CLASH DETECTION OPTIMIZATION IN BIM: A CASE STUDY ON COORDINATION AND DESIGN EFFICIENCY IN INFRASTRUCTURE PROJECTS

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Abstract- This Paper presents a methodology for Building Information Modeling (BIM) based clash detection, with a focus on a case study of the National University of Technology Admin Block in Capital Smart City, Islamabad. We detailed standardized modeling protocols, precise Levels of Detail (LOD), clash detection criteria, and structured resolution workflows to optimize interdisciplinary coordination. Using Autodesk Revit for individual discipline models (architectural, structural and MEP) and Navisworks Manage for clash detection, we identified 1,344 hard clashes at a 0.003 ft tolerance. Detailed quantification of clash penetration depths (ranging from 0.479 ft to o.664 ft) and spatial clustering analyses guided targeted resolution efforts. We compare our findings against benchmarks from similar infrastructure projects, demonstrating that early, rigorous clash detection reduces downstream rework relative to traditional workflows. Based on project findings, we propose a practical framework comprising modeling standards, naming conventions, phased review cycles and prioritized resolution to guide local and regional firms in infrastructure projects. A critical literature synthesis, clear definitions of technical terms and a discussion of limitations, challenges and future research directions are included to strengthen the paper's contribution to both academia and practice.

Keywords- Building Information Modeling (BIM), Clash Detection, Autodesk Revit, Navisworks Manage

1 Introduction

The construction industry contributes significantly to global GDP but remains plagued by costly design errors, rework and schedule delays arising from fragmented interdisciplinary coordination [1]. Traditional two-dimensional (2D) drawings often fail to capture spatial conflicts until late design or construction phases, leading to expensive redesign and material waste [2]. Building Information Modeling (BIM) has emerged as a transformative approach to integrate architectural, structural and mechanical, electrical and plumbing (MEP) disciplines into a unified three-dimensional (3D) digital platform, enabling early detection of geometric conflicts (clashes) and reducing rework [1-4].

In BIM, clashes are categorized into three main types: First are hard clashes which involve direct geometric intersections between elements (e.g., insufficient duct penetration a structural beam). Second ones are soft clashes occurring when clearance requirements are violated (e.g., insufficient maintenance or installation access). Third are the time clashes related to sequencing or scheduling conflicts that may cause on-site congestion ore delays [1, 2].

Successful clash detection depends on standardized modeling practices, clear levels of detail (LOD), consistent naming conventions and collaborative workflows among project stakeholders [3, 5]. Although various studies demonstrate BIM's potential to reduce errors and waste [6-8], gaps remain in defining a structured framework that can be readily adopted by local or regional infrastructure firms.

Although earlier studies ([2, 3, 8]) have demonstrated that BIM-based clash detection reduces coordination errors, they typically focus on small-scale or residential buildings, lack in depth benchmarking with similar infrastructure projects, and provide limited justification for tolerance thresholds and clash detection protocols.

2 Literature Review

2.1 BIM and Clash Detection: Evolution and Impact

BIM has revolutionized design coordination by integrating multidisciplinary models into a single digital environment. Early research by Kermanshahi, Tahir [1] and Yönder and Çavka [2] focused on demonstrating BIM's capability to identify clashes in small to medium scale building. Yönder and Çavka [2] reported that early phase clash detection in a two-story structure reduced on-site issues by 20% compared to 2D workflows. Abdalhameed [3] highlighted that careful assignment of LOD and standardized families improved model consistency, thereby minimizing false positive clashes.

2.2 Modeling Standards and Levels of Detail

Model accuracy and consistency are important for reliable clash detection. Abdalhameed [3] and Nair, Anilkumar [4] emphasize the importance of standardized families , naming conventions, and metadata (e.g., gridlines, levels) to ensure interoperable models across disciplines. LOD definitions (e.g., LOD 300 for design development) determine geometric granularity: architectural elements should include walls, floors, doors and windows; structure models should include beams, columns and slabs; MEP Models should include ducts, pipes, cable, trays and equipment [3, 9]. Hasan [5] suggested that inconsistent LOD assignments often generate false positive clashes, thereby inflating coordination efforts.

2.3 Clash Detection Tools and Methods

Autodesk Revit facilitates individual discipline modeling, while Navisworks Manage remains the de facto standard for combined clash analysis due to its robust clash detection engine and reporting capabilities [1, 2, 9]. Researchers have explored automation plugins (Hasannejad, Sardrud [10]) and cloud-based solutions (Baltabekov, Zharassov [9]) to streamline clash detection cycles. Bitaraf, Salimpour [7] proposed prioritized algorithms to rank clashes by cost impact and spatial urgency. However, adoption barriers persist, including steep software licenses, interoperability issues and limited expertise among local firms [6, 11].

2.4 Benchmarking and Comparative Analyses

Comparative benchmarks contextualize clash detection performance. Yönder and Çavka [2] reported 528 hard clashes in their case study, whereas Baltabekov, Zharassov [9] identified 2,132 clashes in a mid-rise residential complex. Chahrour, Hafeez [8] suggested that projects with rigorous modeling protocols experienced 25-30% fewer clashes than those with ad hoc standards. These benchmarks underscore the need for region specific guidelines, such as structural typologies, local codes and resources constraints vary widely.

However, these studies often: (a) do not clearly justify why their chosen tolerance value represent fabrication accuracy thresholds; (b) rely on small buildings typologies with limited generalizability; (c) rarely compare results quantitively with similar benchmarks. This critique indicates a need for more rigorously justified methodologies and comparative analyses in large infrastructure projects.

3 Research Methodology

The approach comprises of three phases as shown in Figure 1 (a-c). First was the model creation in Autodesk Revit. This was followed by Model Integration and Clash Detection in Navisworks Manage. Finally, the identified clashes were analyzed, classified and benchmarked. Emphasis was placed on replicability, clarity and alignment with best practice modeling standards.

3.1 Phase I: Model Creation in Autodesk Revit

3.1.1 Modeling Standards and LOD Definitions

- **Architectural Model (LOD 300):** Walls, floors, doors, windows, slab edges and basic finishes. Families follow ISO compliant naming (e.g., ARC_WALL_EXT_R15 for an exterior wall). Materials assigned for clash detection metadata.
- **Structural Model (LOD 300):** Columns, beams, slabs, footings and load bearing walls. Structural elements use Revit's structural analytical models to maintain geometric accuracy. Naming convention: STR_BEAM_W14X22, STR_COLUMN_W10X30.
- **MEP Model (LOD 300):** Ductwork, piping (HVAC, Plumbing), Cable trays, services equipment (e.g., pumps, air handling units). Families contain metadata fields for system type, size and maintenance clearances. Naming: MEP_DUCT_MAIN_24X12, MEP_PIPE_CW_ø14in.

All models align to a shared project coordination system and level/grid metadata. A centralized BIM Execution Plan (BEP) mandates:

- **Naming Conventions:** Discipline prefix (ARCH/STR/MEP), element type, size and unique identifier.
- **Shared Coordinates:** All models use a common origin point tied to site survey benchmarks.
- **LOD Consistency:** All disciplines commit to LOD 300 (design development) to ensure adequate geometric fidelity for clash detection [3,5].
- **Metadata Standards:** Parameter sets include material type, fire rating (for architectural), load capacities (for structural) and system attributes (for MEP) to facilitate clash filtering.

3.1.2 Modeling Development and Intra-Discipline Checks

Each Discipline team builds and internally reviews its model for:

- **Geometric Integrity:** Verify Walls align to grids; slabs have corrected thickness and MEP services follow routing protocols.
- **Self-Clash Checks:** Utilizing Revit's interference checks to identify internal conflicts (e.g., overlapping walls, intersecting ducts with the HVAC Model). All Self-Clashes must be resolved before combined export.
- **Family Standardization:** Ensuring families are loaded from a controlled library to avoid duplicate or inconsistent geometry.

Upon Completion, each discipline exports to Navisworks Cache (NWC) format, preserving metadata fields (e.g., unique elements IDs, system references).

3.2 Phase II: Model Integration and Clash Detection in Navisworks Manage

3.2.1 Combined Model Assembly

- **Import Process:** NWC files from Revit disciplines are loaded into Navisworks Manage.
- **Alignment Verification:** Visual inspection and measurement checks ensure all discipline models share exact coordinates. Minor misalignments (<1mm) are corrected by adjusting clip coordination or re-exporting from Revit.
- **Model Consolidation:** Layers and selection sets are created:
  - **Selection Set 1:** Architecture (walls, floors, openings)
  - **Selection Set 2:** Structure (Columns, beams, slabs, footings)
  - **Selection Set 3:** MEP (ducts, pipes, trays, equipment)

A "Clash Coordination" workspace is established to streamline filtering and report generation.

3.2.2 Clash Detection Configuration

- **Test Definition:** We focus exclusively on **hard clashes** (geometric intersections) as these direct interferences require immediate resolutions. Soft clashes (clearance) and time clashes (4D sequencing) are out of scope for this study but acknowledgement as future work.
- **Tolerance Setting:** A 0.003ft (~0.9mm) tolerance is selected to balance false positives with detection sensitivity; this corresponds to the minimum fabrication tolerance for structural members and MEP conduits [9].
- **Clash Tests:** Three primary tests are established:
    - **Architecture vs. Structure** (A-S)
    - **Architecture vs. MEP** (A-M)
    - **Structure vs. MEP** (S-M)

Each test employs "**Hard Clash"** rules, ignoring adjacent elements sharing faces (e.g., wall-floor connections) by using property filters (e.g., exclude elements where "Host On" metadata matches). All tests are run concurrently. Navisworks combines clashes into a single report with unique ID, source elements, coordinates, severity and penetration depth measurements. Clashes are grouped by **level** (e.g., Ground Floor, First Floor) and **grid intersection** (e.g., Grid H-10) to identify spatial hotspots. Severity is ranked by penetration depth: **High Severity** (Penetration > 0.5 ft), **Medium Severity** (Penetration 0.25 ft – 0.5 ft) and **Low Severity** (Penetration < 0.25 ft).

3.2.3 Clash Report Generation

The clash report includes:

1. **Clash ID** (unique)
2. **Discipline Pair** (e.g., S-M)
3. **Element IDs** (with metadata for quick identification)
4. **Level/Location** (e.g., Level 0, Grid H-10)
5. **Penetration Depth** (measured by Navisworks)
6. **Bounding Box Coordination** (for 3D localization)
7. **Severity Classification** (High/Medium/Low)
8. **Annotated 3D Snapshot** (exported PNG showing clash in context)

3.3 Phase III: Analysis and Classification

The final phase includes an intensive analysis and classification of the clashes identified in phase II. The Clash report generated by Navisworks is carefully reviewed, and each clash is classified based on its type (hard, soft or time related), severity and possible impact on the project. This classification helps to prefer the decision on the clash, focusing on elements with the most important potential results. The analysis also considers the context of each clash, considering the factors such as the location of the clash, the element and the construction sequence. The purpose of the analysis is to identify patterns and trends in the types and locations of the clashes, which provide insight into the design process or possible improvements in the workflow. The results of this analysis are used to evaluate the efficiency of the construction process, identify areas of improvement and notify recommendations for adapting future projects. The final product in this phase is a comprehensive report that summarizes the findings, including the number and type of clashes, their severity and recommendations for improvement.

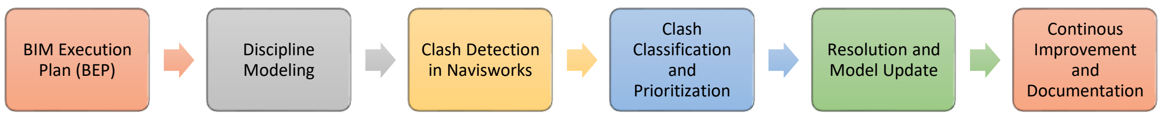
All clashes are classified as hard, since every intersection represents direct geometric overlap rather than clearance deficiency. No soft or 4D/time clashes were detected under current settings. Penetration depths ranged from a minimal 0.051 ft to a maximum 0.664 ft.

The tolerance of 0.003ft (~0.9mm) aligns with fabrication tolerances for structural and MEP components, ensuring that only meaningful geometric interferences are flagged, rather than normal manufacturing variations. The combined Revit-

Navisworks workflow is recognized standard in AEC coordination, offering reliable clash detection accuracy, robust metadata handling and compatibility across disciplines [2, 3]. Such methodologies grounding ensures this approach is both academically justified and industrially relevant.

4 Clash Detection Framework

Based on our analysis and literature review, we propose a BIM-Based Clash Detection Framework for Infrastructure Projects. This Framework is designed for local or regional firms seeking to implement robust BIM coordination practices without prohibitive resource investments.



1 **BIM Execution Plan (BEP):** Define project scope, roles, responsibilities, LOD requirements, naming conventions and data management protocols.
2 **Discipline Modeling:** Each team develops models in Revit, performs self-clash detection and reviews against BEP standards.
3 **Clash Detection in Navisworks:** Export models, align coordinates, configure clash tests (hard, soft, time) and generate reports.
4 **Clash Classification and Prioritization:** Classify by type, severity, cost impact and location. Organize regular coordination meetings to review and assign resolution tasks.
5 **Resolution and Model Update:** Discipline teams resolve clashes in Revit, update combined model and re-run clash tests in iterative cycles.
6 **Continuous Improvement and Documentation:** Record lesson learned, updated BEP for future projects and document clash resolution protocols.

5 Results and Discussion

The use of three-phase methodology gained significant insight into the effectiveness of BIM-based clash detection . The analysis gives the results that show the effect of early clash detection identity on project coordination, material waste deficiency and stability.

5.1 Clash Detection Overview

By using 0.003 feet tolerance, integrated structural and plumbing models in Navisworks produce 1344 new Hard Clash Institutes. Figure 1 shows clash detection report screenshot, clash detection report was generated using Autodesk Navisworks Software. All clashes were classified as "new"; No one was reviewed, approved or resolved at the time of reporting.

AUTODESK® NAVISWORKS® **Clash Report**

	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
Test 1	0.003ft	1344	1344	0	0	0	0	Hard	OK

a)

Figure 1: Clash Detection Report, a. Screenshot from Clash Detection Report

5.2 Penetration Depth

The depth of Clash Penetration - was replaced as a full overlap among the objection elements - was recorded up to 0.664 feet. These values emphasize sufficient geometric interventions, especially where large diameter pipes cross structural slabs and beams. In Figure 2 (a) shows that a plumbing fixture had a clash with foundation slab , plumbing fixture is shown in green colour and foundation slab shown in red colour for differentiation of both elements. Figure 2 (b) shows a pipe is going through foundation slab and it needs to be fix, pipe in green colour and foundation slab in red colour.

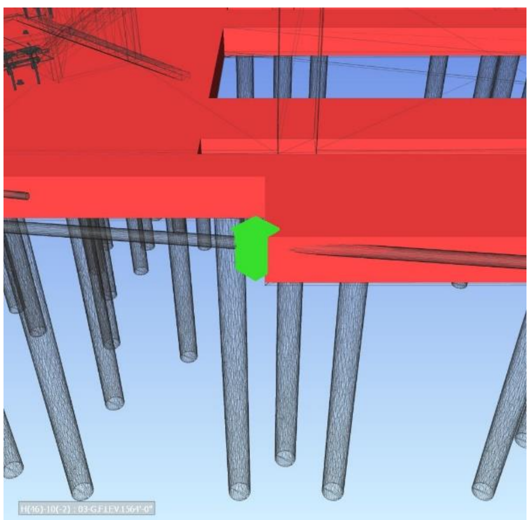
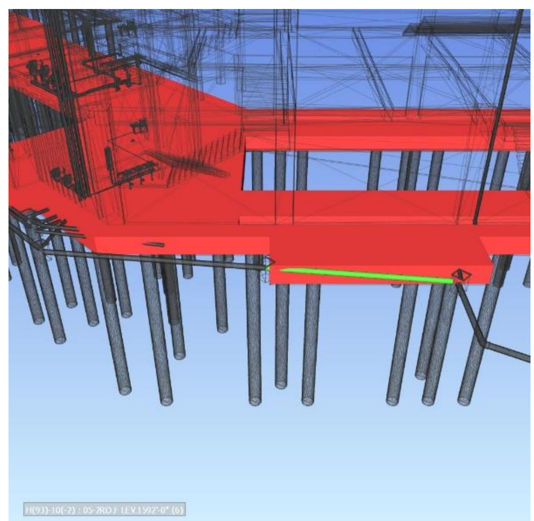
a)  b) 

Figure 2: Clash Detection 3D View, a. Clash of Foundation slab with plumbing fixture, b. Clash of Foundation slab with pipe.

Figure 3 (a) shows a pipe is penetrating through a RCC (Reinforced cement concrete) wall and it is a clear clash between pipe (shown in green colour) and RCC (Reinforced cement concrete) wall (shown in red colour). b) shows a pipe penetrates through a grade beam and it is a clear clash between pipe (shown in green colour) and grade beam (shown in red colour).

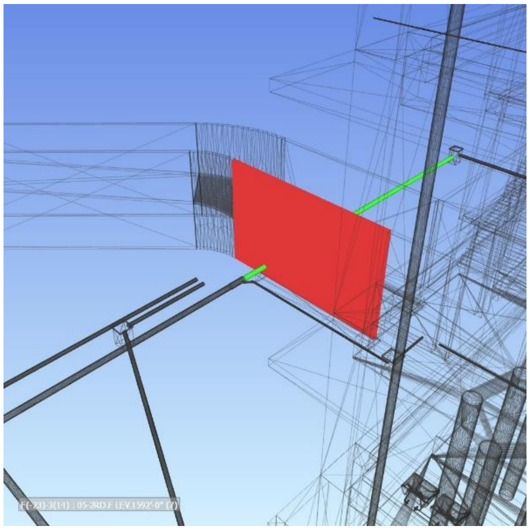
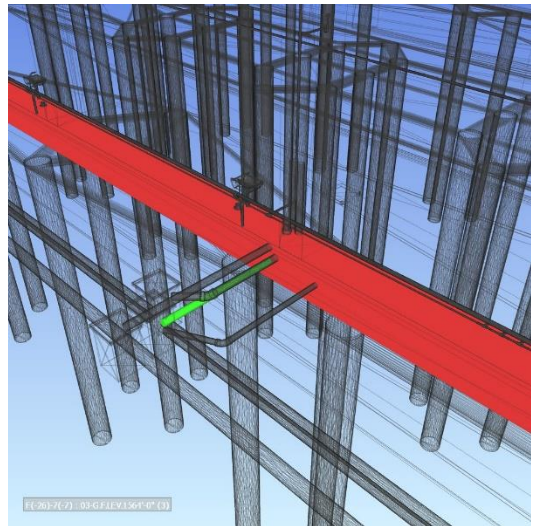
a)  b) 

Figure 3: Clash Detection 3D View, a. Clash of pipe with RCC wall, b. Clash of pipe with grade beam.

5.3 Spatial Hotspots

Analysis of grid sites and level tasks shows two primary battle areas:

1 Roof on the ground floor (H10: Level 0), where densely packed plumbing pipes interfered with structural clearances.
2 Roof slab crosses, especially around the emergency core and vertical service shaft.

5.4 Limitations and Challenges

1 Navisworks Manage Licenses are expensive for small firms; alternative open source or cloud-based clash detection tools may be explored, even though with potential limitations in functionality [11].
2 Although using NWC format preserve most metadata, certain parameters (e.g., complex family attributes) can be lost, leading to incomplete clash reports. Adoption of Standardized Industry Foundation Classes (IFC) could mitigate this but requires additional coordination [3].
3 While this paper aimed for LOD 300, occasional deviations occurred particularly in MEP routing details. Resulting in minor false positive clashes. Enforcing stricter model reviews can address this.
4 This study focused solely on hard clashes. Integrating 4D simulations to detect schedule-based clashes (e.g., overlapping tasks) remains an area for future work.

5.5 Future Research Directions

1 Extend the framework to include clearance checks and 4D sequencing analysis, enabling comprehensive detection of spatial and temporal conflicts.
2 Leverage machine learning techniques to predict clash severity based on historical data and cost impact.
3 Investigate the use of openBIM and IFC to improve interoperability among diverse software platforms, reducing metadata loss.
4 Explore BIM-based clash detection beyond design, incorporating as built data from laser scanning (Point Clouds) to identify on site clashes in real time.

6 Conclusion

This research has shown the value of a structured workflow for hard-clash detection with Navisworks for NUTECH Admin Block in the Capital Smart City. Disciplinary Revit model has been administered with the Navisworks. A total of 1,344 hard clashes of 0.003-foot tolerance were identified, which remained in the "new" position, and emphasized the requirement for an early, complete coordination passport before any design change. Detailed penetration - depth measurements (0.479 ft - 0.664 ft) and spatial clustering (basic and floor sealing and ceilings in level core) provided clear guidance to focus on subsequent coordination efforts.

Beyond the study of this single case, the conclusions strengthen the best BIM best practices:

1 The identity of the preliminary conflict, prevention of design overruns and reduction of material waste lowers the likelihood of project delays.

2 Standardized modeling protocols - including frequent names conferences, shared coordination systems and disciplined levels and grid metadata are important for reliable collection detection in different project types .

3 With extensive reporting features such as element IDs, clash detection and severity classification this paper has enough data to empowers design review and enable stakeholders to efficiently prioritize coordination.

In large-scale construction projects, the integration of a repetitive BIM workflow offers a significant advantage: it enhances interdisciplinary collaboration. Even in projects with complex structural and MEP interferences, the use of time-synchronized collection and analysis enables to achieve sustainable efficiency gains.

7 Acknowledgement

The authors would like to express their sincere granitite to Syed Hussnain Ali Shah and Noor Hassan of the National University of Technology, Islamabad, for their invaluable support and participation throughout this study. Their contributions, particularly in model validation and coordination feedback, were instrumental in the successful development and completion of the clash detection workflow.

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