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TECHNICAL PAPER

Optimizing building information modeling through clash detection and resolution for sustainable high-rise construction

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Abstract

Building information modeling (BIM) is advancing quickly, providing new potential to increase the efficacy and efficiency of the process of building and improve the application of innovative technology in buildings across the project life cycle. This study aims to improve the BIM process with the help of clash detection analysis in the pre-design phase of a G+19 structure to reduce the overall cost of construction and energy consumption of the embodied energy. The research methodology minimizes clashes and eliminates them in a complex structure that involves multiple stakeholders. The BIM model covers the architectural, structural, fire, plumbing, and electrical models subjected to clash detection analysis and resolution. The clash detection test performed on each model yielded a total of 5534 clash detections. In all clashes, one clash resolution in structural elements resolved caused the volumetric reduction from 0.124 m^3 to 0.097 m^3 and 0.407 m^3 to 0.405 m^3. The result of this study shows that with the help of effective clash detection in construction projects, we can save resources, which saves cost, time, and possible discrepancies between the project stakeholders and promotes sustainability in the construction sector.

Keywords 3D modeling · Cost saving · Embodied energy · Sustainability · Resource optimization

Introduction

Building information modeling (BIM) has transformed the architecture, engineering, and construction (AEC) industry by enabling integrated design, construction, and management through digital representations of building systems. Its applications are particularly critical in complex projects such as high-rise structures, where coordination, clash detection, and sustainability play a decisive role. Level of development (LOD) 300 represents a stage where model elements defined with accurate geometry, dimensions, and spatial relationships, suitable for coordination across disciplines such as architectural, structural, and (MEP) systems [38]. At this level, the model is sufficiently detailed to support clash detection, quantity estimation, and early-stage decision-making in complex projects like high-rise buildings. This study applies BIM to a G+19 high-rise building with a basement, achieving LOD 300, and employs clash detection to reduce material waste, improve efficiency, and enhance sustainability.

Clash detection recognized as a key efficiency driver in BIM, resolving geometric overlaps, tolerance issues, and scheduling conflicts [22, 39]. Tools like Navisworks have shown significant potential in minimizing rework and material waste, but most studies emphasize small- or medium-scale projects [8, 17, 21], leaving a gap in high-rise contexts. BIM's sustainability dimension has advanced, with research highlighting energy-efficient design, cost integration, and the role of 5D and 6D BIM [23, 28, 35, 37], but embodied energy reduction in high-rise projects seldom addressed. Broader research also notes adoption barriers, including cost–benefit uncertainties, lack of training, and organizational constraints [7, 25, 33], with regional studies across

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Asia, Europe, and the Middle East reflecting varying levels of maturity and implementation [14, 29, 30, 34, 40].

The literature consistently highlights BIM's potential in improving collaboration, reducing disputes, and minimizing costs [11, 26, 27]. However, most research has remained generic, with limited insights specific to high-rise construction. LOD standards are well-established, ranging from conceptual models (LOD 100–200) to detailed (LOD 300) and operational stages (LOD 400–500) [5, 24, 41], yet their applications to high-rise projects, particularly those involving basements and complex MEP systems, remain underexplored.

Despite these advancements, significant gaps remain in the existing body of research. There is a lack of focus on high-rise structures with basements, particularly in the Indian context where such projects are rapidly increasing. The integration of clash detection with embodied energy reduction strategies scarcely addressed, even though it holds immense potential for sustainability. There is limited evidence of scalable BIM frameworks tailored to urban high-rise projects in India, where policy, awareness, and adoption barriers continue to restrict full-scale implementation.

This study bridges these gaps by developing a LOD 300 BIM model for a G+19 high-rise with a basement, using Autodesk Revit 2024 and Navisworks Manage 2024 for clash detection to quantify material savings (133.4 m^3 concrete), embodied energy reductions (388,433 MJ), and carbon credits (47.51). This study uses a hypothetical G+19 high-rise with a basement as a representative case to demonstrate BIM-based clash detection and LOD 300 implementation. Research contributions lie in formulating a high-rise-specific BIM workflow, demonstrating carbon emission reduction through clash resolution, and proposing a scalable framework for BIM adoption in India to support sustainability and enhance stakeholder coordination in high-rise construction.

Methodology

This study conducted using a detailed G+19 high-rise building project with a basement, designed to replicate the complexity of real urban projects in India. The model represents multidisciplinary collaboration among architects, structural engineers, and MEP consultants, ensuring practical relevance while allowing controlled evaluation of BIM processes. Revit and Navisworks used to develop and integrate architectural, structural, and MEP models, followed by clash detection and resolution. The chosen model reflects the scale and multidisciplinary complexity of real projects, while allowing controlled evaluation of clash detection and LOD 300 implementation.

BIM overview and rationale for software selection

BIM is a digital process increasingly adopted in the AEC industry for creating and managing 3D models that integrate architectural, structural, and MEP systems. By enabling seamless coordination among disciplines, BIM enhances project efficiency, reduces design errors, and supports sustainability goals through optimized resource utilization [12]. Several commercial BIM platforms are available, including Autodesk Revit, Bentley AECOsim, and Graphisoft ArchiCAD. Each of these tools provides specialized functionalities, but the choice of software depends on project requirements and the level of integration demanded. For the present study, Autodesk Revit 2024 selected due to its extensive library of parametric components, its proven interoperability with Navisworks Manage 2024 for clash detection, and its widespread adoption within India's construction sector [1]. These capabilities align with the project's objective of achieving precise LOD 300/350 modeling while facilitating effective collaboration among multiple stakeholders.

Complementing Revit, Navisworks serves as a powerful project review platform developed by Autodesk, offering advanced features such as clash detection, design coordination, and 4D simulation. Its ability to integrate multidisciplinary BIM models ensures that design conflicts detected and resolved during the pre-construction stage, thereby minimizing rework and cost overruns [2]. In this study, Navisworks was employed to improve accuracy and enhance communication across project teams. While Bentley AECOsim is particularly suited for infrastructure-heavy projects (Bentley [4]) and Archicad is highly effective in addressing architectural design needs [15], Revit provides superior interoperability with clash detection tools and a user-friendly interface tailored for multidisciplinary coordination. These advantages make Revit, in conjunction with Navisworks, the most suitable choice for analyzing the complex G+19 high-rise residential structure considered in this study.

Design development stages

This study's methodology, outlined in Fig. 1, details the design stages using the LOD framework. At LOD 200 (Schematic Level), models replace mass elements with generic components. The study develops schematic designs, performs clash detection using Navisworks, resolves identified clashes, and advances to the next stage. At LOD 300 (Tender/DD Level), generic components replaced with fully specified assemblies, enabling system-based research and material quantity derivation. The model incorporates non-geometric data (e.g., text, dimensions, notes, 2D details).

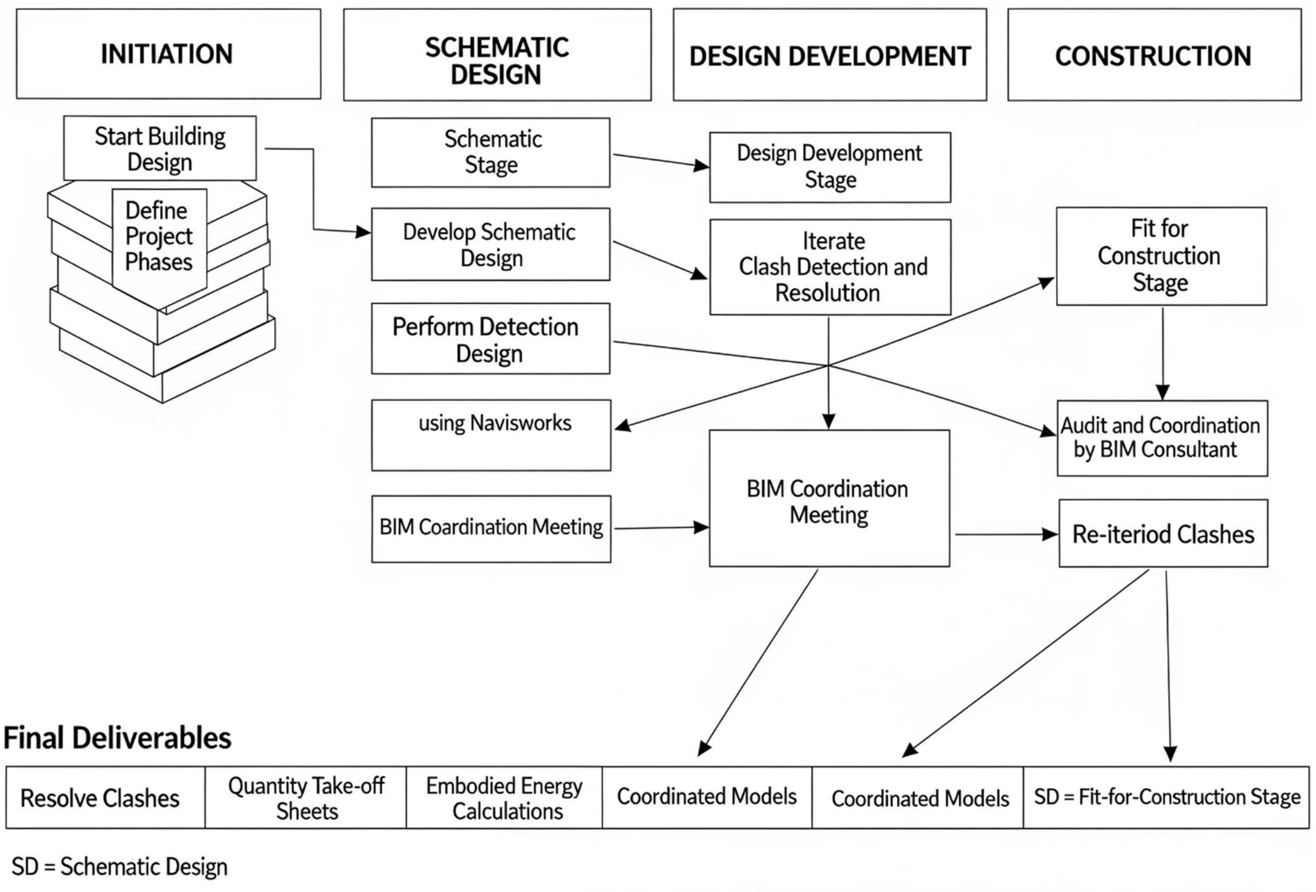

Fig. 1 Design stages

Clash detection and resolution iterated, followed by stakeholder meetings to coordinate changes and address queries. At LOD 350 (Detailed GFC Level), fully defined assemblies include support and installation details, audited and coordinated by the BIM consultant. The model again includes non-geometric data. After resolving all clashes, material quantities calculated, and energy savings are determined using the embodied energy concept, finalizing coordinated models and concluding the coordination stages.

Clash detection and analysis

The clash detection and analysis for the G+19 construction project, as outlined in Fig. 2, begins with collecting relevant BIM models and project documents. After securing BIM software licenses, all design and construction data integrated into Navisworks. Detailed 3D BIM models developed, accurately representing architectural, structural, mechanical, electrical, and plumbing components to align with project objectives. A clash detection protocol established, defining criteria, tolerances, and priorities based on industry standards and project requirements. Navisworks performed clash detection, identified and classified clashes by their severity and construction impact.

Quantitative analysis counts clashes, evaluates their intensity, and maps their spatial distribution, while qualitative analysis identifies causes and proposes mitigation strategies. Clashes prioritized by impact, and detailed reports generated. Stakeholders collaborate to resolve clashes through documented design or construction revisions, as referenced in Fig. 1. Clash detections rerun to validate resolutions, minimizing recurrence. Post-resolution, data analysis reassesses clash numbers and severity, evaluating impacts on project coordination. Embodied energy savings from clash resolution and material optimization calculated. The process concludes with a summary of findings and recommendations for enhancing BIM coordination in future projects.

Data collection

The project modeled to LOD 300 standards, providing a practical context for evaluating BIM applications in high-rise construction. Primary data generated using Revit,

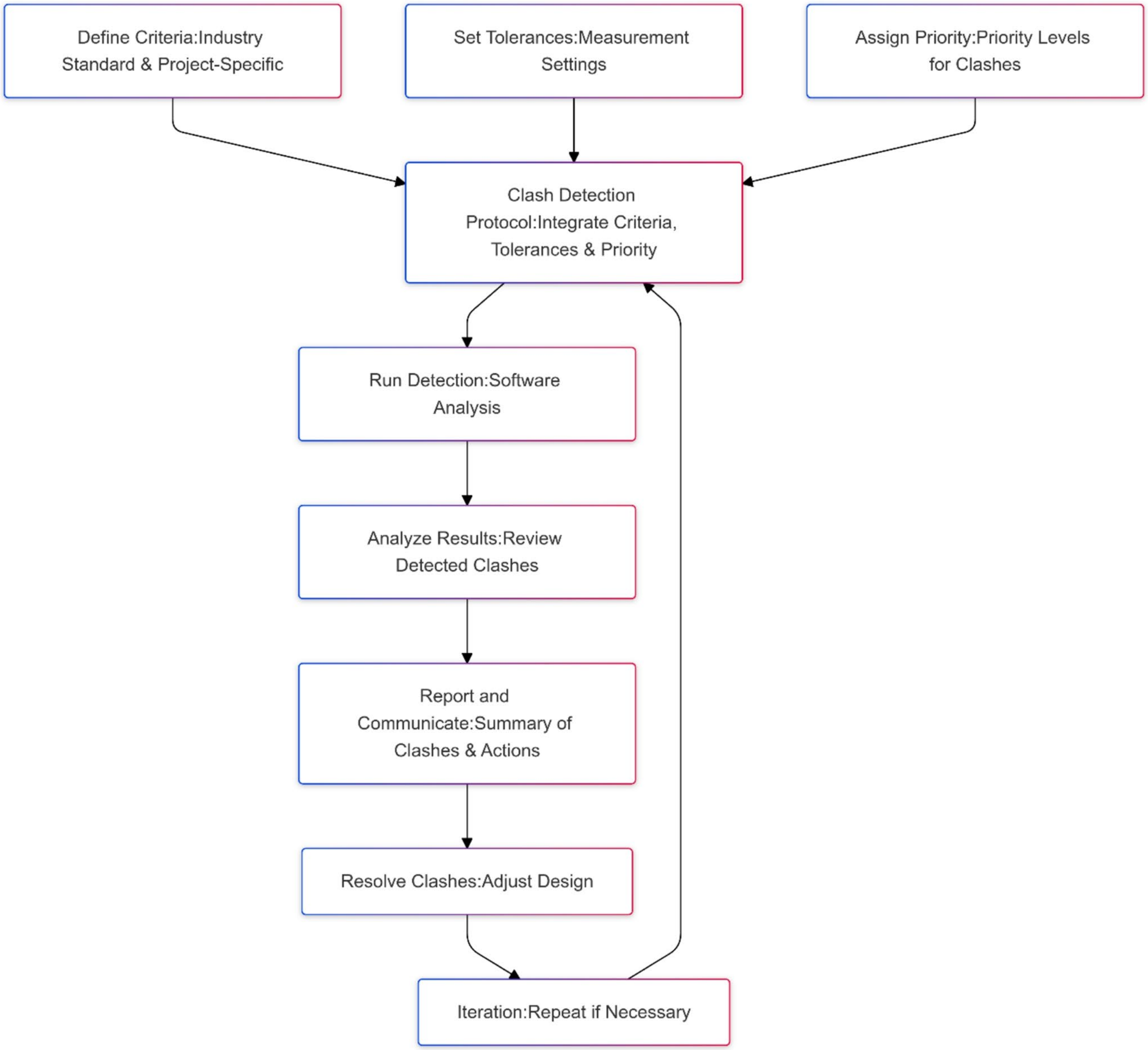

Fig. 2 Clash detection and analysis

comprising 3D models for architectural, structural, fire, plumbing, and electrical systems, developed to simulate multidisciplinary collaboration among architects, engineers, and contractors. These models, illustrated in Fig. 3, serve as a detailed digital representation of the building, enabling clash detection and analysis of material and energy savings. The data collection process integrated multidisciplinary design inputs into Revit, incorporating both geometric and non-geometric information (e.g., material specifications, system interfaces) to support the study's objectives of enhancing resource efficiency, reducing embodied energy, and improving stakeholder coordination.

Architectural model

Figure 4 depicts the 3D model and section of the architectural file in Revit. The architectural elements of this model are essential to the building's construction and operation, and its representation helps stakeholders comprehend how various components work together to produce the overall framework. The figure's parts enable us to study the design of the building. Sections offered a cut-away perspective that shows the internal design, spatial arrangement, and connections between the building's many levels and areas. The aspects like circulation flow, space efficiency, and design

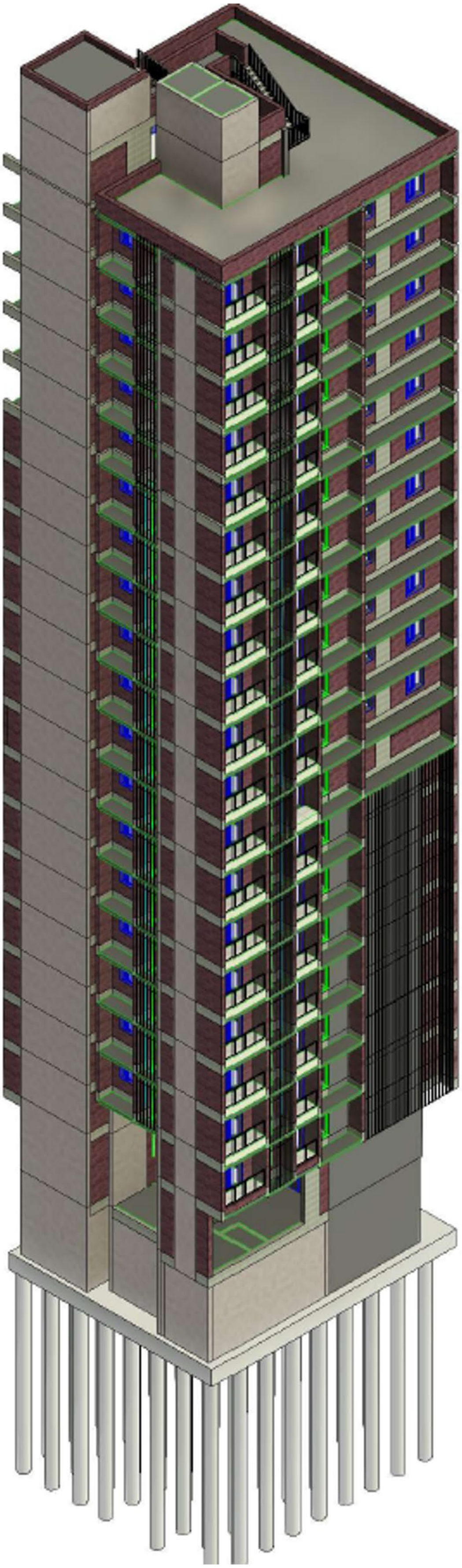

Fig. 3 3D G+19 model

specification have been evaluated conformance with this essential insight.

Structural model

The section and structural 3D model shown in Fig. 5 have provided a detailed depiction of the building's structural integrity, including the foundation and all-important structural components. 3D visualization has been crucial to the study because it gives a thorough picture of how the building is supported and loads are distributed throughout the structure. Since the foundation serves as the framework for the entire building, its inclusion in the model is especially crucial. The 3D model shows all the other structural components, including walls, slabs, columns, and beams. These elements are essential for distributing weight, offering stability, and guaranteeing the building's structural integrity. These components are arranged and connected, locating any possible weak points or inefficiencies by the 3D model and section. The section has offered a cross-sectional picture of the structure, enabling interested parties to see how the structural components are arranged. This realization facilitates comprehension of the building's spatial arrangement and the interactions between its various components.

Fire model

The fire model evaluates the thoughtful positioning of the fire pipe systems as shown in Fig. 6. Figure 6 shows the fire protection system on a single representative floor, along with the vertical riser to indicate continuity across levels. The fire model coverage has been assessed to make sure that every part of the building is sufficiently secured by visualizing the layout. Examining of these systems have been incorporated into the building's infrastructure to ensure that areas at fire risk receive an effective supply of water or fire suppression agents.

Plumbing model

The plumbing section and model's visualization have assessed the effectiveness, usefulness, and compliance of the plumbing systems. Plumbing section has given a thorough visual of the plumbing infrastructure in the building by Fig. 7, which displays the plumbing section and model. The plumbing model has evaluated the capacity and size of pipes, for sufficient water flow and pressure throughout the facility.

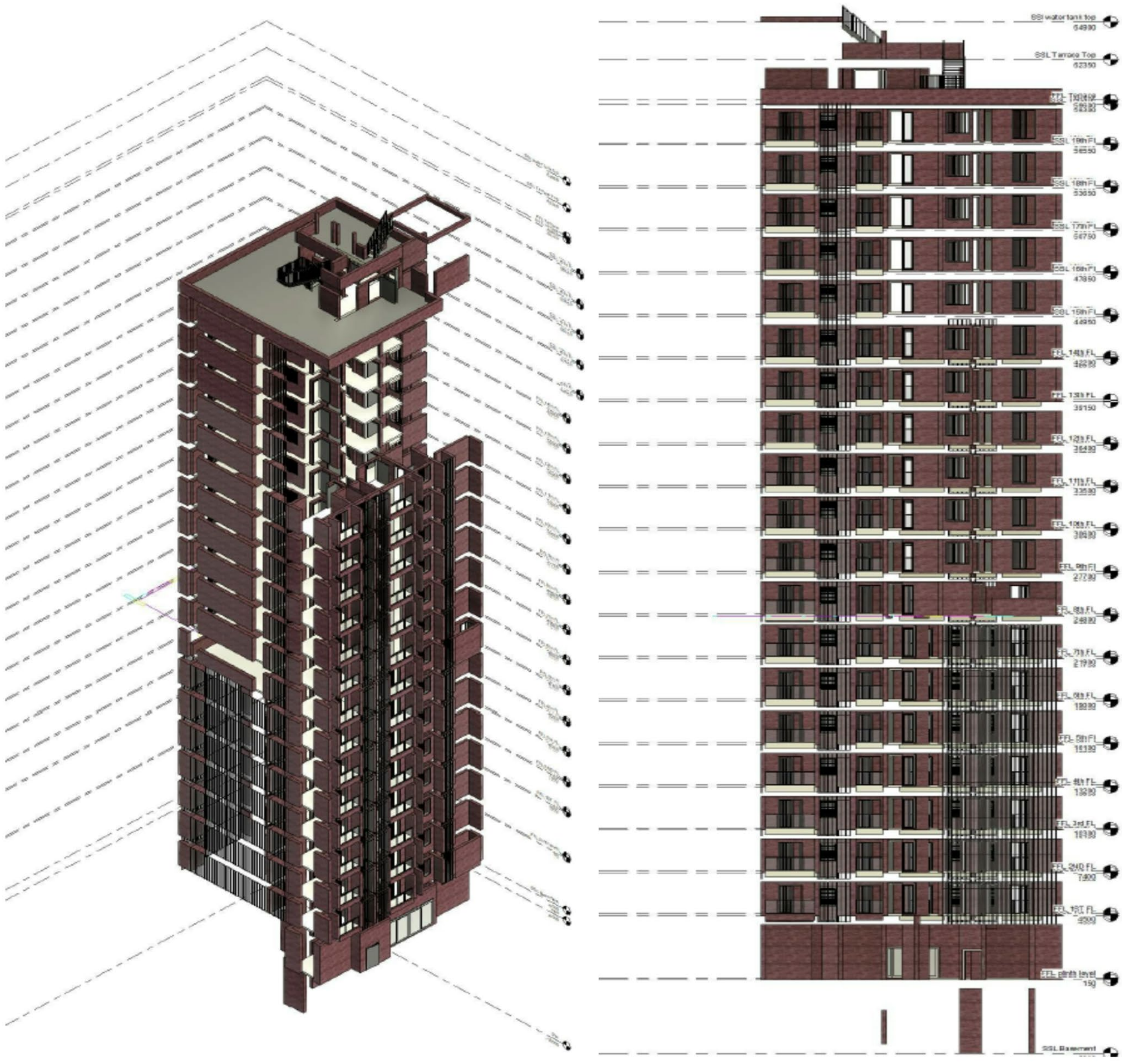

Fig. 4 3D view and section architectural model

Electrical plan

The Revit model's ceiling plan provided a detailed representation of the building's ceiling layout, ensuring proper integration of electrical systems with architectural and mechanical components. This integration allowed evaluation of system interactions and early identification of potential conflicts during construction. Using 3D views and ceiling plans, electrical elements such as lighting fixtures, conduits, and junction boxes were precisely placed within ceiling spaces for effective coordination across disciplines. Visualization tools, including rendering engines, further enhanced spatial understanding and communication, supporting accurate design decisions and interdisciplinary collaboration.

Data analysis

The G+19 construction project will undergo a comprehensive data analysis process in stages. The first stage involves a BIM-based 3D modeling process using Revit, integrating structural, architectural, and MEP components. This process ensures a precise digital representation aligned

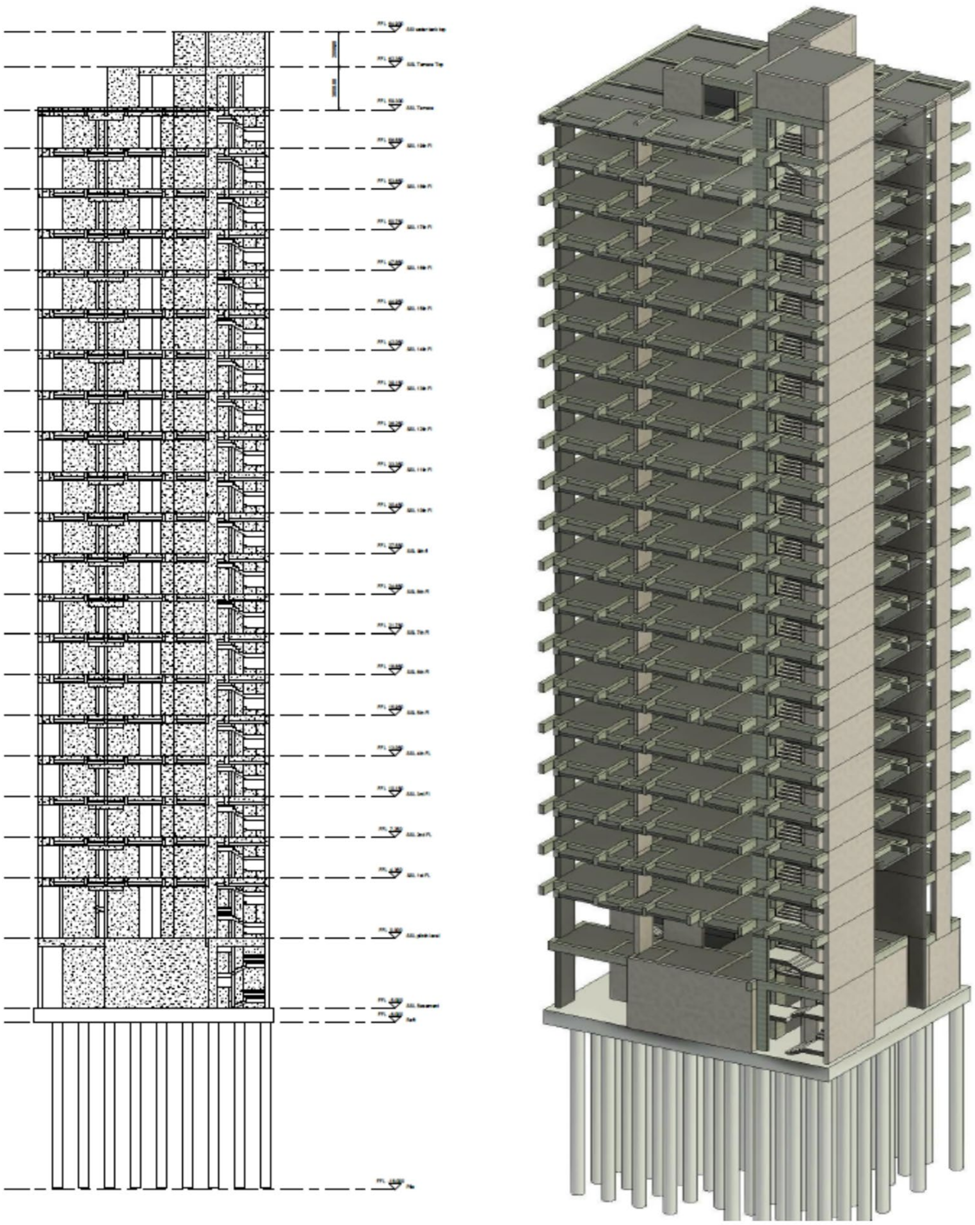

Fig. 5 Section and 3D structural model

with the project's design goal. The second stage involves a clash detection phase using Navisworks, identifying potential clashes between elements. These clashes are classified into clash groups based on their severity and impact on the construction process. The final stage involves clash resolution, involving stakeholder engagement and strategic design changes to reduce clashes and ensure effective settlement of identified issues. This comprehensive data analysis strategy will enhance the project's efficiency and coordination, enabling informed decision-making and resolution solutions.

This study investigates the use of Revit software for 3D modeling outputs, following the LOD 300/350 standards. A methodical strategy was employed to resolve clashes, starting with identifying specific clashes within the model. Navisworks was used to assign unique clash codes, enabling accurate position pinpointing. These codes were then used as references to update the impacted components within the design software. This necessitated a variety of changes, such as moving, resizing, or changing components, to eliminate these clashes. We ensured a thorough and effective resolution of clashes within the project's BIM model by following this methodical process of identification, clash code assignment, and targeted editing. This contributed to improved coordination and a streamlined construction process.

The element ID is a unique identifier for each building element within the Revit software. It is a numerical label assigned to elements like walls, doors, and windows that

Fig. 6 Fire system

allow for precise identification and tracking throughout the modeling and documentation process. This identification system ensures clarity and precision when managing and referencing elements in the Revit environment. The clash ID from Navisworks has been used to find clash no. in Architectural model vs Structural model in the elements. Navisworks analyze the areas and identifies areas creating clashes where these components intersect or overlap.

The clash detection test run in Navisworks identified a total of 4942 clashes between different elements of the structural and architectural models. Among the 4942 clashes, one specific clash has been identified between the concrete rectangle beam and the slab. The software found an overlap or intersection between these two elements in the 3D models. Once the clashes have been identified, they have been resolved to ensure that the building design is clash-free and constructed without issues.

The clash was found in Navisworks into Revit for resolution using element ID. The clash has been investigated and resolved between overlapping elements of beam and slab in this instance. This makes it simple to move between the conflicts, and the stakeholders can focus on resolving each one individually to clarify the design strategy. The clash resolution between concrete rectangle beam and slab elements necessitates a careful process to maintain structural integrity and architectural coherence. Finding the precise position of the clash in the Revit model is the first step in the process. Understanding the exact type of interference is crucial, and this can be done either visually by analyzing the model or by looking into clash reports. The clash features such as a vertical overlap, horizontal junction, obstructions are carefully examined. The extra overlap has been cut off which was the main cause of the clash between the beam and slab; after the successful resolution of this clash the quantity of the material saved.

Before resolution, the component exhibits overlap or intersection with another element, as determined by clash detection. This condition leads to disagreements during construction. Following clash resolution, the component was adjusted to eliminate the overlap or intersection. The properties after resolution show a changed state, ensuring that the component no longer collides with other elements. This process ensures a more coherent and conflict-free design, reducing construction challenges and improving overall component integrity within the 3D model. In the original design, the overlap between the concrete beam and the slab increased in concrete volume, indicating potential inefficiencies and added construction costs. By addressing this clash, the overlay is removed from the original design, significantly reducing the cross-sectional area. This is substantiated by examining the properties of the model, where the overall volume for the respective elements is reduced from 0.124 m^3 to 0.097 m^3 for a solitary clash ID.

This process not only ensures the elimination of design conflicts but also optimizes material usage and minimizes construction expenses. Overall energy consumption has been reduced by calculating the embodied energy which was saved using this process and the carbon credit that can be earned with the help of it. Clash detection and resolution tools not only enhance coordination but also contribute to cost savings and more efficient construction processes, ultimately leading to better project outcomes.

This study quantifies the environmental and economic benefits of Building Information Modeling (BIM)-based clash detection during the pre-design phase of a G+19 reinforced concrete structure with a basement, focusing on material savings, embodied energy, embodied carbon, and carbon credits. Clash detection between structural and architectural drawings yields an average concrete saving of

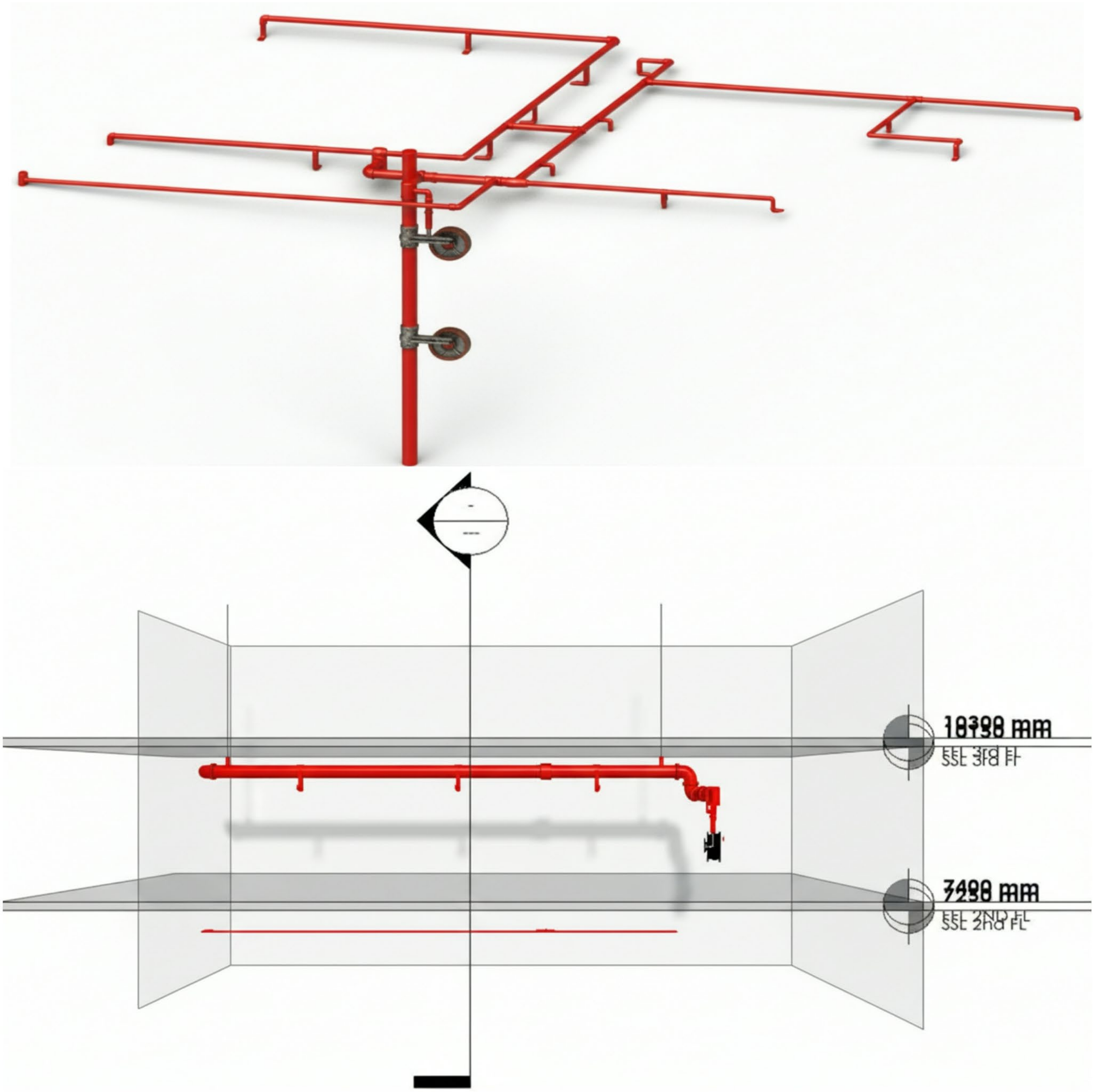

Fig. 7 Plumbing section and model

0.027 m^3 per clash, derived from differential volume analysis (0.124 m^3–0.097 m^3) in high-rise construction projects [10].

For 4,942 identified clashes, the total concrete volume saved is $4{,}942 \times 0.027 = 133.434$ m^3, rounded to 133.4 m^3 for reporting consistency. UsingUsing M25 grade concrete at USD 73.23/m^3 (market rate in India, 2021, adjusted for inflation), the cost savings are $133.4 \times 73.23 =$ USD 9,761.45, highlighting the economic benefits of BIM in optimizing high-rise construction. Using M25 grade concrete at USD 73.23/m^3 (market rate in India, 2021, adjusted for inflation), the cost savings are $133.4 \times 73.23 =$ USD 9,761.45, highlighting the economic benefits of BIM in optimizing high-rise construction.

For embodied energy calculations, the density of M25 reinforced concrete is taken as 2,406.53 kg/m^3, based on standard specifications (ACI 318–19). The mass of saved concrete is 133.4 $m^3 \times$ 2,406.53 kg/$m^3 \approx$ 321,019 kg. Applying an embodied energy coefficient of 1.21 MJ/kg, sourced from life cycle assessment (LCA) data for cement and aggregate production [16], the embodied energy saved is 321,019 × 1.21 ≈ 388,433 MJ. For embodied carbon, an emission factor of 0.148 $kgCO_2/kg$, reflecting the carbon intensity of concrete production [16], yields avoided emissions of 321,019 × 0.148 ≈ 47,511 $kgCO_2$.

Carbon credits calculated using the standard conversion of 1 carbon credit per 1,000 $kgCO_2$, per Verified Carbon Standard protocols. Thus, 47,510.827/1,000 = 47.51 carbon credits earned. These calculations assume uniform clash severity and consistent concrete mix properties (e.g., cement content, reinforcement ratio). Variations in mix design or clash complexity could affect outcomes, and future studies should validate the 0.027 m^3 saving per clash across diverse project typologies [10]. The clash detection process employed Revit and Navisworks, using automated geometric analysis and manual resolution by multidisciplinary teams. Secondary benefits, such as reduced labor or schedule delays, excluded but could amplify savings. These results demonstrate BIM's potential to reduce material waste, lower embodied carbon, and achieve cost efficiencies, supporting sustainable construction practices in India's high-rise sector.

Clash detection between the structural and fire models performed using the clash detective feature of Navisworks. The test identified a total of 306 clashes between various elements of the structural and fire models. Once these clashes detected, each required careful analysis and resolution to ensure that the building design was clash-free and constructible without conflicts.

The overlapping elements systematically reviewed, and appropriate measures taken to resolve conflicts between structural and fire components. Stakeholders were able to navigate between clashes within the software, providing clarity and coordination in the design process. Resolution of these clashes led to more efficient integration of structural and fire safety systems, optimizing material usage and minimizing unnecessary concrete consumption. Following clash resolution, the 3D BIM model achieved a harmonized state where structural and fire safety elements coexist without conflict. This coordinated model enhances constructability, reduces potential on-site issues, and ensures a more robust and reliable building design.

The properties of structural elements analyzed before and after clash resolution. One common type of clash involved a beam requiring a core cut for fire pipe insertion. This clash resolved by incorporating the necessary core cut in the beam, which led to a reduction in concrete usage. For example, the volume of concrete required for a single element reduced from 0.407 m^3 to 0.405 m^3. While the saving for a single element may appear minor, the cumulative effect across all 306 detected clashes results in a substantial reduction in material use, lowering construction costs and minimizing potential resource wastage.

Considering that reinforced concrete will be used in construction, the embodied energy is 1.21 MJ/kg, and the embodied carbon is 0.148 $kgCO_2/kg$ (Sabnis et al., 2015). The resolution of a single clash results in a small concrete volume saving of 0.407–0.405 = 0.002 m^3. Assuming an average saving of 0.002 m^3 per clash across all 306 clashes between the structural and fire models, the total concrete saved amounts to approximately 0.612 m^3. At a cost of 61.37 USD/m^3 for M25 grade concrete, this translates to a total cost saving of about 39.63 USD, demonstrating the financial benefits of clash detection and resolution during the pre-design phase.

For embodied energy calculations, the weight of the saved concrete is 0.612 m^3 × 2,406.53 kg/m^3 ≈ 1,473 kg, which, when multiplied by the embodied energy coefficient of 1.21 MJ/kg, results in approximately 1,782 MJ of energy saved. Applying the embodied carbon factor of 0.148 $kgCO_2/kg$ to this mass yields a reduction in carbon emissions of approximately 264 $kgCO_2$. Using the standard conversion for carbon credits, one credit per 1,000 kg of CO_2, the energy savings correspond to 0.264 carbon credits. Therefore, resolving clashes not only reduces material usage and construction costs but also contributes to energy conservation and carbon emission reduction, highlighting the sustainability benefits of coordinated clash management in the design process.

Clash detection performed between the structural and plumbing models, identified a total of 286 clashes. Upon closer examination, many of these clashes deemed insignificant. For instance, some `clashes detected due to portions of bolts intersecting structural members. In practice, these would not pose construction issues, as fittings can be adjusted on-site to accommodate the elements. This highlights the importance of interpreting clash detection results carefully, considering their practical implications during construction. While digital models are essential for identifying potential conflicts, the ability to make real-time adjustments on-site ensures that minor clashes do not impact the overall construction process. Such an approach allows for efficient coordination, minimizing unnecessary redesigns and supporting a more adaptable and constructible building model.

Clash detection between the structural and electrical models revealed no conflicts. The analysis showed that the electrical elements were inherently compatible with the structural components, resulting in zero detected clashes. This outcome highlights the effective coordination between electrical and structural models, confirming their harmonious integration. The absence of clashes can be attributed to the nature of electrical systems, which do not interfere with structural elements. This successful integration ensures a clash-free 3D model, facilitating smoother construction, reducing potential on-site issues, and reflecting careful planning in the design of both electrical and structural components.

In addition to material savings, the clash resolution process has measurable impacts on sustainability metrics. The reduction in concrete volume contributes to decreased embodied energy and associated carbon emissions, enhancing the overall environmental performance of the building. This integrated approach demonstrates how coordinated clash management in BIM not only improves constructability but also supports energy-efficient and sustainable construction practices.

Results and discussion

The study concentrated on using 3D BIM modeling outputs while following LOD 300/350 guidelines. The aim was to enhance the coordination and conflict resolution of building projects. The efficacy of the meticulous clash resolution approach used is demonstrated by the outcomes and discussion that follow. 4942 conflicts between structural and architectural models were found by using Navisworks, which was the study's method of choice. Clashes were successfully managed using methodical resolution techniques, including conflict code assignment and focused editing in Revit. A concrete rectangle beam and slab clash was specifically resolved, demonstrating the methodical approach's actual application.

Comparing the attributes before and after the collision resolution showed that the design coherence and component integrity had significantly improved. For example, the concrete volume of the rectangular beam was lowered from 0.124 m^3 to 0.097 m^3, indicating that the material usage has been improved and the building expenses were minimized. Simplifying clash resolution procedures was made possible by the incorporation of clash detection systems like Navisworks. The ability to visually indicate construction challenges in the BIM model has allowed for targeted amending to identify and resolve conflicts quickly.

Apart from these results, the study investigated the consequences of carbon credit and embodied energy. Calculations showed that through clash resolution procedures, significant energy savings and carbon credits are obtained. The economic and environmental advantages of systematic clash resolution methods are further supported by these factors. The pre-design phase's clash detection and resolution study produced significant advantages in terms of financial savings and environmental sustainability. A total of 133.4 m^3 of concrete was saved by using careful clash resolution techniques, which resulted in significant cost savings of approximately USD 8,166 (based on the rate of 61.37 USD/m^3 for M25 grade concrete). The cost benefits of initiative-taking clash control are demonstrated by this significant decrease in the use of concrete.

The embodied energy estimates showed that the smaller concrete volume resulted in an energy savings of 38,7282.87 MJ. With the embodied carbon constant of 0.148 $kgCO_2/kg$, this corresponds to about 57.40 earned carbon credits. By helping to reduce the carbon emissions linked to construction operations, these carbon credits offer a noticeable advantage to the environment. The case was similar for another clash test for structural versus fire which gave us energy savings of 1,782.07 MJ which corresponds to 0.2638 of carbon credits earned. The study focused on the useful applications of dispute resolution in maximizing resource efficiency and lowering construction-related cost overruns. The financial advantages of initiative-taking clash management are highlighted by the accumulated savings across a series of clashes, even when individual clash settlements may not seem like much.

Rapid advancements in BIM gives new potential for enhancing the effectiveness and efficiency of the building procedure as well as boosting the use of emerging technologies throughout a project's lifespan, not just in buildings but also in infrastructure. Although several scholars have pushed for the use of BIM in infrastructure and numerous studies of BIM implementation have been undertaken, there has been no comparison assessment of BIM implementation in the construction and infrastructure industries. As a result, the purpose of this research is to determine the extent to which BIM adoption has happened in the construction and infrastructure industries [34]. Similarly, study emphasizes the significance of ongoing integration with design techniques and focuses on the increasing significance of Environmental Impact Assessments (EIAs) for infrastructure projects. Although it is being used, BIM has limitations with its current approaches [31]. The study suggests revolutionary architecture for ongoing BIM-based to integrate and send data in both directions between BIM and EIA technologies, EIA has a standardized data structure. A prototype is evaluated for scalability, functionality, and feasibility using a case study. Expert comments have highlighted the tool's efficiency in delivering rapid and accurate environmental impact assessments, expediting the EIA procedure, and enhancing sustainability considerations in infrastructure design decision-making.

This research emphasized how crucial it is to interpret clash results carefully, especially when it comes to the importance of clashes found. Clashes between bolts in structural parts, for example, were judged to be negligible, highlighting the necessity of using common sense when resolving clashes. To summarize, the process of detecting and resolving clashes not only reduced building costs and maximized the use of materials, but it also produced significant energy savings and earned carbon credit. These results highlight how crucial systematic clash resolution methods are for optimizing resource efficiency, cutting costs associated with construction, and fostering environmental sustainability in building projects. The building's overall embodied energy was decreased by preventing clashes and reducing the amount of material needed. By lowering carbon emissions linked to energy-intensive construction processes, this reduction in embodied energy supports worldwide efforts to mitigate climate change in addition to promoting environmental sustainability.

Research limitations

The results of this study might not be immediately relevant to all construction projects because they are based on a particular project scenario. Clash detection and resolution solutions may not be as effective in certain situations due to differences in project size, complexity, and stakeholder dynamics. As a result, care should be taken when extrapolating the findings to other situations. To find and resolve clashes, a thorough inspection and modification of various aspects within the building model are required. It takes a lot of time and works to complete this process, especially when working on intricate architectural designs or large-scale building projects. This study does not resolve all clashes and estimates cost and energy savings based on the assumption that all clashes yield comparable benefits, which may not hold true in practice. The time-consuming nature of comprehensive clash analysis could limit the adoption of this approach.

Real-world construction projects frequently include trade-offs between the depth of clash identification and time and resource constraints. Project teams may prioritize resolving confrontations that represent the greatest risk to construction efficiency or safety, while less critical clashes may be overlooked. In our study, the necessity to combine research aims with practical constraints may have resulted in a limited evaluation of confrontations, focusing on those regarded as most significant or representative. Despite efforts to evaluate conflict outcomes carefully, the relevance of individual confrontations remains subjective. Certain confrontations may be considered trivial by experts, but their actual impact on construction processes may differ. Further research could investigate objective criteria for ranking clashes based on their potential outcomes.

Conclusion

This study addressed the challenge of enhancing efficiency and sustainability in high-rise construction by optimizing BIM through clash detection and resolution for a G+19 structure with a basement. The research aimed to reduce construction costs, material waste, and embodied energy while promoting stakeholder coordination and environmental sustainability. The methodology involved a systematic BIM-based approach using Revit and Navisworks, adhering to LOD 300/350 standards. The process included developing 3D models for architectural, structural, fire, plumbing, and electrical systems, followed by clash detection, classification, and resolution through stakeholder collaboration. Key steps encompassed integrating design data, establishing clash detection protocols, and iterating resolutions to ensure a conflict-free design. The main findings are as follows:

- Clash detection outcomes: A total of 5534 clashes identified across models, with 4942 clashes between structural and architectural models and 306 between structural and fire models. No clashes found between structural and electrical models, indicating effective design coordination.
- Material and cost savings: Resolving clashes saved 133.4 m^3 of M25 grade concrete across 4942 structural-architectural clashes, yielding cost savings of approximately USD 8644 at USD 64.77/m^3. For 306 structural-fire clashes, 0.612 m^3 of concrete saved, resulting in approximately USD 40 in savings.
- Embodied energy and carbon reductions: Clash resolutions reduced embodied energy by 388,433.113 MJ for structural-architectural clashes and 1,782.07 MJ for structural-fire clashes. Corresponding embodied carbon savings were 47,510.827 $kgCO_2$ and 263.85 $kgCO_2$, earning 47.51 and 0.26385 carbon credits, respectively.
- Improved coordination and sustainability: The systematic clash resolution process enhanced stakeholder collaboration, streamlined construction workflows, and minimized design discrepancies, contributing to resource efficiency and environmental sustainability.

These findings demonstrate that initiative-taking clash detection and resolution in the pre-design phase significantly optimize resource use, reduce construction costs, and lower environmental impacts, fostering sustainable practices in India's high-rise construction sector. This study demonstrates the effectiveness of the proposed methodology in reducing material waste, construction costs, and embodied energy, offering actionable insights for high-rise developments in India's construction sector. The future research work will extend the proposed framework to real high-rise projects in collaboration with industry partners. Such validation will strengthen the practical applicability of the workflow and allow deeper assessment of embodied energy savings and carbon reduction under real-world constraints.

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Data availability The datasets generated during the current study are available from the corresponding author on reasonable prior request.

Declarations

Conflict of interest The writers say that they have no significant financial or non-financial interests that could be seen as conflicts of interest with the study, writing, and/or publication of this article.

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