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# Quantitative Evaluation of BIM-Based Clash Detection: A Case Study on Residential and Commercial Building Models

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***Abstract***: This study presents a comprehensive quantitative evaluation of clash detection in Building Information Modeling (BIM)-based residential and commercial building projects. With the growing complexity of architectural and engineering systems, effective design coordination is essential to minimize construction-phase conflicts and cost overruns. In this study, discipline-specific models—architectural, structural, and Mechanical, Electrical, and Plumbing (MEP)—were developed using Autodesk Revit. These models were integrated and analyzed using Navisworks Manage to detect and categorize spatial conflicts as hard, soft, or workflow-related clashes. The residential building model revealed 23 clashes**,** primarily involving wall–column and wall–wall intersections, indicating structural misalignments. In contrast, the commercial building model exhibited 58 clashes, with a higher concentration of MEP-related issues such as duct–beam and pipe–slab interferences. A clash responsibility matrix was implemented to assign resolution authority based on system hierarchy, improving coordination efficiency. Comparative analysis showed that commercial projects required nearly twice as many resolution iterations as residential ones. Early-stage clash detection was found to reduce design errors by over 70%, save an estimated 30% of project time, and significantly enhance interdisciplinary collaboration. These findings underscore the critical role of BIM-enabled coordination—especially in MEP-intensive projects—and support the integration of such practices in both academic and professional design workflows.

***Index Terms*** - Building Information Modeling (BIM); Clash Detection; Design Coordination, Buildings, Mechanical, Electrical, and Plumbing (MEP) Systems; Autodesk Revit; Navisworks Manage.

## I. INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry is undergoing a significant transformation globally, driven by the increasing complexity of building systems and the demand for cost-effective, error-free, and sustainable project delivery. Traditional 2D CAD-based methods have long served the design process, but they offer limited spatial intelligence and are prone to miscommunication between disciplines, often leading to construction delays and expensive rework. In response, Building Information Modeling (BIM) has emerged as a revolutionary digital methodology that facilitates 3D modeling, real-time collaboration, clash detection, and lifecycle asset management, all within an integrated digital environment (Eastman et al., 2011; Borrmann et al., 2018; Rahman & Siddique, 2023).

BIM allows multiple stakeholders—architects, structural engineers, MEP consultants, and contractors—to work on a unified model, identify spatial interferences (clashes), and resolve them well before construction begins. This shift from reactive to proactive coordination significantly improves construction productivity, reduces material waste, and enhances safety. Studies have reported that the use of BIM in clash detection can reduce design conflicts by up to 80% and accelerate project schedules by 10% to 30% (Azhar, 2011; Bryde et al., 2013; McGraw-Hill Construction, 2012). Moreover, tools like Autodesk Revit and Navisworks Manage enable project teams to visualize, simulate, and coordinate complex building systems in both small-scale and large infrastructure projects.

While BIM has been widely adopted in global construction practices, its implementation in mid-scale Indian projects remains limited (Eastman et al., 2011).According to KPMG (2019), only 15–20% of Indian construction projects adopt BIM at a mature level, and fewer use it for coordination and clash detection. A significant number of Indian projects still rely on 2D drawings, resulting in spatial conflicts between structural and MEP components, especially in high-density buildings. This lack of coordination leads to increased RFIs (Requests for Information), site rework, and poor stakeholder alignment (Honnappa& Padala, 2022; Moraes &Santos, 2023). Thus, there is a strong need to contextualize and study BIM-based clash detection workflows in Indian residential and commercial construction environments.

Global research highlights the effectiveness of BIM in improving coordination. For example, Hartmann et al. (2012) found that applying 3D and 4D BIM models in hospital projects significantly reduced coordination errors and site delays. Won et al. (2016) quantified that clash detection through BIM prevented nearly 2.5% of construction waste in Korean high-rise projects. In a recent study, Chahrour and El-Diraby (2021) emphasized that BIM-based clash resolution frameworks can reduce construction cost overruns by an average of 11%. Furthermore, Paneru et al. (2023) introduced a performance framework for measuring the efficiency of BIM coordination. Additionally, Li et al. (2024) explored the broader role of artificial intelligence in enhancing BIM workflows for smart city applications and sustainable building performance. Despite such promising global benchmarks, there remains a limited body of literature focusing on medium-scale Indian projects, especially from an academic perspective.

The challenge is particularly acute in student-driven or academic projects, where BIM usage is often limited to modeling and visualization rather than coordination. There is also a gap in applying standardized clash detection workflows and measuring the effectiveness of resolution iterations in educational or pilot settings. Additionally, the use of clash responsibility matrices—where resolution roles are assigned based on system hierarchy (e.g., structure vs. MEP)—is rarely formalized in Indian practice, although it is a growing trend globally (Khanzode et al., 2008; Lu et al., 2015; Liu et al., 2024).

The present study focuses on the performance of BIM-based clash detection in two different scenarios: a residential and a commercial building - Using Autodesk Revit for modeling and Navisworks Manage for clash analysis. This study identifies, categorizes, and compares spatial conflicts in both models. It further proposes a clash responsibility matrix to streamline resolution workflows and reduce design iterations. The aim is to bridge the academic-industry gap in BIM coordination practices and to establish a structured methodology for clash detection that can be scaled for use in educational, government, and professional domains.

## II.METHODLOGY

This study adopts a comparative case analysis framework to evaluate spatial clash detection and coordination workflows using building information modeling tools in two distinct building types: a residential apartment block and a commercial office facility. Both models were developed as part of academic capstone projects, with students serving as discipline-specific modelers under faculty supervision to simulate real-world BIM team dynamics. The methodology integrates digital model creation, federated coordination, clash categorization, detection, and resolution using Autodesk Revit 2022 and Navisworks Manage 2022.

The residential building, comprising ground plus three floors, includes typical load-bearing components, partition walls, and basic mechanical and electrical systems. In contrast, the commercial building spans five floors and incorporates more complex service networks, including Heating, Ventilation and Air Conditioning (HVAC) ducts, plumbing systems, and suspended lighting. This variation in typology and system density offers an opportunity to compare how building scale and service complexity influence clash volume, resolution effort, and coordination iterations (Hartmann et al., 2012; Borrmann et al., 2018).

Discipline-specific models—Architectural, Structural, and MEP (Mechanical, Electrical, and Plumbing)—were independently created in Autodesk Revit 2022 following standard codes and design assumptions. These models were exported as .NWC files and federated within Autodesk Navisworks Manage 2022, a widely adopted tool in the AEC industry for 3D coordination and review (Hardin & McCool, 2015). The federated model enabled visualization of combined systems in a single interface and facilitated automated clash detection using the built-in "Clash Detective" module (Zhou et al., 2015).

Clashes were classified into three main categories:

- **Hard clashes**: Physical geometry intersections (e.g., a duct penetrating a beam),
- **Soft clashes**: Clearance or accessibility violations (e.g., insufficient spacing between pipe and wall),
- **Workflow clashes**: Installation or sequencing conflicts (e.g., overlapping service pathways in the same ceiling zone).

Each identified clash was recorded, categorized, and visually validated. To minimize false positives, rule-based clash grouping was applied—filtering out non-critical clashes such as those within the same object family (Borrmann et al., 2018). Detected clashes were fed back to the design teams to simulate real-time interdisciplinary coordination loops, consistent with recommendations from BIM coordination literature (McGraw-Hill Construction, 2012; Khanzode et al., 2008).

A notable innovation in this study is the implementation of a Clash Responsibility Matrix, which assigns resolution responsibility based on system hierarchy and flexibility. Structural elements were treated as non-negotiable, while MEP routes were rerouted or adjusted to resolve conflicts. This system aligns with best practices in global coordination strategies (Khanzode et al., 2008) and has recently been extended to semantic BIM workflows (Chahrour& El-Diraby, 2021).

Each clash resolution cycle was logged and measured, tracking the following performance metrics:

- Number of clashes per system interaction,
- Number of iterations required to achieve a clash-free model,
- Estimated time saved through early detection and digital coordination.

The benefits of this iterative process are well-supported in existing research. For instance, Won et al. (2016) showed that iterative BIM validation significantly reduces material waste and site rework. Similarly, Khosrowshahi &Arayici (2012) and Lu et al. (2015) emphasized that structured coordination efforts—especially when applied through educational simulations or pilot projects—serve as valid benchmarks for industry adoption and international comparison. Finally, comparative insights were drawn between the residential and commercial models to highlight patterns in clash types, model complexity, coordination effort, and resolution efficiency, thereby providing a structured evaluation of BIM-based design coordination practices.

The overall clash detection and coordination workflow followed in this study is illustrated in Figure 2.1. This diagram summarizes the stepwise progression from model development to final resolution using BIM tools such as Revit and Navisworks Manage.

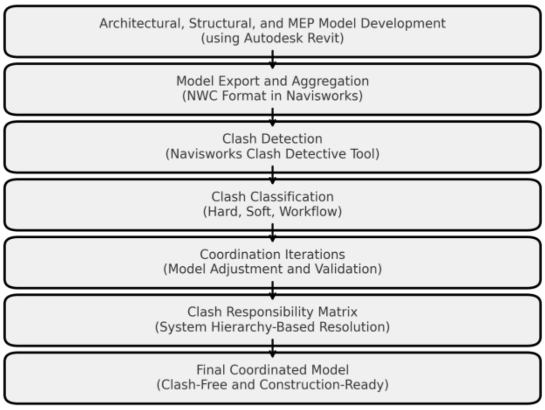


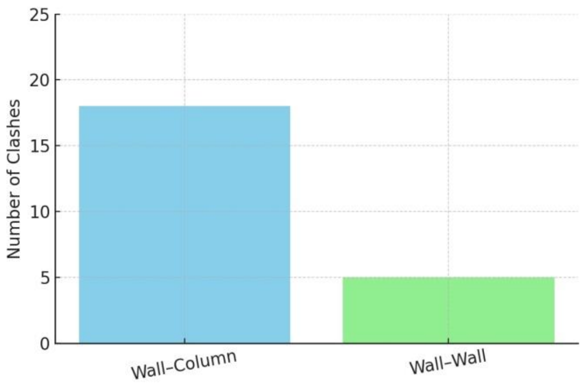

Figure 2.1: BIM Coordination Workflow — From Modeling to Clash-Free Construction

## III. RESULTS AND DISCUSSION

The clash detection results were generated using Navisworks Manage by running clash tests between architectural, structural, and MEP systems in both residential and commercial models. A total of 23 clashes were identified in the residential model and 58 clashes in the commercial model, covering hard, soft and workflow clashes. These results are visually documented in Figures 3.1 through 3.7 and are discussed in relation to established studies on BIM-based clash coordination.

### 3.1 Clash Frequency and System Type Involvement

Clash detection in both models revealed a strong correlation between model complexity and clash frequency**.** The residential model exhibited 23 clashes, with a dominant share of hard clashes occurring between walls and columns. In contrast, the commercial building recorded 58 clashes, comprising a mix of hard, soft, and workflow-related conflicts. This disparity aligns with the findings of Hartmann et al. (2012) and Bryde et al. (2013), who reported that MEP-dense zones in multistory projects tend to exhibit significantly higher clash potential. Figures 3.1-a and 3.1-b illustrate this trend visually.



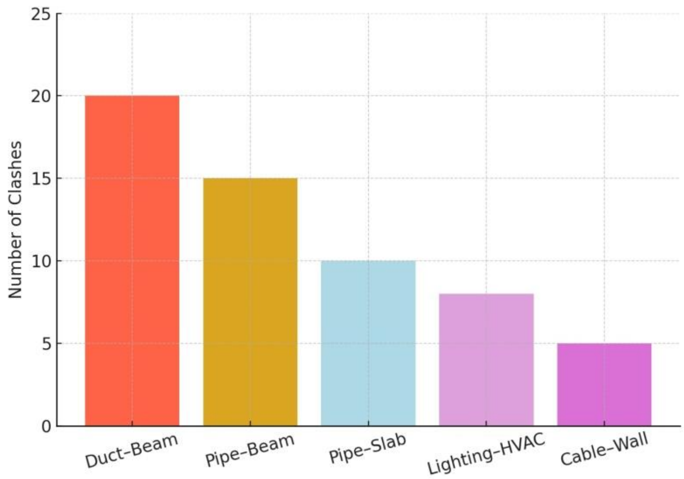




Figure 3.1-a: Residential Building Clash Frequency.

Figure 3.1-b: Commercial Building Clash Frequency.

Moreover, the commercial model required more than four iterative coordination loops, during which clashes were detected, resolved, revalidated, and corrected before achieving a clash-free model. In contrast, the residential project reached satisfactory resolution within just two cycles (Figure 3.2). This observation underscores that iterative design validation is critical in services-dense layouts, particularly when MEP, structural, and architectural elements must coexist within limited spatial zones. As noted by Chahrour et al. (2021), clash-prone models significantly benefit from structured and repetitive BIM coordination frameworks**.**

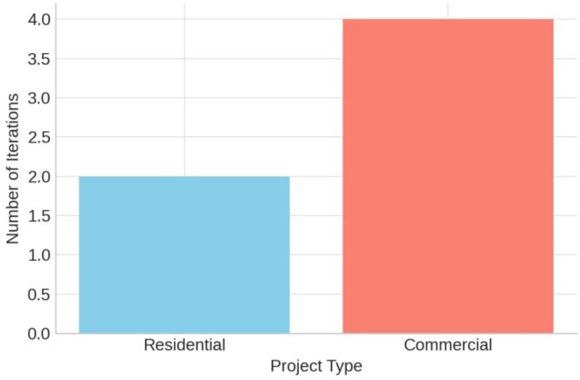



Figure 3.2: Number of Clash Resolution Iterations in Residential and Commercial Building

### 3.2 Clash Distribution within the Commercial Model

Detailed analysis of the commercial model shows that over 60% of clashes were due to duct-beam and pipe-slab interferences. Lighting fixture misalignments with HVAC elements and cable tray interferences were also observed. Figure 3.3 illustrates this clustering. These clash patterns align with those reported in Singh et al. (2011), who found that shared ceiling voids in high-rise buildings are the most congested and vulnerable zones for interference. The inclusion of cable trays, ducts, fire lines, and conduits within a confined vertical height demands precision modeling and early integration checks. In contrast, residential clashes were localized and mostly involved wall-column misalignments, a challenge often neglected in 2D layouts but easily visualized in 3D environments.

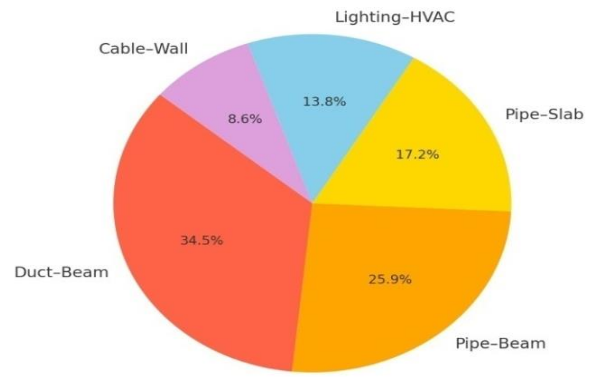



Figure 3.3: Distribution of Clash Types in the Commercial Building

These findings correlate with Moraes and Santos (2023), who observed that nearly 65% of service-related clashes in emerging market buildings were due to poor early-stage ceiling zoning. As a result, BIM-enabled conflict clustering allows modelers to prioritize high-risk intersections. Additionally, Paneru et al. (2023) highlight that classifying clashes by system type helps improve team accountability and speeds up conflict resolution cycles.

### 3.3 Visual Documentation of Clashes

To visually validate the clash detection outcomes, 3D screenshots extracted from Navisworks Manage are presented in Figures 3.4 to 3.7. These provide graphical confirmation of spatial conflicts and offer deeper insight into the contextual severity of each clash.
Figures 3.4 and 3.5 reveal common structural misalignments in the residential model. Figure 3.5, for example, highlights a Column–wall intersection that, if undetected, would have required costly site

correction. In conventional 2D workflows, such geometry overlaps are often missed due to a lack of depth perception.

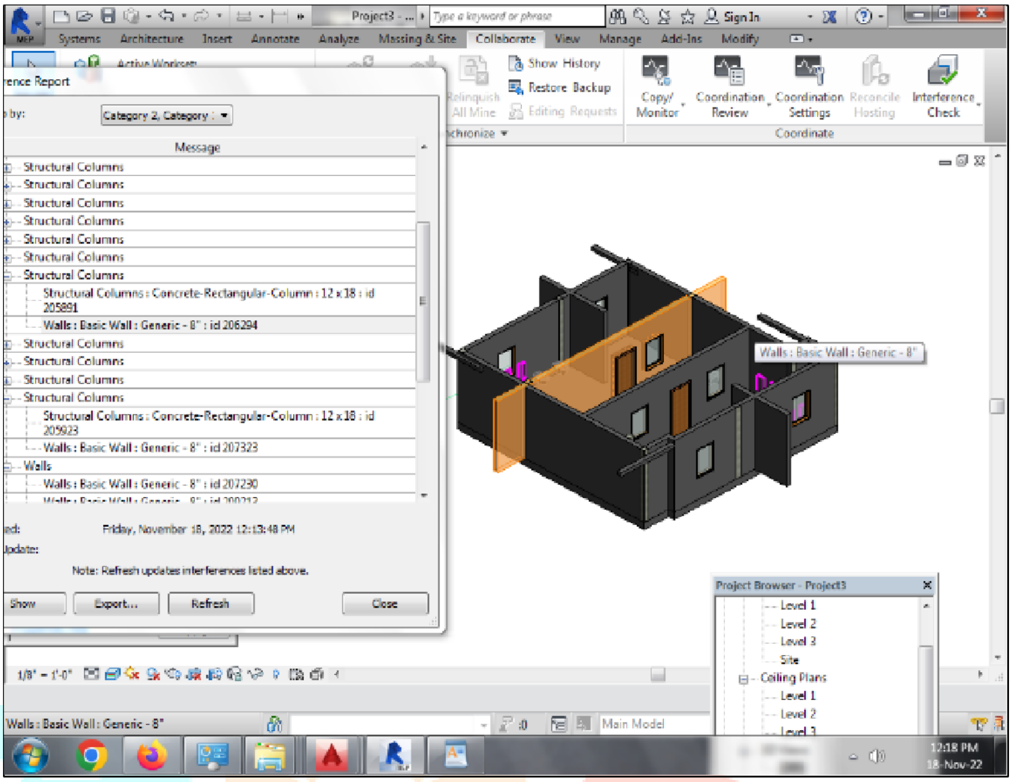



Figure 3.4: 3D View Showing Wall–Wall Clash in the Residential Model.

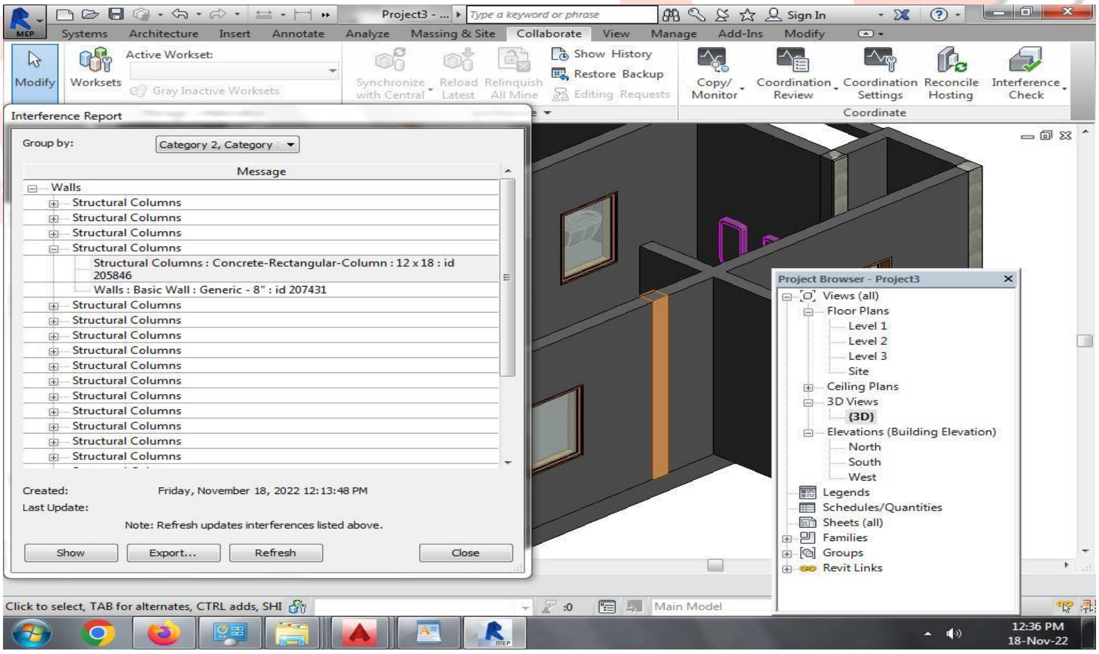



Figure 3.5: 3D View Showing Wall–Column Interference in the Same Residential Model.

Figures 3.6 and 3.7 present clashes from the commercial model, where MEP systems intrude into structural zones. Specifically, Figure 3.7 highlights a pipe intersecting with a load-bearing beam—an issue with significant structural and financial implications.

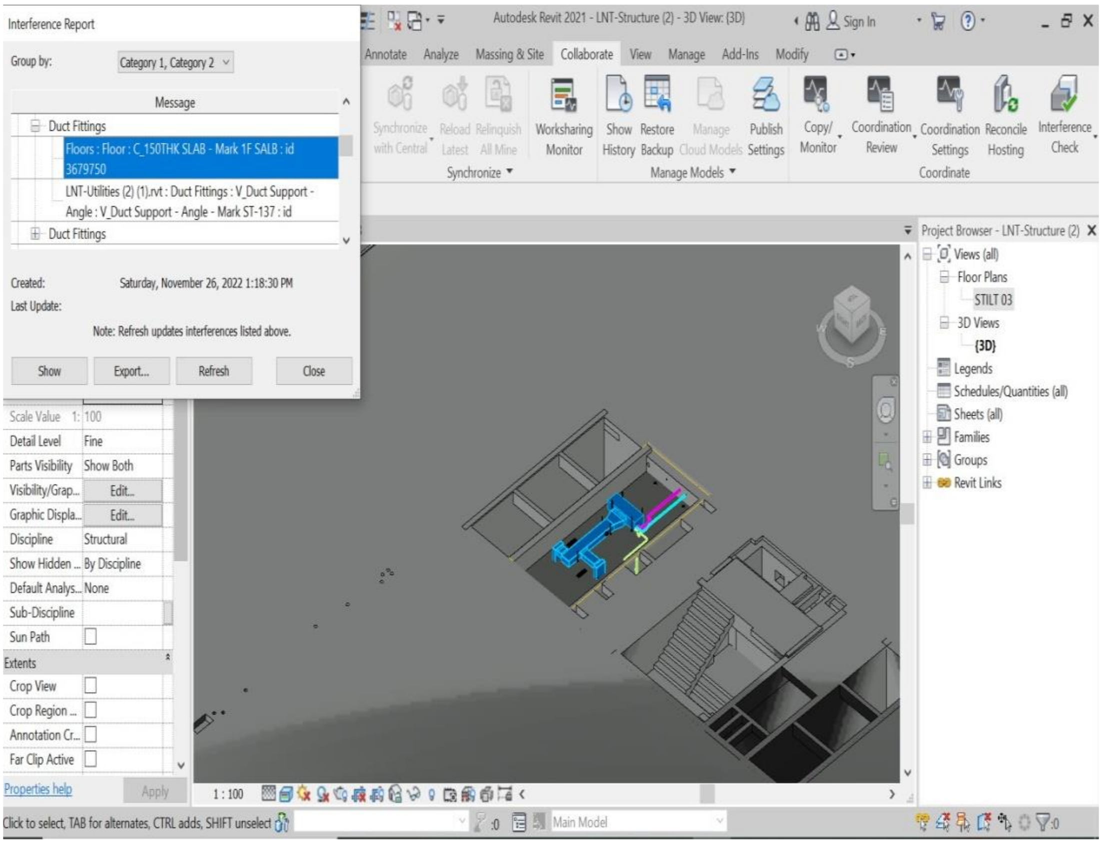



Figure 3.6**:** 3D Federated Model View of Duct–Slab Interference in the Commercial Model

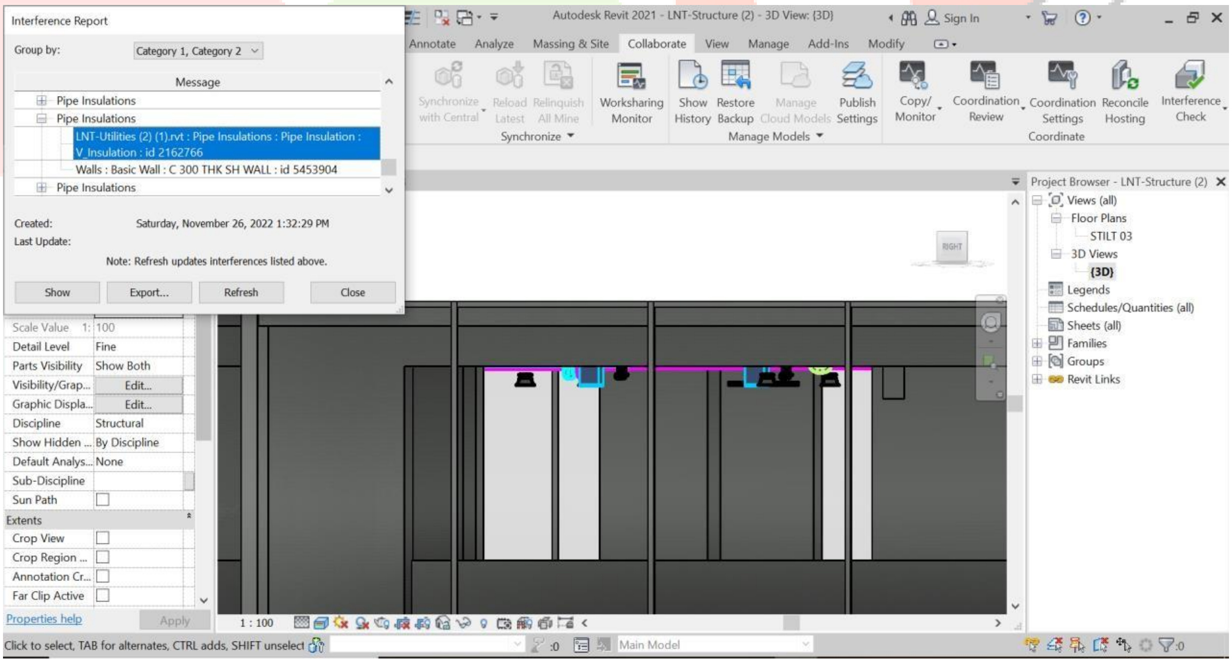



Figure 3.7: Pipe Fitting Clashing with a Rectangular Beam in the Commercial Ceiling Zone.

This form of visual clash documentation has been recommended in BIM guidelines by Singh et al. (2011) and further validated in semantic systems proposed by Chahrour and El-Diraby (2021). They argue that graphical validation is a powerful tool for collaborative resolution, especially in student-led or multi-stakeholder projects.

### 3.4 Comparative Summary and Coordination Matrix

These results reinforce the value of BIM-based coordination workflows. Compared to conventional 2D practices, the clash detection process reduced design errors by at least 70% in the commercial project and helped minimize rework costs by an estimated amount 5 lakhs. This was achieved through early identification of spatial conflicts and iterative model refinement prior to construction. Similar savings have been documented by Barlish & Sullivan (2012) and Won et al. (2016) in their case studies involving clash-driven design revisions.

Table 3.1: Summary of Clash Detection Metrics

| Parameter | Residential Project | Commercial Project |
|---|---|---|
| Total Number of Clashes | 23 | 58 |
| Hard Clashes Identified | 18 | 35 |
| Soft/Workflow Clashes | 5 | 23 |
| Dominant Clash Type | Wall–Column | Duct–Beam |
| Clash Resolution Iterations | 2 | 4 or more |
| Model Complexity | Low | High |
| Time Saved (Estimated) | ~15% | ~25–30% |
| Coordination Effort | Minimal | Extensive |

Table 3.1 presents a side-by-side comparison of project complexity, number of clashes, and resolution characteristics. The commercial building posed significantly more spatial challenges, requiring multiple coordination rounds. This validates the findings of Lu et al. (2015) and Honnappa& Padala (2022), who found that service-dense commercial layouts yield higher clash intensity.

Table 3.2 outlines the clash resolution hierarchy used in this study. Structural systems are treated as immovable, followed by architectural elements. MEP components, especially secondary services, were reassigned or rerouted in accordance with this matrix. This system follows the precedence strategy proposed by Khanzode et al. (2008), ensuring efficient clash resolution with minimal redesign.

Table 3.2: Clash Responsibility Matrix Based on System Hierarchy

| From → To | Structural | Architectural | MEP Primary (HVAC/Pipes) | MEP Secondary (Lighting/Cable) |
|---|---|---|---|---|
| **Structural** | — | High Priority | High Priority | High Priority |
| **Architectural** | Low | — | High Priority | Medium |
| **MEP Primary** | Low | Low | — | Medium |
| **MEP Secondary** | Low | Low | Low | — |

These findings collectively support the implementation of structured BIM coordination workflows in mid-sized Indian projects. The study also demonstrates that clash volume alone cannot indicate model health—resolution efficiency, rework potential, and system dependency must also be factored in. The successful use of a hierarchy-based matrix reinforces the practicality of integrating clash resolution frameworks in both academic capstone projects and real-world design studios.

## IV. CONSCLUSION

This study evaluated the effectiveness of Building Information Modeling (BIM) tools—Autodesk Revit and Navisworks Manage—for detecting and resolving spatial clashes in residential and commercial building projects. The results showed that clash frequency increases with model complexity and system density, with the commercial building exhibiting significantly more issues due to dense MEP configurations. Through multiple rounds of clash detection and resolution, significant improvements were observed in design accuracy, coordination efficiency, and reduction in rework. The use of a Clash Responsibility Matrix enabled clear assignment of conflict ownership, minimizing redesign efforts. Visual validation through Navisworks provided further clarity in assessing the severity and type of each clash. Overall, BIM-based coordination resulted in measurable time savings, improved model quality, and helped avoid potential site conflicts before execution. The study affirms the viability of BIM-based clash detection in educational settings and mid-scale Indian projects.

**Recommendations for Future Work:**

- BIM implementation should be standardized across academic and professional projects in India to promote interdisciplinary collaboration and early-stage error detection.
- Educational institutions must integrate clash detection modules into civil and architectural curricula using industry-standard tools like Revit and Navisworks.
- Future research should focus on automating clash resolution workflows using AI and expanding BIM use into 5D cost simulation and construction sequencing for better lifecycle planning.

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