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A Comparative Study of Quantity and Scheduling Using 4D BIM and Conventional Methods in Column, Beam, and Slab Construction

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ABSTRACT

Deficiencies in the conceptualization and assessment of construction scheduling frameworks may disrupt project execution continuity, which in turn compromises procedural coherence and operational efficiency. Accurate and detailed material quantity planning is essential for ensuring precise resource forecasting and developing efficient, reliable construction schedules. This research investigates the influence of methodological selection on the accuracy and efficiency of construction planning, with a particular focus on material quantification and scheduling performance within a comparative framework. The methodological approach undertaken involves quantity surveying practices using two modeling-based techniques, namely CAD-Revit and CAD-Conventional. Construction shop drawings serve as the primary data source, with material quantities derived from each method forming the basis for schedule development. This process culminates in the integration of 4D Building Information Modeling to facilitate temporal visualization of construction sequences, supporting a more comprehensive evaluation of the implications of each quantity derivation method on project planning accuracy. Comparative analysis revealed notable variations in material quantities between the two methods, with the CAD-Revit approach demonstrating enhanced efficiency in the utilization of concrete, rebar, and formwork. These disparities were also reflected in the scheduling results, where the 4D BIM methodology produced divergent progress timelines across different building levels, with the Revit-based schedule completing the project 21 days earlier.

Keywords: BIM, Quantity, Deviation, Scheduling

1. INTRODUCTION

A construction project underpinned by comprehensive digital planning can be regarded as effectively executed when its temporal, financial, and methodological dimensions align with the intended physical trajectory and procedural implementation logic (Stylianou et al., 2016). In particular, the planning, scheduling, and cost estimation phases require careful consideration to avoid work conflicts and ensure cost efficiency throughout the construction process (Hamledari et al., 2017).

Sheikhkhoshkar et al. (2019) reported that the critical path for concrete works remains suboptimal due to design limitations. Furthermore, operational constraints during the pouring of concrete lead to inefficient time extensions, indicating a gap between design knowledge and on-site execution. Therefore, the procedure for measuring construction progress is crucial as a project control tool that provides information to detect performance deviations and take corrective actions to prevent or minimize their impact (Han et al., 2015).

Building Information Modelling (BIM) represents a knowledge-based approach to construction management, integrating digital design with data-driven

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processes (Chegu et al., 2019). Its epistemological strength lies in its ability to visualize and communicate construction information through accurate graphical models, enhancing cognitive clarity and evidence-based decision making across all project phases (Gong et al., 2019). On another note, BIM integrates all disciplines and materials through a virtual model in both planning and execution, subsequently increasing knowledge management to enable the efficient coordination of BIM multi-project (Sampaio et al., 2023). The visualization of construction materials significantly influences quantity takeoff accuracy by enhancing the analysis of material requirements, thereby improving the precision of material estimation (Aprillia et al., 2024).

BIM 4D can be used to dynamically detect time-space conflicts through the integration of secondary planning data, while enhancing operational efficiency and ensuring precise coordination of resource activities (Mirzaei et al., 2018). Implementing the BIM 4D methodology also positively impacts the enhancement of Knowledge Management (KM) over the course of the project lifecycle (Utama et al., 2024). Moreover, the BIM 4D method enables real-time updates of construction schedules by reducing reliance on manual processes by integrating as-built and as-planned data via 3D point cloud, providing project managers with critical real-time schedule information (Son et al., 2017). Also, BIM 4D develops construction knowledge objectively by integrating digital data simulations to link physical building components with the construction schedule, enabling empirical validation of design effectiveness in terms of time schedule (Aziz et al., 2024).

In the case study project, BIM 4D can visualize and estimate the appropriate work stages for the reconstruction phase, while improving work efficiency (Alzarrad et al., 2021). BIM 4D supports fundamental scheduling optimization and enables the implementation of constraint-based simulation techniques to assess the feasibility of four alternative structural component methods for high-rise building construction in Iran (Hadavi et al., 2018).

Despite the demonstrated advantages and capabilities of the BIM 4D method in optimizing construction scheduling, its implementation remains limited by several inherent challenges and methodological constraints. However, the manual and complex data input process remains a significant challenge in its implementation (Doukari et al., 2022). Compared to conventional manual methods, the development of construction schedules using BIM 4D demands more time, primarily due to its dependence on comprehensive data integration and the use of model-driven planning processes, which are essential for achieving higher levels of accuracy and coordination (Candelario et al., 2017). Continuous updates to the digital models of all structural components are required to maintain alignment between planning documents and actual construction progress. However, the high demands on time and labor resources associated with this process have contributed to the reluctance of many contractors to adopt the BIM method (Lopez et al., 2016).

The knowledge base surrounding BIM methodology is inherently fluid, constantly evolving in alignment with technological progress and the complexities of business practices and construction protocols, which fosters a more conservative approach to resolving case study issues (Liang et al., 2016). Mitigating these limitations necessitates the implementation of a methodologically rigorous BIM 4D framework capable of generating integrated and detailed construction scheduling data. However, the effectiveness of such an approach is highly dependent on

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foundational proficiency in BIM utilization, highlighting the critical importance of technical maturity for its successful deployment.

Based on existing literature, a critical evaluation is necessary to clarify the fundamental performance differences between BIM and conventional methodologies in construction scheduling and quantity takeoff. This study aims to identify the key factors contributing to the discrepancies in outputs produced by both approaches, with particular emphasis on the accuracy of material quantity estimation and the reliability of scheduling data. Additionally, the research seeks to quantify and analyze the extent of deviations in material quantities and project durations arising from the implementation of BIM in comparison to conventional methods.

2. LITERATURE REVIEW

High-rise Building Construction Management

Executing construction projects requires a carefully calibrated integration of procedural planning and structural intent, where managerial and physical systems evolve in parallel as interconnected layers of project execution. Allocations of time, budget, and physical space are not static decisions but are continuously adjusted in response to shifting performance demands (Syamsuir et al., 2023). In this context, the structural form should not be seen as a collection of isolated components but as a responsive system shaped by subsurface conditions and spatial constraints. These interdependent systems, while distinct in spatial layout, function convergently. Foundational depths and vertical extensions follow a unified logic of structural stability and functional serviceability, expressing both geotechnical realities and architectural needs through material choices and project management practices (Haryati et al., 2021).

Structure Material Quantity

A material quantity dataset is essential for determining the scope of construction work within a specified unit of measurement. It plays a critical role in multiple areas, including cost estimation, cost control, procurement planning, and construction scheduling (Khosakitchalert et al., 2019). These quantities are obtained by systematically interpreting project components, tailored to meet the specific requirements of individual construction activities as outlined in the Bill of Quantities (BOQ). This process forms the foundation for integrating resource planning with cost and time management strategies across the project lifecycle.

Building Information Modeling

BIM is a multifaceted representation of a construction project, wherein an interconnected framework of databases and software tools underpins advanced 3D visualization and project information management. These digital ecosystems facilitate the management, synthesis, and dissemination of information throughout the entire lifecycle of a building or infrastructure project, enabling dynamic interaction with evolving project data. BIM is a pivotal enabler in optimizing the efficiency and coordination of construction processes, while fostering a

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comprehensive understanding of the project's performance metrics across various stages (Sacks et al., 2018).

Work Breakdown Structure

The sequence of structural work based on the Work Breakdown Structure (WBS) to ensure that construction implementation methods remain systematically organized. This approach significantly influences decision-making processes related to delays or schedule adjustments during reviews conducted through the integration of the 3D model within the 4D BIM environment (Heigermoser et al., 2019). The WBS serves as a foundational framework that integrates construction methodology with the logical sequencing of structural components (Park et al., 2017).

3. RESEARCH METHODOLOGY

This study is based on real project data obtained from the construction of a multistory hotel located in a central urban area of East Java. The research focuses on a comparative analysis of scheduling durations for structural building components ranging from the basement and 1st floor up to the 8th floor, as illustrated in **Figure 1**.

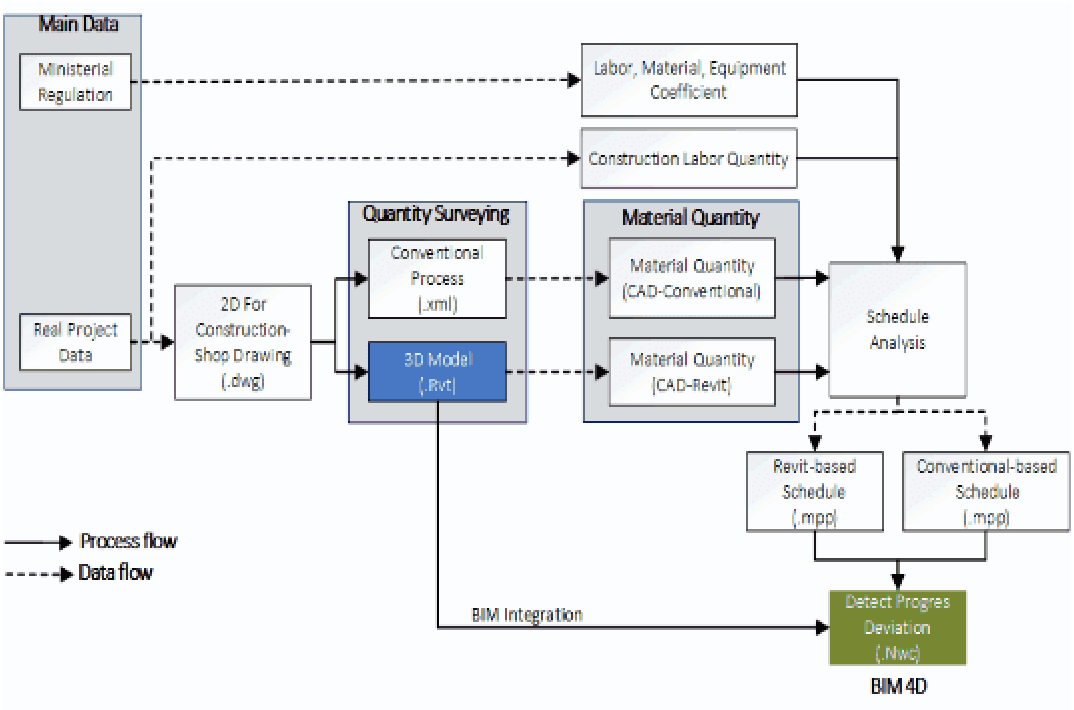

Figure 1. Proposed data flow and system for material quantity and scheduling

Main Data

The real project data primarily consist of construction drawings (for construction-shop drawings), which serve as the primary reference for both methods in quantifying material quantities, as shown in Table 1. In addition, construction labor quantity data are used as one of the determining factors in

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estimating task durations. Complementing these, the regulatory data include labor productivity coefficients stipulated in the relevant ministerial regulations (Indonesia, 2023).

Table 1. Labor allocation and coefficient for each structural task item

Task item	Labor coefficient (man-day unit)	Structure component	Labor quantity (people)
Rebar installation	0.007	Beam & slab	8
		Column	6
Formwork installation	0.100	Beam & slab	10
		Column	4
Concrete casting	0.330	Beam & slab	6
		Column	3

Quantity Surveying

The process of determining material quantities for structural components is conducted using two distinct methods. Firstly, the CAD-Conventional method involves manually computing material quantities in Microsoft Excel, using data extracted from 2D construction drawings.

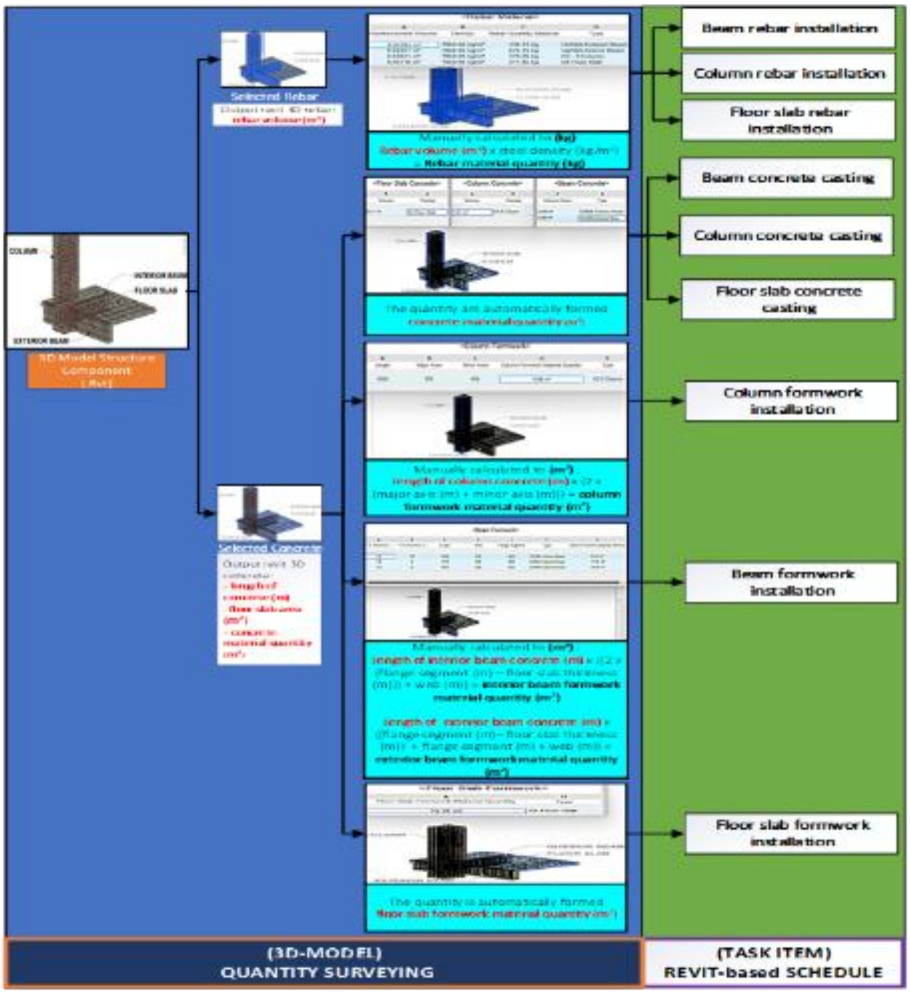

Figure 2. Workflow illustrating the transformation of a 3D BIM model into task item Revit-based schedule components via quantity surveying procedures

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The second method adopts a BIM-integrated workflow utilizing CAD-Revit, as illustrated in Figure 2. Material quantification is inherently linked to the parametric modeling environment. Volumetric data for both concrete and rebar are computed directly from embedded geometric attributes, facilitating efficient data extraction without additional computational processes. Formwork requirements for beams and columns are inferred through geometric analysis, while slab elements inherently provide surface area values. The associative nature of the model ensures that modifications to cross-sectional dimensions or member lengths are automatically propagated throughout the system. This preserves data consistency and enables iterative refinement during the design process.

Scheduling Analysis

The scheduling process begins with estimating the duration of each construction task across structural components, based on a quantitative relationship derived from Equation (1). This relationship incorporates labor productivity and material quantity as key factors influencing task duration.

$$Task\ duration = \frac{labor\ coefficient \times material\ quantity}{labor\ quantity} \qquad (1)$$

The duration calculation yields two outputs from CAD-Revit and CAD-Conventional. These outputs are integrated into the WBS for scheduling, and the resulting schedules are then managed using Microsoft Project.

4. RESULTS AND DISCUSSION

This section explains how integrating 3D modeling into conventional construction workflows, followed by the transition to a 4D BIM system, leads to a new way of understanding and managing project schedules. The shift moves from static drawings to dynamic simulations that integrate temporal and spatial data, allowing time-related aspects to be built into the construction sequence. Using 4D BIM makes it possible to analyze project phases more accurately and uncover hidden connections between construction activities and their schedules. This improvement increases the accuracy of scheduling and helps project teams make better, more informed decisions.

Material Quantity

Discrepancies in material estimations based on two-dimensional construction drawings often arise from differences in how geometric data is interpreted and processed. These subtle differences arise from the distinct assumptions, measurement techniques, and interpretive approaches applied in the surveying process. The resulting uncertainty highlights the complex relationship between the data itself and the methodologies used to transform it into material projections. Therefore, the accuracy of material estimations is intricately linked to the alignment and consistency of the interpretive processes employed, suggesting that methodological coherence is essential to reduce discrepancies and improve the reliability of cost forecasts.

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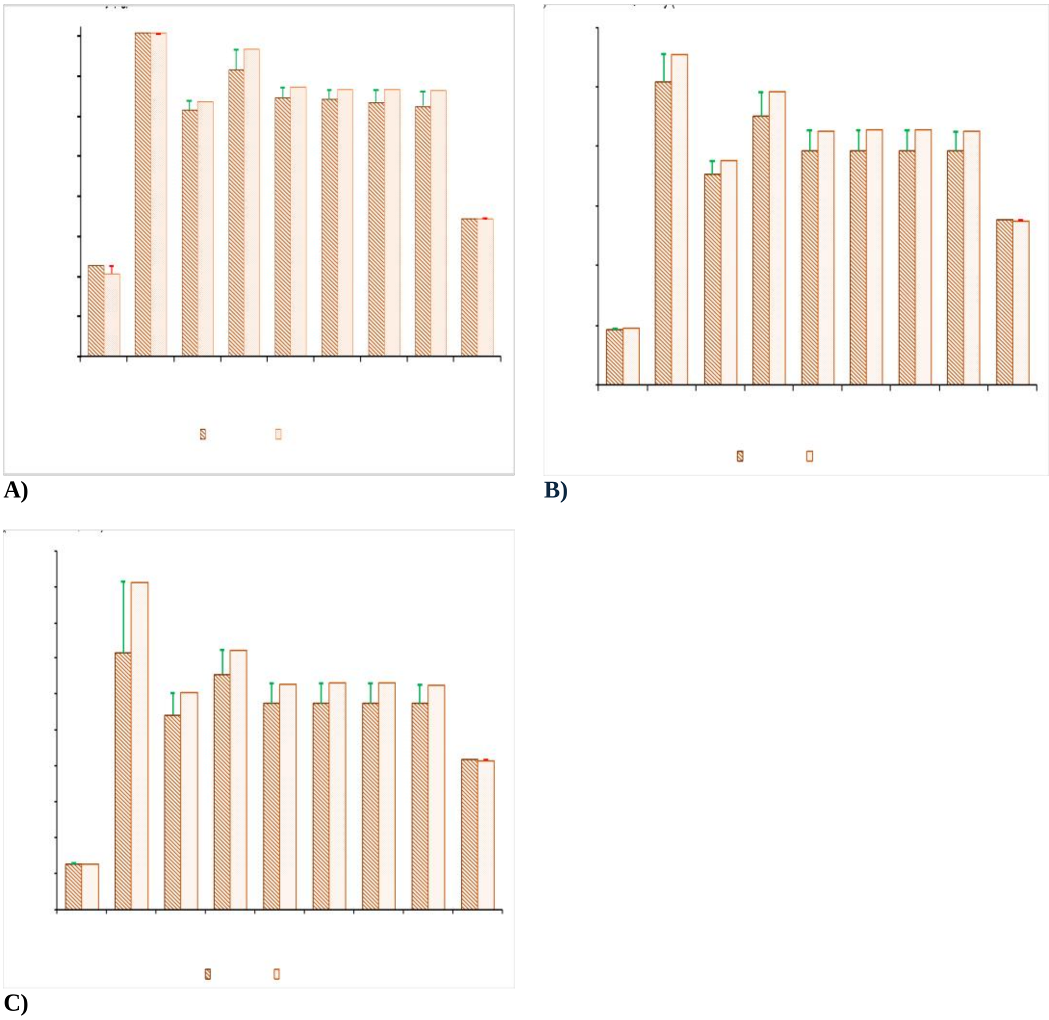

Figure 3. Deviation-based comparative of material quantities between CAD-Revit and CAD-Conventional methods: A) rebar material quantity; B) concrete material quantity; C) formwork material quantity.

The variations shown in Figure 3, highlight differences in the quantities of rebar, formwork, and concrete materials, resulting from the enhanced geometric precision enabled by advanced 3D modeling techniques. In this context, the need for distinct material breakdowns is reduced, as the inherent spatial alignment and functional relationships between structural components implicitly define their interconnectedness. This simplification is particularly evident in model-based digital workflows, such as those facilitated by Revit, where the quantification of formwork is directly linked to the geometry of the concrete due to their dimensional compatibility, especially in linear measurements. As a result, integrating digital methodologies facilitates the translation of design geometry into material estimations. This integration helps minimize discrepancies and enhances the consistency between the visual representation of the structure and the calculated material quantities. This further accentuates the potential of digital tools in ensuring more accurate, aligned, and efficient material quantification throughout the project lifecycle.

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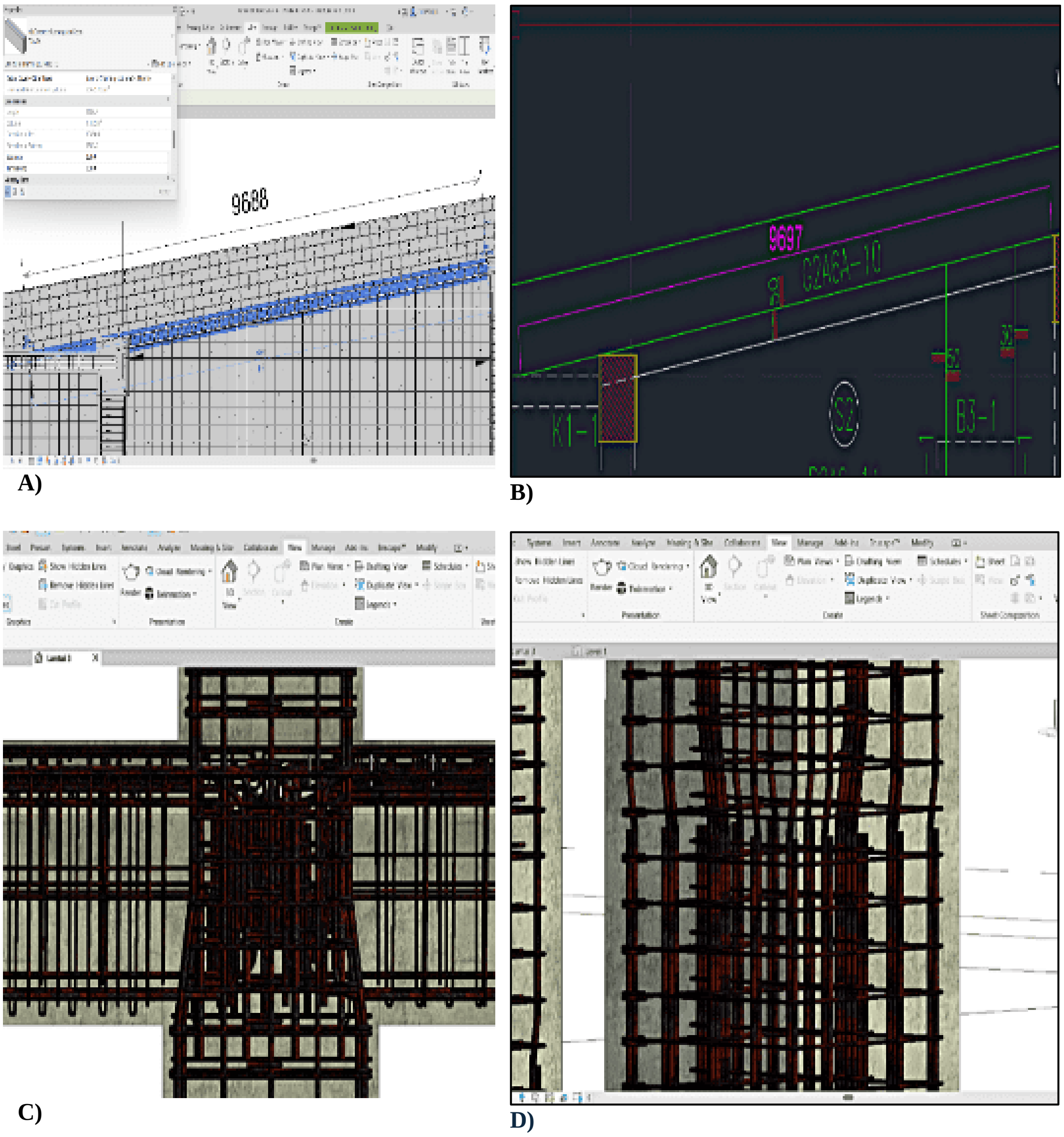

Figure 4. Two primary factors contributing to discrepancies in material quantities: A) and B) variations in clear span measurement for beams; C) and D) differences in the detailing of longitudinal column rebar within beam-column joint regions and lap splices located at mid-height of the columns.

In the case of beam elements, span length discrepancies arise due to diagonal intersections with columns, necessitating meticulous measurement in CAD-Conventional methods. As illustrated in Figure 4, CAD-Revit streamlines this process by allowing direct placement of beam elements along predefined structural axes, which in turn reduces manual geometric interpretation. These span differences subsequently influence the estimated quantities of formwork and rebar. Rebar quantity variations also arise in columns with reduced cross-sections on upper floors, where bars require bending at a 1:6 diagonal angle to ensure proper anchorage. While such detailing is intricate to measure precisely using CAD-conventional methods due to the complexity of bar bending and incremental stirrup adjustments, CAD-Revit modeling enables accurate visualization and quantification of these geometries.

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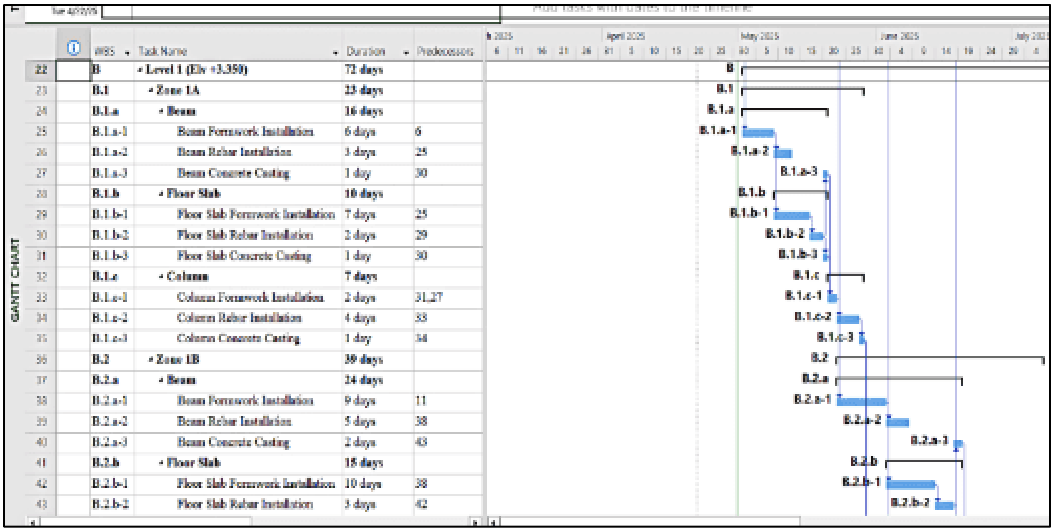
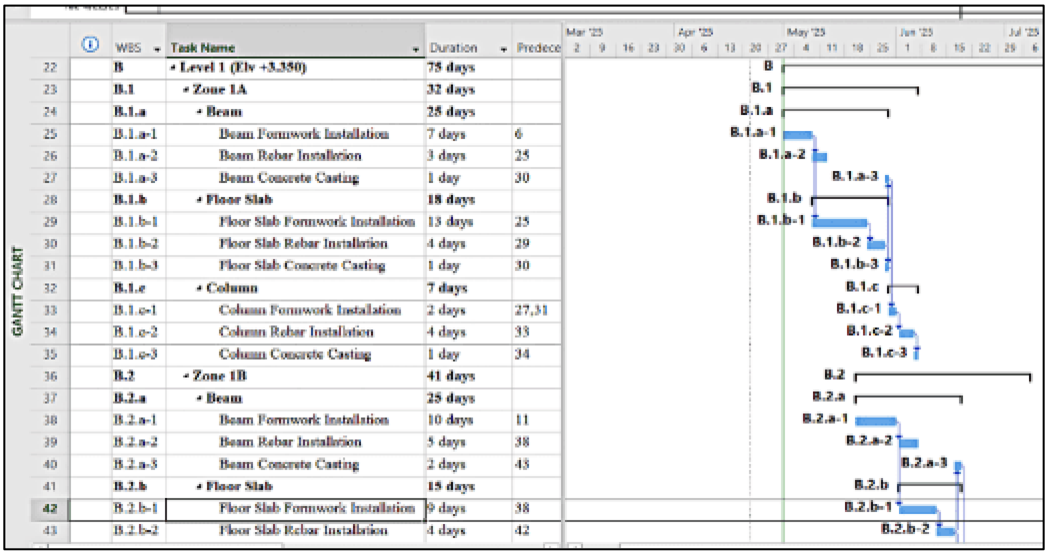
Development of Systematic Construction Schedules

The derivation of task durations for primary structural elements, formulated through both conventional CAD-Conventional and CAD-Revit workflows as depicted in Figure 5, was subsequently embedded within a structured scheduling environment. This integration into a hierarchical WBS within Microsoft Project enabled the temporal coordination of construction activities to reflect methodological assumptions and quantified material data.



A)



B)

Figure 5. Results of developed schedule based on the WBS: A) Revit-based schedule; B) Conventional-based schedule

The codification of the WBS adopts a four-tier hierarchical schema, abstracting the structural system spatial and functional dimensions into sequential identifiers. Using a systematic alphanumeric logic, the framework encapsulates a bottom-up stratification that aligns with the principles of construction sequencing in vertical building systems.

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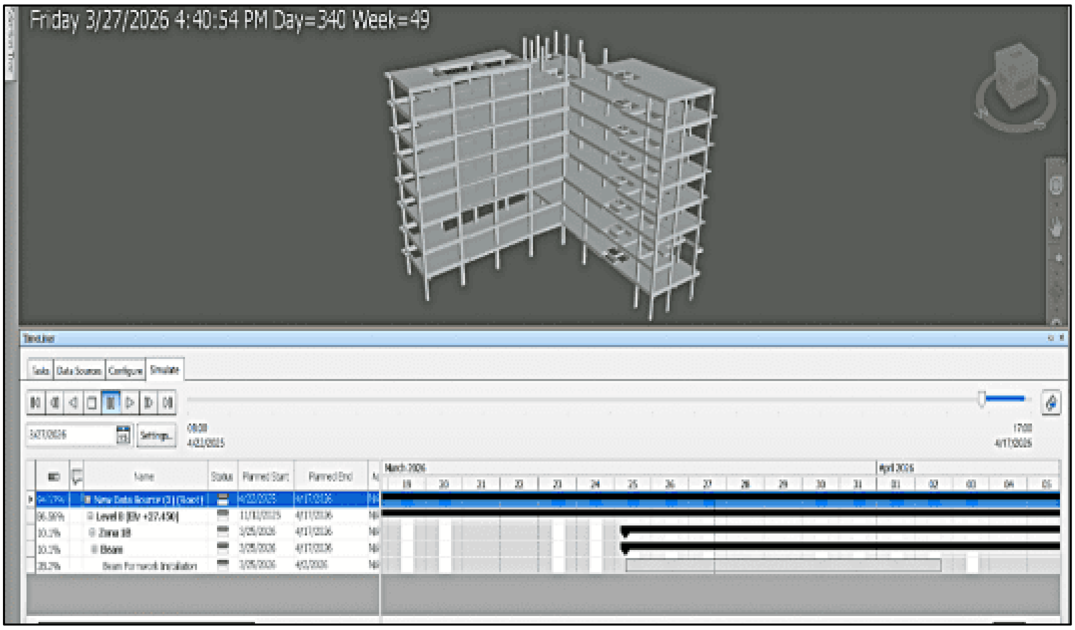
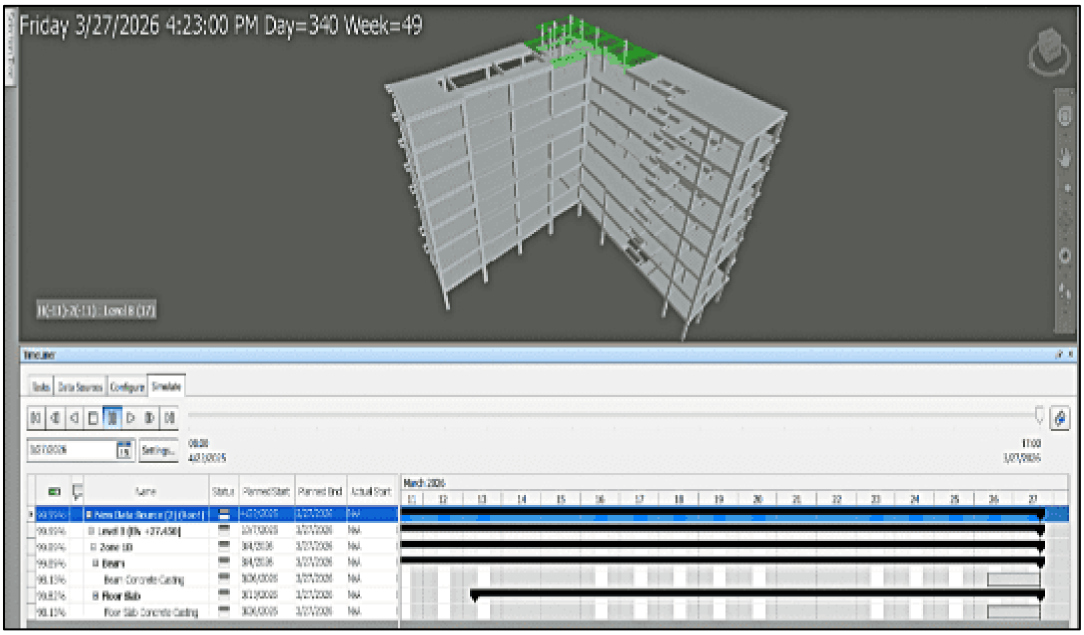
Detect Progress Deviation

The 4D BIM method, with its capability to perform deviation analysis, was utilized to compare the extent of differences in scheduling outcomes and to specifically evaluate the variance in project duration produced by the developed schedules.



A)



B)

Figure 6. Construction progress comparison on day 340 indicates that: A) Conventional-based schedule remained in the beam formwork installation phase; B) Revit-based schedule had reached full completion progress.

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By examining the scheduling visualizations, as shown in Figure 6, it is evident that the two methods exhibit different durations in completing the structural work for a single level.

Table 2. Recapitulation of structural work duration

Material quantity data source	Structural work completion duration (day-)								
	Basement 1	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8
CAD-Revit	57	94	119	162	200	239	277	316	340
CAD-Conventional	53	96	121	170	211	253	295	337	361
Deviation	7.5%	-2.1%	-1.6%	-4.7%	-5.2%	-5.5%	-6.1%	-6.2%	-5.8%

A discernible deviation was identified between the Revit-based schedule derived from material quantities generated through the CAD-Revit method and the Conventional-based schedule formulated from quantities obtained via the CAD-Conventional approach. This variance highlights those substantial disparities in material quantification significantly influence the resulting duration estimations, thereby affirming the critical role of quantity derivation methodologies in shaping the accuracy and reliability of construction scheduling outcomes. The magnitude and pattern of these scheduling deviations are presented in Table 2, which illustrates the temporal divergence across structural elements and construction levels between the two methodological frameworks.

5. CONCLUSION

The material quantity estimates generated from both the CAD-Revit and CAD-Conventional methodologies for structural components, including beams, columns, and floor slabs from basement 1 through to level 8, exhibited measurable variability. These discrepancies are predominantly attributable to two key factors: errors in the dimensional data extraction of structural elements and insufficient precision in reinforcement quantification, particularly in areas requiring specialized bending treatments. Although the construction of structural columns commenced concurrently for both methods at the basement level 1, their respective project timelines diverged significantly due to variations in material quantity outputs, which directly impacted labor productivity and daily work rates. These disparities were further manifested in the scheduling results, where the 4D BIM methodology presented divergent progress timelines across different building levels, with the Revit-based schedule completing the project 21 days earlier. Therefore, a comprehensive assessment of quantity derivation methodologies is essential, as deviations in material estimates substantially impact cost control, time management, and the overall alignment of construction outcomes with design specifications.

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