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Detection and Resolution of Interdisciplinary Construction Design Clashes of a Residential Building using Revit and Navisworks

Thangavelu EswaryDevi[1], Abdul Latheef Vahidha Banu[2], Ravindran Mugilvannan[3]

[1,2,3]Department of Civil Engineering, Meenakshi Sundararajan Engineering College, Kodambakkam, Chennai, Tamil Nadu, India-600024.

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Abstract - *The design of construction projects involve several stakeholders and inter-disciplinary data which include architectural, structural, plumbing and electrical aspects making the process highly complex. Numerous clashes may arise between the building elements attributed to the design demands of different disciplines which must be identified at an early design stage to avoid the risk of project delays and financial overburden. In General, majority of the clashes were identified during project execution which delayed the projects and involved schedule and cost implications. Recently, with the extensive application of Building Information Modeling (BIM), the clash detection has become easier, faster and utmost accurate reducing the project time and saving on contract value due to early clash detection. sAmong the clash detection software available in the Architecture, Engineering and Construction (AEC) industry viz., Autodesk Navisworks Manage was the most efficient BIM based software. In this study, Autodesk Revit was used to create 3D model of a G+3 residential building which integrated Architectural, Structural, Electrical and Plumbing models. After model completion in Revit, the detailed 3D model was exported to Navisworks and Clash detection was carried out. Around six interdisciplinary model combinations were used and 251 hard clashes were identified with a significant portion arising between the architectural and structural models. The detected clashes were resolved using Revit software. The clash detection technique using BIM facilitates early detection of construction risks such as project delays and cost overruns that may arise during execution if the clashes were not detected at design stage itself.*

Key Words: Clash Detection, Building Information Modeling (BIM), Revit, Navisworks, Clash Resolution

1.INTRODUCTION

The design of construction projects involve multiple stakeholders and inter-disciplinary data which include architectural, structural, plumbing, electrical and mechanical aspects making the process highly complex [1,2]. Numerous clashes may arise between the building elements attributed to the design demands of different disciplines which must be identified at an early design stage to avoid the risk of project delays and financial overburden [3]. In general, clash or conflict occurs when components that makes up a built asset viz., architectural, structural, electrical and plumbing systems are not spatially coordinated [4, 5, 6]. The primary causes of these clashes are design uncertainties, complexities, design errors, failing of design rules, designers working in isolation, exceedance of allowable clearance, using 2D drawings and insufficient time [7]. Two-dimensional design and lack of communication or collaboration were the major reasons for clashes [8]. Lately, clashes between different disciplines of construction projects were identified manually or by using 2D CAD tools which were both time consuming, unreliable and involves exceptional expertise [1, 7]. Clash identification was therefore a major concern in the construction projects. Majority of the clashes were identified during project execution which delayed the projects and involved schedule and cost implications.

Recently, with the extensive application of BIM (Building Information Modeling), the clash detection has become easier, faster and utmost accurate reducing the project time and saving on contract value due to early clash detection [2]. BIM, a rapidly evolving collaboration tool involves creation of comprehensive and integrated master model which included design models from various disciplines [9, 10]. During the design stage, BIM enables three-dimensional visualization of clashes between independent designs for solving inter-disciplinary clashes [3, 4, 11]. Among the clash detection software available in the Architecture, Engineering and Construction (AEC) industry viz., Autodesk Navisworks Manage was the most efficient BIM based software available for detection of clashes as well as clash report generation [1, 12, 13].

Autodesk Navisworks allows users to combine 3D models; navigate around them in real-time and review the model using a set of tools [14]. This software offers Clash Detection modules that check BIM model and shows areas of interference or clash with one another. The BIM tool allows to set rules, detect clashes, generate reports, trace and manage clashes. Navisworks software specifically checks clashes between specified systems based on geometry and rule algorithms that are embedded into the BIM object [11]. Navisworks also helps in the resolution of clashes, saving on rework and material costs, and keeps projects within the budget and schedule [1, 15]. The clash detection could be performed to any level of detail and across any number of building systems. Independent models created by Architects, Structural, Electrical and Plumbing consultants are integrated into a single BIM model for clash detection. The integrated approach of clash detection leads to precise engineering design documentation, lesser change orders during construction phase, better coordination and collaboration between teams, and automatic clash and conflict resolution [11]. Clash detection aids in effectively identifying, inspecting, and reporting interference in a construction project model. It is useful in checking work status and wanes down human errors during model inspections. The merits of Navisworks include cost effectiveness, reduced errors, single model framework, photorealistic visualization, time-based clash detection and cloud accessibility [11]. Therefore, the objective of the current study was to expedite the process of generating integrated 3D models, clash detection, and resolution of identified clashes in an interdisciplinary residential project utilizing the applications of BIM viz., Autodesk Revit and Autodesk Navisworks Manage.

2. MATERIALS AND METHODS

2.1 Methodology

The workflow of this study was split into 7 phases as displayed in Figure 1.

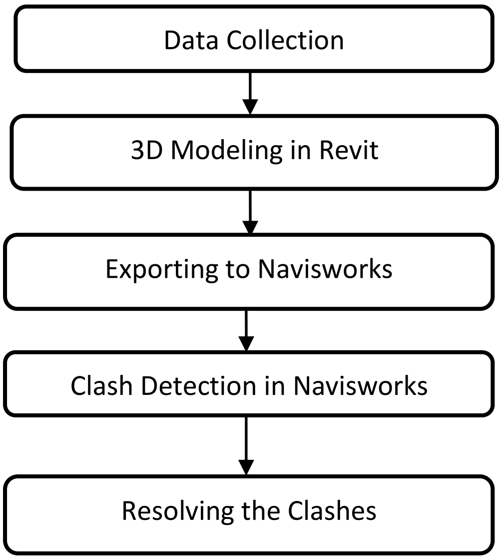


Fig - 1: Methodology flowchart

2.2 Data Collection

The first phase of the study involved collection of Architectural, Structural, Plumbing and Electrical drawings of a three-floor accommodation building of land area 2000 square feet. Architectural drawings included site plan, floor plans, sections and elevations. Structural drawings contained details of footing, columns, plinth beam, lintels, staircase and roof slab arrangements etc. Electrical drawings provided information on electrical circuits, wiring, connections, switches, fixtures, fans, lighting, air-conditioning or heating systems and the load capacity in the building. Likewise, marking and location of plumbing fixtures like water pipes, drainage and sanitary pipes etc. was displayed in plumbing drawings. Sample drawings were displayed in Figures 2 to 5.

2.3 Generating 3D Models in Revit

Autodesk Revit provides several templates for different disciplines which include Architectural, Structural, Plumbing and Electrical [16]. It consists of a huge library for modeling, plug-in supports, family features and advanced data management systems which enables visualization process as well as retraction of building information easier and faster. It enables professionals to capture and analyze the design concepts through 3D visual throughout the construction phase [11]. Besides, the changes applied to any view gets automatically updated throughout the model. The construction drawings were exported to Autodesk Revit 2021 to generate three-dimensional models; Architectural model, Structural model, Electrical model and Plumbing model of the case study building.

2.4 Clash Detection using Navisworks

Using 'Navisworks 2021' plugin support in Autodesk Revit platform, the four interdisciplinary viz., Architectural, Structural, Electrical and Plumbing models generated in Revit format (.rvt files) were converted to Navisworks file format (.nwc files). These multiple NWC files from different disciplines were first imported into Autodesk 'Navisworks Manage 2021' software and integrated into a single model [11]. Different inter-model combinations were used for clash detection as illustrated in Table 1. Intra-model combinations were not considered in the present study as they resulted in null clash. The 'Clash Detective' feature of Navisworks was used to perform clash detection in the merged models using default and customized clash rules [11]. This tool enables search through complete 3D project model and helps in effective identification, inspection and reporting of cross-discipline interferences (clashes) in the design stage itself besides reducing the risk of human error.

Table – 1: Matrix of Clash Models Combinations

Model Description	Architectural Model (A)	Structural Model (S)	Electrical Model (E)	Plumbing Model (P)	Total
Architectural Model (A)	A vs A	A vs S	A vs E	A vs P	4
Structural Model (S)	-	S vs S	S vs E	S vs P	3
Electrical Model (E)	-	-	E vs E	E vs P	2
Plumbing Model (P)	-	-	-	P vs P	1
Total	1	2	3	4	10

2.5 Analysis and Resolution of Clashes

Generally, clash resolution was a tedious process involving in-depth knowledge about the different disciplines. The clash reports generated in Navisworks were carefully analyzed to understand the cause of each conflict between the interdisciplinary models. The 'Element ID' in the clash report enabled easy identification of clashes in Revit and expedited the clash resolution process.

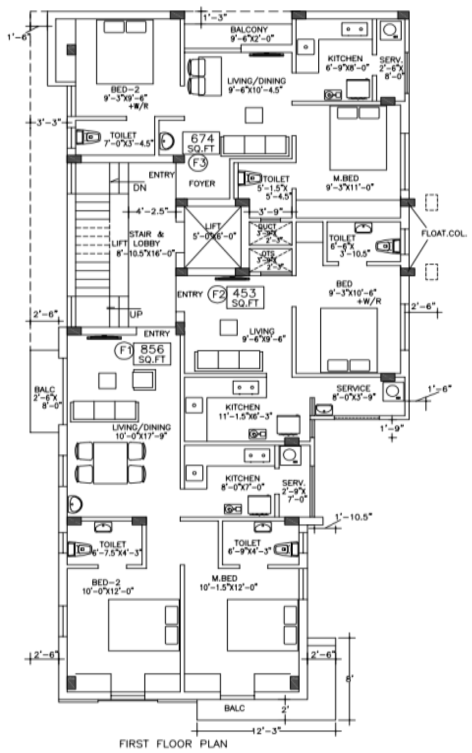


Fig - 2: Floor plan

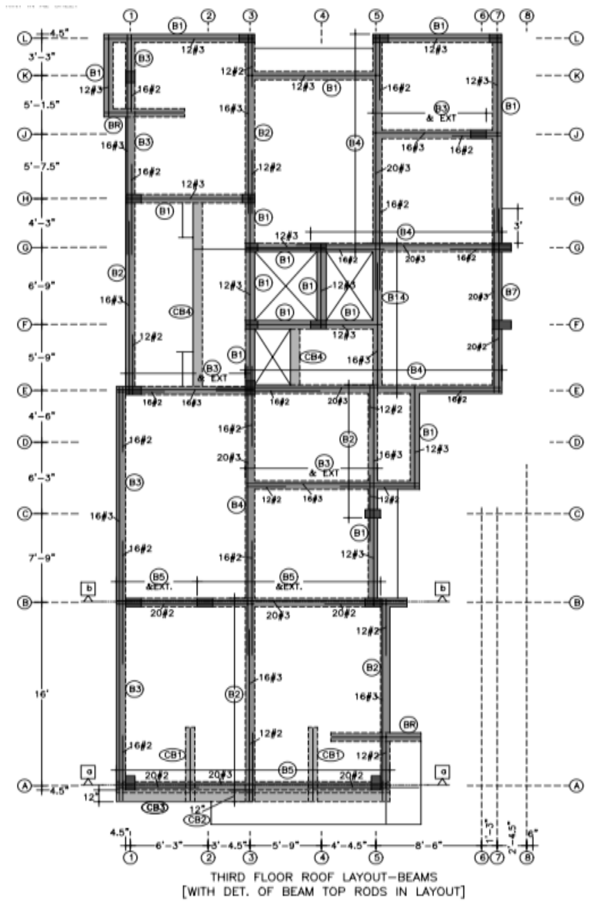


Fig – 3: Beam layout

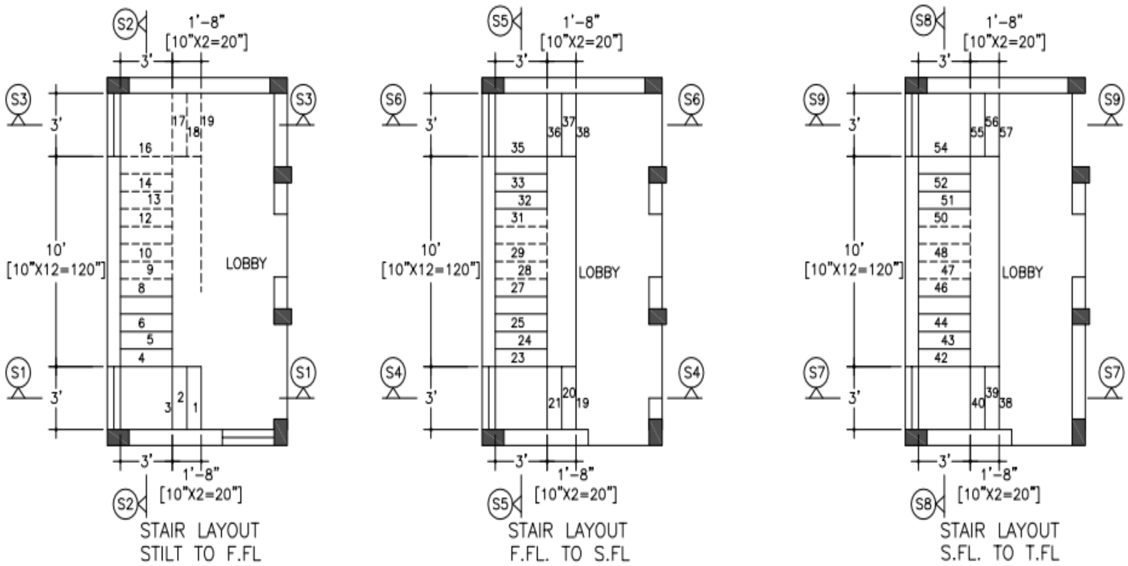


Fig – 4: Staircase details

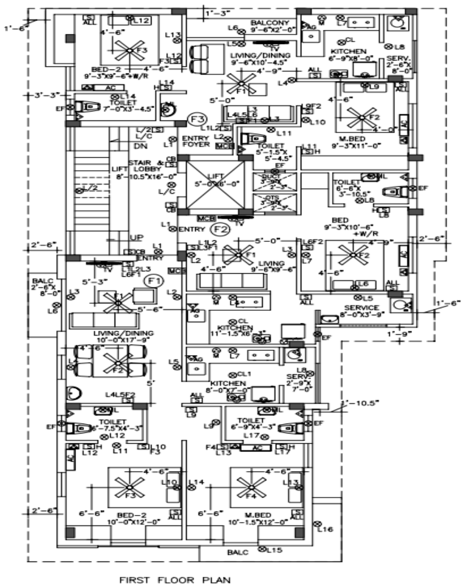


Fig – 5: Electrical drawing

3. Results and Discussion

The present study involved clash detection between multi-disciplinary 3D models of a four-storey residential building and subsequent resolution of those clashes.

3.1 Creation of 3D Models

The building drawings were used to develop four different types of 3D Models viz., Architectural model, Structural model, Electrical model and Plumbing models for the case study building using Revit software as shown in figures 6 to 9.

3.2 Integration of multidisciplinary models in Navisworks

The architectural, structural, electrical and plumbing models of the case study building were exported to Navisworks and integrated into a single model as shown in figure 10 which was then used to perform clash detection.

3.3 Clash detection using Navisworks

Clash detection for the integrated building model was accomplished using Navisworks software. The clashes between four disciplines viz., Architectural, Structural, Electrical and Plumbing were performed in six combinations and the number of clashes detected was illustrated in Table 2.

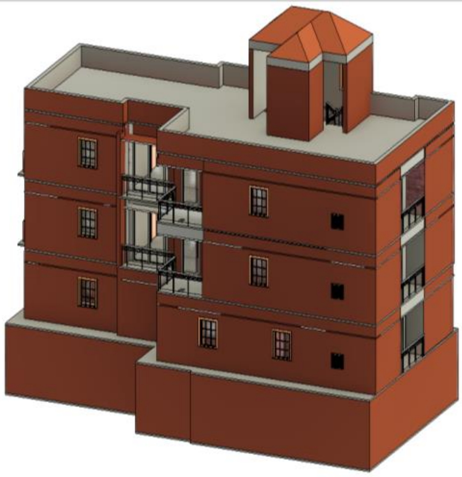


Fig – 6: 3D view of Architectural Model

Fig – 7: 3D view of Structural Model

Fig – 8: 3D view of Electrical Model

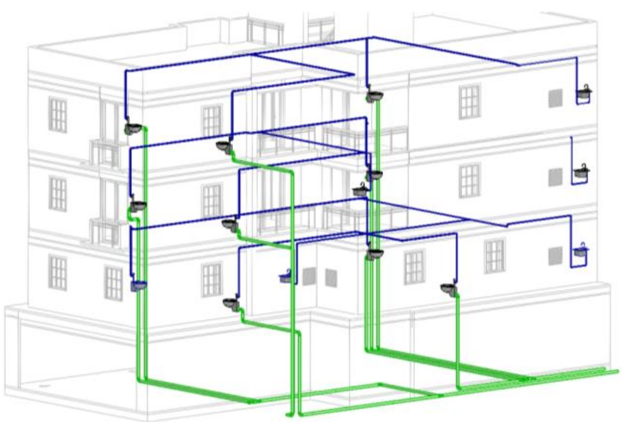


Fig – 9: 3D view of Plumbing Model

Fig – 10: Integrated 3D model in Navisworks

Table – 2: Clashes detected between different disciplines

Interdisciplinary Models used for clash test	No. of Clashes detected	Percentage	Major / Common clashes identified	Solutions to resolve clashes
Architectural versus Structural	187	74%	Structural framing element running within a wall	Change in the height or thickness of architectural elements.
Architectural versus Electrical	11	4%	Lighting fixtures interfering with ceilings	Relocate or reroute or lower electrical elements with drops and junctions.
Architectural versus Plumbing	24	10%	Pipelines embedded through wall	Reroute or relocate or resize plumbing elements.
Structural versus Plumbing	27	11%	Pipelines routed through beam	Reroute or relocate plumbing elements.
Structural versus Electrical	2	1%	Misplacement of Electrical elements	Relocate or Reroute or lower electrical elements with drops and junctions.
Electrical versus Plumbing	Null clash	0%	-	-

Overall 251 hard clashes were detected, with maximum of 187 clashes between Architectural and Structural models. Lowest number of clashes was observed between Structural and Electrical models. No clashes or null clash was obtained between Plumbing and Electrical models. These clashes if not detected at the design stage itself would pose high risk during execution resulting in project delay and increase in cost. The distribution of clash percentage among various interdisciplinary models was shown in the Figure 11. A similar study also showed major clashes of about 192 between Architectural and Structural elements, 10 between MEP & Structural, and 6 between MEP & Architectural elements [14]. Likewise, nearly 1800 clashes were detected between Architecture, Structure and Sanitary in a case study on the Malaysian Police Headquarter Building using BIM [11].

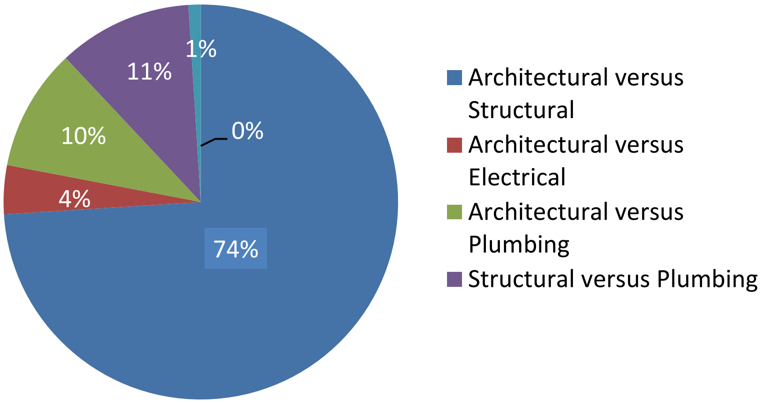


Fig – 11: Interdisciplinary model clashes

3.4 Analysis of Identified Clashes

The clashes identified between interdisciplinary models were analyzed and same has been illustrated in Table 2. Some common conflicts noticed were: structural elements running through wall, wrong placement of electrical fixtures in roof, improper routing of plumbing lines through structural elements etc. The major clash identified between Architectural and Structural models viz., interference of wall and column was displayed in Figure 12. Likewise, Figure 13 shows the clash between Architectural and Electrical models viz., clash between ceiling and lighting fixtures. The green color points out to lighting fixture while red colour indicated ceiling. The clash between Architectural and Plumbing models was illustrated in Figure 14 wherein green colour represented pipeline and red colour showing the wall. The clash between Structural and Plumbing models due to improper routing of plumbing lines was displayed in Figure 15. The green color designates pipeline and red color indicates beam. Similarly, clash between Structural (column) and Electrical (lihting fixture) was showin in Figure 16. The green color indicated electrical equipment while red color indicates column. A sample clash report as shown in Figure 17 was clearly indicative of the type of clash, status, element ID etc. which was helpful in identifying and resolving the clashes.

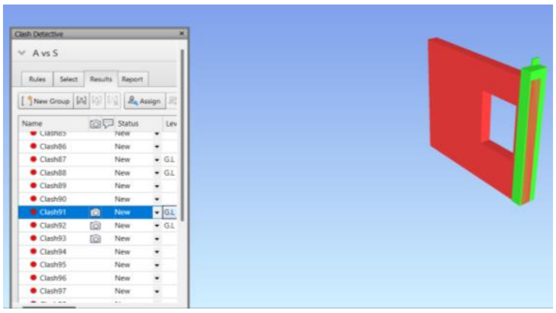


Fig – 12: Architectural versus Structural clash

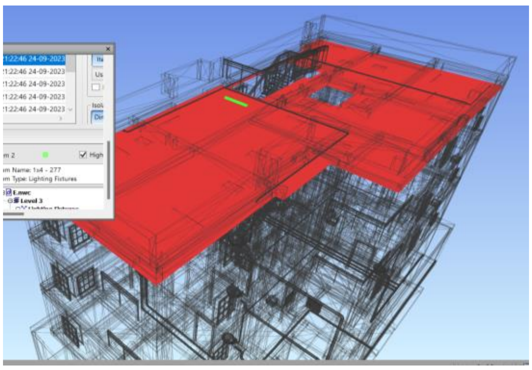


Fig – 13: Architectural versus Electrical clash

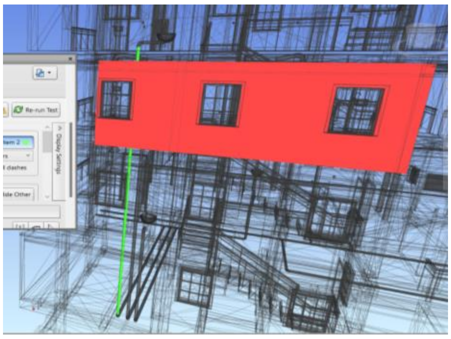


Fig – 14: Architectural versus Plumbing clash

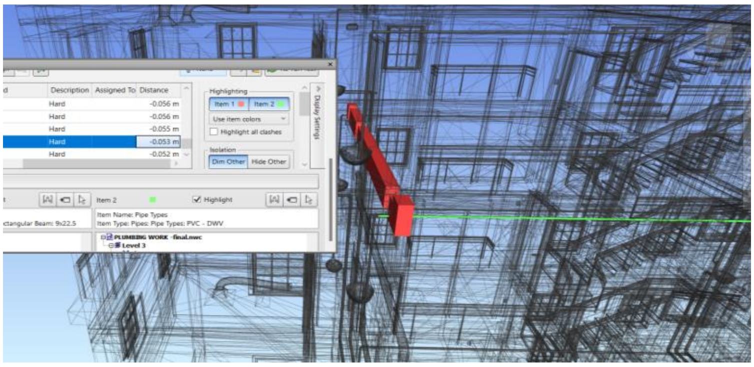


Fig – 15: Structural versus Plumbing clash

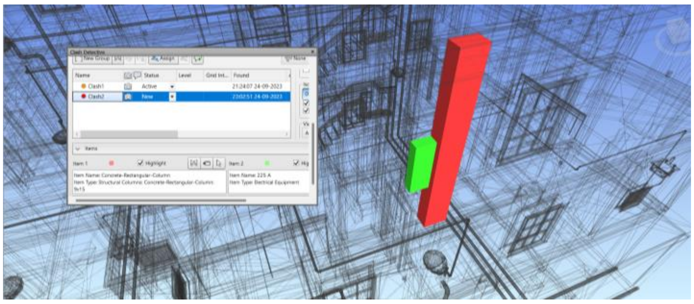


Fig – 16: Structural versus Electrical clash

AUTODESK® NAVISWORKS® **Clash Report**

S vs P	Tolerance	Clashes	New	Active	Reviewed	Approved	Resolved	Type	Status
	0.050m	27	27	0	0	0	0	Hard	OK

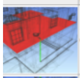
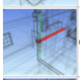
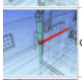
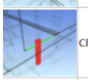
								Item 1				Item 2			
Image	**Clash Name**	**Status**	**Distance**	**Grid Location**	**Description**	**Date Found**	**Clash Point**	**Item ID**	**Layer**	**Item Name**	**Item Type**	**Item ID**	**Layer**	**Item Name**	**Item Type**
	Clash1	New	-0.119		Hard	2023/9/25 04:24	x:11.020, y:15.927, z:3.048	*Element ID*: 586328	<No level>	Analytical Floor Surface	Solid	*Element ID*: 1333411	Level 2	Polyvinyl Chloride - Rigid	Solid
	Clash2	New	-0.110	124-126 : G.L	Hard	2023/9/25 04:24	x:1.728, y:8.160, z:2.667	*Element ID*: 576340	Level 2	Concrete, Cast-in-Place gray	Solid	*Element ID*: 1333642	Level 4	Polyvinyl Chloride - Rigid	Solid
	Clash3	New	-0.110		Hard	2023/9/25 04:24	x:1.735, y:8.165, z:5.715	*Element ID*: 577047	Level 3	Concrete, Cast-in-Place gray	Solid	*Element ID*: 1333642	Level 4	Polyvinyl Chloride - Rigid	Solid
	Clash4	New	-0.101	124-126 : G.L	Hard	2023/9/25 04:24	x:1.723, y:7.866, z:2.921	*Element ID*: 576340	Level 2	Metal Deck	Solid	*Element ID*: 1333595	Level 3	Polyvinyl Chloride - Rigid	Solid
	Clash5	New	-0.096	119-132 : foundation	Hard	2023/9/25 04:24	x:11.012, y:17.301, z:-0.388	*Element ID*: 599442	foundation	Concrete, Cast-in-Place gray	Solid	*Element ID*: 1333483	Level 2	Polyvinyl Chloride - Rigid	Solid

Fig – 17: Sample Clash report

3.5 Resolving Clashes

The causes behind each clash were identified and solutions as expressed in Table 2 were arrived to resolve the interdisciplinary model clashes. The 'Element ID' generated in the clash reports helped to locate and visualize the elements in Revit as well as to resolve the clashes easily and quickly. Changing dimensions of architectural elements and relocating or rerouting plumbing and electrical fixtures were some solutions which helped to resolve major number of clashes. For example, figure 18 shows that clash between wall and column was resolved by changing the wall dimensions. Likewise, pipelines passing through beam were the common clash between structural and plumbing models. With a single relocation of pipeline, we could resolve higher number of clashes. For example, when a single run of pipeline clashes with five beams, it appears as 5 clashes in the clash report, but proper relocation of the pipeline as exhibited in figure 19 could solve all the 5 clashes. Sample report generated after resolving the 27 clashes amid Structural model and Plumbing model was shown in Figure 20.

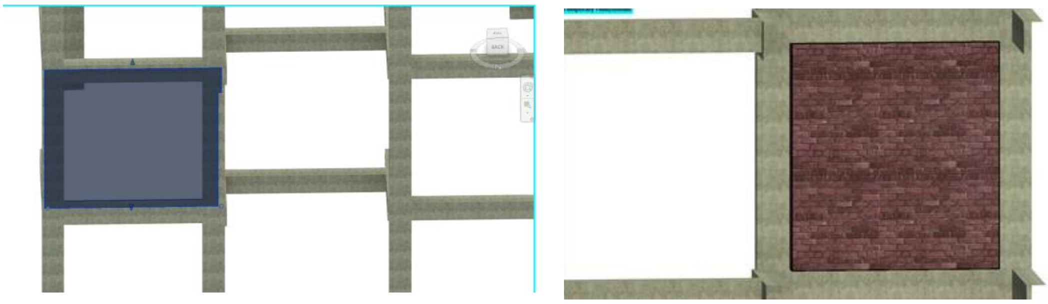


Fig – 18: Wall component before and after resolving clash

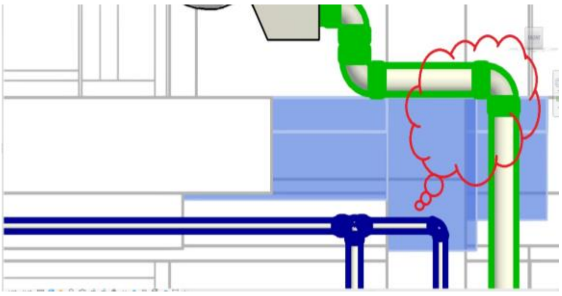
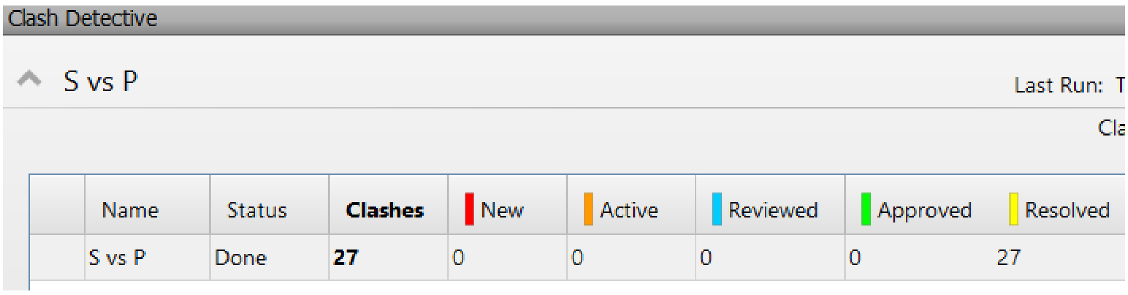


Fig – 19: Relocation of pipe position for resolving clash



	Name	Status	Clashes	New	Active	Reviewed	Approved	Resolved
	S vs P	Done	**27**	0	0	0	0	27

Fig – 20: Sample report showing resolved clashes

4. CONCLUSIONS

Building Information Modelling (BIM) is developing significantly in the Architecture, Engineering, and Construction (AEC) sector, where its current application has a major beneficial effect on projects' performance, timelines, and cost. In this work, clash detection was used in place of the conventional way to identify conflicts in 3D models prior to the start of actual construction. Autodesk Revit and Navisworks Manage were employed to reduce the coordination mistakes and human errors by construction players, which led to high levels of model correctness. Therefore, it is crucial to carry out Clash detection in order to resolve clashes in the model. In this study, totally 251 clashes were identified on G+3 model and majority of clashes were found between the combination of Architectural and Structural models. Detection of clashes earlier in the design stage helps to reduce rework and saves time on real time construction. The research work enables us to enhance the project performance by detecting clashes earlier in the design stage itself thus saving the time and cost of reworks in the construction stage.

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