

# Comparative Analysis of Manual, BIM-Based, and AI-Assisted Quantity Takeoff for Residential Construction Cost Estimation: An Illustrative Human-in-the-Loop Framework

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**Abstract** - Accurate quantity takeoff determines the reliability of construction cost estimates from tender pricing to project budgeting, yet the shift from manual to digital and AI-assisted workflows raises practical questions about estimator control, error classification, and output validation. Traditional manual quantity takeoff using drawings and spreadsheets remains common in residential construction, especially in small and mid-sized firms, but it is time-consuming and vulnerable to drawing interpretation, scale, unit conversion, and omission errors. BIM-based and digital takeoff workflows improve consistency by connecting model geometry, two-dimensional drawings, classification systems, and cost data. More recently, AI-assisted drawing recognition and quantity extraction tools have introduced automated first-pass measurement support. However, AI-assisted estimation remains dependent on drawing quality, training data, scope definition, local rate assumptions, and estimator judgment. This paper proposes and demonstrates a comparative methodology for evaluating manual, BIM/digital, and AI-assisted quantity takeoff workflows for residential building cost estimation. A clearly labelled illustrative residential case study is used to compare quantity deviation, cost variance, time effort, error types, and human correction requirements. The paper proposes an Estimator-Controlled AI-Assisted Quantity Takeoff Framework that positions AI as a reviewable support tool rather than a replacement for estimators. The contribution is a practical human-in-the-loop validation framework for estimators, contractors, BIM/VDC teams, and construction management researchers working in Indian and similar developing construction markets.

**Keywords** - BIM, quantity takeoff, cost estimation, AI-assisted estimation, human-in-the-loop, construction management, 5D BIM

## I. INTRODUCTION

Quantity takeoff (QTO) is the process of identifying, measuring, and organizing construction quantities from drawings, specifications, digital plans, or BIM models. It is foundational to bill of quantities (BOQ) preparation, tender pricing, procurement planning, project budgeting, and cost control. RICS NRM 2 defines a bill of quantities as a list of work items with detailed descriptions and firm quantities, while Indian measurement practice uses the IS 1200 series to standardize measurement methods across work trades [1], [2].

Errors in takeoff can affect the entire preconstruction chain. Overestimated quantities may make a bid uncompetitive, while underestimated quantities can create procurement shortages, margin loss, change-order disputes, and budget overruns. In India, measurement and estimating practices are often linked to standardized methods such as IS 1200 and public cost references such as CPWD schedules, state schedules of rates, and market rate analysis. CPWD Plinth Area Rates can support preliminary reasonableness checks, but they should not be treated as detailed BOQ item rates [3].

Manual takeoff using printed drawings, PDF drawings, measurement sheets, and spreadsheets remains common because it is accessible, low-cost, and familiar. However, it is labor-intensive and prone to errors such as missing openings, double-counting wall lengths, applying the wrong drawing scale, or mixing units. Digital tools such as Bluebeam and Autodesk takeoff environments improve traceability by supporting calibrated measurements, reusable tool sets, counts,

areas, volumes, custom columns, classification, and spreadsheet export [19], [20].

Building Information Modeling (BIM) extends digital takeoff by linking quantities to model elements. BIM-based QTO and 5D BIM can improve productivity, collaboration, and consistency, but extracted quantities still depend on model quality, level of development, element naming, material layer definition, and measurement rules [4]-[14]. AI-assisted takeoff represents a newer shift. Instead of relying only on manual measurements or model parameters, AI-assisted tools attempt to detect drawing objects, classify elements, infer quantities, and generate draft BOQs. The framing of this paper is practical: AI and BIM can reduce repetitive measurement effort, but estimator judgment remains essential for scope boundaries, trade classification, opening deductions, constructability, local rates, assumptions, and final BOQ validation.

The research gap is that existing studies often compare manual and BIM-based takeoff, or separately examine machine learning in cost estimation. Fewer papers present a practical estimator-controlled workflow that compares manual, BIM/digital, and AI-assisted takeoff while also classifying error types and human review requirements for residential construction estimation.

The objectives are to compare three QTO workflows for residential construction, examine time efficiency, quantity deviation, cost variance, and error types, develop a human-in-the-loop quality assurance framework, and provide a practical validation checklist for estimators and BIM/VDC teams. The

research questions ask how the three workflows differ, what errors occur, how human review improves reliability, and what framework can be used to validate AI-assisted outputs.

## II. LITERATURE REVIEW

Traditional QTO depends on reading architectural and structural drawings, identifying work items, measuring dimensions, applying deduction rules, and transferring quantities into BOQ or Excel formats. Manual takeoff remains valuable because it forces the estimator to understand project scope, drawing notes, specification boundaries, sequencing, and site assumptions. Its weaknesses are mainly productivity and repeatability. Different estimators may interpret the same drawing differently unless measurement rules and review procedures are standardized.

BIM-based QTO uses model elements to extract quantities such as concrete volume, wall area, floor finish area, door/window counts, and material quantities. When cost data is linked to model quantities, the workflow becomes part of 5D BIM. Studies report BIM-QTO benefits in productivity, accuracy, clarity, and collaboration, but also note persistent implementation barriers such as skills, cost, model quality, and software interoperability [5], [6].

BIM-based extraction is not automatically correct. Compound elements such as layered walls and floors can produce inaccurate quantities if material layers, overlaps, and modeling assumptions are not properly handled [7], [8]. Other studies propose rule-based logic, semantic auditing, knowledge graphs, and quantity precision checks to improve automated QTO reliability [9]-[12]. Integrated BIM cost studies also show that quantity extraction must be connected to measurement rules, item descriptions, and cost databases rather than treated as isolated geometry export [13], [14].

AI in construction cost estimation includes machine learning prediction models, data-driven cost forecasting, BIM-integrated cost models, and emerging AI-supported estimation workflows. Systematic reviews show growing interest in machine learning for cost estimation, but they also warn that models require reliable historical data and may struggle when project types, market rates, or project conditions differ from training data [15]-[17]. For construction estimation, the most appropriate near-term model is not full automation. It is estimator-controlled automation, where AI produces draft quantities, the estimator checks assumptions and high-risk items, and corrections inform later workflows [18].

Table 1 summarizes the main literature used to frame this study.

Table 1. Literature summary

Author/year	Focus area	Method	Key finding	Relevance
Alathamneh et al., 2024	BIM-QTO	Review	Identifies benefits, challenges, and future opportunities	BIM-QTO research gap
Wahab and Wang, 2022	BIM vs. 2D QTO	Survey and case study	Reports productivity, accuracy, clarity, and collaboration benefits	Direct comparison foundation
Khosakitchalert et al., 2019, 2020	BIM-QTO accuracy	Technical studies	Compound elements and overlaps can affect quantities	Model-quality caution
Liu et al., 2022	Code-compliant QTO	Knowledge model	Semantic rules improve automated QTO reliability	Supports QA framework
Valinejadshoubi et al., 2024	Automated BIM-QTO	System development	Structured validation supports high-accuracy QTO	Automation with controls
Hashemi et al., 2020	ML cost estimation	Systematic review	Machine learning is promising but data dependent	AI limitations
Mosqueira-Rey et al., 2023	Human-in-loop ML	Review	Human interaction can improve systems and users	HITL framing

## III. METHODOLOGY

This paper uses a comparative case-based methodology. Since no confidential project data is used, the numerical application is clearly labelled as illustrative. It demonstrates how an estimator can compare manual, BIM/digital, and AI-assisted workflows without treating any software output as ground truth.

The illustrative case is a small single-storey residential building with a built-up area of approximately 80 m<sup>2</sup>. The measured categories are RCC concrete, reinforcement steel, masonry, internal and external plaster, flooring, internal and external paint, and doors/windows. These items are common in Indian residential BOQ practice and can be measured across the three workflows.

The three workflows are defined as follows. In the manual Excel-based workflow, the estimator reads PDF drawings, records measurements manually, applies formulas, deducts openings, and prepares BOQ quantities. In the BIM/digital workflow, the estimator uses Revit schedules, Bluebeam calibrated measurements, Autodesk 2D/3D takeoff, or similar tools, then reviews exported quantities. In the AI-assisted workflow, the tool generates draft quantities or detected objects from drawings, and the estimator validates calibration, detections, scope, deductions, assumptions, and BOQ mapping.

The verified baseline is not software-generated ground truth. It is an expert-estimator-reviewed quantity set created using measurement rules, cross-checks, and documented

assumptions. The baseline is used only as a reference for comparing the illustrative workflows.

The comparison uses total time taken, quantity deviation from the estimator-reviewed baseline, missing items, duplicate items, scale or unit errors, cost variance, and human correction effort. The error taxonomy includes drawing interpretation errors, scale/calibration errors, unit conversion errors, scope

classification errors, opening deduction errors, duplicate measurements, missing trade items, and rate assumption errors. Figure 1 illustrates the overall methodology, while Figure 2 compares the three workflow paths. Table 2 to Table 8 present the main illustrative quantities, costs, time, errors, and review checklist.

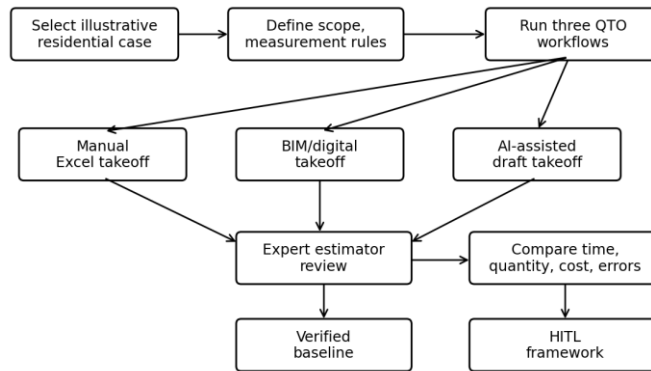


Figure 1. Research methodology flowchart.

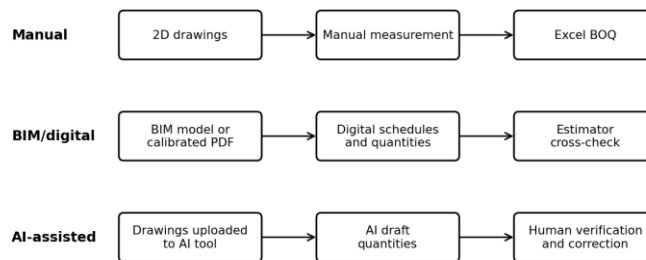


Figure 2. Manual, BIM/digital, and AI-assisted workflow comparison.

#### IV. ILLUSTRATIVE CASE STUDY APPLICATION

The following dataset is illustrative only. It demonstrates the method and does not represent measured data from a real construction project. The assumed residential unit is approximately 10 m by 8 m, with a floor-to-floor height of 3.0 m. External walls, internal partitions, RCC slab and structural items, doors and windows, floor finish, plaster, and paint are included. The rates are hypothetical and are expressed in INR. For any formal empirical version, the author should replace

these values with measured quantities from a public, self-created, or permission-cleared drawing set and documented rates from CPWD/state SORs or market quotations.

Table 2 gives the verified illustrative baseline. Table 3 gives the BOQ calculation using assumed rates. Table 4 to Table 7 compare quantities, costs, time, and observed error totals. Figure 4 summarizes the illustrative cost breakdown by trade, and Figure 5 visualizes the error distribution by workflow. The amounts have been recalculated and the total illustrative cost is INR 980,940.

Table 2. Verified baseline quantities for illustrative case

Work item	Unit	Baseline quantity	Basis
RCC concrete	m <sup>3</sup>	21.60	Slab plus structural allowance
Reinforcement steel	kg	1,836	85 kg/m <sup>3</sup> of RCC
Masonry	m <sup>3</sup>	28.52	Walls after openings
Plaster	m <sup>2</sup>	312.00	Internal and external surfaces
Flooring	m <sup>2</sup>	72.00	Net finish area
Paint	m <sup>2</sup>	392.00	Wall and ceiling area
Doors/windows	no.	15	Door and window count

**Table 3. Illustrative BOQ using assumed rates**

Work item	Unit	Qty.	Rate (INR)	Amount (INR)
RCC concrete	m <sup>3</sup>	21.60	8,500	183,600
Reinforcement steel	kg	1,836	75	137,700
Masonry	m <sup>3</sup>	28.52	8,000	228,160
Plaster	m <sup>2</sup>	312.00	280	87,360
Flooring	m <sup>2</sup>	72.00	1,200	86,400
Paint	m <sup>2</sup>	392.00	160	62,720
Doors/windows	no.	15	13,000	195,000
<b>Total</b>				<b>980,940</b>

**Table 4. Quantity takeoff comparison**

Work item	Baseline	Manual	BIM/digital	AI after review
RCC concrete, m <sup>3</sup>	21.60	22.20	21.35	21.50
Reinforcement, kg	1,836	1,900	1,805	1,848
Masonry, m <sup>3</sup>	28.52	29.70	28.10	28.60
Plaster, m <sup>2</sup>	312.00	326.00	308.00	315.00
Flooring, m <sup>2</sup>	72.00	74.00	72.40	72.50
Paint, m <sup>2</sup>	392.00	404.00	389.00	395.00
Doors/windows, no.	15	16	15	15

**Table 5. Cost estimate comparison**

Workflow	Total cost (INR)	Variance (INR)	Variance (%)
Verified baseline	980,940	0	0.00
Manual Excel-based	1,021,520	+40,580	+4.14
BIM/digital	972,010	-8,930	-0.91
AI-assisted after review	983,550	+2,610	+0.27

**Table 6. Time and review comparison**

Workflow	Initial time	Review time	Total time	Main review burden
Manual	7.0 h	1.5 h	8.5 h	Formulas and deductions
BIM/digital	3.5 h	1.0 h	4.5 h	Calibration and classification
AI-assisted	1.5 h	1.8 h	3.3 h	Detections, scope, missed items

**Table 7. Error comparison**

Error type	Manual	BIM/digital	AI before review	AI after review
Drawing interpretation	2	1	3	1
Scale/calibration	1	1	1	0
Unit conversion	1	0	1	0
Opening deduction	3	1	4	1
Duplicate measurement	2	0	1	0
Missing item	1	1	2	0
Rate assumption	1	1	1	1
<b>Total observed errors</b>	<b>11</b>	<b>5</b>	<b>13</b>	<b>3</b>

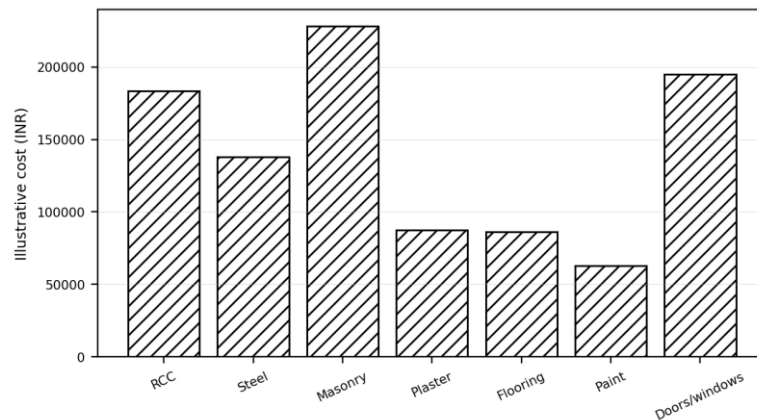


Figure 4. Cost breakdown by trade for illustrative BOQ.

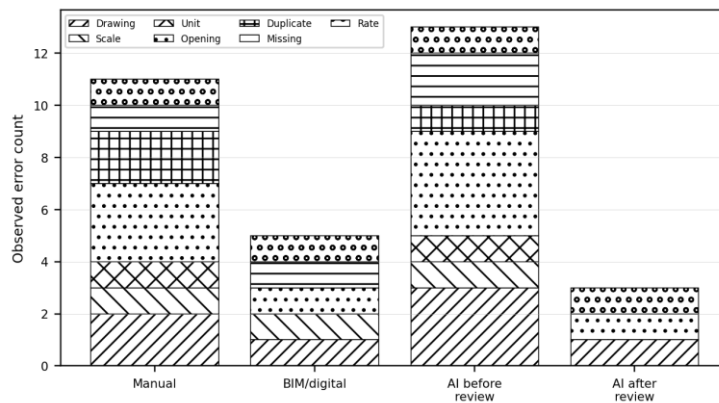


Figure 5. Error distribution by workflow for illustrative case.

## V. RESULTS AND DISCUSSION

The illustrative results show that manual takeoff required the highest total time. This is expected because the estimator manually reads dimensions, measures repeated items, transfers values into Excel, and rechecks formulas. Manual workflows are transparent but depend heavily on individual discipline, especially for opening deductions, repeated wall segments, and drawing revisions.

The BIM/digital workflow reduced measurement time and produced lower cost variance in the illustrative application. This is consistent with prior literature showing that BIM-based QTO can improve productivity and consistency compared with 2D/manual approaches [5], [6]. However, these results should not be interpreted as proof that BIM is always more accurate. BIM output is only as reliable as the model geometry, element classification, family parameters, and measurement rule mapping [7]-[12].

The AI-assisted workflow showed the lowest total time after human review, but its raw output had more errors before correction. This is the central practical finding of the illustrative demonstration. AI can reduce repetitive measurement effort and generate first-pass quantities, but it may misclassify symbols, miss openings, incorrectly group trades, or overlook drawing notes. After human review, the AI-assisted output can be useful for BOQ preparation, but reliability comes from estimator correction rather than blind automation.

The most dangerous errors are not always the largest by count. A single rate assumption error or scope classification error can affect cost more than several small quantity deviations. Therefore, quantity accuracy alone is not sufficient. A reliable estimate also requires rate analysis, specification interpretation, constructability review, waste

factors, taxes, overheads, profit, contingencies, and local market assumptions [16], [17].

For Indian residential construction, the proposed workflow is practical because many firms still operate with PDF drawings and Excel while gradually adopting digital tools. A hybrid workflow using calibrated digital takeoff, AI-assisted first-pass detection, and estimator-controlled review is more realistic than assuming that every small residential project has a fully reliable BIM model.

## VI. ESTIMATOR-CONTROLLED QTO FRAMEWORK

The proposed framework treats AI output as reviewable draft information. It does not treat AI output, BIM output, or vendor-generated quantities as final cost-estimation authority. Figure 3 summarizes the framework and Table 8 provides the human review checklist.

The framework contains ten stages: drawing input and scope definition; drawing calibration and trade package selection; automated or AI-assisted quantity extraction; BIM/digital cross-check; estimator validation; BOQ generation; rate and assumption review; variance check; final cost estimate approval; and lessons learned feedback. In practice, the estimator should check wall lengths, opening deductions, slab areas, duplicate measurements, missing items, scope classification, and rate mapping before accepting any automated output.

The framework is not intended to replace professional judgement. Its purpose is to reduce repetitive measurement effort while preserving estimator control over scope, assumptions, local rates, BOQ structure, and final validation.

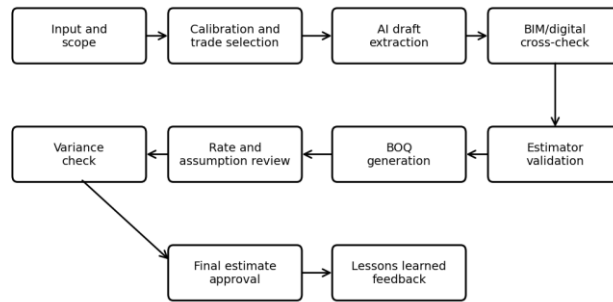


Figure 3. Estimator-controlled AI validation framework.

Table 8. Human review checklist

Review item	Status (estimator to complete)	Notes
Latest drawing revision verified		
Drawing scale calibrated		
Units confirmed		
Scope boundaries defined		
Openings deducted correctly		
Duplicate measurements removed		
Missing trade items checked		
BIM/digital quantities cross-checked		
Rate source documented		
Assumptions and exclusions recorded		
Final BOQ reviewed by estimator		

## VII. LIMITATIONS

This study has several limitations. First, the case study data is illustrative and must not be interpreted as measured data from a real project. Second, the scope is limited to common residential building items and does not fully address MEP, waterproofing, external development, temporary works, or complex structural systems. Third, AI-assisted tool performance may vary across vendors, drawing styles, languages, symbol conventions, and training datasets. Fourth, no confidential project data is used, so real project results may differ. Fifth, rates and construction practices vary across Indian cities and states. Sixth, residential findings may not generalize to hospitals, high-rise buildings, industrial projects, or infrastructure works. Seventh, BIM model quality strongly affects BIM-QTO reliability. Estimator expertise remains necessary for scope interpretation, assumptions, constructability review, and final cost validation.

## VIII. FUTURE WORK

Future work should test the framework using public residential drawings, open BIM sample models, or self-created academic designs. The study can be expanded to compare raw AI output and corrected AI output across multiple drawing sets. Future research should include MEP quantities, waterproofing, formwork, excavation, and finishing trades. It should also test inter-estimator variation by asking multiple estimators to measure the same drawings. A localized Indian rate study comparing CPWD DSR, state SOR, and market quotations would further improve practical relevance.

## IX. CONCLUSION

Manual takeoff continues to offer value because it requires direct reading and interpretation of drawings, which can build scope

understanding that automated workflows may bypass. However, it is time-consuming and vulnerable to repetitive measurement errors. BIM-based and digital takeoff workflows improve structure, traceability, and consistency, but their accuracy depends on model quality, classification, and measurement rules. AI-assisted takeoff can reduce repetitive first-pass measurement effort, but it should not be treated as a final estimator.

The most practical near-term model is a human-in-the-loop workflow in which AI produces draft quantities and the estimator validates calibration, scope, deductions, BOQ mapping, and rates. The proposed Estimator-Controlled AI-Assisted Quantity Takeoff Framework provides a practical approach for contractors, estimators, BIM/VDC teams, and construction management students. The central conclusion is that AI and BIM can support better estimation, but professional estimator judgment remains the controlling factor for reliable construction cost estimates.

## DATA AVAILABILITY STATEMENT

No confidential project data was used. The numerical case study data in this manuscript is illustrative and was created only to demonstrate the proposed methodology. Any empirical version of the study should provide a public/sample drawing reference, a self-created residential plan, or an anonymized dataset with written permission.

## ETHICS AND CONFIDENTIALITY STATEMENT

This study does not use confidential client drawings, project estimates, bids, contracts, or proprietary commercial data. Future empirical work should use public drawings, self-created academic drawings, open BIM examples, or anonymized project data with permission.

## CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest. No software vendor sponsored this study. Product names such as Revit, Bluebeam, and Autodesk Construction Cloud are mentioned only as examples of common digital takeoff workflows.

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