Verification of Material Quantity Takeoffs from Building Information Models: Duplicate Elements, Revision Conflicts, and Procurement Consequences

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Abstract

Material quantity takeoffs can change because of model-processing errors rather than design changes. This paper develops a verification method for revision-aware material quantities, with explicit treatment of element identity, quantity meaning, units, and procurement allowances. A synthetic element ledger contains an approved 12 cubic meter revision of one wall and an 8 cubic meter second wall. The reference net quantity is 20 cubic meters. Summing a superseded revision increases it to 30 cubic meters; joining the current elements to repeated classifications increases it to 32. Under an illustrative 5% allowance and a price of 120 currency units per cubic meter, the revision error increases the calculated purchase amount by 1,260 currency units. Worked calculations and invariance checks establish these effects under the stated assumptions. The example operates on an extracted ledger and makes no claim of IFC parser performance or project savings. The contribution is an auditable quantity-verification procedure that distinguishes model quantities, revision selection, and procurement assumptions.

Keywords: building information modeling; quantity takeoff; revision control; material procurement; data verification.

1. Introduction

Building information models connect geometry, classifications, and project records. IFC provides an exchange structure [1], while research on quantity-takeoff guidelines examines how model information supports measurement and estimating [2, 3]. A successful file import does not establish that a material total includes the correct elements and revisions.

This study concentrates on that verification problem. Its synthetic case is intentionally small enough to inspect element by element. It separates errors in selecting records from assumptions used to convert design quantities into a purchase request.

The contribution is organized around three separable transformations: selecting an approved model state, summing quantities at a physical-element grain, and applying procurement rules. A failure in one stage can propagate through otherwise correct arithmetic in later stages. The example therefore retains intermediate quantities and deliberately includes a case where descriptive classifications multiply material. This makes the verification problem concrete without implying that the study has tested a complete building-authoring, model-exchange, or estimating platform.

2. Quantity definition and model scope

2.1 Measurement meaning

A quantity record needs more than a number and an element identifier. It requires a physical dimension, measurement method, scope, and interpretation such as net volume or gross volume. IFC's IfcElementQuantity supports sets of element quantities and an associated measurement-method concept [4]. Different valid quantities can coexist for the same element, so selecting the first volume-like property is not a defensible extraction rule.

The reporting contract used here requests net material volume for specified approved elements in one project snapshot. Openings and voids are assumed already accounted for in the supplied net values. The study does not independently derive volumes from geometry. Such derivation would require geometry-processing tests and agreement on the measurement convention.

2.2 Units and exchange

IFC unit assignment is relevant to interpreting exchanged quantities [5]. A project-level unit may apply unless a valid local definition supplies the relevant unit, depending on the entity and representation. The extraction should record the unit actually used and convert into a declared output unit. One cubic meter equals one billion cubic millimeters; applying a linear conversion to a volume would be a major dimensional error [6].

Geometric exchange has its own interoperability issues [7]. Consequently, an apparently valid quantity field should not be assumed equivalent to a separately derived geometric volume without checking representation and measurement conventions. A difference can reflect intended gross-versus-net semantics rather than parser failure.

The proposed report lists the model snapshot, element population, selected quantity name, measurement rule, and unit. This preserves the distinction between a design quantity extracted from a model and an amount approved for purchase, which may include allowances, packaging, or supplier constraints.

Material roles require care when assemblies contain several components. Summing an assembly volume together with the volumes of its constituent parts can count the same material twice. Conversely, using only an assembly total can be insufficient when the request concerns a particular material layer. The quantity contract should identify the level of decomposition and the selected material role. A general element count or geometry-volume sum cannot decide that scope without additional model semantics and estimating rules.

3. Revision and identity model

3.1 Approved snapshot

The synthetic ledger includes wall W1 at revision 1 with 10 cubic meters, marked superseded; W1 at revision 2 with 12 cubic meters, marked approved; and W2 at revision 1 with 8 cubic meters, marked approved. Selecting the approved records gives 20 cubic meters. Summing all revisions gives 30, although only one W1 exists in the selected design state.

Table 1. Synthetic element revision ledger.

Element	Revision and status	Net volume
W1	1, superseded	10 cubic meters
W1	2, approved	12 cubic meters
W2	1, approved	8 cubic meters

A real snapshot should identify a mutually consistent approved set of model versions. Selecting the highest revision of every element independently can produce a combination that was never approved together. Information-management principles in ISO 19650-1 provide relevant context for controlling project information [8], but the present selection rule is a specific implementation proposal.

3.2 Federation and classifications

Element identifiers should be interpreted within their project and source-model context. Copies in a federated model may represent duplicated export content, references, or distinct physical objects. Identical geometry is not sufficient evidence to delete an element. The identity resolution must follow model ownership and federation rules.

Classification and document associations are often one-to-many. If W1 has two classification rows, joining them before summing element volume produces 12 + 12 + 8 = 32 cubic meters. The classifications add descriptive context, not material. Cleaning and integration methods address these representation problems [9], while fitness for the specific estimating task remains essential [10].

Revision selection should distinguish element modification from withdrawal. If an element is deleted in a later approved model, selecting its latest surviving row from historical exports can incorrectly restore it to the takeoff. A snapshot-aware ledger therefore needs either explicit deletion status or a complete membership manifest for the approved model. The synthetic example uses status fields only because its membership is stipulated. A real ingestion process must verify that the absence of a row means deletion rather than an incomplete export.

4. Procurement calculation and consequences

4.1 Separate quantity from purchasing assumptions

For the scenario, the purchase volume is Q_buy = Q_net(1+a), where a = 0.05 is an illustrative allowance. Cost is C = p Q_buy with p = 120 currency units per cubic meter. The reference values are 21 cubic meters and 2,520 currency units. The allowance and price are assumed inputs, not market observations or recommendations.

The all-revisions quantity gives 31.5 cubic meters and 3,780 currency units. The difference is 10.5 cubic meters and 1,260 currency units. This is a calculated consequence of the fixture; no actual over-order, expenditure, or saving is claimed. The classification fan-out variant gives 32 cubic meters before allowance.

Table 2. Computed quantity and purchase variants.

Quantity variant	Net quantity used	Purchase quantity at 5%
Approved reference	20 cubic meters	21 cubic meters
All revisions summed	30 cubic meters	31.5 cubic meters
Classification fan-out	32 cubic meters	33.6 cubic meters
Gross quantity substituted	24 cubic meters	25.2 cubic meters

4.2 Interpretation

The gross-quantity variant is a separate constructed value, not a result derived from the ledger geometry. It illustrates that the correct number for one measurement convention can be wrong for another procurement question. The extractor should report which quantity was used rather than silently prefer the larger or more readily available value.

Procurement may also require rounding to delivery increments, minimum order quantities, and staged releases. Those rules are excluded here to isolate takeoff verification. An operational estimate should retain both unrounded design quantity and the transformed purchase quantity, with every allowance and rounding operation visible.

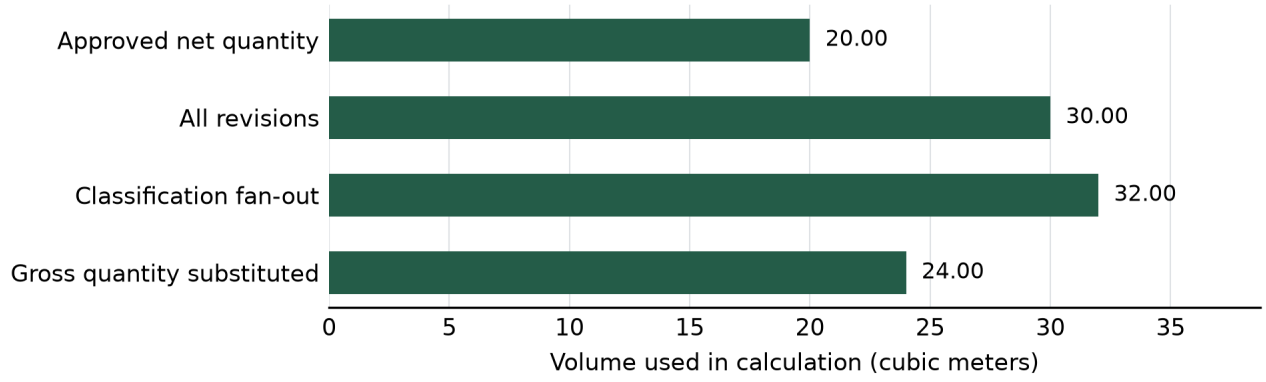


Figure 1. Computed volumes under four extraction conventions or faults. Values are from a synthetic ledger, not a project model.

5. Verification rules

5.1 Structural checks

The first check establishes the approved project snapshot and eligible elements. The second verifies that each selected physical element contributes once to the requested material quantity. The third checks the quantity's meaning and units. Only after those steps should classifications, costs, or document references be joined for reporting.

Automatic rule-based checking of building designs provides a broader context for formalizing such checks [11]. Information Delivery Specification offers a way to express computer-interpretable information requirements [12]. Neither reference implies that every required geometric or procurement rule can be expressed or validated by one standard mechanism. The implementation must state which checks it actually performs.

Table 3. Verification controls for a quantity extraction.

Check	Expected evidence	Exception
Snapshot consistency	Approved model-version set	Conflicting or unresolved revision
Contribution uniqueness	One selected quantity per element and role	Repeated element contribution
Quantity semantics	Net/gross and measurement rule	Ambiguous quantity field
Unit compatibility	Dimension and conversion	Incompatible or missing unit

Data-quality assessment should report excluded elements and their reasons [13]. Simply omitting elements without quantities can make a report appear clean while understating the total. If missing quantities prevent completeness, the result should be described as a partial takeoff with known coverage rather than a complete project quantity.

Remediation should distinguish modeling omissions, export defects, and extraction errors [14]. Each requires a different owner and corrective action. A spreadsheet adjustment to the total should not replace a traceable correction at the responsible stage.

A useful coverage measure reports the eligible elements with valid quantities as a fraction of all eligible elements, but this does not measure the fraction of material represented. One missing large slab can matter more than many small missing fixtures. The report should therefore show element coverage and, where defensible, a separate material-importance estimate or unresolved-quantity range. It should avoid assigning zero material to an element solely because its quantity property is absent.

6. Quantity verification and uncertainty

6.1 Quantity and partition checks

Selecting the approved records gives 12 + 8 = 20 cubic meters before allowance and pricing. Partitioning W1 into two nonoverlapping 6 cubic meter contributions gives 6 + 6 + 8 = 20 cubic meters, preserving the quantity. The partition check assumes the same material and measurement scope; overlapping geometric parts would violate that premise. A unit check must also preserve the represented volume: one cubic meter equals 1,000 liters, so the reference quantity is 20,000 liters.

These are metamorphic relationships between controlled input representations [15]. The explicit three-row ledger also provides a hand-checkable oracle [16]. Agreement with these cases establishes selected properties of the calculation, not correctness of all IFC files or modeling practices.

6.2 Scope of uncertainty

The synthetic net quantities are exact inputs. An actual geometry-derived volume can depend on dimensional tolerances, model detail, and conversion assumptions. An uncertainty model should distinguish uncertainty in measured dimensions from incompleteness or ambiguity of design information. The GUM provides a general framework for measurement uncertainty [17], but it does not turn a superseded revision into a probabilistic measurement error.

The 5% allowance is a procurement assumption and must not be presented as a statistical confidence interval. A project may use a policy allowance, a historical waste model, or a construction-method estimate; each has a different evidential basis. The verification report should make that basis explicit.

Verification and validation also differ [18]. The present analysis checks the quantities calculated from the stated element ledger. Validation would require checking the extraction and measurement convention against a real model and the estimating task. No such project-level comparison is reported, and no claim about commercial authoring or estimating software follows from this fixture.

The classification-fan-out test can be generalized by adding a new descriptive association to an existing element. Its material contribution should remain unchanged unless the requested population itself is defined by that association. For a filtered request, the test must specify whether the element is selected once when any association matches or contributes separately to an intentionally overlapping category report. A grouped report can legitimately repeat an element across categories while its grand total must still disclose overlap rather than add those category totals blindly.

7. Traceability and automated quantity reporting

7.1 Evidence record

A quantity report should link every contribution to its source element, model version, material role, selected property, and unit conversion. Provenance concepts provide a vocabulary for recording these derivations [19]. The purchase calculation should then link to the quantity report and a separate allowance-and-price record.

This separation allows an estimator to identify whether a changed purchase amount comes from design revision, corrected extraction, changed allowance, or changed price. Without it, a large difference between two reports may be incorrectly attributed to design growth. It also allows a supplier-facing summary to remain concise while preserving a detailed audit trail.

7.2 Generated database queries

ReToolSQL studies iterative verification and repair in text-to-SQL generation [20]. A related application could assist in querying an approved quantity ledger. Its execution-feedback approach does not determine which project revision is contractually applicable or whether a quantity is net, gross, or appropriate for a purchase request.

The proposed query interface should expose approved views whose identities and measurement meanings have been verified. Candidate queries should be checked for one-to-many joins that multiply quantities and for revision predicates that reproduce a consistent snapshot. A repair should not delete a record merely because its geometry or quantity matches another row.

The system should also separate a request for design volume from a request for ordered volume. If allowance or packaging rules are unspecified, they should be identified as missing assumptions. Automatically choosing a familiar percentage would conceal a decision that belongs to the estimating workflow.

This discussion motivates constraints for future reporting tools. The present study does not benchmark a language model, parse an IFC file, or measure the accuracy of automated construction estimating.

An approved revision change should generate a difference report with added, removed, and modified contributions. Comparing only the final total can hide compensating changes, such as removal of one large element and addition of several smaller ones. The same aggregate volume can therefore represent a substantially different design and procurement schedule. Retaining element-level differences supports review of material type, delivery timing, and package scope without requiring the total itself to change.

8. Discussion and conclusions

8.1 Findings and boundaries

The constructed results show that superseded revisions and descriptive joins can change material totals without changing the approved physical design. Applying an allowance and price propagates those errors into a purchase calculation. The magnitude in this fixture follows directly from the chosen quantities and is not an estimate of project risk.

The method assumes that net element quantities have already been extracted. It does not resolve intersecting solids, layered assemblies, temporary works, reinforcement laps, or contractual measurement exceptions. Those topics require additional domain rules and geometry-specific test cases. They should not be hidden inside a generic sum of volume properties.

8.2 Evaluation on project data

A field study should compare selected elements with an independently reviewed takeoff, documenting quantity conventions and model maturity. It should evaluate missing contributions as well as duplicates, and test whether a consistent approved snapshot can be reconstructed across federated models. Disagreements should be classified by identity, revision, geometry, semantics, or procurement transformation.

The study should also record the review effort needed to resolve exceptions. A high detection count is not necessarily useful if most exceptions are legitimate repeated elements or intended alternative quantities. A complete evaluation should include valid model variations and clearly defined acceptance criteria.

The procurement sensitivity is linear only under the simplified allowance-and-price model used here. Delivery rounding, tiered pricing, minimum quantities, and staged purchasing can produce discontinuous consequences. Those rules should be added as separately tested transformations when operationally relevant. The present calculation provides an auditable starting point: it identifies exactly which part of the purchase difference comes from a quantity-selection fault before introducing further commercial assumptions that could obscure that cause.

8.3 Conclusion

Reliable quantity takeoffs require explicit element identity, revision scope, quantity meaning, and units. Procurement allowances and prices should remain separate transformations. In the synthetic case, these distinctions prevent an approved 20 cubic meter quantity from becoming 30 or 32 cubic meters through record-processing errors.

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