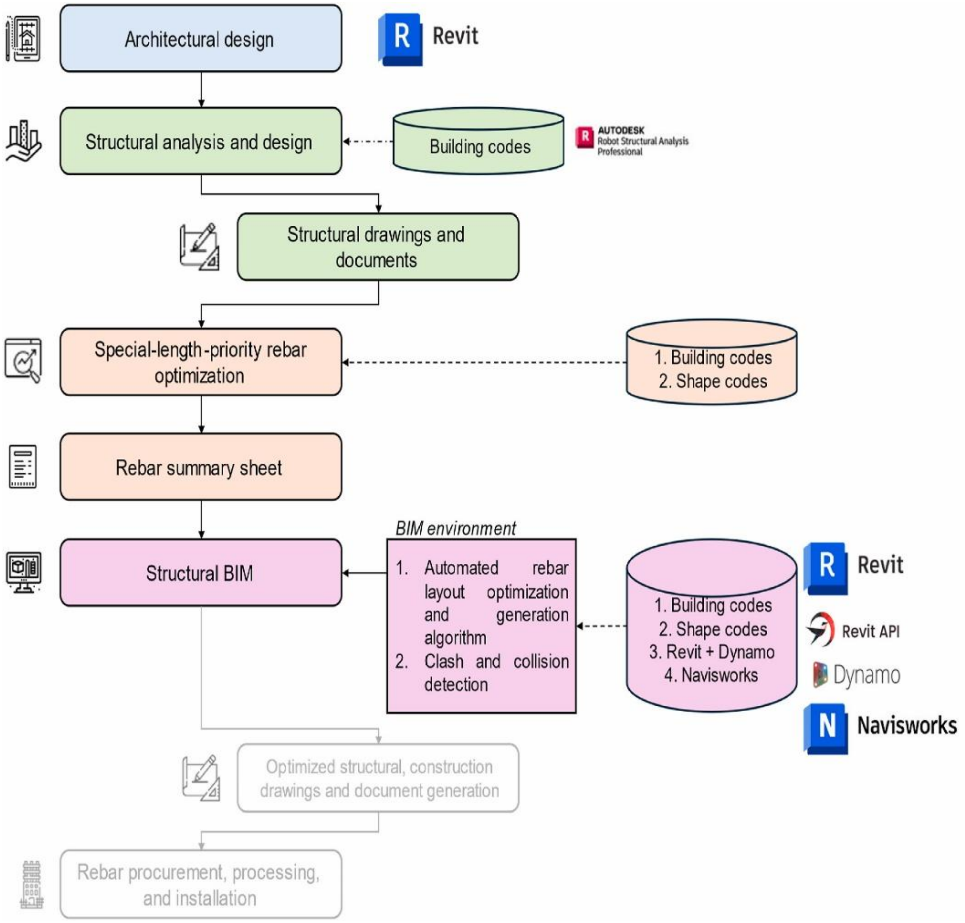


Figure 3. Semi-automated rebar working process [19].

5. Conclusions

This review paper explored commercially available software and emergence of BIM Tools and develop an insight to advanced functions that are developed in BIM Tools through review of high quality research articles. Base on the literature research, following are the conclusions:

- All commercially available softwares have benefits and limitations but Autodesk Robot Structural Analysis Professional due to its accurate results of forces, moments and interoperability and Tekla structure designer software due its user friendly interface and direct input of properties on base of standards, are best for analysis and design for large scale projects.
- Revit and RSA being BIM Tools are effective for analysis and design due to its interoperability, and near to realistic visualization but further programming can be done to make work more time saving.
- Revit offer v ray rendering which enhances visualization and RSAP offer wind load simulation, various meshing options, load distribution on base of relative stiffness of structural elements rather being based on diaphragm. Furthermore, Dynamo-Revit is used in modelling, rebar layout optimization and but in design and analysis there is still need of automation.

So, for seismic analysis and design of high-rise irregular and regular building new add-ons can be developed for making it more time saving like automation is done in Revit for modelling, rebar layout optimization and workload can be managed more efficiently. Furthermore, proper guidelines and tutorials must be established so that structural designer can use it and make their work easier and accurate.

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