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Research Paper

Integrated BIM 5D, PERT, and Earned Value Management for Cost-Schedule Planning and Performance Evaluation: A Government Building Case Study in Indonesia

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ABSTRACT: *Building Information Modeling (BIM) can improve quantity and cost traceability, but its practical value increases when model-based quantities are connected to uncertainty-aware scheduling and performance evaluation. This study develops and applies an integrated BIM 5D-PERT-EVM workflow to a two-story government building project in Malang Regency, Indonesia. Autodesk Revit 2025 was used for BIM 3D modeling and quantity take-off (QTO); non-modeled work items were calculated manually and explicitly identified. PERT durations were derived from optimistic, most likely, and pessimistic estimates provided by 10 construction experts and then scheduled in Microsoft Project. The PERT schedule produced an expected duration of 18.52 weeks compared with the contractor target of 18 weeks, with a 7.64% probability of meeting that target. QTO validation showed generally close concrete quantities but substantial sensitivity in reinforcement quantities, producing a 33.38% difference for the directly comparable Revit-based cost scope. The integrated cost baseline was Rp4.523 billion. At week 10, actual cumulative progress was 26.029% against 48.92% planned, giving SPI=0.53. Future periods were treated as forecasts rather than actual performance. The workflow demonstrates a traceable approach to integrated cost-schedule planning and makes schedule risk visible before project completion.*

KEYWORDS: *Building Information Modeling, Earned Value Management, PERT, project cost, project scheduling*

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I. INTRODUCTION

Construction projects require coordinated control of scope, quantities, cost, and time. When quantity take-off, cost estimation, and scheduling are developed in separate files, a design or quantity change may propagate inconsistently through the project-control system. Building Information Modeling (BIM) addresses part of this problem by linking geometric and non-geometric information in a digital model. BIM 3D can therefore support model-based quantity take-off, while BIM 5D extends the model to cost information and enables a more traceable relationship between design, quantity, and budget [1]-[3].

The benefits of BIM-based estimation do not imply that all quantities are automatically reliable. Model-based quantities remain dependent on model completeness, object definition, level of detail, measurement rules, and the treatment of temporary or process-related work. Previous studies have shown both productivity benefits and quantity discrepancies in BIM-based take-off, particularly when model detail and estimating rules are not aligned [2], [4]-[6]. Accordingly, practical BIM 5D implementation requires validation against project documents and transparent identification of items that remain outside the model.

Time planning introduces another uncertainty. Deterministic schedules commonly assign one duration to each activity, although construction productivity, weather, material availability, field conditions, and activity interfaces can change actual durations. The Program Evaluation and Review Technique (PERT) represents this uncertainty using optimistic, most-likely, and pessimistic duration estimates and converts them into expected activity durations and variances [8]. When these durations are combined with logical relationships in scheduling software, the result can be used to identify the critical path and quantify the probability of completing the project within a target duration.

Project performance evaluation additionally requires a consistent baseline and observed progress. Earned Value Management (EVM) integrates Planned Value (PV), Earned Value (EV), and Actual Cost (AC) to indicate schedule and cost performance [9]-[12]. However, EVM indices are only meaningful when values labeled as actual are based on observed data for the same reporting period. A forecast should not be interpreted as realized performance. This distinction becomes particularly important when only part of the project has actual field progress or cost records available.

This study applies a sequential, traceable workflow that links BIM 3D and QTO, PERT, Microsoft Project, BIM 5D, an S-curve baseline, and EVM-based performance evaluation on a government building project in Indonesia. The study contributes an integrated case-study workflow that explicitly distinguishes model-derived and manually calculated quantities, links probabilistic durations with the cost baseline, and separates observed performance from post-observation forecasts. The objectives are to: (1) evaluate BIM-based quantity and cost traceability, (2) quantify schedule uncertainty and critical-path risk using PERT, and (3) assess schedule performance during the available actual reporting period using EVM.

II. LITERATURE REVIEW

2.1 BIM 5D and quantity-cost integration

BIM enables digital representation of building elements and associated attributes throughout design and construction. For estimating, the core benefit is the ability to extract quantities directly from modeled objects and link those quantities to unit rates or cost databases [1]. Forgues et al. [2] emphasized that 5D BIM can restructure estimating workflows but also noted that missing model elements and non-modeled temporary work may reduce estimate completeness. Lu et al. [3] extended 5D BIM toward financial decision making by integrating time and cost information, illustrating the value of a connected information chain rather than isolated estimating outputs.

More recent research has reinforced the need for validation. Fazeli et al. [4] linked BIM quantity outputs with cost-estimation standards, while Han et al. [5] demonstrated the potential of model-based QTO for construction estimates. Kim et al. [6] showed that quantity discrepancies can arise from modeling detail, especially for building components whose measurement depends on how objects are represented. Systematic reviews further identify 5D BIM as a useful platform for cost management while highlighting interoperability, standardization, and information-governance limitations [7]. Therefore, BIM 5D should be treated as a traceable estimating system, not as an assumption that every extracted quantity is automatically correct.

2.2 Probabilistic scheduling and earned value control

PERT was originally developed to evaluate program schedules under uncertain activity durations [8]. Its three-time-estimate structure is useful when activity duration cannot be represented confidently by one deterministic value. In construction, expert judgment can provide the optimistic (a), most-likely (m), and pessimistic (b) inputs, after which expected duration and variance are calculated for each activity. The activity network then determines which uncertainty contributes directly to the project completion risk.

EVM provides a complementary control layer by comparing planned, earned, and actual values [9], [10]. The Schedule Performance Index (SPI=EV/PV) indicates schedule efficiency, while the Cost Performance Index (CPI=EV/AC) requires actual incurred cost data. Fleming and Koppelman [10] and Vanhoucke [11] emphasize that EVM is most useful when the baseline, progress measurement, and cost data are defined consistently. Research on index stability also shows that performance indicators may evolve during the project life cycle [12]. For that reason, the present study uses actual progress only for the period supported by contractor reports and labels later values as forecasts.

III. RESEARCH METHOD

3.1 Case project and research data

The case study is the Construction of the Malang Regency Public Prosecutor's Office Building in Kepanjen, East Java, Indonesia. The planned building consists of two floors with an approximate total floor area of 1,140 m². The project planning documents indicate an owner estimate (HPS) of Rp7,799,986,427.34 and an initial contractual duration of approximately 120 calendar days. The analytical scope of this paper is limited to the structural, architectural, and perimeter-fence work included in the study dataset; mechanical, electrical, plumbing, other utilities, and detailed site-development works are outside the cost-analysis scope.

The study used Detail Engineering Design (DED) drawings, project cost documents and unit prices, the contractor time schedule, weekly progress reports, and a PERT questionnaire. Ten respondents were selected purposively based on construction competence and experience. The panel comprised three design-consultant personnel, two supervision-consultant personnel, three technical-agency supervisors, and two contractor personnel; their construction experience ranged from 3 to 19 years. The software environment consisted of Autodesk Revit 2025 for BIM modeling and QTO, Microsoft Excel for data processing, and Microsoft Project for scheduling and critical-path identification. Actual field progress was available through week 10. The analytical workflow is shown in Fig. 1.

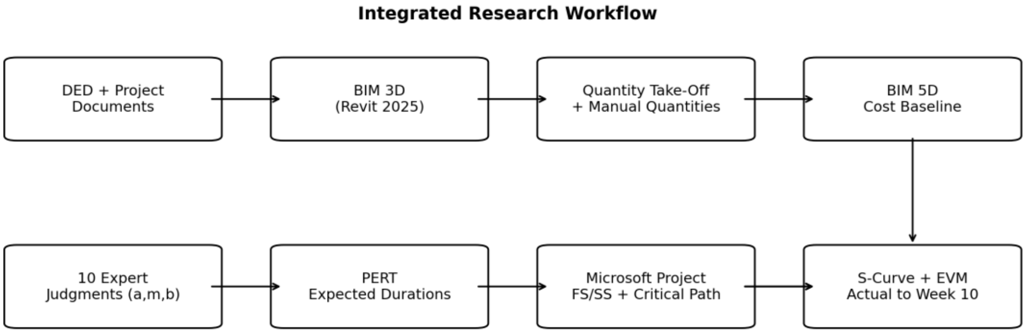

Fig. 1 Integrated research workflow.

3.2 BIM 3D modeling and quantity take-off

Structural and architectural elements were modeled parametrically from the DED, including foundations, columns, beams, slabs, stairs, roof structure, walls, doors, windows, floors, ceilings, and other relevant architectural components. Each object was assigned dimensions, elevation, position, material information, and element identity. QTO was generated using the Revit Schedule/Quantities feature. Items that were not explicitly represented by model objects, such as selected excavation, backfill, concrete vibration, formwork dismantling, and other process-based activities, were calculated manually from project drawings and specifications and labeled as manual quantities.

For cost validation, Revit quantities were aligned with comparable items in the contractor cost estimate. Identical unit prices were applied to both sides of the comparison so that the resulting cost difference reflected quantity differences rather than rate differences. This step was used to identify items requiring additional modeling or measurement review before the quantities were incorporated into the BIM 5D baseline.

3.3 PERT analysis and project scheduling

Each respondent estimated activity durations in weeks using three PERT parameters: optimistic duration a, most likely duration m, and pessimistic duration b. The mean values of the 10 respondents were used as the activity inputs. Expected time, variance, project standard deviation, and the target-completion Z-score were calculated as follows:

$$T_e = (a + 4m + b) / 6 \quad (1)$$

$$V = ((b - a) / 6)^2 \quad (2)$$

$$\sigma_p = \sqrt{(\Sigma V_i)} \text{ for activities on the critical path} \quad (3)$$

$$Z = (T_s - T_e) / \sigma_p \quad (4)$$

The expected duration T_e for each activity was entered in Microsoft Project. Finish-to-Start (FS) relationships were used for sequential work and Start-to-Start (SS) relationships were used where technical overlap was feasible. The resulting network provided start and finish dates, project duration, and the critical path. The total variance of critical activities was then used to estimate the probability of meeting the contractor target duration.

3.4 BIM 5D baseline, S-curve, and EVM

BIM 5D cost was obtained by multiplying validated quantities by project unit prices. Revit-derived and explicitly manual quantities were combined to obtain a complete analytical cost baseline for the defined scope. Each activity cost was converted to a weight relative to the Budget at Completion (BAC) and distributed across the PERT-based Microsoft Project schedule. Weekly weights were accumulated to form the planned S-curve.

$$PV\_i = BAC \text{ x planned cumulative progress\_i} \quad (5)$$

$$EV\_i = BAC \text{ x actual cumulative progress\_i} \quad (6)$$

$$SPI\_i = EV\_i / PV\_i \quad (7)$$

Observed EV was calculated only for weeks 1-10 because contractor progress data were available only through week 10. Weeks 11-19 in the thesis dataset were generated as proportional forecasts based on the remaining planned S-curve weight. These forecast values are not treated as actual project performance in this paper. A model-based AC series was also available, but it was generated from a cost-allocation assumption after separating overhead and profit rather than from a complete independent expenditure ledger. Consequently, CPI and EAC derived from that series are discussed only as scenario indicators, not as independent evidence of realized cost efficiency. This interpretation boundary was adopted to maintain consistency between the data source and the meaning of each EVM parameter.

IV. RESULTS AND DISCUSSION

4.1 BIM model and QTO traceability

The Revit model integrated the major structural elements from foundations to roof structure and provided a common digital source for quantity extraction. Fig. 2 shows the integrated structural model. Because the objects were parametrically defined, quantities could be regenerated after model changes without repeating the entire manual measurement process. This supports traceability between the drawing geometry, the modeled object, and the extracted quantity.

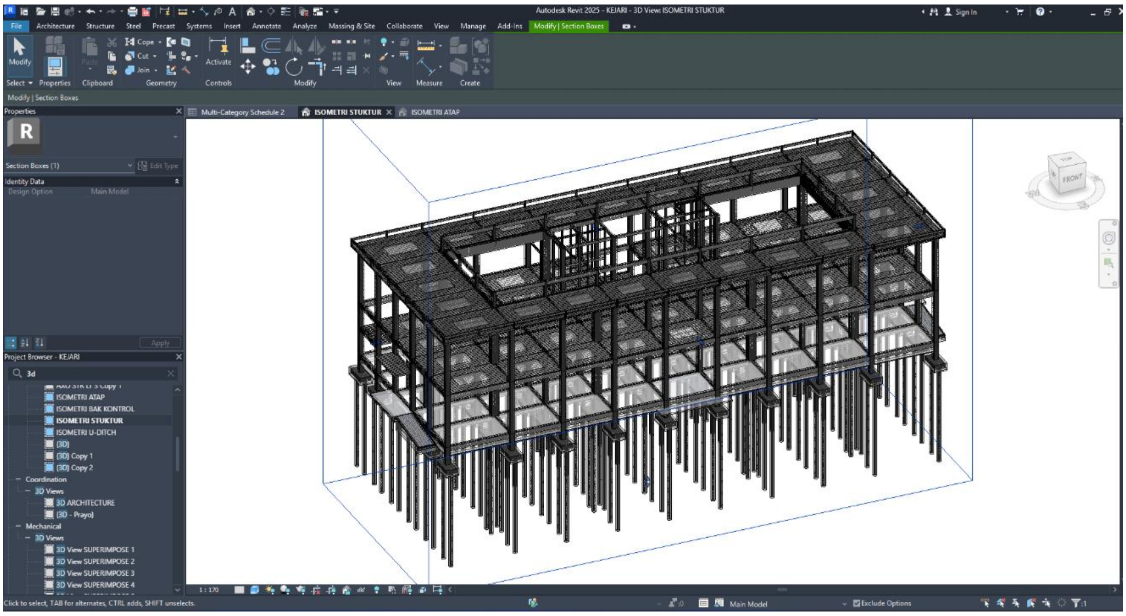

Fig. 2 Integrated structural BIM model developed in Autodesk Revit 2025.

A simple foundation example illustrates the model-to-quantity link. Revit produced 11.560 m³ of concrete for pile cap PC1 and 49.372 m³ for pile cap PC2. The corresponding contractor quantities were 11.60 m³ and 49.40 m³, respectively. The differences for these concrete items were small, supporting the use of object-based QTO for directly modeled geometric quantities. The same conclusion cannot be generalized automatically to reinforcement or non-modeled process items, which require separate validation.

Table 1 Example of BIM-Based QTO Validation for Pile Cap Concrete

Item	Revit QTO (m³)	Contractor quantity (m³)	Absolute difference (m³)
Pile cap PC1 concrete	11.560	11.60	0.040
Pile cap PC2 concrete	49.372	49.40	0.028

4.2 PERT schedule, critical path, and completion probability

The PERT-based schedule started on 2 September 2025 and finished on 8 January 2026, corresponding to an expected project duration of 18.52 weeks. The contractor schedule targeted 18 weeks and finished on 30 December 2025. Thus, the PERT schedule was approximately 0.52 week, or about four calendar days, longer than the deterministic target. The difference is small in absolute duration but significant probabilistically because the target lies below the expected PERT duration.

Microsoft Project identified five critical activities. Their variances are summarized in Table 2. The sum of the critical-path variances was 0.131419, producing a project standard deviation of 0.3625 week. For an 18-week target, the calculated Z-score was -1.43 and the corresponding probability of completing within the target was 7.64%. The result indicates that the 18-week target was relatively optimistic under the uncertainty represented by the expert judgments.

Table 2 Critical-Path Activities and PERT Variances

Critical activity	Variance (week²)
Strauss pile drilling	0.041344
Half-brick masonry (1:5 cement-sand mortar)	0.014003
15-mm plastering (1:5 cement-sand mortar)	0.034844
Wall skim coating	0.023003
Exterior wall painting	0.018225
Total variance	0.131419

4.3 BIM 5D cost integration and QTO validation

The cost analysis produced two related but distinct results. First, directly comparable modeled structural and architectural quantities were evaluated against the reorganized contractor estimate using the same unit prices. The Revit-based amount for this directly modeled comparison was Rp2,926,927,772.82, compared with Rp4,393,612,592.53 in the contractor estimate. The difference was Rp1,466,684,819.71, or 33.38% of the contractor amount. Detailed review showed that the largest discrepancies were concentrated in structural reinforcement quantities, while most concrete and architectural quantities were comparatively close.

Second, the complete analytical baseline combined Revit quantities with explicitly identified manual quantities and included the structural, architectural, and perimeter-fence scope used for scheduling and EVM. This integrated BAC was Rp4,522,525,758.45. The two totals should not be interpreted as alternative estimates of the same scope: the Rp2.927 billion amount represents the directly modeled comparison subset, whereas the Rp4.523 billion BAC includes manual/non-modeled items and the full analytical scope. This distinction is essential because an apparently large difference can otherwise be misinterpreted as a BIM “saving” when it actually reflects different quantity sources and scope composition.

Table 3 Summary of Cost Results and Interpretation

Cost indicator	Value (Rp)	Interpretation
Revit-based comparable modeled scope	2,926,927,772.82	Model-derived structure and architecture items
Contractor RAB for comparable scope	4,393,612,592.53	Comparison basis using the same unit prices
Difference	1,466,684,819.71 (33.38%)	Mainly associated with reinforcement quantity differences
Integrated BAC	4,522,525,758.45	BIM + manual quantities for analysis scope including fence

These findings are consistent with prior BIM-QTO research: automation improves repeatability, but the extracted quantity is only as dependable as the modeled object definition and measurement logic [5], [6], [13], [14]. Reinforcement is particularly sensitive to detailing assumptions because small changes in bar layout, hook length, lap treatment, or modeled coverage can create large cumulative mass differences. A robust BIM 5D workflow should therefore retain an audit trail showing which quantity came from the model, which was calculated manually, and which requires validation before cost loading.

4.4 Observed schedule performance through week 10

The planned S-curve based on the PERT schedule reached 48.92% cumulative progress by week 10. Contractor reports showed actual cumulative progress of 26.029% at the same reporting point. Fig. 3 shows the increasing gap between planned and actual progress over the observed period. Using the integrated BAC, week-10 PV was Rp2,212,419,601.03 and EV was Rp1,177,168,229.67. The resulting SPI was 0.532, rounded to 0.53. Because SPI is below 1.00, the project was materially behind the PERT-based cost-loaded baseline at week 10.

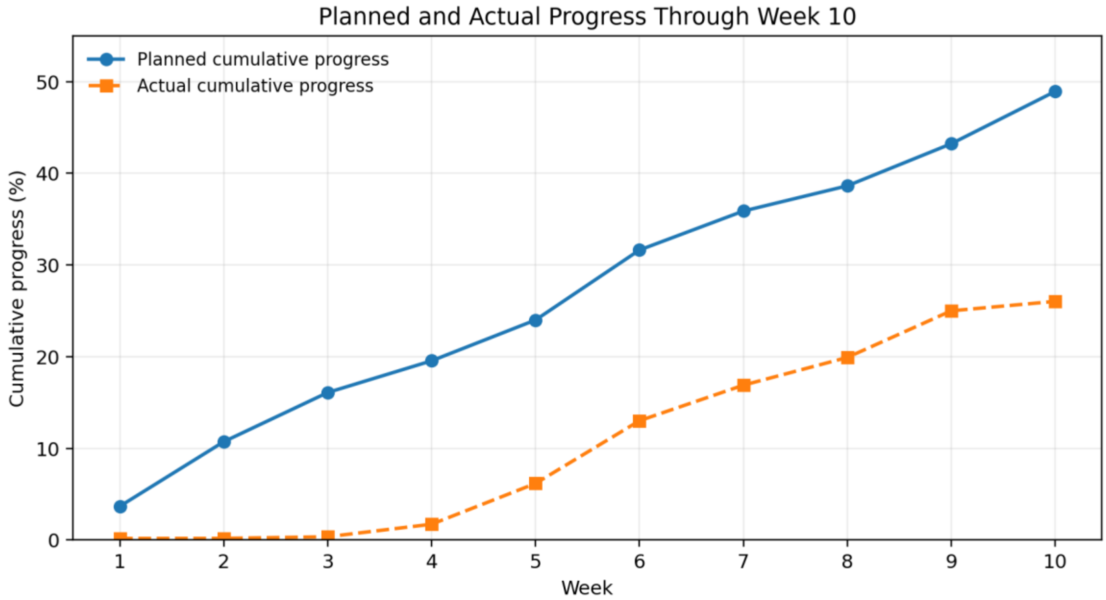

Fig. 3 Planned and actual cumulative progress through week 10.

Table 4 Week-10 EVM Status and Data Interpretation

Parameter	Week-10 value	Status / interpretation
Planned cumulative progress	48.92%	Baseline from PERT-BIM 5D S-curve
Actual cumulative progress	26.029%	Observed contractor progress
Planned Value (PV)	Rp2,212,419,601.03	Planned budgeted value
Earned Value (EV)	Rp1,177,168,229.67	Budgeted value of completed work
Schedule Performance Index	0.53	Behind schedule (SPI < 1.00)
Modeled AC scenario	Rp1,070,152,936.06	Derived cost-allocation series; not an independent ledger
Modeled CPI scenario	1.10	Scenario indicator; interpreted cautiously

The cost scenario in Table 4 requires a different interpretation from the schedule result. The model-based AC series generated a CPI of about 1.10, but this ratio remained nearly constant because AC was constructed after excluding an assumed overhead-and-profit component from the value of work. Therefore, the CPI cannot be used as independent evidence that actual project expenditure was 10% more efficient than the earned value. A reviewer or project manager should require an observed AC ledger for the same reporting period before making a realized cost-performance claim. This limitation is not a weakness of EVM itself; it is a data-governance issue. EVM is strongest when PV, EV, and AC all refer to the same scope, period, and measurement basis [9]-[12].

For weeks 11-19, the study dataset projected the remaining progress proportionally using the planned S-curve distribution until cumulative progress reached 100%. Those values are useful as a forecast scenario for visualizing a possible completion path, but they do not prove that the project later recovered to SPI=1.00. The distinction between observed and forecast periods prevents future scenarios from being reported as historical performance and improves the reproducibility of the analysis.

4.5 Implications for integrated project controls

The case study indicates that the main value of integration is traceability across decisions. A quantity extracted from Revit can be traced to a model object; a manually calculated item can be distinguished from a modeled item; each cost can be assigned to a scheduled activity; PERT exposes the uncertainty underlying that activity duration; and EVM compares the resulting baseline with observed field progress. This chain makes it easier to identify whether a deviation originates in modeling, measurement, scheduling logic, or actual execution.

For public building projects, this approach can support preconstruction validation and early control. The low 7.64% probability of meeting the 18-week target provides a schedule-risk signal before interpreting actual progress, while the week-10 SPI of 0.53 confirms that the observed execution was substantially behind the integrated baseline at that date. At the same time, the reinforcement discrepancy shows why automated QTO should be verified rather than accepted without checking. The combined lesson is that digital integration should reduce information fragmentation without removing engineering judgment.

V. CONCLUSION

This study applied an integrated BIM 5D, PERT, Microsoft Project, S-curve, and EVM workflow to a two-story government building project in Malang Regency, Indonesia. BIM 3D provided a structured source for QTO and cost linking, while manual quantities were retained transparently for work items that were not explicitly modeled. Concrete quantities from Revit showed close agreement with the contractor estimate in the illustrated foundation items, but the directly comparable modeled cost scope differed by 33.38%, mainly because of reinforcement quantity differences. This confirms that BIM-based automation supports traceability but does not remove the need for quantity validation.

PERT produced an expected duration of 18.52 weeks compared with the contractor target of 18 weeks. Five activities formed the critical path, the project standard deviation was 0.3625 week, and the calculated probability of completing within 18 weeks was only 7.64%. The result indicates that the contractor target was optimistic relative to the uncertainty captured from 10 expert judgments.

The integrated BAC for the analytical scope was Rp4,522,525,758.45. At week 10, observed cumulative progress was 26.029% compared with 48.92% planned, yielding SPI=0.53 and confirming a substantial schedule delay at the observation date. Later weeks were forecasts and were therefore not used as evidence of realized recovery. Similarly, the available AC series was derived from a modeled cost allocation; its CPI of approximately 1.10 should be treated as a scenario indicator rather than independent proof of actual cost efficiency.

The practical advantage of the workflow is the ability to connect model objects, quantities, unit prices, uncertain durations, activity logic, baseline weights, and observed progress in one auditable chain. Its limitations are the single-project case design, the use of 10 expert judgments for PERT, the exclusion of detailed MEP and site-development costs, the absence of resource optimization, and the availability of actual progress only through week 10. Future research should validate the workflow with complete actual-cost ledgers and multi-project data, and should test automated model-to-schedule linking for real-time 4D/5D control.

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