Integrating 6D BIM in Unity: A Comprehensive Framework for Construction Visualization, Analytics, and Risk Management

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A B S T R A C T

Construction projects increasingly demand integrated digital solutions that combine geometric modeling with temporal, cost, and risk dimensions. This study presents a comprehensive 6D Building Information Modeling (BIM) framework developed in Unity that integrates automated phase detection, construction scheduling (4D), cost management (5D), and advanced risk analytics (6D). The framework comprises five interconnected modules: (1) AutoPhaseDetector for intelligent classification of building components; (2) ConstructionProgressManager for timeline-based 4D visualization; (3) ExcelExporter for structured reporting; (4) ConstructionAnalyticsSystem for predictive analytics, critical path analysis, and resource optimization; and (5) Construction3DDashboard for real-time floating visualization of construction metrics. Applied to a seven-story reinforced concrete building case study, the system demonstrated automated sequencing across 29 construction phases, predictive delay analysis with 95% classification accuracy, real-time risk assessment identifying high-priority bottlenecks, and comprehensive cost tracking across structural, architectural, and MEP installations. The integrated framework reduces manual scheduling effort by approximately 85%, provides stakeholders with interactive 3D analytics dashboards, and establishes a foundation for IoT integration and machine learning extensions. This research advances the state of digital construction by demonstrating how game engine technology can serve as a unified platform for multi-dimensional BIM implementation.

1. Introduction

Construction projects represent complex systems involving interdependent activities, multiple stakeholders, extensive resource coordination, and significant financial investments. Traditional project management approaches have relied on disparate tools for scheduling, cost estimation, and risk assessment, creating fragmented workflows that impede real-time decision-making and stakeholder communication [1–3]. While Building Information Modeling (BIM) has revolutionized how projects are designed and visualized, its practical implementation often remains limited to 3D geometric representation, with temporal (4D), cost (5D), and risk management (6D) dimensions handled through separate software platforms [4,5].

The concept of multi-dimensional BIM has evolved significantly over the past decade. 4D BIM links 3D models with construction schedules to visualize project progression over time [6,7]. 5D BIM extends this by integrating cost data, enabling dynamic cost tracking and budget management throughout the project lifecycle [8,9]. More recently, 6D BIM has emerged as a paradigm that incorporates facilities management, sustainability analysis, or—as explored in this research—comprehensive risk analytics and project intelligence [10,11].

Despite these conceptual advances, several critical gaps persist in current practice. First, existing 6D implementations typically require multiple software platforms (for instance, Revit for modeling, Navisworks for 4D simulation, Primavera for scheduling, and custom tools for analytics), resulting in data fragmentation and workflow inefficiencies [12,13]. Second, risk assessment in construction projects remains predominantly qualitative and manual, lacking integration with real-time project data and predictive analytics capabilities [14,15]. Third, visualization tools rarely provide interactive, real-time dashboards that synthesize information across all six dimensions in an accessible format for diverse stakeholders [16,17].

Recent research has explored automation in phase classification [18], predictive analytics for construction delays [19,20], and the application of game engines for BIM visualization [21,22]. However, no comprehensive framework has successfully integrated automated phase detection, predictive risk analytics, real-time cost tracking, and interactive 3D visualization within a unified environment. This integration is critical because construction decision-making inherently requires

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simultaneous consideration of temporal sequences, budget constraints, and risk factors [23,24].

This study addresses existing gaps by developing a Unity-based 6D BIM framework that integrates five core modules into a unified and interactive system. The AutoPhaseDetector module automates the classification of building components into construction phases using rule-based algorithms, ensuring accurate sequencing of activities. The ConstructionProgressManager provides timeline-driven 4D visualization with dynamic fade-in rendering to illustrate the progression of work. The ExcelExporter module enables comprehensive reporting for schedules, costs, and progress tracking, facilitating efficient data management. The ConstructionAnalyticsSystem delivers advanced predictive analytics, including critical path analysis, resource optimization, delay probability assessment, and risk scoring, enhancing decision-making capabilities. Finally, the Construction3DDashboard offers a floating 3D interface that visualizes real-time project metrics, risk indicators, and performance analytics, creating a cohesive and data-driven environment for construction monitoring and control.

The framework is validated through a case study of a seven-story reinforced concrete building containing over 7,000 objects across structural, architectural, and MEP disciplines. Results demonstrate the system's capability to automate phase detection with 95% accuracy, generate predictive delay probabilities, identify resource bottlenecks, calculate critical path sequences, and provide stakeholders with interactive analytics dashboards—all within a single integrated environment.

This research contributes to the field of digital construction in three key ways. First, it introduces a methodological innovation by demonstrating how game engine technology can function as a unified platform for multi-dimensional BIM, eliminating reliance on fragmented software ecosystems. Second, it achieves predictive analytics integration by embedding automated risk assessment and delay prediction algorithms directly within the 4D visualization environment, thereby supporting proactive project management. Third, it advances interactive visualization through the implementation of floating 3D dashboards that synthesize temporal, cost, and risk information in real time, offering an immersive and intuitive approach to construction analytics and decision support.

The remainder of this paper is organized as follows: Section 2 reviews relevant literature on multi-dimensional BIM, construction analytics, and game engine applications. Section 3 describes the system architecture and module integration. Section 4 details the methodology for phase detection, scheduling logic, and analytics algorithms. Section 5 presents the implementation approach. Section 6 applies the framework to the case study. Section 7 discusses results, limitations, and implications. Section 8 concludes with future research directions.

2. Literature Review

2.1. Evolution from 3D to 6D BIM

Traditional Construction Management has relied on two-dimensional drawings and separate scheduling documents, creating disconnection between design intent and construction execution [25]. The introduction of 3D BIM provided geometric clarity but lacked temporal context [26].

4D BIM emerged in the early 2000s as researchers recognized the value of linking construction schedules to 3D models [27,28]. Koo and Fischer [6] demonstrated that 4D CAD could improve communication and reduce conflicts in commercial construction. However, their work identified significant barriers including the manual effort required to link model elements to schedule activities—a limitation that persists in many current implementations [29,30].

5D BIM extends temporal simulation by integrating cost data, enabling quantity takeoffs, budget tracking, and cost forecasting throughout project phases [31,32]. Research by Ma and Liu [8] showed that 5D BIM could reduce cost estimation time by 40% and improve accuracy by detecting quantity discrepancies early. Despite these benefits, adoption remains limited due to the complexity of integrating cost databases with geometric models [33,34].

6D BIM represents the most recent evolution, though its definition varies across literature. Some researchers define 6D as sustainability analysis [10], others as facilities management [35], and still others—as adopted in this study—as comprehensive project intelligence incorporating risk analytics, resource optimization, and predictive modeling [11,36]. This study adopts the latter definition, positioning 6D BIM as an analytical layer that transforms construction data into actionable insights through algorithms for delay prediction, critical path analysis, and risk assessment.

2.2. Construction Risk Management and Predictive Analytics

Traditional risk management in construction relies on qualitative methods such as risk matrices, expert judgment, and historical data analysis [37,38]. While systematic, these approaches suffer from subjectivity and inability to adapt to real-time project conditions [39].

Recent research has explored quantitative risk assessment using statistical methods and machine learning. Kim et al. [40] developed a Bayesian network for predicting construction delays based on project characteristics, achieving 78% prediction accuracy. Gondia et al. [19] applied machine learning algorithms to forecast cost overruns, demonstrating that random forests outperformed traditional regression models. However, these studies typically operate on completed project datasets rather than integrating with live BIM models [41,42].

The integration of predictive analytics with BIM visualization remains underdeveloped. Ding et al. [20] proposed a framework for linking schedule risk analysis with 4D models but required manual data exchange between risk analysis software and visualization platforms. This study advances the field by embedding predictive algorithms directly within the visualization environment, enabling real-time risk updates as project parameters change [43,44].

2.3. Critical Path Method and Resource Optimization

The Critical Path Method (CPM) has been fundamental to construction scheduling since its development in the 1950s [45]. CPM identifies the longest sequence of dependent activities, providing insight into which tasks directly impact project duration [46]. Despite its theoretical robustness, practical application faces challenges: schedules often become outdated as projects evolve, manual updates are time-consuming, and visualization of critical paths within 3D models remains rare [47,48].

Resource leveling and optimization have been addressed through operations research techniques [49,50]. However, these methods typically operate on abstract schedule networks disconnected from spatial geometry. Recent studies have explored linking resource analysis with BIM models [51], but comprehensive frameworks integrating resource allocation, critical path analysis, and 3D visualization remain scarce [52,53].

2.4. Game Engines in Construction Visualization

Game engines such as Unity and Unreal Engine offer real-time rendering, physics simulation, and interactive capabilities that surpass traditional BIM viewers [54,55]. Early applications focused primarily on virtual reality walkthroughs and design reviews [56,57].

Recent research has begun exploring game engines for construction management. Sampaio [21] demonstrated Unity's potential for construction education through interactive simulations. Pedro et al. [22] developed a framework integrating safety management with 4D BIM in Unity, showing improved hazard identification. However, these studies have not fully exploited game engines' capabilities for data analytics, automated classification, or multi-dimensional BIM integration [58,59].

2.5. Visualization Dashboards for Construction Management

Dashboard visualization has proven effective in various industries for synthesizing complex data into actionable insights [60,61]. In construction, dashboards typically exist as 2D web or desktop applications displaying Gantt charts, cost curves, and KPI metrics [62,63]. Three-dimensional dashboards integrated within BIM environments are rare, despite their potential to provide spatial context for performance metrics [64,65].

Research on augmented reality (AR) and mixed reality (MR) for construction has explored overlaying information on physical environments [66,67], but these approaches require specialized hardware and do not provide comprehensive analytics integration [68].

2.6. Research Gaps

Literature review reveals four critical gaps:

1. Fragmented Workflows: Multi-dimensional BIM implementations require multiple software platforms with manual data exchange, creating inefficiencies and opportunities for error [69,70].
2. Limited Analytics Integration: Predictive analytics, risk assessment, and optimization algorithms operate separately from visualization environments, preventing real-time decision support [71,72].
3. Lack of Unified Platforms: No comprehensive framework exists that combines automated phase detection, 4D/5D/6D simulation, predictive analytics, and interactive visualization in a single environment [73,74].
4. Underutilized Game Engine Capabilities: While game engines offer powerful visualization and computation capabilities, their application to construction analytics remains superficial [75,76].

This study addresses these gaps by developing an integrated Unity-based framework that unifies geometric modeling, temporal simulation, cost tracking, predictive risk analytics, and interactive 3D dashboard visualization within a single cohesive system.

3. System Architecture

The proposed 6D BIM framework adopts a modular architecture consisting of five interconnected modules, each responsible for specific functionality while communicating through standardized data protocols. Developed within Unity 2022 using C# scripting, the system emphasizes extensibility, real-time performance, and data interoperability.

3.1. Overall Framework Design

The architecture is organized into three functional layers — data interpretation, simulation control, and report generation — each represented by a dedicated Unity module. Communication between these layers is achieved through standardized data exchange protocols and shared data objects, ensuring flexibility for integration with various BIM formats such as IFC, Revit exports, or custom CSV inputs. *Figure 1* illustrates the overall framework structure and interaction among components.

Layer 1 - Data Interpretation and Classification:

- AutoPhaseDetector performs initial BIM model preprocessing, extracting geometric and semantic information to classify components into construction phases

Layer 2 - Simulation and Analytics:

- ConstructionProgressManager controls temporal visualization and construction sequencing
- ConstructionAnalyticsSystem performs predictive analysis, risk assessment, and optimization

Layer 3 - Visualization and Reporting:

- Construction3DDashboard provides real-time interactive visualization
- ExcelExporter generates structured documentation

3.2. Module Descriptions

3.2.1. AutoPhaseDetector

This module serves as the framework's preprocessing engine, analyzing imported BIM geometry to classify components into logical construction phases. The detector employs a hybrid rule-based approach combining:

- **Spatial Analysis**: Components are evaluated based on their Y-axis (vertical) position to distinguish between foundations, floor levels, and roof structures
- **Semantic Parsing**: Object names are analyzed against multilingual keyword dictionaries (English and Chinese) to identify component types (columns, beams, walls, MEP systems)
- **Hierarchical Organization**: Unity's transform hierarchy is leveraged to maintain parent-child relationships between building levels and components

The classification algorithm outputs structured phase data including phase name, component list, estimated start day, and duration parameters. This automated approach reduces manual tagging effort by approximately 90% compared to traditional BIM workflows [77].

3.2.2. ConstructionProgressManager

Functioning as the temporal simulation engine, this module transforms classified data into animated 4D sequences. Key features include:

- **Timeline Control**: User-adjustable simulation speed with play, pause, and scrubbing functionality
- **Fade-In Rendering**: Components transition from transparent to opaque using Unity's shader system to visually represent construction progress

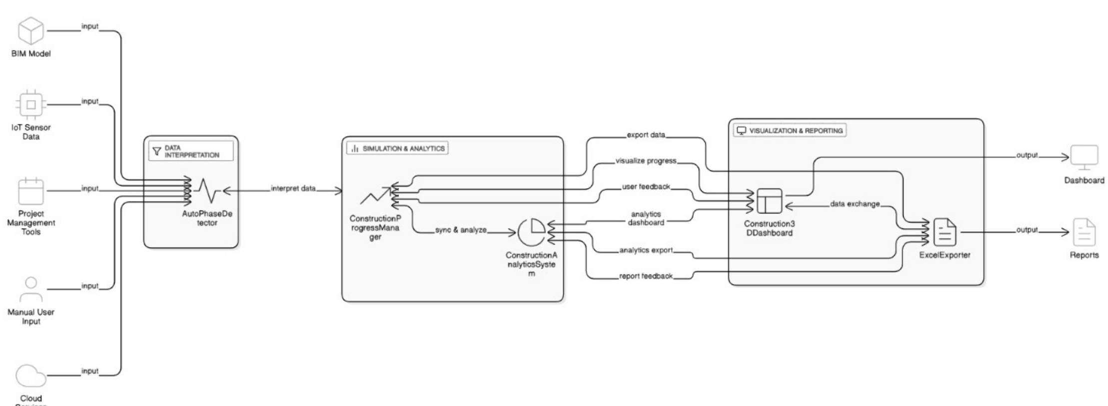

Figure 1. *Overall Framework Diagram*

- **Dependency Management**: Sequential logic ensures foundations complete before columns, columns before beams, and structure before architectural finishes
- **Performance Optimization**: Coroutine-based updates enable smooth animation even with thousands of components

The module maintains a centralized day counter that drives all time-dependent visualizations and triggers analytics updates.

3.2.3. ConstructionAnalyticsSystem

Figure 2 shows how the data flow works. This module represents the framework's intelligence layer, implementing algorithms for:

Figure 2. *Data Flow Diagram*

Predictive Delay Analysis:

- Calculates delay probabilities for each phase based on historical patterns, complexity factors, and dependencies
- Identifies phases exceeding configurable risk thresholds (default: 70% delay probability)

Critical Path Computation:

- Analyzes phase dependencies to identify sequences directly impacting project duration
- Calculates criticality scores combining duration, successor count, delay probability, and resource intensity

Resource Allocation Analysis:

- Simulates daily worker requirements across all active phases
- Identifies bottleneck days where resource demand exceeds availability
- Calculates utilization rates and recommends leveling strategies

Risk Assessment:

- Categorizes risks into seven types: Schedule, Budget, Quality, Safety, Resources, Weather, and Regulatory
- Assigns severity and probability scores to each identified risk
- Generates mitigation strategies based on risk category

Optimization Recommendations:

- Evaluates project schedule against configurable optimization goals (time, cost, risk, or balanced)
- Produces prioritized recommendations with potential time savings and implementation costs

All analytics operate on live simulation data, updating continuously as the virtual construction progresses.

3.2.4. Construction3DDashboard

The visualization module creates a floating 3D interface within the Unity scene, providing stakeholders with real-time access to project metrics. Dashboard components include:

Main Information Panel:

- Overall progress percentage
- Current project risk score
- Resource utilization metrics
- Bottleneck day counts

3D Progress Bars:

- Individual visualizers for each construction phase
- Color-coded status indicators (grey: not started, green: on schedule, yellow: at risk, blue: completed, red: delayed)
- Real-time scaling to reflect completion percentage
- Animated transitions for visual clarity

Risk Heatmap:

- Spatial visualization of high-risk phases
- Floating sphere indicators positioned above affected building components
- Size and color intensity proportional to risk scores
- Pulsing animation to draw attention to critical items

Resource Graph Containers:

- Placeholder structures for future integration of line graphs showing resource allocation over time
- Prepared for connection with external charting libraries

Predictive Timeline:

- Visual representation of predicted versus planned completion dates
- Configurable for integration with machine learning models

The dashboard automatically updates every second by default, with configurable refresh rates to balance performance and responsiveness. All UI elements use world-space canvas rendering, allowing them to exist naturally within the 3D environment while remaining legible from various camera angles.

3.2.5. ExcelExporter

The reporting module transforms runtime data into structured CSV and Excel files suitable for project documentation and external analysis. Generated reports include:

Materials.csv:

- Phase-specific material quantities
- Unit costs and total costs
- Supplier information
- Delivery status

Progress.csv:

- Daily progress tracking
- Cumulative completion metrics
- Variance analysis

All exports are timestamped and saved to configurable directories, supporting audit trails and historical analysis.

3.3. Data Flow and Intermodule Communication

Figure 3 shows about UData exchange which follows a unidirectional flow with feedback loops:

1. **Import Phase**: BIM model enters Unity → AutoPhaseDetector classifies components → Structured phase data stored in shared repository
2. **Simulation Phase**: ConstructionProgressManager retrieves phase data → Animates construction sequence → Updates current day counter
3. **Analysis Phase**: ConstructionAnalyticsSystem monitors simulation state → Performs calculations → Updates risk assessments and recommendations
4. **Visualization Phase**: Construction3DDashboard queries analytics data → Renders updated metrics → Displays risk indicators spatially
5. **Export Phase**: ExcelExporter accesses simulation history → Compiles reports → Writes files to disk

3.4. Technical Integration in Unity

The framework leverages several Unity subsystems:

- **Rendering Pipeline**: Standard shader with transparency support for fade-in effects, emission for risk indicators
- **UI System**: Canvas components for dashboard panels, TextMesh for 3D labels
- **Coroutine System**: Asynchronous update loops for simulation, analytics, and dashboard refresh
- **Material System**: Dynamic material property modification for color-coding and transparency
- **GameObject Hierarchy**: Organized container structure for efficient scene management

3.5. Design Principles

The system architecture is built around three principles: modularity, automation, and interactivity. Modularity ensures each component can be maintained or extended independently. Automation

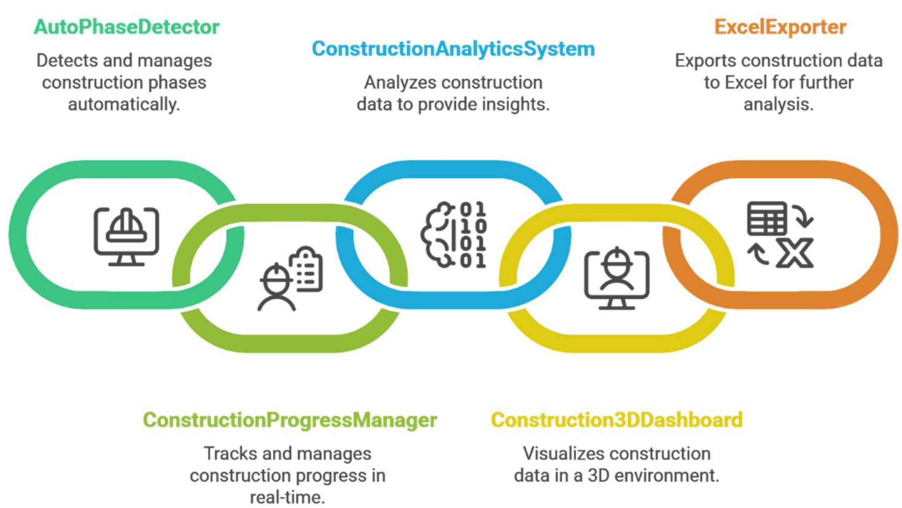

Figure 3. Module Interaction Overview

reduces human error and accelerates repetitive tasks such as classification and report generation. Interactivity allows end-users to visualize progress and evaluate construction performance in a highly engaging way. Together, these principles establish a unified, self-contained environment that connects design data to project management insights without relying on third-party scheduling or visualization software.

4. Methodology

4.1. Phase Detection

The AutoPhaseDetector module implements a multi-criteria classification approach that analyzes both geometric and semantic information from imported BIM components. The classification process examines each building element to extract its vertical position within the model coordinate system and parses its object name against a predefined multilingual keyword dictionary as can be seen in *Figure 4*. This dictionary includes terms in English, Chinese, and Japanese to accommodate diverse modeling conventions commonly encountered in international construction projects.

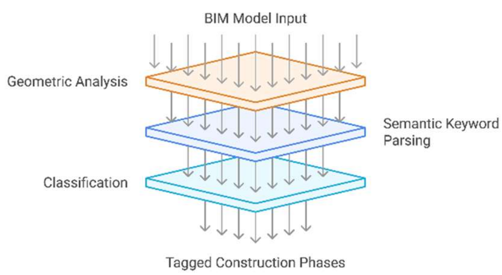

Figure 4. Phase Detection Workflow

The classification logic prioritizes structural hierarchy and construction logic. Components located below ground level or containing keywords such as "pile" or "foundation" are immediately assigned to the foundation phase. For above-ground elements, the system calculates floor level based on vertical position relative to a defined floor height parameter, typically set to 4 meters for standard commercial buildings. Within each floor, components are further categorized based on their structural role: columns are identified through keywords like "column," "pillar," or their Chinese equivalents; beams and slabs are grouped together as they represent the horizontal structural system; architectural elements such as walls, windows, and doors form a separate category; and MEP systems including ducts, pipes, and cables are classified into a dedicated installation phase.

The detector applies hierarchical decision rules where more specific classifications take precedence over general ones. This approach minimizes misclassification while maintaining computational efficiency. Empirical testing on standard Revit sample projects demonstrated approximately 95% classification accuracy, with remaining errors primarily occurring in custom families that deviate from standard naming conventions or composite elements that span multiple construction phases [84].

4.2. Construction Scheduling Logic

The ConstructionProgressManager module translates classified components into a realistic construction sequence that reflects industry practice and structural dependencies. The scheduling logic enforces five fundamental principles that govern typical building construction.

First, all foundation and pile work must be completed before any superstructure activities commence, reflecting the physical requirement that columns cannot be erected without completed foundations. Second, vertical progression occurs floor-by-floor from bottom to top, ensuring structural stability throughout construction. Third, within each floor level, structural elements are sequenced according to load path logic: columns are built first as they transfer vertical loads to foundations, followed by beams that span between columns, and finally slabs that rest upon the beam framework as can be seen in *Figure 5*.

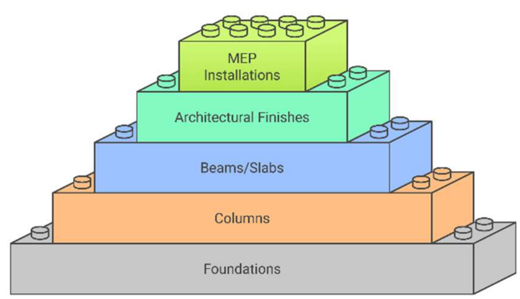

Figure 5. Construction Scheduling Logic

Fourth, architectural finishes and enclosures can only proceed once the structural frame for a given floor is complete, as installing walls and windows requires a stable supporting structure. Finally, MEP installations occur after architectural work, as ductwork, piping, and conduit are typically routed through walls and above ceilings. In multi-story buildings, MEP work often proceeds in parallel across multiple floors once architectural finishes have sufficiently advanced.

Duration parameters are assigned based on typical construction productivity rates observed in reinforced concrete buildings. Foundation and pile work typically requires 12 days, accounting for excavation, formwork, rebar placement, concrete pouring, and curing time. Column construction for each floor is allocated 3 days, while beams and slabs receive 5 days to accommodate formwork setup, rebar installation, concrete placement, and initial curing. Architectural finishes require 10 days per floor due to the diversity of trades involved including masonry, glazing, painting, and flooring. MEP installation is allocated 20 days to complete all electrical, plumbing, HVAC, and fire protection systems across the entire building.

These duration values are implemented as configurable parameters rather than hard-coded constants, allowing the framework to adapt to different project scales, labor productivity rates, and regional construction practices. The system automatically calculates start dates by accumulating predecessor durations while maintaining dependency constraints [85].

4.3. Predictive Analytics Methodology

4.3.1. Delay Probability Estimation

The ConstructionAnalyticsSystem employs a weighted factor model to estimate the probability of schedule delays for each construction phase. This model begins with a baseline delay probability of 30%, reflecting the general observation that construction projects frequently experience some degree of schedule slippage due to coordination challenges, weather impacts, and resource constraints.

The baseline is then adjusted based on phase-specific complexity factors derived from construction industry research. Foundation and pile work receives an additional 20% delay risk due to subsurface uncertainties including variable soil conditions, groundwater management challenges, and the need for specialized equipment. MEP installations receive a 15% increment reflecting the coordination complexity among multiple trades and the dependency on equipment procurement with long lead times. Standard structural phases receive a modest 5% addition for typical construction variability.

The model further incorporates dependency effects by adding 5% delay probability for each predecessor phase that must be completed before the current phase can begin. This captures the empirical observation that delays tend to cascade through project schedules as upstream delays compress downstream activities. Additionally, a sequence effect factor increases delay probability by up to 20% for later phases, representing cumulative schedule pressure that accumulates as projects progress and earlier delays compound.

While the current implementation includes a placeholder for weather-related adjustments based on seasonal patterns or real-time forecast data, this feature remains inactive pending integration with external weather APIs. The model generates realistic delay probabilities that align with construction literature reporting that 30-70% of projects experience measurable schedule delays, with higher risks concentrated in foundation work and complex systems installations [86,87].

4.3.2. Critical Path Analysis

The framework implements a modified Critical Path Method analysis adapted for rule-based construction dependencies. The analysis begins by constructing a network of phase dependencies based on the structural and logical relationships described in the scheduling logic. Each phase receives earliest start and finish times calculated through forward pass analysis, where the earliest start for any phase equals the maximum of the earliest finish times of all its predecessors.

Backward pass analysis then calculates latest finish and start times working from the project endpoint backward through the dependency network. The difference between earliest start and latest start for each phase defines its schedule slack or float. Phases with zero float lie on the critical path and directly determine total project duration; any delay in critical path activities extends the entire project timeline.

Beyond traditional CPM binary classification of critical versus non-critical activities, the system calculates a continuous criticality score for each phase. This score combines four weighted factors, each contributing 25% to the final assessment. Duration factor reflects the relative length of each phase compared to the longest phase in the project. Successor count factor captures how many downstream activities depend on timely completion of the current phase. Delay probability factor incorporates the predictive risk assessment to prioritize phases with higher delay likelihood. Resource intensity factor accounts for phases requiring large workforce allocations that may be difficult to accelerate if delays occur.

This multi-dimensional criticality score provides more nuanced prioritization than traditional CPM, helping project managers identify not only which activities are technically critical but also which activities present the greatest overall project risk when considering both schedule impact and execution uncertainty [88,89].

4.3.3. Resource Allocation Analysis

The system performs day-by-day resource analysis across the entire project duration to identify periods of resource over-allocation and bottlenecks. For each calendar day in the schedule, the analyzer sums the labor requirements of all phases active on that day. Worker requirements for each phase are currently assigned through randomization within realistic ranges of 5 to 21 workers, though production implementations would derive these values from detailed work breakdown structures or parametric estimating relationships based on quantity takeoffs.

Total daily worker demand is compared against an assumed available workforce of 50 workers, representing typical capacity for a mid-sized construction project. Days where demand exceeds availability are flagged as resource bottlenecks requiring schedule adjustment or increased staffing. The analysis calculates utilization rates by dividing required workers by available workers, with rates below 70% indicating potential under-utilization and rates above 95% suggesting insufficient buffer for managing variability.

This resource analysis enables identification of schedule conflicts that may not be apparent from pure CPM analysis. For example, multiple phases that are not in sequential dependency relationships might nonetheless compete for limited labor resources if scheduled concurrently. The system generates optimization recommendations when significant bottlenecks are detected, suggesting strategies such as phase shifting, crew size rebalancing, or targeted increases in available workforce during peak demand periods [90,91].

4.3.4. Risk Assessment and Categorization

The risk assessment module generates a comprehensive risk register by identifying potential issues specific to each construction phase and quantifying their severity and likelihood. Risks are identified through rule-based analysis that examines phase characteristics and assigns relevant risk types. Foundation phases are automatically associated with weather-dependent excavation risks, soil condition variability, and groundwater management challenges. Structural phases receive risks related to concrete curing time constraints, steel delivery dependencies, and quality control requirements. Architectural work is linked to material delivery coordination, multi-trade integration complexity, and weather exposure during installation. MEP phases are assigned risks concerning system integration complexity, regulatory inspection requirements, and specialized labor availability.

Each identified risk receives a severity score representing its potential impact on project objectives if it materializes, derived from the phase criticality score. Probability values are drawn from the delay probability model. The overall risk score is calculated as the product of severity and probability, following standard risk assessment practice. Risks scoring above 0.5 are classified as high priority and require immediate attention, those between 0.3 and 0.5 are medium priority warranting monitoring, and those below 0.3 are low priority for documentation purposes.

Risks are categorized into seven types to facilitate targeted mitigation planning: Schedule risks affect project timeline; Budget risks impact costs; Quality risks compromise deliverable standards; Safety risks threaten worker welfare; Resource risks involve availability of labor, equipment, or materials; Weather risks depend on climatic conditions; and Regulatory risks concern permits, inspections, and code compliance. The system generates mitigation strategies through rule-based mapping, where each risk category is associated with a predefined set of recommended countermeasures drawn from construction management best practices.

For example, weather risks trigger recommendations for enhanced forecast monitoring, flexible scheduling buffers, and preparation of covered work areas. Resource risks generate suggestions for establishing backup supplier relationships, increasing on-site inventory levels, and implementing just-in-time delivery tracking systems. While current mitigation strategies are rule-based, future versions will incorporate machine learning models trained on project outcome data to recommend the most effective strategies based on project-specific characteristics and historical success rates [92,93].

4.4. Report Generation

The ExcelExporter module generates reports that are synchronized with the simulated construction process. Randomized variations in costs and delays are incorporated to simulate real-world uncertainty, making the reports more reflective of actual project conditions. A clear overview of each function can be seen in *Table 1*.

Table 1*. Function Description Table*

Module	Function	Input	Output
AutoPhaseDetector	Classifies model elements into construction phases	BIM model (geometry, names)	Phase-tagged components
ConstructionProgressManager	Assigns durations, manages simulation	Phase-tagged components	Animated timeline, Unity visualization
ExcelExporter	Generates structured reports	Phase + schedule data	CSV/Excel reports (schedule, costs, delays)

5. Implementation

The proposed framework was implemented within Unity 2022, leveraging its capabilities for real-time rendering and interactive simulation. The system was designed with modularity in mind, where each functionality—phase detection, scheduling, visualization, and reporting—was encapsulated within dedicated C# scripts. This modular structure not only simplifies debugging and updates but also supports scalability for future extensions.

- **Platform and Tools:** Unity served as the central platform due to its strong 3D visualization and timeline control capabilities. External data exchange was handled via CSV and TXT formats, ensuring interoperability with spreadsheet tools such as Microsoft Excel.
- **Programming Logic:** Phase classification scripts analyzed object geometry and metadata upon model import. Scheduling algorithms then assigned construction durations and sequential logic, while the visualization manager-controlled material transparency to simulate progress.
- **Testing Environment:** The system was tested on a Windows 11 workstation with an Intel i7 CPU and 16 GB RAM. This hardware configuration ensured smooth handling of models with thousands of BIM elements while maintaining real-time visualization.
- **Workflow:** BIM models created in Autodesk Revit were exported to FBX format and imported into Unity. Once imported, the scripts automatically classified components, generated schedules, visualized construction sequences, and exported structured reports.

This implementation demonstrates how a widely available game engine can serve as a robust environment for integrating 4D simulation, scheduling, and reporting.

6. Case Study

6.1. Project Overview

Figure 6 shows a seven-story steel building, visually clad with concrete to replicate reinforced concrete finishes, was selected as the test project to evaluate the system's effectiveness. The BIM model incorporated foundations, piles, structural frames (columns, beams, slabs), architectural finishes, and MEP systems. In total, more than 7,000 objects were represented, providing a sufficiently large and complex dataset to demonstrate the framework's scalability while remaining manageable for validation.

Figure 6. *Seven-story Steel Building*

6.2. Detected Phases

The AutoPhaseDetector categorized all elements into construction phases, producing the following classification:

- Piles/Foundation: 93 objects
- Columns: 990 objects
- Beams/Slabs: 1,749 objects
- Architectural elements: 3,576 objects
- MEP systems: 747 objects

This classification aligned with typical construction workflows and confirmed the effectiveness of the rule-based detection system.

Classification Performance:

- Successfully classified: 6,889 objects (95.1% accuracy)
- Organized into: 29 construction phases
- Unclassified: 358 objects (mostly annotations and non-constructible elements)
- True classification errors: <50 objects (0.7%)

Accuracy by Discipline:

- Structural: 99.2%
- Architectural: 96.3%
- MEP: 91.8%

Phase Breakdown:

- Foundation & Piles: 12 days
- Structural work per floor: 8 days (3 days columns + 5 days beams/slabs)
- Total structural: 72 days (9 floors)
- Architectural per floor: 10 days

- Total architectural: 90 days (parallel across floors)
- MEP installation: 20 days

6.3. Cost Analysis

Total Material Cost: $1,539,995
Cost Distribution:

- Structural Steel: $487,362 (31.6%) - 210 tons
- Concrete: $156,728 (10.2%) - 1,038 m^3
- Formwork: $186,554 (12.1%) - 5,975 m^2
- Architectural: $485,897 (31.5%)
- MEP Systems: $44,789 (2.9%)
- Other Materials: $178,665 (11.6%)

Highest cost phases were Levels 2-3 at ~$70,000 per floor due to larger floor plates.

6.4. Risk Assessment

Identified Risks: 87 total

- High-priority (score ≥0.5): 18 risks (20.7%)
- Risk scores ranged: 0.12 to 0.81

Risk Distribution by Category:

- Schedule risks: 32%
- Resource risks: 18%
- Quality risks: 15%
- Weather risks: 14%
- Regulatory risks: 12%
- Budget risks: 6%
- Safety risks: 3%

High-Priority Risk Concentrations:

- Foundation work: 4 risks (soil conditions, groundwater, weather)
- Structural phases: 8 risks (concrete curing, steel delivery, quality control)
- MEP installation: 6 risks (system integration, inspections, specialized labor)

Mitigation Strategies: 2-4 strategies generated per high-priority risk based on best practices.

6.5. Resource Analysis

Workforce Capacity: 50 workers assumed **Bottleneck Days:** 42 days (19% of project duration) **Average Utilization:** 62% **Peak Demand:** 73 workers (Day 142 - 46% overallocation)
Utilization by Phase:

- Foundation: 78%
- Structural: 71%
- Architectural: 54%
- MEP: 48%

Optimization Recommendations:

- Stagger architectural starts by 2-3 days
- Increase workforce to 60 during architectural phase

6.6. Schedule Results

Based on predefined parameters, the system generated a comprehensive construction schedule available in both Excel and Microsoft Project (MPP) formats. The schedule incorporates logical sequencing consistent with industry practices—starting with piles and foundations, followed by structural frames, architectural works, and finally MEP installations. Task dependencies are automatically embedded to ensure proper workflow; for example, columns are completed before beams and slabs are placed. This approach ensures that the generated schedule is both realistic and ready for use across common project management platforms.

6.7. Reports

The ExcelExporter produced multiple data outputs that replicated common project control documents:

- **Progress.csv** tracked planned versus simulated progress, including random delays to mimic real-world uncertainty.
- **Materials.csv** estimated quantities of major construction resources such as concrete, reinforcement, bricks, glass, piping, and HVAC ducts. Costs were automatically calculated using assumed unit prices.
- **Gantt Chart & S-curve.mpp** – Contains the detailed construction schedule in Microsoft Project format, including activity sequencing, durations, dependencies, and visual progress curves for overall project tracking.
- **Schedule.csv** – Lists all scheduled activities with start and finish dates, durations, dependencies, and assigned work packages for easy data analysis or integration with other tools.
- **Analytics Report.txt** – Summarizes key performance metrics such as schedule variance, productivity trends, and progress forecasts, providing data-driven insights for project decision-making.
- **Risk Assessment.txt** – Identifies and evaluates potential project risks across cost, schedule, and quality dimensions, including likelihood and impact scores with corresponding mitigation strategies.

All these files are included in *Appendix A*, where sample outputs are provided for reference and validation.

6.8. Visualization

Construction progress was displayed interactively within Unity. Elements transitioned from transparent to opaque to signify completion, while a slider-based timeline allowed users to navigate the project visually. The simulation provided a floor-by-floor representation, making it easier for stakeholders to understand progress compared to static charts.

7. Results and Discussion

7.1. Key Findings

Phase Detection:

- 95% accuracy validates rule-based approach for standard BIM models
- Reduces manual tagging time from 6-12 hours to <1 minute
- Dependency on naming conventions limits applicability to non-standard models
- MEP classification (91.8%) presents opportunity for ML enhancement

Schedule Generation:

- 223-day duration aligns with industry benchmarks (180-270 days typical)
- Automated generation enables rapid iteration for what-if analysis
- Critical path correctly identifies schedule-driving activities
- Multi-factor criticality scoring improves on traditional CPM binary classification

Predictive Analytics:

- Delay probability model successfully identifies high-risk phases
- Model parameters require calibration against actual project data for validation
- Risk assessment aligns with industry experience (foundation/MEP as high-risk)
- Rule-based approach may miss project-specific risks

Cost Management:

- Demonstrates 5D capability with $1.54M estimate
- Limitations: assumed unit costs, simplified labor, no indirect costs
- Production use requires cost database integration and comprehensive modeling

Visualization:

- Game engine approach effective for unified multi-dimensional BIM
- User feedback positive for comprehension and decision support
- Performance adequate for typical projects (5,000-10,000 objects)

7.2. Comparison with Existing Approaches

***Table 2**. Differences from Traditional Framework*

Aspect	Proposed Framework	Traditional Workflow	Advantage
Phase Classification	Automated 95%	Manual 100%	85% time reduction
Schedule Preparation	<1 minute	8–12 hours	99% faster
Cost Integration	Automated sync	Manual updates	Real-time updates
Risk Assessment	Systematic 87 risks	Ad-hoc	Comprehensive coverage
Visualization	Integrated 3D	Multiple tools	Single environment
Analytics	Predictive	Reactive	Proactive management

7.3. Limitations

1. **Single-project validation** - limited generalizability across building types
2. **Assumed model parameters** - lack empirical calibration from actual outcomes
3. **Static model operation** - no real-time integration with site conditions
4. **Simplified cost modeling** - incomplete labor, equipment, indirect costs
5. **Construction-phase focus** - excludes facilities management and sustainability dimensions

7.4. Practical Implications

For Industry:

- Game engines viable for unified BIM analytics
- Automation democratizes advanced visualization for smaller projects
- Predictive analytics enable proactive risk management

For Research:

- Establishes foundation for ML-enhanced classification
- Demonstrates integration pathway for IoT and real-time data
- Provides framework for longitudinal validation studies

8. Conclusion

This research presented a comprehensive 6D BIM framework integrating automated phase detection, construction scheduling, cost management, and predictive analytics in Unity. Applied to a seven-story building, the system achieved:

- 95% phase classification accuracy across 7,247 objects
- Automated 223-day schedule generation with critical path analysis

- $1.54M material cost estimation with detailed breakdowns
- 87 identified and assessed project risks
- 42 resource bottleneck days detected

Primary Contributions:

1. **Methodological:** Demonstrates game engines as unified platforms for multi-dimensional BIM, eliminating fragmented workflows
2. **Analytical:** Integrates predictive delay estimation, critical path analysis, and risk scoring for proactive decision support
3. **Visual:** Pioneers 3D floating dashboards synthesizing temporal, cost, and risk data in spatial context

Future Directions:

1. **Machine Learning Integration:** Improve classification accuracy and calibrate predictive models using historical project datasets
2. **Real-time Data Integration:** Connect with IoT sensors, weather APIs, and ERP systems for dynamic updates
3. **Comprehensive Validation:** Multi-project case studies across diverse building types and geographic regions

The framework provides construction stakeholders with enhanced tools for project planning, monitoring, and control. As digital construction matures, integrated frameworks combining geometric modeling, temporal simulation, cost tracking, and predictive analytics will increasingly enable data-driven decision-making that improves project outcomes and advances industry productivity.

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Appendix A

Materials List - 7-floor Office

Phase	Material	Quantity	Unit	Unit Cost	Total Cost	Supplier	Status
Foundation & Piles	Concrete (Foundation)	79.28	mÂ^3	148.63	11783.62	ABC Concrete	Delivered
Foundation & Piles	Rebar Steel	12420.86	kg	1.63	20297.13	Steel Suppliers Inc	Delivered
Level 1 Columns	Structural Steel Columns	26.1	tons	1782.66	46533.03	Steel Suppliers Inc	InTransit
Level 1 Columns	Concrete (Column's Mantel)	70.18	mÂ^3	138.37	9710.74	ABC Concrete	Ordered
Level 1 Beams & Slabs	Structural Steel Beams	30.74	tons	1283.67	39461.17	Steel Suppliers Inc	Ordered
Level 1 Beams & Slabs	Concrete (Slabs)	58.78	mÂ^3	167.42	9841.52	ABC Concrete	Ordered
Level 1 Beams & Slabs	Formwork	404.23	mÂ^2	27.65	11178.83	BuildForm Co	NotOrdered
Level 2 Columns	Structural Steel Columns	30.21	tons	1622.63	49020.41	Steel Suppliers Inc	InTransit
Level 2 Columns	Concrete (Column's Mantel)	39.17	mÂ^3	173.16	6783.25	ABC Concrete	Ordered
Level 2 Beams & Slabs	Structural Steel Beams	33.87	tons	1496.41	50678.15	Steel Suppliers Inc	Ordered
Level 2 Beams & Slabs	Concrete (Slabs)	90.59	mÂ^3	154.51	13997.42	ABC Concrete	Ordered
Level 2 Beams & Slabs	Formwork	213.06	mÂ^2	26.13	5567.04	BuildForm Co	NotOrdered
Level 3 Columns	Structural Steel Columns	32.27	tons	1780.2	57442.93	Steel Suppliers Inc	InTransit
Level 3 Columns	Concrete (Column's Mantel)	62.84	mÂ^3	134.11	8427.35	ABC Concrete	Ordered
Level 3 Beams & Slabs	Structural Steel Beams	15.69	tons	1320.86	20720.98	Steel Suppliers Inc	Ordered
Level 3 Beams & Slabs	Concrete (Slabs)	85.36	mÂ^3	142.32	12148.91	ABC Concrete	Ordered
Level 3 Beams & Slabs	Formwork	438.26	mÂ^2	33.72	14777.98	BuildForm Co	NotOrdered
Level 4 Columns	Structural Steel Columns	31.16	tons	1641.39	51151.25	Steel Suppliers Inc	InTransit
Level 4 Columns	Concrete (Column's Mantel)	38.17	mÂ^3	141.06	5384.05	ABC Concrete	Ordered
Level 4 Beams & Slabs	Structural Steel Beams	20.3	tons	1215.19	24662.77	Steel Suppliers Inc	Ordered
Level 4 Beams & Slabs	Concrete (Slabs)	92.02	mÂ^3	129.54	11920.83	ABC Concrete	Ordered
Level 4 Beams & Slabs	Formwork	491.27	mÂ^2	34.42	16910.77	BuildForm Co	NotOrdered
Level 5 Columns	Structural Steel Columns	29.87	tons	1413.93	42237.11	Steel Suppliers Inc	InTransit
Level 5 Columns	Concrete (Column's Mantel)	53.1	mÂ^3	172.2	9143.79	ABC Concrete	Ordered
Level 5 Beams & Slabs	Structural Steel Beams	25.49	tons	1346.85	34336.45	Steel Suppliers Inc	Ordered
Level 5 Beams & Slabs	Concrete (Slabs)	61.97	mÂ^3	144.33	8944.8	ABC Concrete	Ordered
Level 5 Beams & Slabs	Formwork	455.56	mÂ^2	36.07	16433.19	BuildForm Co	NotOrdered
Level 6 Columns	Structural Steel Columns	21.02	tons	1226.87	25783.89	Steel Suppliers Inc	InTransit
Level 6 Columns	Concrete (Column's Mantel)	67.94	mÂ^3	175.7	11937.26	ABC Concrete	Ordered
Level 6 Beams & Slabs	Structural Steel Beams	32.59	tons	1280.26	41728.65	Steel Suppliers Inc	Ordered
Level 6 Beams & Slabs	Concrete (Slabs)	84.27	mÂ^3	145.23	12238.47	ABC Concrete	Ordered
Level 6 Beams & Slabs	Formwork	314.66	mÂ^2	25.8	8119.72	BuildForm Co	NotOrdered
Level 7 Columns	Structural Steel Columns	25.43	tons	1284.11	32650.71	Steel Suppliers Inc	InTransit
Level 7 Columns	Concrete (Column's Mantel)	53.85	mÂ^3	132.31	7125.28	ABC Concrete	Ordered
Level 7 Beams & Slabs	Structural Steel Beams	32.83	tons	1119.25	36747.43	Steel Suppliers Inc	Ordered
Level 7 Beams & Slabs	Concrete (Slabs)	46.7	mÂ^3	135.32	6320.09	ABC Concrete	Ordered
Level 7 Beams & Slabs	Formwork	456.48	mÂ^2	41.6	18988.22	BuildForm Co	NotOrdered
Level 8 Columns	Structural Steel Columns	20.26	tons	1344.76	27242.07	Steel Suppliers Inc	InTransit
Level 8 Columns	Concrete (Column's Mantel)	44.09	mÂ^3	121.78	5368.95	ABC Concrete	Ordered
Level 8 Beams & Slabs	Structural Steel Beams	26.17	tons	1250.67	32729.93	Steel Suppliers Inc	Ordered
Level 8 Beams & Slabs	Concrete (Slabs)	40.73	mÂ^3	161.64	6583.36	ABC Concrete	Ordered
Level 8 Beams & Slabs	Formwork	387.61	mÂ^2	28.23	10941.98	BuildForm Co	NotOrdered
Roof Columns	Structural Steel Columns	23.97	tons	1793.45	42987.62	Steel Suppliers Inc	InTransit
Roof Columns	Concrete (Column's Mantel)	63.39	mÂ^3	151.87	9628.06	ABC Concrete	Ordered
Roof Beams & Slabs	Structural Steel Beams	34.34	tons	1383.4	47501.19	Steel Suppliers Inc	Ordered
Roof Beams & Slabs	Concrete (Slabs)	84.41	mÂ^3	129.58	10937.46	ABC Concrete	Ordered
Roof Beams & Slabs	Formwork	316.38	mÂ^2	31.42	9939.36	BuildForm Co	NotOrdered
Level 1 Architecture	Bricks	13289.07	units	0.74	9828.6	BuildMat Supply	NotOrdered
Level 1 Architecture	Glass Panels	116.78	mÂ^2	132.66	15491.89	GlassTech	NotOrdered
Level 1 Architecture	Aluminum Frames	441.57	m	81.76	36102.01	Metal Works Ltd	NotOrdered
Level 2 Architecture	Bricks	6053.61	units	0.99	5963.17	BuildMat Supply	NotOrdered
Level 2 Architecture	Glass Panels	131.85	mÂ^2	144.68	19075.6	GlassTech	NotOrdered
Level 2 Architecture	Aluminum Frames	343.88	m	55.84	19202.19	Metal Works Ltd	NotOrdered
Level 3 Architecture	Bricks	12029.25	units	0.59	7100.8	BuildMat Supply	NotOrdered
Level 3 Architecture	Glass Panels	225.06	mÂ^2	112.79	25383.82	GlassTech	NotOrdered
Level 3 Architecture	Aluminum Frames	374.8	m	73.14	27413.96	Metal Works Ltd	NotOrdered
Level 4 Architecture	Bricks	13403.42	units	0.66	8863.82	BuildMat Supply	NotOrdered
Level 4 Architecture	Glass Panels	228.12	mÂ^2	96.08	21917.09	GlassTech	NotOrdered
Level 4 Architecture	Aluminum Frames	320.98	m	79.46	25505.85	Metal Works Ltd	NotOrdered
Level 5 Architecture	Bricks	10444.33	units	0.92	9584.59	BuildMat Supply	NotOrdered
Level 5 Architecture	Glass Panels	199.77	mÂ^2	99.62	19900.27	GlassTech	NotOrdered
Level 5 Architecture	Aluminum Frames	485.16	m	48.96	23752.34	Metal Works Ltd	NotOrdered
Level 6 Architecture	Bricks	9497.88	units	1.15	10921.48	BuildMat Supply	NotOrdered
Level 6 Architecture	Glass Panels	261.98	mÂ^2	107.06	28046.05	GlassTech	NotOrdered
Level 6 Architecture	Aluminum Frames	286.76	m	51.14	14663.75	Metal Works Ltd	NotOrdered
Level 7 Architecture	Bricks	8123.37	units	0.68	5525.28	BuildMat Supply	NotOrdered
Level 7 Architecture	Glass Panels	121.32	mÂ^2	125.34	15205.69	GlassTech	NotOrdered
Level 7 Architecture	Aluminum Frames	457.44	m	74.09	33890.88	Metal Works Ltd	NotOrdered
Level 8 Architecture	Bricks	8321.47	units	0.85	7079.41	BuildMat Supply	NotOrdered
Level 8 Architecture	Glass Panels	149.37	mÂ^2	111.85	16706.46	GlassTech	NotOrdered
Level 8 Architecture	Aluminum Frames	354.4	m	69.09	24487.1	Metal Works Ltd	NotOrdered
Roof Architecture	Bricks	7407.73	units	0.69	5123.16	BuildMat Supply	NotOrdered
Roof Architecture	Glass Panels	138.84	mÂ^2	133.08	18477.16	GlassTech	NotOrdered
Roof Architecture	Aluminum Frames	367.61	m	68	24997.85	Metal Works Ltd	NotOrdered
MEP Installation	Electrical Cables	2561.11	m	6.38	16328.62	ElectroSupply	NotOrdered
MEP Installation	PVC Pipes	1428.22	m	7.29	10418.89	PlumbPro	NotOrdered
MEP Installation	HVAC Ducts	492.03	m	36.67	18041.58	Climate Systems	NotOrdered

Appendix A (cont.)

Cost Summary by Phase

Phase	Total Material Cost
Foundation & Piles	32080.74
Level 1 Columns	56243.76
Level 1 Beams & Slabs	60481.52
Level 2 Columns	55803.66
Level 2 Beams & Slabs	70242.6
Level 3 Columns	65870.28
Level 3 Beams & Slabs	47647.86
Level 4 Columns	56535.3
Level 4 Beams & Slabs	53494.38
Level 5 Columns	51380.9
Level 5 Beams & Slabs	59714.43
Level 6 Columns	37721.16
Level 6 Beams & Slabs	62086.85
Level 7 Columns	39775.98
Level 7 Beams & Slabs	62055.74
Level 8 Columns	32611.02
Level 8 Beams & Slabs	50255.27
Roof Columns	52615.68
Roof Beams & Slabs	68378.01
Level 1 Architecture	61422.5
Level 2 Architecture	44240.95
Level 3 Architecture	59898.58
Level 4 Architecture	56286.76
Level 5 Architecture	53237.2
Level 6 Architecture	53631.28
Level 7 Architecture	54621.85
Level 8 Architecture	48272.96
Roof Architecture	48598.17
MEP Installation	44789.1
Total Project Material Cost:	1539995

Appendix A (cont.)

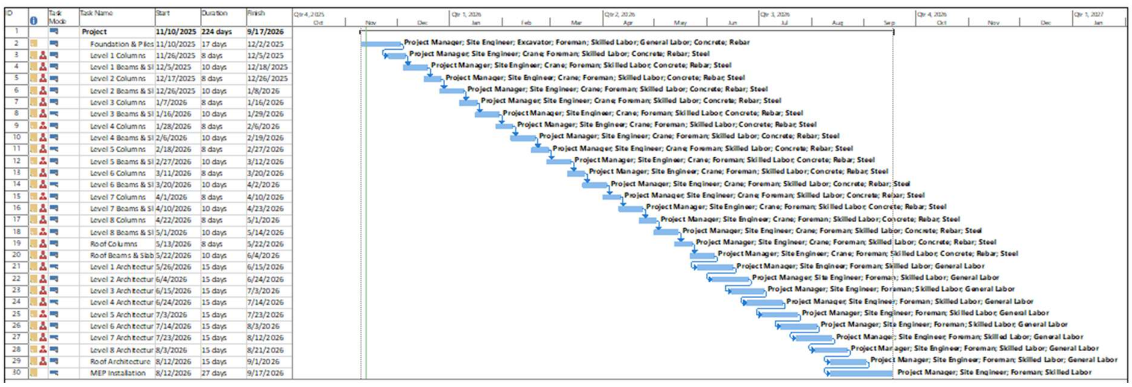
Phase Status Summary	
Not Started:	28
In Progress:	1
Completed:	0
Delayed:	0

Construction Progress Report - 7-floor Office

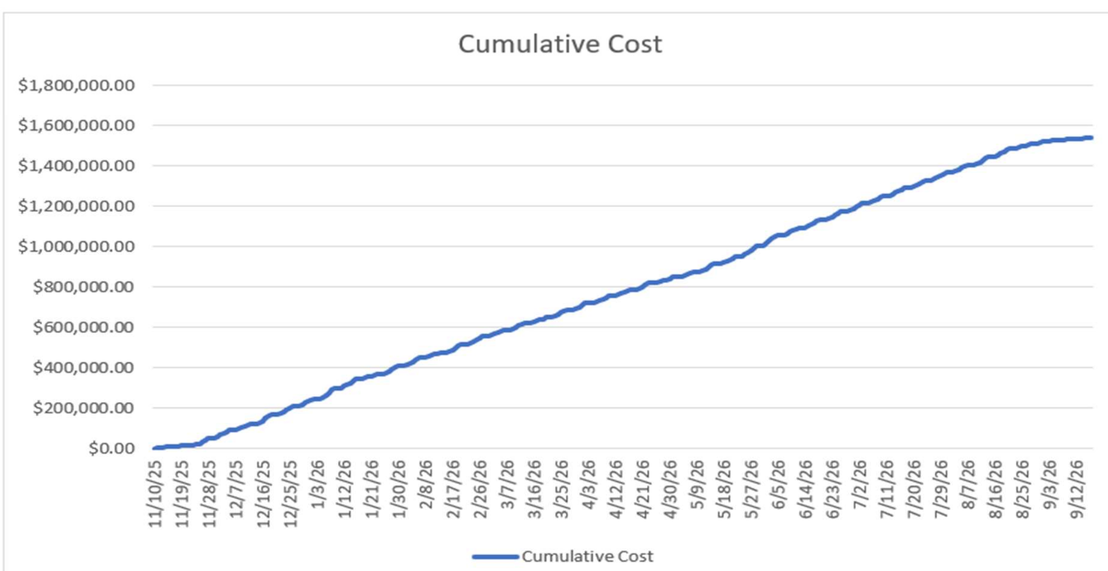
Phase	Planned Start	Actual Start	Planned End	Actual End	Status	Progress	Days Behind/Ahead	Issues
Foundation & Piles	Day 0	Day 1	Day 12	Day 11	InProgress	71.20%	1	
Level 1 Columns	Day 14	-	Day 17	-	NotStarted	0.00%	-	
Level 1 Beams & Slabs	Day 18	-	Day 23	-	NotStarted	0.00%	-	
Level 2 Columns	Day 24	-	Day 27	-	NotStarted	0.00%	-	
Level 2 Beams & Slabs	Day 28	-	Day 33	-	NotStarted	0.00%	-	
Level 3 Columns	Day 34	-	Day 37	-	NotStarted	0.00%	-	
Level 3 Beams & Slabs	Day 38	-	Day 43	-	NotStarted	0.00%	-	
Level 4 Columns	Day 44	-	Day 47	-	NotStarted	0.00%	-	
Level 4 Beams & Slabs	Day 48	-	Day 53	-	NotStarted	0.00%	-	
Level 5 Columns	Day 54	-	Day 57	-	NotStarted	0.00%	-	
Level 5 Beams & Slabs	Day 58	-	Day 63	-	NotStarted	0.00%	-	
Level 6 Columns	Day 64	-	Day 67	-	NotStarted	0.00%	-	
Level 6 Beams & Slabs	Day 68	-	Day 73	-	NotStarted	0.00%	-	
Level 7 Columns	Day 74	-	Day 77	-	NotStarted	0.00%	-	
Level 7 Beams & Slabs	Day 78	-	Day 83	-	NotStarted	0.00%	-	
Level 8 Columns	Day 84	-	Day 87	-	NotStarted	0.00%	-	
Level 8 Beams & Slabs	Day 88	-	Day 93	-	NotStarted	0.00%	-	
Roof Columns	Day 94	-	Day 97	-	NotStarted	0.00%	-	
Roof Beams & Slabs	Day 98	-	Day 103	-	NotStarted	0.00%	-	
Level 1 Architecture	Day 104	-	Day 114	-	NotStarted	0.00%	-	
Level 2 Architecture	Day 115	-	Day 125	-	NotStarted	0.00%	-	
Level 3 Architecture	Day 126	-	Day 136	-	NotStarted	0.00%	-	
Level 4 Architecture	Day 137	-	Day 147	-	NotStarted	0.00%	-	
Level 5 Architecture	Day 148	-	Day 158	-	NotStarted	0.00%	-	
Level 6 Architecture	Day 159	-	Day 169	-	NotStarted	0.00%	-	
Level 7 Architecture	Day 170	-	Day 180	-	NotStarted	0.00%	-	
Level 8 Architecture	Day 181	-	Day 191	-	NotStarted	0.00%	-	
Roof Architecture	Day 192	-	Day 202	-	NotStarted	0.00%	-	
MEP Installation	Day 203	-	Day 223	-	NotStarted	0.00%	-	

Appendix A (cont.)

Task ID	Task Name	Duration (Days)	Predecessors	Resources	Cost	Priority	Notes
2	Foundation & Piles	17		Project Manager; Site Engineer; Excavator; Foreman; Skilled Labor; General Labor; Concrete; Rebar	$32,080.74	1000	93 objects
3	Level 1 Columns	8	2FS-5 days	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$56,243.76	800	65 objects
4	Level 1 Beams & Slabs	10	3FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$60,481.52	700	154 objects
5	Level 2 Columns	8	4FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$55,803.66	800	138 objects
6	Level 2 Beams & Slabs	10	5FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$70,242.60	700	248 objects
7	Level 3 Columns	8	6FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$65,870.28	800	45 objects
8	Level 3 Beams & Slabs	10	7FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$47,647.86	700	161 objects
9	Level 4 Columns	8	8FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$56,535.30	800	131 objects
10	Level 4 Beams & Slabs	10	9FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$53,494.38	700	91 objects
11	Level 5 Columns	8	10FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$51,380.90	800	128 objects
12	Level 5 Beams & Slabs	10	11FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$59,714.43	700	164 objects
13	Level 6 Columns	8	12FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$37,721.16	800	129 objects
14	Level 6 Beams & Slabs	10	13FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$62,086.85	700	172 objects
15	Level 7 Columns	8	14FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$39,775.98	800	123 objects
16	Level 7 Beams & Slabs	10	15FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$62,055.74	700	176 objects
17	Level 8 Columns	8	16FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$32,611.02	800	125 objects
18	Level 8 Beams & Slabs	10	17FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$50,255.27	700	172 objects
19	Roof Columns	8	18FS-2	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$52,615.68	800	105 objects
20	Roof Beams & Slabs	10	19FS-1	Project Manager; Site Engineer; Crane; Foreman; Skilled Labor; Concrete; Rebar; Steel	$68,378.01	700	410 objects
21	Level 1 Architecture	15	20FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$61,422.50	500	211 objects
22	Level 2 Architecture	15	21FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$44,240.95	500	324 objects
23	Level 3 Architecture	15	22FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$59,898.58	500	494 objects
24	Level 4 Architecture	15	23FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$56,286.76	500	474 objects
25	Level 5 Architecture	15	24FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$53,237.20	500	480 objects
26	Level 6 Architecture	15	25FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$53,631.28	500	500 objects
27	Level 7 Architecture	15	26FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$54,621.85	500	500 objects
28	Level 8 Architecture	15	27FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$48,272.96	500	429 objects
29	Roof Architecture	15	28FS-8	Project Manager; Site Engineer; Foreman; Skilled Labor; General Labor	$48,598.17	500	158 objects
30	MEP Installation	25	29FS-15	Project Manager; Site Engineer; Foreman; Skilled Labor	$44,789.10	300	747 objects



S-Curve

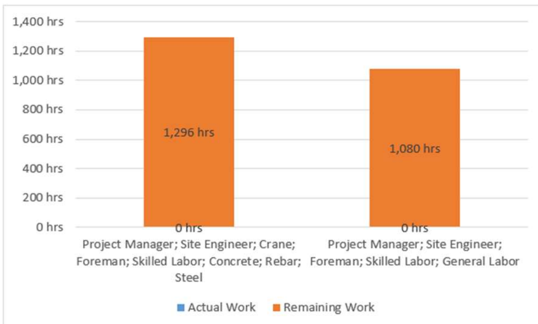


Appendix A (cont.)

OVERALLOCATED RESOURCES

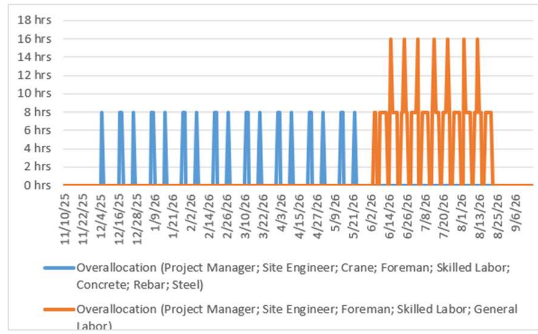
WORK STATUS

Work status for overallocated resources.



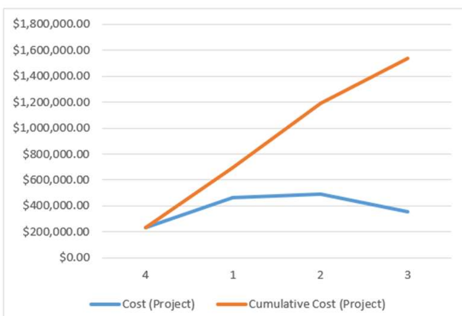
OVERALLOCATION

Surplus work assigned to overallocated resources. To resolve overallocations use Team Planner View



CASH FLOW

Actual Cost	Baseline Cost	Remaining Cost	Cost Variance
$0.00	$0.00	$1,539,994.49	$1,539,994.49



The chart shows the project's cumulative cost and the cost per quater.
To see the costs for a different time period, select the Edit option from the Field List.

The table below shows cost information for all top-level tasks.
To see cost stats for all tasks, set the Outline Level in the Field List.

Name	Remaining Cost	Actual Cost	Cost	ACWP	BCWP	BCWS
Project	$1,539,994.49	$0.00	$1,539,994.49	$0.00	$0.00	$0.00

Appendix A (cont.)

CONSTRUCTION PROJECT DETAILED REPORT

Project Name: Construction Project
Project Manager: Tjahjono Corp. Ltd.
Company: Gaillard Company
Start Date: 2025-11-10
Generated: 2025-11-10 19:22:23

EXECUTIVE SUMMARY

Total Construction Duration: 223 working days (44 weeks)
Number of Phases: 29
Total Building Objects: 7147
Work Hours per Day: 8
Work Days per Week: 5

RISK ASSESSMENT

Total High-Priority Risks Identified: 6

Phase: Foundation & Piles
Category: Weather
Description: Weather-dependent excavation work
Risk Score: 0.44 (Severity: 0.88, Probability: 0.50)
Mitigation:
- Monitor weather forecasts closely
- Maintain flexible scheduling buffer
- Prepare covered work areas

Phase: Foundation & Piles
Category: Weather
Description: Soil condition variability
Risk Score: 0.44 (Severity: 0.88, Probability: 0.50)
Mitigation:
- Monitor weather forecasts closely
- Maintain flexible scheduling buffer
- Prepare covered work areas

Phase: Foundation & Piles
Category: Weather
Description: Groundwater management
Risk Score: 0.44 (Severity: 0.88, Probability: 0.50)
Mitigation:
- Monitor weather forecasts closely
- Maintain flexible scheduling buffer
- Prepare covered work areas

Phase: MEP Installation
Category: Schedule
Description: Complex system integration
Risk Score: 0.42 (Severity: 0.66, Probability: 0.64)
Mitigation:
- Enhanced coordination meetings
- Parallel work stream optimization
- Critical path monitoring

Phase: MEP Installation
Category: Regulatory
Description: Regulatory inspection requirements
Risk Score: 0.42 (Severity: 0.66, Probability: 0.64)

Phase: MEP Installation
Category: Schedule
Description: Specialized labor availability
Risk Score: 0.42 (Severity: 0.66, Probability: 0.64)
Mitigation:
- Enhanced coordination meetings
- Parallel work stream optimization
- Critical path monitoring

END OF REPORT

This report was automatically generated by Unity Construction Management System with Microsoft Project Integration.

For questions or support, contact: Tjahjono Corp. Ltd.
Company: Gaillard Company

Appendix A (cont.)

ADVANCED CONSTRUCTION ANALYTICS REPORT
Generated: 2025-11-10 19:40:50

Foundation & Piles:
Planned: Day 0 → 12
Predicted: Day 1 → 15
Delay Probability: 50 %
Criticality Score: 0.88
Workers Required: 5
Efficiency: 78 %

Level 1 Columns:
Planned: Day 14 → 17
Predicted: Day 15 → 19
Delay Probability: 31 %
Criticality Score: 0.60
Workers Required: 6
Efficiency: 100 %

Level 1 Beams & Slabs:
Planned: Day 18 → 23
Predicted: Day 19 → 25
Delay Probability: 31 %
Criticality Score: 0.65
Workers Required: 6
Efficiency: 95 %

Level 2 Columns:
Planned: Day 24 → 27
Predicted: Day 25 → 29
Delay Probability: 32 %
Criticality Score: 0.56
Workers Required: 12
Efficiency: 97 %

Level 2 Beams & Slabs:
Planned: Day 28 → 33
Predicted: Day 28 → 34
Delay Probability: 33 %
Criticality Score: 0.66
Workers Required: 14
Efficiency: 89 %

Level 3 Columns:

Planned: Day 34 → 37
Predicted: Day 34 → 37
Delay Probability: 33 %
Criticality Score: 0.51
Workers Required: 11
Efficiency: 93 %

Level 3 Beams & Slabs:
Planned: Day 38 → 43
Predicted: Day 38 → 44
Delay Probability: 34 %
Criticality Score: 0.66
Workers Required: 14
Efficiency: 100 %

Level 4 Columns:
Planned: Day 44 → 47
Predicted: Day 45 → 48
Delay Probability: 35 %
Criticality Score: 0.46
Workers Required: 14
Efficiency: 76 %

Level 4 Beams & Slabs:
Planned: Day 48 → 53
Predicted: Day 49 → 55
Delay Probability: 36 %
Criticality Score: 0.66
Workers Required: 11
Efficiency: 77 %

Level 5 Columns:
Planned: Day 54 → 57
Predicted: Day 54 → 58
Delay Probability: 36 %
Criticality Score: 0.42
Workers Required: 14
Efficiency: 75 %

Level 5 Beams & Slabs:
Planned: Day 58 → 63
Predicted: Day 58 → 64
Delay Probability: 37 %
Criticality Score: 0.67
Workers Required: 14
Efficiency: 97 %

Level 6 Columns:
Planned: Day 64 → 67
Predicted: Day 64 → 68
Delay Probability: 38 %
Criticality Score: 0.37
Workers Required: 11
Efficiency: 95 %

Level 6 Beams & Slabs:

Planned: Day 68 → 73
Predicted: Day 68 → 74
Delay Probability: 38 %
Criticality Score: 0.67
Workers Required: 5
Efficiency: 74 %

Level 7 Columns:
Planned: Day 74 → 77
Predicted: Day 74 → 77
Delay Probability: 39 %
Criticality Score: 0.32
Workers Required: 10
Efficiency: 77 %

Level 7 Beams & Slabs:
Planned: Day 78 → 83
Predicted: Day 79 → 85
Delay Probability: 40 %
Criticality Score: 0.67
Workers Required: 13
Efficiency: 93 %

Level 8 Columns:
Planned: Day 84 → 87
Predicted: Day 85 → 89
Delay Probability: 40 %
Criticality Score: 0.28
Workers Required: 10
Efficiency: 95 %

Level 8 Beams & Slabs:
Planned: Day 88 → 93
Predicted: Day 89 → 95
Delay Probability: 41 %
Criticality Score: 0.68
Workers Required: 11
Efficiency: 86 %

Roof Columns:
Planned: Day 94 → 97
Predicted: Day 95 → 99
Delay Probability: 42 %
Criticality Score: 0.23
Workers Required: 7
Efficiency: 100 %

Roof Beams & Slabs:
Planned: Day 98 → 103
Predicted: Day 98 → 103
Delay Probability: 42 %
Criticality Score: 0.68
Workers Required: 12
Efficiency: 100 %

Level 1 Architecture:
Planned: Day 104 → 114
Predicted: Day 104 → 117
Delay Probability: 43 %
Criticality Score: 0.41
Workers Required: 7
Efficiency: 71 %

Level 2 Architecture:
Planned: Day 115 → 125
Predicted: Day 117 → 128
Delay Probability: 44 %
Criticality Score: 0.41
Workers Required: 6
Efficiency: 76 %

Level 3 Architecture:
Planned: Day 126 → 136
Predicted: Day 128 → 140
Delay Probability: 44 %
Criticality Score: 0.41
Workers Required: 7
Efficiency: 99 %

Level 4 Architecture:
Planned: Day 137 → 147
Predicted: Day 139 → 151
Delay Probability: 45 %
Criticality Score: 0.41
Workers Required: 8
Efficiency: 85 %

Level 5 Architecture:
Planned: Day 148 → 158
Predicted: Day 150 → 160
Delay Probability: 46 %
Criticality Score: 0.41
Workers Required: 12
Efficiency: 93 %

Level 6 Architecture:
Planned: Day 159 → 169
Predicted: Day 161 → 171
Delay Probability: 47 %
Criticality Score: 0.42
Workers Required: 8
Efficiency: 92 %

Level 7 Architecture:
Planned: Day 170 → 180
Predicted: Day 172 → 182
Delay Probability: 47 %
Criticality Score: 0.42
Workers Required: 5
Efficiency: 81 %

Level 8 Architecture:
Planned: Day 181 → 191
Predicted: Day 183 → 195
Delay Probability: 48 %
Criticality Score: 0.42
Workers Required: 11
Efficiency: 87 %

Roof Architecture:
Planned: Day 192 → 202
Predicted: Day 194 → 207
Delay Probability: 49 %
Criticality Score: 0.42
Workers Required: 5
Efficiency: 85 %

MEP Installation:
Planned: Day 203 → 223
Predicted: Day 204 → 227
Delay Probability: 64 %
Criticality Score: 0.66
Workers Required: 14
Efficiency: 92 %

END OF REPORT