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BIM-Based Cost Estimation and Scheduling: A Comparative Evaluation of Manual, CAD, BIM-QTO and Integrated 5D BIM Methods

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Abstract - Construction projects commonly depend on drawing-based quantity take-off, spreadsheet cost estimation and independently prepared schedules. Such disconnected workflows can increase re-measurement effort and create inconsistencies when designs change. This study develops and evaluates an integrated BIM-based cost estimation and scheduling framework for a representative G+5 reinforced-concrete moment-resisting frame. The model is developed progressively from LOD 200 to LOD 400 and evaluated under one baseline condition and seven design-change scenarios. Four methods are compared: Manual Quantity Take-Off (M-QTO), CAD-Based Take-Off (CAD-TO), BIM Model-Based Take-Off (BIM-QTO), and Integrated 5D BIM (BIM-5D). The integrated workflow combines Autodesk Revit quantities, a linked cost database, Autodesk Navisworks 4D schedule linkage and automated clash detection. Performance is assessed using quantity, cost and schedule accuracy, composite accuracy and turnaround time. For the baseline case, BIM-5D achieved 96.7% composite accuracy, followed by BIM-QTO at 91.9%, CAD-TO at 85.0% and M-QTO at 78.4%. Average re-estimation time after a design change was 1.2 h for BIM-5D compared with 6.0 h, 24.0 h and 42.0 h for BIM-QTO, CAD-TO and M-QTO, respectively. Under the most severe design-change scenario, BIM-5D retained 93.8% accuracy while the manual method declined to 55.9%. Automated clash detection identified 88 clashes with an estimated avoided rework cost of INR 16.2 lakh. The results indicate that integrated 3D+4D+5D BIM provides the strongest combination of accuracy, change resilience and turnaround efficiency for the studied multi-storey RC building.

Keywords: Building Information Modeling; 4D BIM; 5D BIM; Cost Estimation; Quantity Take-Off

1. INTRODUCTION

Construction cost estimation and scheduling have traditionally been performed through largely independent workflows. Quantities are measured from 2D drawings, prices are compiled in spreadsheets, and construction programmes are prepared separately. This separation becomes increasingly problematic when design revisions occur because affected quantities, costs and schedule activities must be re-identified and updated manually. Building Information Modeling (BIM) provides a parametric digital representation in which geometric and information attributes are associated with model elements. 4D BIM connects model elements with time-based construction activities, while 5D BIM links model quantities with cost information.The central problem addressed in this study is the lack of an integrated and change-resilient workflow that maintains consistency between quantities, cost estimates and construction schedules. The research therefore compares four methods under the same benchmark conditions and explicitly tests their response to controlled design changes.The study aims to: (i) develop a G+5 RC BIM model from LOD 200 to LOD 400; (ii) define baseline and seven design-change conditions; (iii) implement Manual, CAD-Based, BIM-QTO and Integrated 5D BIM methods; (iv) compare quantity, cost and schedule accuracy and turnaround time; (v) evaluate the contribution of 3D, 4D and 5D integration; and (vi) quantify clash-detection and avoided-rework benefits.The benchmark is a regular, symmetric G+5 reinforced-concrete frame with 3.0 m storey height, 15 m × 15 m plan dimensions and three bays in each principal direction at 5 m spacing. The analysis covers concrete, reinforcement steel, formwork, masonry and finishes. The study uses representative unit rates and controlled design-change scenarios rather than live commercial project data. [1,2].

2. LITERATURE REVIEW

2.1 Traditional Estimation and Scheduling

Traditional quantity surveying relies on measurement from drawings and rate application, while Critical Path Method (CPM) provides a conventional basis for construction scheduling. The literature reviewed in the source study identifies manual measurement as labour-intensive and vulnerable to error, while conventional schedules lack direct geometric linkage to the building model. [1,2].

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2.2 BIM-Based Cost Estimation

Previous BIM research has established that model-based quantity take-off can reduce measurement effort and improve consistency. The reviewed studies also emphasize that reliable automated take-off depends on model quality, object classification, parameter completeness and suitable Level of Development. [5–12,30].

2.3 4D BIM Scheduling and Clash Detection

4D BIM extends the model by linking elements to time-based activities, supporting construction-sequence visualization and identification of spatial or temporal conflicts. Automated clash detection can identify hard, soft and workflow/4D conflicts before construction, potentially reducing late rework. [3,4,13,16,22–24].

2.4 Research Gap

The thesis identifies four principal gaps: limited controlled quantitative comparisons of multiple methods; insufficient dimension-by-dimension evaluation of 3D, 4D and 5D contributions; limited systematic testing under design-change scenarios; and inconsistent benchmarking protocols across studies. The present framework addresses these gaps through a common benchmark structure, common cost data, common validation and eight controlled design conditions. [6,7,11,17,18,25–27].

3. RESEARCH METHODOLOGY

3.1 Benchmark Building Model

The benchmark is a regular G+5 reinforced-concrete moment-resisting frame. It has six floor levels, 3.0 m uniform storey height, 18.0 m total height, 15 m × 15 m plan dimensions and 3 bays at 5 m spacing in each direction. Columns are 400 × 400 mm and beams are 250 × 450 mm, with M25 concrete and Fe415 reinforcement. The slab is 125 mm thick.

3.2 Design-Change Scenarios

Eight conditions are evaluated: CS0 baseline; CS1 beam depth +10%; CS2 beam depth +20%; CS3 column section +20%; CS4 slab thickness +20 mm on all floors; CS5 additional storey; CS6 beam and column resizing; and CS7 an additional bay with beam/column resizing. These conditions represent minor, moderate and major revisions.

3.3 Level of Development

LOD 200 represents approximate geometry, LOD 300 defined geometry, LOD 350 coordinated interfaces, and LOD 400 fabrication-level detail. The study evaluates how increasing model maturity affects estimating accuracy and coordination. [29,30].

3.4 Estimation Methods

Manual QTO uses 2D drawings and manual measurement. CAD-TO uses on-screen AutoCAD measurement. BIM-QTO extracts quantities from Revit schedules but retains external manual pricing and scheduling. BIM-5D links Revit quantities to a structured cost database and connects the model to Navisworks TimeLiner for 4D scheduling and Clash Detective. [5,9,10,20,21].

3.5 Schedule Development

Manual, CAD and BIM-QTO methods use independently developed CPM schedules. BIM-5D links schedule activities directly to model elements, allowing time-based simulation and more direct propagation of design changes. [2,3,13,16].

3.6 Validation and Metrics

A validated LOD 400 bill of quantities, cost estimate and schedule is established for every design condition. A representative 20% sample of model elements was manually spot-checked, with less than 1% discrepancy reported. Quantity and cost accuracy, schedule accuracy, turnaround time and a composite accuracy score are used as evaluation metrics. [17,18].

3.7 Software and Data Exchange

Autodesk Revit is used for 3D BIM authoring; AutoCAD for CAD-based take-off; Autodesk Navisworks Manage for 4D simulation and clash detection; Microsoft Project for non-integrated CPM scheduling; and Microsoft Excel/a linked cost plug-in for cost compilation. IFC-based exchange is also considered for interoperability. [5,30].

4. RESULTS AND DISCUSSION

4.1 Baseline Performance

The baseline composite accuracy was 78.4% for Manual QTO, 85.0% for CAD-TO, 91.9% for BIM-QTO and 96.7% for BIM-5D. BIM-5D also achieved 98.1% quantity accuracy, 96.7% cost accuracy and 95.4% schedule accuracy.

Table 1. Baseline performance comparison

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Method	QTO Accuracy (%)	Cost Accuracy (%)	Schedule Accuracy (%)	Composite (%)
Manual (M-QTO)	82.1	78.4	74.6	78.4
CAD-Based (CAD-TO)	88.6	85.2	81.3	85.0
BIM Model-Based (BIM-QTO)	94.3	91.8	89.7	91.9
Integrated 5D BIM (BIM-5D)	98.1	96.7	95.4	96.7

4.2 Design-Change Sensitivity

Accuracy decreased as design-change severity increased for all methods, but the reduction was much smaller for BIM-5D. From CS0 to CS7, Manual QTO declined from 78.4% to 55.9%, whereas BIM-5D declined from 96.7% to 93.8%. This indicates substantially higher resilience of the integrated parametric workflow. [17,18,20,21].

Table 2. Composite accuracy under design-change scenarios

Scenario	Manual	CAD-TO	BIM-QTO	BIM-5D
CS0 Baseline	78.4	85.0	91.9	96.7
CS1 Beam +10%	74.1	82.6	90.8	96.2
CS2 Beam +20%	71.8	80.4	89.6	95.8
CS3 Column +20%	70.2	79.1	88.9	95.5
CS4 Slab +20 mm	66.5	76.3	87.1	94.9
CS5 Additional storey	58.7	69.8	85.4	94.1
CS6 Beam + Column	63.4	74.0	86.2	94.6
CS7 Additional bay	55.9	67.2	84.7	93.8

4.3 Input-Dimension Contribution

3D quantities alone produced 91.9% composite accuracy. Adding 5D cost linkage increased accuracy to 94.6%, while adding 4D schedule linkage alone produced 93.2%. The combined 3D+4D+5D configuration achieved 96.7% and the shortest average re-estimation time of 1.2 h. [20,21].

4.4 Turnaround Time

Initial setup for BIM-5D was 40.0 h, slightly higher than BIM-QTO at 34.0 h. However, average re-estimation after a design change was only 1.2 h for BIM-5D, compared with 6.0 h for BIM-QTO, 24.0 h for CAD-TO and 42.0 h for Manual QTO. Across CS0-CS7, total reported time was 48.4 h for BIM-5D versus 390.0 h for Manual QTO.

Table 3. Turnaround-time comparison

Method	Initial (h)	Re-estimation/change (h)	Total CS0-CS7 (h)
Manual	96.0	42.0	390.0
CAD-Based	68.0	24.0	236.0
BIM-QTO	34.0	6.0	76.0
BIM-5D	40.0	1.2	48.4

4.5 Clash Detection

Across LOD 300 and LOD 350/400, 88 clashes were identified: 46 hard clashes, 27 soft clashes and 15 workflow/4D clashes. The estimated avoided rework cost was INR 16.2 lakh, approximately 9.4% of the baseline project cost. [22–24].

Table 4. Clash detection summary

LOD Stage	Hard	Soft	Workflow/4D	Total	Avoided Rework (INR lakh)
LOD 300	34	19	0	53	6.8
LOD 350/400	12	8	15	35	9.4
Combined	46	27	15	88	16.2

4.6 Work-Category Accuracy

Concrete and formwork were the most accurately estimated categories. Reinforcement steel and finishes were more sensitive to detailing and assumptions. Under BIM-5D, quantity accuracy was 99.2% for concrete, 96.4% for reinforcement, 98.1% for formwork, 97.6% for masonry and 95.8% for finishes.

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Table 5. Per-category accuracy comparison

Work Category	Manual	CAD-TO	BIM-QTO	BIM-5D
Concrete	85.2	90.8	96.1	99.2
Reinforcement Steel	76.4	83.6	91.4	96.4
Formwork	83.9	89.7	95.0	98.1
Masonry	81.1	87.4	93.8	97.6
Finishes	78.6	85.0	91.9	95.8

4.7 LOD Sensitivity and Scale

BIM-5D composite accuracy increased from 81.4% at LOD 200 to 90.6% at LOD 300, 94.3% at LOD 350 and 96.7% at LOD 400. The results indicate diminishing marginal improvement beyond LOD 350 for general cost planning. In scale sensitivity tests, BIM-5D accuracy was 97.4% for G+2, 96.7% for G+5 and 95.3% for G+9, with re-estimation time increasing from 0.6 to 2.4 h.

Table 6. Composite accuracy by Level of Development

LOD	Composite Accuracy (%)
LOD 200	81.4
LOD 300	90.6
LOD 350	94.3
LOD 400	96.7

4.8 AACE Estimate-Class Interpretation

The observed accuracy ranges corresponded approximately to Class 4–5 for Manual QTO, Class 3–4 for CAD-TO, Class 2–3 for BIM-QTO and Class 1–2 for BIM-5D. This mapping provides a cost-engineering interpretation of the comparative results. [28].

5. CONCLUSIONS

5.1 Main Findings

Integrated 5D BIM was the highest-performing method in the controlled study. It combined strong baseline accuracy, high resilience to design changes and substantially lower re-estimation time. BIM-QTO was the strongest intermediate option, while CAD-TO and Manual QTO were progressively less accurate and less change-resilient.

5.2 Principal Numerical Findings

The key results are: 96.7% BIM-5D baseline composite accuracy; 93.8% BIM-5D accuracy under the most severe design change; 1.2 h average BIM-5D re-estimation time; 35-fold approximate time-efficiency improvement over Manual QTO; 88 detected clashes; and INR 16.2 lakh estimated avoided rework cost.

5.3 Practical Recommendations

For multi-storey RC projects, Integrated 5D BIM is recommended as the primary estimating and scheduling approach. Organizations already using 3D BIM should prioritize linked cost databases and 4D schedule integration. LOD 350 is recommended as a practical general target for pre-construction cost planning, with LOD 400 justified for detailed clash detection and procurement. Periodic independent quantity-surveyor audits and BIM-specific training are also recommended. [11,18,20,21].

6. LIMITATIONS

6.1 Study Limitations

The evaluation uses one benchmark structure and one estimator. Design changes are controlled representations rather than the complex, overlapping revisions encountered on live projects. Manual/CAD turnaround times are based on documented productivity benchmarks rather than project-specific time-and-motion measurements. Market escalation, currency fluctuation and contractual risk allocation are not explicitly modeled. These limitations restrict direct generalization to every commercial project.

7. FUTURE SCOPE

7.1 Future Research Directions

Future work should validate the framework using live commercial project data and extend it to irregular, asymmetric, high-rise, steel and composite structures. Further research can integrate machine-learning cost forecasting, generative design, real-time site progress monitoring, drones, mobile AR and IoT sensors. Market escalation and contractual risk can be modeled explicitly. Cloud-

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based common data environments and standardized BIM objects with embedded cost and schedule data can also be investigated. Safety-related workflow clashes and their risk-cost implications represent another important extension. [14,15,19,26,27].

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Supplementary Numerical Summary

Table 7. Key numerical results

Metric	Result
Benchmark building	G+5 RC frame, 15 m × 15 m, 3 bays × 3 bays
Structural elements	148
Design conditions	8 (1 baseline + 7 design changes)
Baseline reference cost	INR 171.6 lakh
Best baseline composite accuracy	96.7% (BIM-5D)

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Major-change BIM-5D accuracy	93.8%
Average BIM-5D re-estimation time	1.2 h/change
Total BIM-5D time, CS0-CS7	48.4 h
Total detected clashes	88
Estimated avoided rework cost	INR 16.2 lakh
Recommended general planning LOD	LOD 350