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FRAMEWORK FOR INTEGRATING 4D/5D BIM, SCAN TO BIM, AND EVM FOR ENHANCED DELIVERY PERFORMANCE

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Abstract

Infrastructure projects frequently experience cost overruns and schedule delays due to fragmented design, planning, and cost management practices. This study presents a techno-managerial implementation of 5D Building Information Modeling (BIM) for infrastructure projects by integrating 3D models with time and cost data through a standardized workflow. The proposed framework employs BIM platform as a unified 5D BIM platform for integrating quantities, schedules, costs, and cash flow analysis. Embedding EVM within the model and visualizing results through a Power BI dashboard enabled reliable, real-time performance monitoring. Scan-to-BIM–based progress verification further improved data accuracy, leading to enhanced cost certainty, forecasting reliability, and informed decision-making in infrastructure projects.

Keywords: 5D BIM implementation; 4D/5D BIM workflow; Cost and schedule integration; Scan-to-BIM; Project digitalization.

1. INTRODUCTION

Infrastructure projects form the backbone of modern economies, enabling mobility, energy distribution, industrial growth, and public services. Despite their importance, such projects are widely recognized as difficult to plan and deliver efficiently. Their complexity arises from large physical scale, long implementation periods, involvement of multiple disciplines, and the need to coordinate numerous stakeholders [1-2]. In addition, construction activities often take place in changing site conditions, while design requirements continue to evolve during execution. These factors contribute to frequent coordination issues, schedule slippage, budget overruns, and rework in infrastructure projects [3-4]. Conventional project delivery approaches continue to rely heavily on 2D drawings, separate construction schedules, and independent cost documents. Although familiar to practitioners, these methods provide limited support for managing the growing volume and interdependency of project information [5-6]. Design, time, and cost data are typically produced in isolation, making it difficult to identify inconsistencies at an early stage. When design changes occur, updates to schedules and cost estimates are often delayed or incomplete, resulting in unreliable forecasts and reactive decision-making [7-8]. Moreover, the lack of a shared digital information environment restricts effective collaboration and timely communication among project participants [9-10]. Building Information Modeling (BIM) has gained attention as a digital approach capable of addressing these shortcomings. By integrating geometric and non-geometric information within a single digital model, BIM provides a shared data environment that supports collaboration throughout the project lifecycle [11-12]. Previous studies have shown that BIM improves information consistency, coordination among disciplines, and overall project transparency [3–5]. As a result, BIM adoption has increased steadily in infrastructure projects, supported by both industry demand and institutional initiatives [13,14]. The application of 3D BIM has significantly improved spatial understanding and coordination by allowing stakeholders to visualize complex geometries and interfaces more clearly [15-16]. Automated clash detection enables early identification of spatial conflicts, reducing design errors and construction rework. However, 3D BIM mainly offers a static representation of the project and does not fully capture how construction activities evolve over time or how costs change during execution [17-18]. To overcome these limitations, BIM has been extended to include additional dimensions, leading to the development of 4D and 5D BIM. 4D BIM links construction schedules with model elements, enabling simulation of construction activities over time. This capability allows project teams to explore construction sequences, assess constructability, and communicate planning strategies more effectively before work begins [19-20]. This study examines the application of an integrated Scan-to-BIM-based 4D and 5D BIM framework for infrastructure projects, with the objective of evaluating its potential to improve coordination, planning accuracy, and cost control.

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2. RESEARCH METHODOLOGY

Design and Case Study

This research adopts a quantitative, case-study-based methodology to develop, implement, and validate an integrated Scan-to-BIM–based 4D and 5D framework for construction progress and cost performance monitoring in infrastructure projects. A quantitative approach is selected to enable objective measurement of schedule and cost performance using Earned Value Management (EVM) metrics, while the case study strategy allows in-depth investigation of the proposed framework within a realistic project environment. Each phase builds upon the outputs of the previous phase, forming a continuous digital workflow that integrates planning, execution, verification, and performance visualization. The proposed methodology is demonstrated using a sample infrastructure project, such as a highway interchange, flyover, or large-scale transportation asset. The selected case represents a typical infrastructure environment characterized by (a) Multiple construction packages and work fronts (b) Complex sequencing and phasing requirements (c) High dependency between civil, structural, and finishing works (d) Significant cost and schedule sensitivity. The project scope includes earthworks, substructure, superstructure, and associated infrastructure elements, making it suitable for testing time- and cost-based BIM applications. The availability of a structured construction schedule, cost data, and access to site scanning facilities is assumed for the purpose of framework validation.

4D Construction Simulation

To incorporate the time dimension, a detailed construction schedule is developed in Primavera P6, including a structured Work Breakdown Structure (WBS) aligned with the BIM model hierarchy. Activities are sequenced logically, considering construction methods, dependencies, and resource constraints as shown in Fig. 1.

The schedule is then imported into Autodesk Navisworks, where individual activities are linked to corresponding 3D model elements. This linkage enables the creation of a 4D construction simulation, allowing visualization of construction sequencing over time as shown in Figure 2. The 4D model supports:

- Validation of construction logic and phasing
- Identification of sequencing conflicts
- Improved understanding of site logistics and work interfaces
- Planned Vs Actual visualization (Status of project).
- Project Forecast
- Critical activities to highlight (colour coding)
- Highlight delay activities and impact of delay on project deadline
- Supporting planning team to prepare catchup plan
- Most importantly reviewing the project schedule (4D visualization) and supporting planning team for schedule optimization

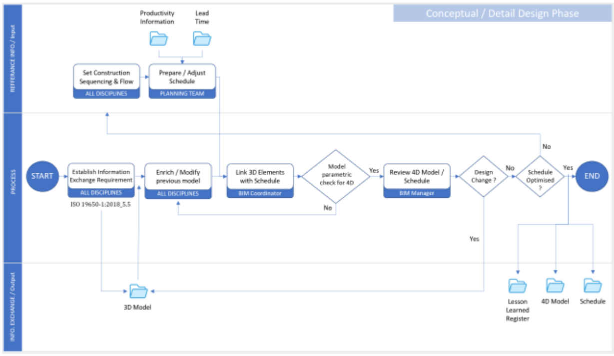

Figure 1 Conceptual/ Detail Design Phase 4D Implementation Procedure

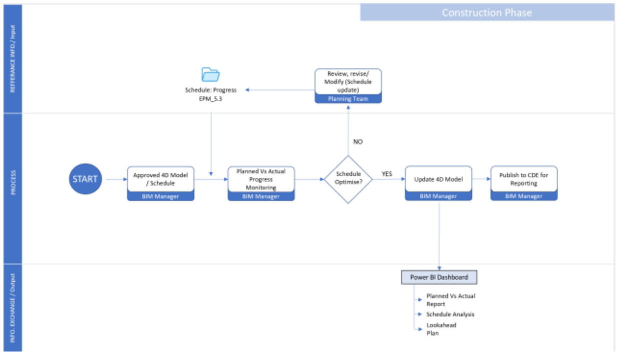

Figure 2 Construction Phase 4D Implementation Procedure

5D Cost Integration

In the final step of Phase 1, cost data are integrated with the 4D model to create a complete 5D BIM environment. Cost information is derived from estimation software or structured spreadsheets and includes quantities, unit rates, and activity-level budgets. Each cost item is assigned to corresponding model elements or construction activities as shown in Figure 3.

The resulting 5D model represents the Performance Measurement Baseline (PMB), containing planned values for scope, schedule, and cost. This baseline provides a reliable reference for progress tracking, earned value calculations, and performance forecasting (Fig. 4).

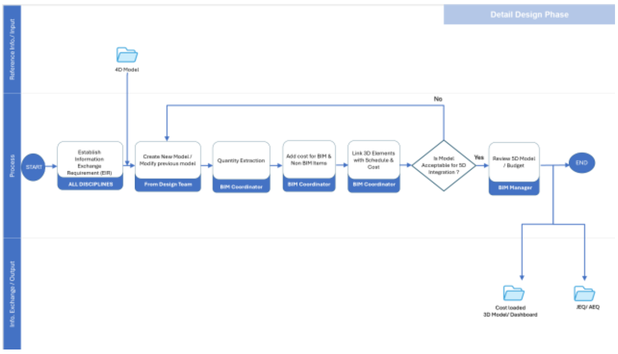

Figure 3 Detail Design Phase 5D Implementation Procedure

3. RESULTS AND DISCUSSION

This section presents the results obtained from the implementation of the proposed 5D BIM–integrated dashboard framework on a selected infrastructure project model. The results are evaluated against the study's defined aim and objectives, directly addressing the identified gaps in cost control, coordination, digitalization, and decision-making.

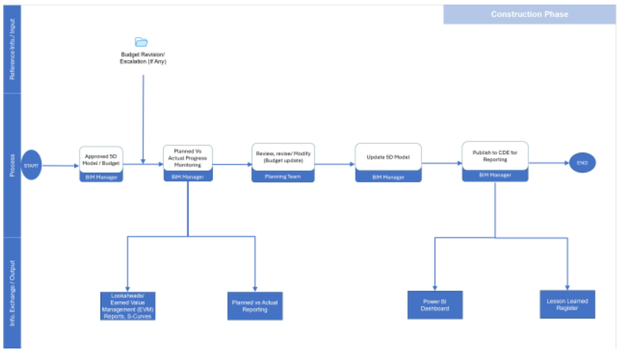

Figure 4 Construction Phase 5D Implementation Procedure

Addressing the Study's Identified Needs

The results demonstrate that the proposed 5D BIM-integrated dashboard, incorporating Scan-to-BIM and Earned Value Management, provides an effective digital framework for infrastructure project control. Implementation on an integrated project model confirmed the framework's ability to enhance cost control, schedule monitoring, coordination, and data-driven decision-making. Figure 5 illustrates deviation identification through a comparative analysis between the Scan-to-BIM model and the original design model, highlighting the framework's capability to support accurate progress validation and corrective decision-making. These findings support the broader adoption of 5D BIM methodologies in infrastructure projects.

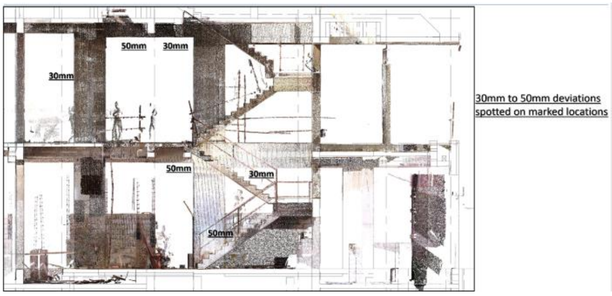

Figure 5 Deviation identification by comparing Scan to BIM model & design

The Role of 4D BIM in Schedule Integration and Construction Planning

Integrating the construction schedule with the 3D BIM model to create a 4D BIM environment proved instrumental in enhancing the visualization and comprehension of construction sequencing. The time-based simulation revealed activity dependencies and potential scheduling conflicts that are often obscured in conventional bar charts or network diagrams. By providing a dynamic visual representation of how the project unfolds over time, the 4D model enabled proactive identification of constructability issues before they materialized on site. These outcomes demonstrate that 4D BIM improves construction planning, enhances communication among stakeholders, and strengthens schedule reliability. The visual clarity offered by 4D simulation is particularly valuable in infrastructure projects, where activities are spatially dispersed and highly interdependent. In such contexts, 4D BIM serves as a critical tool for reducing coordination gaps and mitigating schedule-related risks as shown in Table 1.

Table 1 Traditional Scheduling vs. 4D BIM-Based Scheduling

Aspect	Traditional Scheduling	4D BIM-Based Scheduling
Visualization	2D Gantt charts, limited spatial context	3D time-animated model with spatial clarity
Clash Detection	Manual identification, time-consuming	Automated visual detection of conflicts
Stakeholder Communication	Technical expertise required to interpret	Intuitive visual understanding for all parties
Constructability Analysis	Reactive, identified during execution	Proactive, identified during planning phase
Update Frequency	Periodic (weekly/monthly)	Real-time or near real-time
Coordination Efficiency	Moderate, prone to misinterpretation	High, shared visual reference point

Enhancing Cost Control Through 5d Bim Integration

Extending the 4D model into a 5D BIM environment established a direct linkage between model elements, construction activities, and cost data. This integration shifted cost management from a periodic, manual task to a continuous, automated process. The framework enabled real-time monitoring of expenditures relative to construction progress, providing greater transparency and control throughout the project lifecycle. By creating a reliable Performance Measurement Baseline (PMB), the 5D model ensured that Planned Value was accurately captured, and budget allocations remained aligned with the defined scope. This capability addresses the persistent challenge of cost overruns associated with fragmented design, scheduling, and costing workflows. Embedding financial information within the spatial and temporal context of the project supports more informed and timely decision-making, transforming cost management into a proactive, data-driven process rather than a reactive exercise as shown in Table 2.

Table 2 Advantages of 5D BIM Over Traditional Cost Management

Cost Management Activity	Traditional Approach	5D BIM Approach	Improvement
Quantity Take-off	Manual measurement from 2D drawings	Automated extraction from BIM model	70-85% time reduction
Cost Estimation	Spreadsheet-based, disconnected from design	Directly linked to model elements	Improved accuracy and consistency
Budget Tracking	Periodic manual updates	Continuous automated updates	Real-time visibility
Cost Forecasting	Based on historical trends	Data-driven, progress-integrated	Enhanced predictive accuracy
Stakeholder Reporting	Static reports, delayed distribution	Interactive dashboards, instant access	Improved transparency

Scan-to-BIM for Objective Construction Verification

The implementation of Scan-to-BIM techniques introduced a higher level of objectivity and precision into construction progress verification. Unlike traditional monitoring, which relies on subjective visual inspections and manual reporting, laser scanning captured detailed as-built conditions that could be systematically compared against the as-planned 5D model. This enabled accurate identification of completed and pending work elements. The approach reduced the risk of over-reporting or under-reporting progress, which often distorts performance metrics and weakens project control. For infrastructure projects, where site conditions are dynamic and deviations from plans are frequent, Scan-to-BIM proved essential for maintaining alignment between planned and executed work as shown in Table 3. The verified data also provided a reliable basis for Earned Value calculations, strengthening the credibility and accuracy of the performance monitoring system as shown in Figure 6.

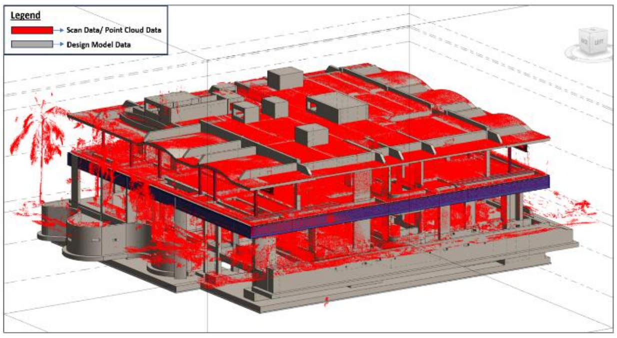

Figure 6 Overlapping point cloud data with design model

Table 3 Scan-to-BIM Progress Verification Accuracy Metrics

Metric	Manual Verification	Scan-to-BIM Verification	Accuracy Improvement
Geometric Accuracy	(+/-)50-100 mm	(+/-)5-10 mm	~90% improvement
Progress Reporting Time	3-5 days per cycle	1-2 days per cycle	40-60% reduction
Data Objectivity	Subjective, inspector-dependent	Objective, measurement-based	Eliminates human bias
Deviation Detection	Qualitative description	Quantitative volumetric analysis	Measurable precision
Documentation Quality	Photo-based, limited coverage	Complete 3D as-built record	Comprehensive verification
Rework Identification	Reactive, post-execution	Proactive, early detection	Reduces rework costs

BIM-Integrated Earned Value Management for Performance Monitoring

Integrating Earned Value Management (EVM) within the BIM framework substantially strengthened the analytical rigor of the proposed system. By deriving Earned Value (EV) from Scan-to-BIM-verified quantities and Planned Value (PV) from the 5D BIM baseline, the framework ensured that EVM metrics were grounded in both physical progress and approved project plans. This integration eliminated common inconsistencies that arise when data sources are disconnected or manually reconciled. The calculated Schedule Performance Index (SPI) and Cost Performance Index (CPI) provided meaningful, quantitative indicators of project health, enabling early detection of performance deviations. Managers could identify emerging problems—such as schedule slippage or budget overruns—while corrective actions were still feasible. This proactive capability contrasts sharply with conventional EVM implementations, which often suffer from delayed reporting and unreliable data sources. The findings reinforce the growing body of research advocating for BIM-EVM integration to improve the reliability, timeliness, and actionability of project performance monitoring as shown in Table 4.

Table 4 Sample EVM Performance Data from Case Study Implementation

Week	Planned Value (PV)	Earned Value (EV)	Actual Cost (AC)	SPI	CPI	Performance Status
Week 4	₹ 25,00,000	₹ 24,00,000	₹ 24,50,000	0.96	0.98	Slight schedule delay
Week 8	₹ 52,00,000	₹ 51,00,000	₹ 52,50,000	0.98	0.97	Minor cost overrun
Week 12	₹ 80,00,000	₹ 82,00,000	₹ 81,50,000	1.03	1.01	Ahead of schedule
Week 16	₹ 1,15,00,000	₹ 1,14,00,000	₹ 1,16,00,000	0.99	0.98	On track
Week 20	₹ 1,50,00,000	₹ 1,52,00,000	₹ 1,51,00,000	1.01	1.01	Optimal performance

4. CONCLUSION

This research demonstrated the development and implementation of a BIM-integrated digital framework combining 4D BIM, 5D BIM, Scan-to-BIM, Earned Value Management (EVM), and dashboard-based visualization for infrastructure projects. The primary objective of enabling effective 5D BIM implementation through an integrated dashboard with EVM was achieved on a representative infrastructure model. Integration of 4D BIM improved construction planning by visualizing sequences and clarifying activity dependencies, supporting proactive schedule management. Extending the model to 5D BIM linked cost data directly with model elements and scheduled activities, enhancing cost transparency, budget tracking, and forecasting accuracy. This approach effectively addressed the inefficiencies and cost overruns common in traditional, fragmented project management practices. Incorporating Scan-to-BIM provided an objective and reliable method for verifying construction progress, reducing subjectivity and ensuring alignment between planned and actual conditions. Coupling verified progress with EVM enabled accurate derivation of performance indicators, such as SPI and CPI, strengthening the reliability of project performance assessment.

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