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From Critical Path to Converged Intelligence: A Narrative Review of Oracle Primavera P6 Integration with Building Information Modelling, Artificial Intelligence, and Unmanned Aerial Systems in Construction Project Delivery

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ABSTRACT

Oracle Primavera P6 is the dominant critical-path-method (CPM) scheduling platform in large-scale construction and infrastructure delivery, yet its proprietary XER and P6-XML data architecture was not designed for native interoperability with the spatial, cognitive, and reality-capture data streams that increasingly define modern project delivery. This paper critically reviews the fragmented and rapidly evolving literature on integrating P6 with three digitally transformative streams: Building Information Modelling (BIM), artificial intelligence and machine learning (AI/ML), and unmanned aerial vehicle (UAV)-based progress monitoring. Adopting a narrative, critical-review approach across peer-reviewed journal articles, conference papers, and industry technical publications, the review finds that practitioners have built substantial bridging infrastructure around P6's architectural limitations: BIM-P6 integration, typically via Revit-Navisworks pipelines, enables 4D sequencing and clash detection with documented double-digit improvements in duration and cost outcomes; AI/ML models trained on exported P6 schedule data achieve meaningful predictive accuracy for delay and risk forecasting; and UAV-based photogrammetry increasingly closes the loop by feeding as-built progress data back into P6 percent-complete fields. However, the three streams remain largely siloed from one another in both research and practice. Building on this synthesis, the paper proposes an original conceptual framework, the Tri-Layer Convergent Scheduling Framework (TCSF), which positions P6's CPM data backbone as the coordinating spine for a Spatial Simulation Layer (BIM), a Predictive Intelligence Layer (AI/ML), and a Reality Verification Layer (UAV), connected through a continuous update-and-recalculation loop. The framework is offered as a research and practice agenda rather than a validated model, and the paper closes with implications for construction project management practitioners and a research agenda for closing the interoperability gap.

INTRODUCTION

Construction project delivery has, for more than half a century, been organised around the critical path method (CPM), a network-scheduling logic first formalised by Morgan Walker and James Kelley in the late 1950s (Walker & Kelley, as cited in IJAIDR, 2025) and subsequently embedded in commercial scheduling software. Among the tools that operationalise CPM at scale, Oracle Primavera P6 has become the de facto industry standard for major infrastructure, energy, and building programmes (Oracle, 2026; ProjectManager.com, 2025), valued for its capacity to structure work breakdown structures, sequence dependent activities, allocate and level resources, and calculate float across portfolios containing thousands of activities (IJFMR, 2026; ResearchGate, 2025). Its origins trace to Primavera Systems, founded in 1983, and its subsequent evolution into a full Enterprise Project Portfolio Management (EPPM) suite reflects several decades of incremental adaptation to the scale and complexity of contemporary construction programmes.

This architectural gap carries real practical stakes.

National-level investigations of construction delay causation consistently identify inadequate schedule control and poor cross-disciplinary data integration as leading contributors to cost and time overruns: studies of public-sector projects in Saudi Arabia (Al-Kharashi & Skitmore, as cited in IJSAT, 2025) and Egypt (Marzouk & El-Rasas, as cited in IJSAT, 2025) both report that inadequate coordination between design, scheduling, and site-monitoring functions ranks among the most frequently cited delay factors, a diagnosis echoed at policy level by the United Kingdom's national roadmap for BIM implementation (Khosrowshahi & Arayici, as cited in IJSAT, 2025), which explicitly frames improved model-schedule integration as a lever for reducing such delays. These findings motivate the specific focus of this review: rather than treating BIM, AI/ML, and UAV integration as isolated technical curiosities, they are better understood as three converging responses to a long-documented and geographically widespread schedule-integration problem. Yet the same features that make P6 durable and trusted, an activity-and-relationship data model optimised for time, cost, and resource logic, also constrain its native ability

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to absorb three classes of information that increasingly define how modern projects are designed, monitored, and de-risked: the three-dimensional, object-based geometry of Building Information Modelling; the pattern-recognition and probabilistic-forecasting capability of artificial intelligence and machine learning; and the reality-capture data streams generated by unmanned aerial vehicles (UAVs) equipped with photogrammetric and LiDAR sensors. P6 was not architected with native application programming interfaces for any of these three domains, and its principal interchange formats (the proprietary XER format and the more portable but still P6-specific P6-XML schema) remain oriented toward exchanging schedule data between P6 installations rather than toward open, cross-platform interoperability.

Despite this architectural gap, a substantial and fast-growing applied literature, spanning peer-reviewed construction management journals, engineering conference proceedings, and vendor and consultancy technical publications, documents practitioners building bridging pipelines around P6 rather than waiting for native integration; industry market analysis places this growth within a wider surge of commercial investment in AI-enabled construction technology more broadly (Fortune Business Insights, as cited in Pinnacle Infotech, 2025). BIM models developed in Revit are federated with P6 schedules through Navisworks to create 4D simulations; machine learning models are trained directly on exported P6 activity and progress data to forecast delays and quantify schedule risk; and drone-captured aerial imagery is reconciled against planned geometry and fed back into P6 progress fields to close the loop between as-built reality and the baseline programme. Each of these three integration streams has, to date, developed largely as an independent body of work, with its own vocabulary, its own case-study traditions, and its own vendor ecosystem. This paper's contribution is to bring these three streams into a single frame of reference, to characterise what

is empirically known about each, to identify where the evidence is thin or commercially self-interested, and to propose a conceptual structure, the Tri-Layer Convergent Scheduling Framework, for thinking about how they might be deliberately rather than incidentally combined. The review is written from the standpoint of a practising project management professional working within a project management consultancy in South Asia, and is intended to be useful both to researchers seeking to identify gaps in the empirical record and to practitioners weighing which integration investment to prioritise.

LITERATURE REVIEW

Primavera P6 and the Critical Path Method: A Brief Background

Comparative practitioner literature situates P6 among competing scheduling platforms: broad overviews of its feature set and licensing model (ProjectManager.com, 2025) and project-management case studies of its practical application (IJFMR, 2026) are complemented by direct comparisons with lighter-weight tools such as Microsoft Project, which consistently find that P6's advantage lies in its capacity for enterprise-scale, multi-project resource and risk management rather than in ease of use for single, smaller projects (ResearchGate, 2025). Practitioner-oriented syntheses of P6's planning and control capabilities reinforce this positioning, presenting it as the platform of choice once portfolio complexity exceeds what spreadsheet-based or single-project tools can support (IJSAT, 2025).

Before turning to CPM logic in more detail, Figure 1 shows the native P6 Professional interface, the Enterprise Project Structure (EPS) view in which projects are organised hierarchically by business unit or programme (here, Engineering & Construction, Energy Services, and Manufacturing) and rolled up into portfolio-level totals of activity count and strategic priority. This enterprise-level structuring, distinct from the activity-level Gantt view

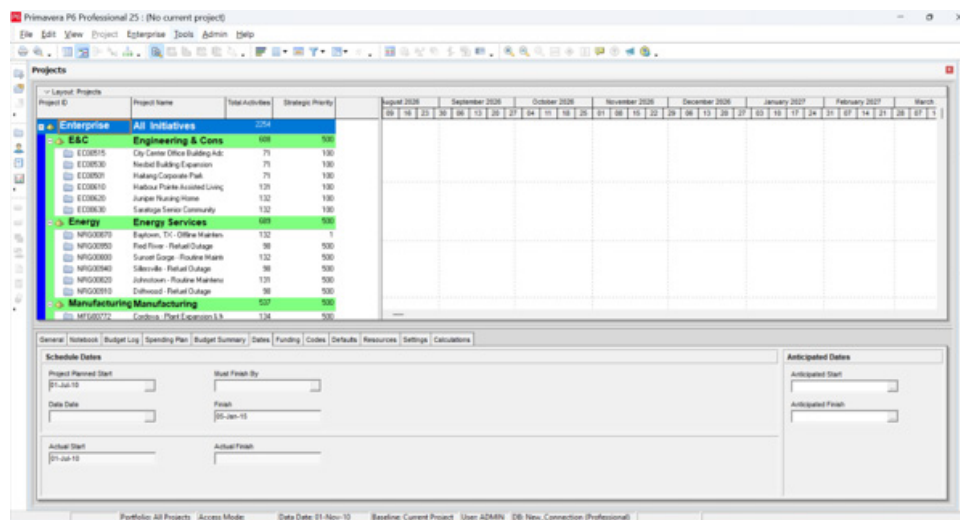


Figure 1: Primavera P6 Professional 25 Enterprise Project Structure (EPS) view, showing a multi-division project portfolio and project-level schedule date fields. Screenshot captured from a demonstration/training database (DB: New_Connection, User: ADMIN); no live client project data is shown

discussed later in this section, is what allows P6 to function as a true Enterprise Project Portfolio Management (EPPM) tool rather than a single-project scheduling utility. CPM scheduling identifies the longest sequence of logically dependent activities in a project network, the activities whose combined duration determines the shortest possible project completion date and whose delay therefore delays the whole project. Primavera P6 operationalises this logic through a relational database architecture spanning well over a hundred underlying tables, in which activities,

relationships, calendars, resources, roles, and user-defined fields are stored and related to one another; P6 offers users the choice of displaying the critical path as either the set of activities with zero total float or the single longest path through the network, a distinction that becomes material on programmes with hard interim milestones. Figure 2 illustrates this activity-network logic schematically.

Beyond pure CPM logic, P6 supports resource loading and levelling, enabling planners to detect over-allocation of

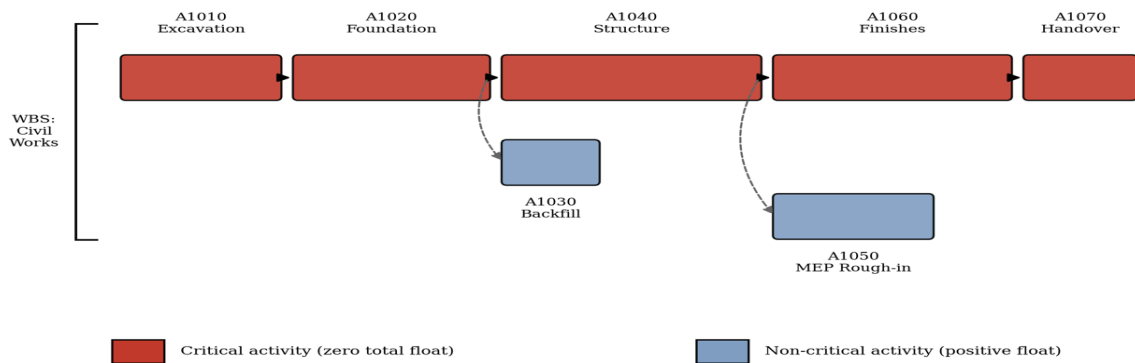


Figure 2: Illustrative reconstruction of P6 activity-network logic for expository purposes; not a screenshot of the software interface

labour, equipment, or materials before it manifests on site, and Monte Carlo-based schedule risk analysis, which runs large numbers of probabilistic simulations against activity duration ranges to estimate the likelihood of meeting a given completion date and to identify which activities contribute most to overall schedule uncertainty (ProjeX Consult, 2025). P6 is frequently discussed alongside, and sometimes contrasted with, Earned Value Management (EVM): where CPM logic governs sequencing and the

identification of schedule-critical work, EVM integrates cost and schedule performance into a single measurement framework, and the literature generally treats the two as complementary rather than substitutable, with P6 capable of supporting both when properly resource- and cost-loaded (IJAIDR, 2025). Figure 3 illustrates the resource-levelling logic underlying this capability.

For interoperability purposes, P6 principally exports data in two formats (Oracle Primavera Cloud Documentation,

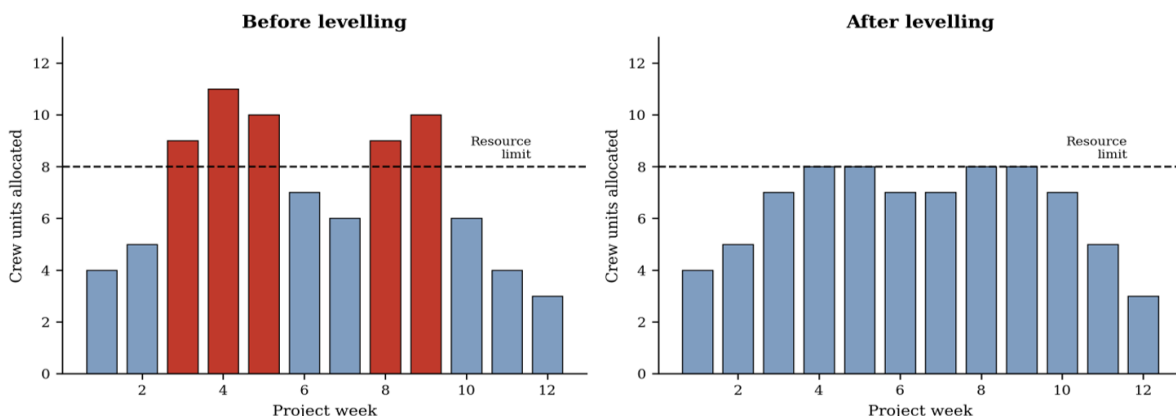


Figure 3: Illustrative reconstruction of P6 resource-levelling logic; not a screenshot of the software interface.

2026; The Skills Age, 2026). XER, described in practitioner literature as Primavera's native, text-based exchange format, remains the format most commonly specified as a contractual deliverable because it preserves the fullest range of P6's internal data structure, though it is proprietary to Primavera environments and offers limited validation of imported data (Global PM, 2025; ScheduleLens, 2026). P6-XML, an XML-based alternative,

trades some of XER's completeness for wider readability and easier integration with third-party systems (Planning Engineer FZE, 2025). Neither format was designed with an eye toward geometric (BIM), probabilistic (AI/ML), or image-based (UAV) data; this is the structural starting point for the three integration streams reviewed below, and is represented schematically in Figure 4.

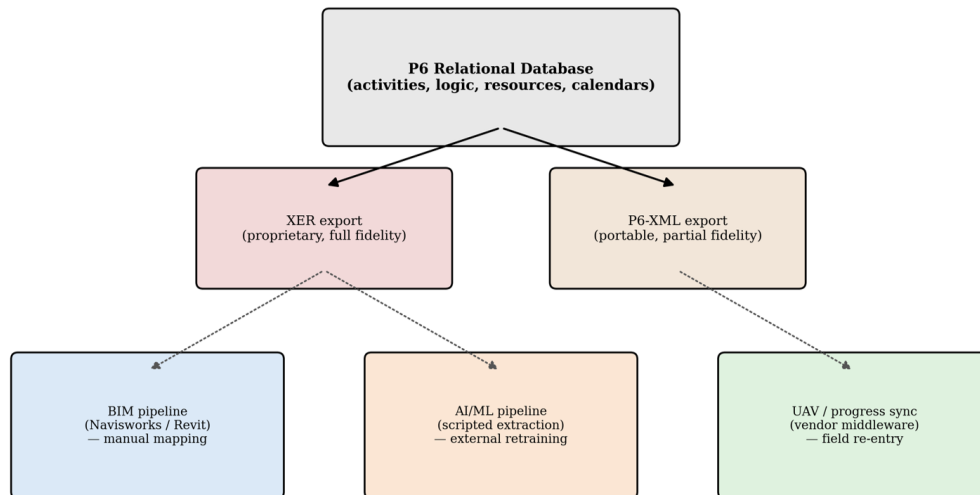


Figure 4: Illustrative reconstruction of P6's export architecture and its downstream dependencies; not a screenshot of the software interface.

P6 and Building Information Modelling

The most mature of the three integration streams links P6's time-based scheduling logic with BIM's geometric and object-based data to produce 4D simulations, models in which the construction sequence can be visualised against the physical building over time (Azhar, 2011; Song, Eastman, & Sacks, as cited in Mohammed, 2025). The dominant technical pattern in the reviewed literature follows a consistent pipeline: a discipline-specific BIM model (architectural, structural, and MEP) is developed in Autodesk Revit; a parallel construction schedule, structured by work breakdown structure and activity logic, is developed in P6; the Revit model is exported to a neutral format and imported into Autodesk Navisworks, which serves as the federating environment where schedule activities are mapped to model elements to enable clash detection and time-based visualisation (IJSRET, 2026).

Case-study evidence for the value of this pipeline, while still limited to a small number of documented projects, is directionally consistent. A recent study of a public housing programme in India reported that BIM-P6 integration was associated with a recovery of 217 days against a delay-adjusted baseline, corresponding to a duration reduction of just over 22% and a cost reduction of nearly 26% relative to the non-integrated delay scenario (Discover Civil Engineering / Springer Nature, 2026). A separate simulation-based study of a five-storey residential structure reported a 13.5% reduction in total project duration, a fall in design changes from fourteen to five, an increase in resource utilisation efficiency from 78 to 92%, and the identification of 48 spatial or temporal conflicts prior to physical execution (Mohammed, 2025). Practitioner literature converges on similar mechanisms of benefit: improved real-time visualisation of schedules for architects, engineers, and contractors, and earlier detection of sequencing conflicts before they manifest as rework on site.

These figures should be read cautiously. Each derives from a single project or simulated case rather than a controlled comparison across a sample of comparable projects, and several of the reviewed sources are conference papers or institutional repositories rather than peer-reviewed journal articles, meaning the reported percentages have not been subject to the scrutiny that would support strong generalisation. What is more robustly supported across sources is the underlying mechanism, that federating a time-logic model (P6) with a geometry-and-metadata model (BIM, via Navisworks) allows conflicts to be identified and construction sequencing to be rehearsed virtually before it is committed to site, a mechanism with clear face validity independent of the specific percentage improvements claimed in any one study.

A persistent limitation noted across the literature is that this integration is achieved through parallel modelling and manual mapping rather than through native software interoperability: BIM and P6 remain separate authoring environments whose outputs are reconciled in a third tool (typically Navisworks), and the mapping between schedule activities and model elements must be actively maintained as either the schedule or the model changes. This manual reconciliation burden, rather than any conceptual limitation of 4D scheduling itself, appears to be the principal barrier to wider adoption noted by practitioner sources.

P6 and Artificial Intelligence / Machine Learning

The second integration stream treats P6's exported schedule data, principally in XER format, as a training corpus for machine learning models aimed at predicting delays, quantifying schedule risk, and, more recently, generating or optimising schedule alternatives. Industry glossaries and vendor documentation frame this broadly as "AI for Primavera P6" (Nomic AI, 2026), a category that in practice spans everything from schedule-adjacent automation add-ins for spreadsheet and P6

environments (Datagrid, 2025) to the more rigorous predictive-modelling literature reviewed below. This stream divides into three sub-applications with differing levels of empirical maturity: predictive delay and risk modelling, generative schedule optimisation, and buffer or contingency estimation.

Predictive modelling is the most empirically developed sub-application. One widely cited hybrid machine learning study assembled a dataset of 302 valid P6 project files (from an initial pool of 560, the remainder excluded for corrupted files or missing actual-versus-planned data) drawn from United Kingdom construction projects completed between 2007 and 2019 and collectively worth approximately £8.9 billion, comprising 293,263 individually classified schedule activities (ResearchGate, 2022); this scale of dataset is unusual in construction management research and lends the study's findings more weight than the single-project case studies common elsewhere in the reviewed literature. A separate, more recent study reported that machine learning models trained on P6 schedule data achieved delay-prediction accuracy of approximately 83% (ResearchGate, 2026), though the authors themselves note that the approach depends on plugins or scripted pipelines to extract usable training data from P6's native environment, and that data quality, version compatibility, and the absence of user-friendly interfaces for construction professionals without a machine learning background remain practical barriers to adoption.

A further application area, buffer and contingency estimation, applies regression-based machine learning to forecast final project duration under uncertainty; one study drawing on a sample of 78 construction projects and 122 associated P6 as-planned schedules from the Jordanian construction sector found that Gaussian Process Regression outperformed competing algorithms when predicting final duration from five delay-relevant parameters (as-planned duration, contractor, weather conditions, owner, and consultant), derived jointly from field interviews and prior literature (Emerald Publishing, 2025).

Generative and prescriptive applications represent the newest and least independently validated sub-application. Commercial platforms, most visibly ALICE Technologies, are reported in industry technical literature to work directly from P6 files without requiring an accompanying BIM model, generating very large numbers of candidate schedule alternatives and identifying near-optimal sequencing options (ALICE Technologies / Dan Cumberland Labs, 2026), while other vendors such as nPlan apply probabilistic forecasting trained on large historical schedule datasets alongside Monte Carlo simulation. P6 itself retains native Monte Carlo-based schedule risk analysis capability, allowing users to run repeated simulations against activity duration ranges to estimate completion-date probability and identify the activities contributing most to overall uncertainty, though this native capability is

deterministic-simulation rather than learning-based, and represents a meaningfully different technical approach from the externally trained ML models discussed above. Across this stream, a broader empirical study using survey data from 204 construction professionals, analysed through a partial least squares structural equation model grounded in the Technology-Organisation-Environment framework, found that despite strong perceived potential for AI in predictive analytics, generative optimisation, and data-driven decision support, actual adoption in scheduling practice remains constrained by technological, organisational, and environmental barriers (Taylor & Francis / International Journal of Construction Management, 2026), a finding broadly consistent with the practical caveats noted by the individual studies above and with wider construction-sector evidence on digital twin and AI adoption, which similarly identifies data interoperability, absence of common standards, and organisational or cultural resistance as persistent constraints rather than problems solved by any single tool.

This adoption gap sits within a broader and fast-growing literature on digital twins in construction, which frames AI-enabled scheduling as one component of a larger vision of continuously updated, sensor-fed virtual representations of physical assets. Industry outlook reporting anticipates accelerating investment in digital twins, automation, and interoperability standards over the near term (Construction Briefing, 2025), while systematic reviews of AI-driven digital twins in industrialised offsite construction (MDPI Buildings, 2025) and broader implementations across the construction sector (Taylor & Francis, 2025; ScienceDirect, 2026) converge on similar conclusions: technical feasibility is well ahead of standardised, cross-vendor interoperability, and generative AI is increasingly discussed as the natural pairing for digital twin environments rather than as a separate technology stream (Pinnacle Infotech, 2025). This literature reinforces, at a broader industry level, the same interoperability diagnosis this review makes specifically with respect to P6.

P6 and Unmanned Aerial Vehicles

The third integration stream is the least represented in the peer-reviewed academic literature and the most represented in industry and vendor technical publications, reflecting its relative youth as a defined research area compared with BIM or AI integration. The underlying technical logic is nonetheless well documented in practitioner sources: UAVs equipped with high-resolution cameras or LiDAR sensors conduct repeated, standardised flights over a construction site, and photogrammetric processing converts the resulting imagery into georeferenced 2D orthomosaics or 3D point clouds and models (Advexure, 2025; Drone as a Service, 2026). These as-built captures are then compared against as-designed CAD or BIM geometry to quantify physical progress, and, in workflows described as integrating

with Primavera P6, this progress quantification is used to update or verify percent-complete values against baseline schedule activities.

Vendor and industry technical sources describe integration with P6 (alongside comparable platforms such as Procore and Autodesk BIM 360) as enabling automated field-update synchronisation, in which drone-derived percent-complete data flows back into the schedule with reduced manual re-entry, and as supporting milestone-level progress tracking intended to surface schedule misalignment before it escalates into costly delay (Eagleview, 2025). Reported operational benefits in this literature include substantially reduced site-walk time relative to manual progress inspection and the ability to generate standardised, dated comparison imagery for recurring stakeholder reporting (RoboticsTomorrow, 2026).

Because this sub-literature is dominated by vendor and consultancy publications rather than independent peer-reviewed studies, the specific efficiency and accuracy claims reported (flight-time reductions, inspection-time savings, and similar figures) should be treated as illustrative of an active and commercially motivated technology market rather than as independently validated research findings. What can be stated with more confidence, because it follows from the underlying photogrammetric and data-integration mechanics rather than from any single vendor's marketing claims, is that UAV-based reality capture offers a genuinely distinct data type, direct physical evidence of as-built condition, that neither BIM (a design-intent model) nor AI trained on historical schedule data (a pattern-based forecast) can independently supply, and that this makes UAV integration a structurally complementary rather than competing addition to the other two streams.

MATERIALS AND METHODS

This paper adopts a narrative, critical-review methodology rather than a formal systematic review conforming to PRISMA-type protocols. This choice reflects the nature of the evidence base itself: research on P6 integration with BIM, AI, and UAV technologies is distributed across peer-reviewed construction management and engineering journals, graduate and practitioner conference papers, professional blog and vendor technical content, and product documentation, with no single indexed corpus large or homogeneous enough to support a defensible quantitative synthesis or meta-analysis at this stage of the field's maturity. A systematic protocol applied to such a heterogeneous, partly grey-literature evidence base risks manufacturing a false appearance of methodological rigour; this paper instead makes its selection logic and its limitations explicit.

Sources were identified through iterative, keyword-based searches (combining terms such as “Primavera P6”, “BIM integration”, “machine learning schedule risk”, “UAV progress monitoring”, “digital twin construction

scheduling”, and “XER interoperability”) across academic databases, publisher platforms, and the open web, and were purposively selected to populate each of the three integration streams with both empirical case studies and broader contextual or industry-outlook material. Priority was given, where available, to peer-reviewed journal articles reporting quantitative outcomes; where the peer-reviewed record was thin, as is currently the case for UAV-P6 integration specifically, industry technical publications and vendor documentation were used to characterise current practice, with this reliance flagged explicitly in the relevant sections rather than presented as equivalent to peer-reviewed evidence.

Sources were screened for direct relevance to at least one of the three integration streams and for the specificity of their claims about P6 itself, rather than generic discussion of BIM, AI, or UAV technology in isolation; sources meeting neither criterion were excluded from the synthesis. Where multiple sources reported overlapping findings, preference was given to the most methodologically detailed or most recently published account, with earlier or thinner sources retained only where they contributed a distinct example, geographic context, or dataset not otherwise represented.

The review does not claim exhaustiveness. It is limited to English-language sources, weighted toward material published between 2020 and 2026, and inevitably reflects the commercial visibility of certain vendors (notably Oracle, Autodesk, and specialist AI-scheduling firms) whose own publications are more discoverable than independent academic replication of their claims. Readers should treat quantitative outcomes drawn from single case studies or vendor-authored sources as indicative rather than generalisable, a caveat repeated at relevant points in the synthesis below.

RESULTS AND DISCUSSION

Cross-Cutting Themes and Gaps

Read together, the three integration streams reveal a consistent underlying pattern. P6 supplies the authoritative time-and-logic backbone of a construction programme, but none of the three transformative data types reviewed here, geometric (BIM), predictive (AI/ML), or evidentiary (UAV), integrates with that backbone natively. In every stream, practitioners have built bridging infrastructure around P6's proprietary XER and P6-XML formats rather than through interoperability designed into the platform itself: Navisworks mediates between P6 and Revit; scripted extraction pipelines or third-party plugins mediate between P6 and machine learning models; and vendor middleware mediates between P6 and drone-derived progress data. This convergence of workaround architecture across three otherwise unrelated technology domains is, in itself, one of the more notable findings of this review, and it suggests that the interoperability gap is a structural property of P6's data model r

Table 1: Comparative summary of the three P6 integration streams

Dimension	BIM – P6	AI/ML – P6	UAV – P6
Evidence maturity	Moderate — several documented single-project case studies	Highest of the three — includes one large-scale (302-project) dataset	Lowest — mostly vendor/industry sources, minimal peer-reviewed evidence
Primary data flow	Largely one-way: P6 → Navisworks visualisation	One-way: exported P6 data → trained model → forecast output	One-way: UAV capture → P6 progress field update
Mediating technology	Autodesk Navisworks (manual element-activity mapping)	Scripted XER/XML extraction, third-party plugins	Photogrammetry software, vendor middleware
Key limitation / gap	Manual reconciliation burden as schedule/model change	Adoption lags demonstrated potential; data-quality dependent	Weak independent/peer-reviewed validation of vendor claims

A second cross-cutting theme is the uneven maturity of the evidence base. BIM-P6 integration is supported by the largest number of documented case studies with quantified outcomes, though these remain single-project studies rather than controlled comparative samples. AI/ML integration is supported by at least one dataset of genuinely substantial scale (the 302-project, 293,263-activity UK dataset discussed above), giving this sub-stream a stronger empirical footing than either of the others, but adoption research consistently finds a gap between demonstrated technical potential and actual practitioner uptake. UAV-P6 integration is the least academically documented of the three, with the current evidence base weighted heavily toward industry and vendor sources; this is plausibly a function of the field's youth rather than of any inherent limitation in the technology, and represents the clearest opportunity for near-term peer-reviewed research.

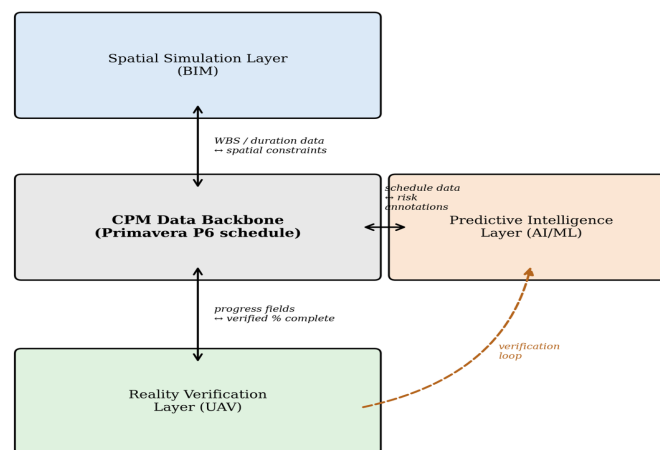
Third, all three streams are individually pursued but essentially never combined in a single documented case in the reviewed literature. No source identified for this review describes a project in which BIM-derived 4D sequencing, AI-derived risk forecasting, and UAV-derived as-built verification were deliberately integrated around a shared P6 schedule as a unified system, despite each

pairwise combination (BIM with P6, AI with P6, UAV with P6) being independently well established. This absence of a documented tri-integrated case is the specific gap the framework proposed in the following section is intended to address conceptually, pending empirical validation.

Proposed Framework: The Tri-Layer Convergent Scheduling Framework (TCSF)

Building on the synthesis above, this paper proposes the Tri-Layer Convergent Scheduling Framework (TCSF) as a conceptual structure for organising deliberate, rather than incidental, integration of BIM, AI/ML, and UAV data streams around a P6 CPM backbone. The framework is offered as a scaffold for future empirical research and pilot implementation, not as a validated model; no claim is made that it has been tested on an actual project.

TCSF is organised around a central CPM Data Backbone, the P6 schedule itself, understood not merely as a Gantt chart but as the authoritative record of activity logic, dependencies, float, and resource allocation. Three functional layers connect to this backbone through defined, bidirectional data flows rather than the largely one-directional or manually reconciled flows characteristic of current practice, illustrated in Figure 5:


Figure 5: The Tri-Layer Convergent Scheduling Framework (TCSF)

Note: solid arrows denote the three primary bidirectional links to the CPM backbone; the dashed arrow denotes TCSF's proposed verification loop from the Reality Verification Layer to the Predictive Intelligence Layer.

Spatial Simulation Layer (BIM): receives WBS and activity-duration data from the CPM backbone to drive 4D sequencing and clash detection, and returns geometry-derived constraints, such as spatial conflicts or access-sequencing requirements identified during simulation, as logic ties or constraints back into the P6 schedule, rather than leaving these findings as a one-way visualisation output.

Predictive Intelligence Layer (AI/ML): consumes historical and live P6 activity, duration, and progress data (extracted via XER or P6-XML) to generate delay-risk scores and schedule-alternative recommendations, and returns these as flagged risk annotations or suggested logic revisions on specific activities, positioning AI output as a decision-support overlay on the schedule rather than a replacement for planner judgement.

Reality Verification Layer (UAV): supplies photogrammetrically derived percent-complete and as-built condition data at defined intervals, which updates progress fields on the CPM backbone directly, and, critically in this framework, also feeds the Predictive Intelligence Layer, so that AI-driven forecasts are continuously recalibrated against verified physical progress rather than against self-reported or estimated percent-complete values, which the literature reviewed above identifies as a common source of forecasting error.

The framework's central proposition, and its principal point of departure from current practice as documented in the reviewed literature, is that the Reality Verification Layer should feed the Predictive Intelligence Layer directly, rather than each of the three layers connecting only to the CPM backbone in isolation. This closes what might be termed a verification loop: AI-driven schedule forecasts, which in the reviewed literature are trained on historical schedule data and validated against actual-versus-planned records after project completion, could instead be continuously recalibrated during project execution against UAV-verified physical progress, potentially reducing the lag between an emerging delay and its detection. Whether this proposed loop meaningfully improves forecast accuracy relative to current single-stream approaches is an empirical question this paper does not resolve; it is offered as the framework's core testable hypothesis for future research.

Implementing TCSF on an actual programme would require addressing the same interoperability constraints identified throughout this review: a defined, ideally IFC-aligned, exchange schema for the Spatial Simulation Layer; a governed, scripted extraction and re-import pipeline for the Predictive Intelligence Layer; and a standardised, geo-referenced progress-mapping protocol for the Reality Verification Layer. None of these is technically novel in isolation, each already exists in some form in the sources reviewed above, but their deliberate combination into a single governed data architecture, rather than three independent point-to-point integrations, is what TCSF proposes as a research and practice agenda.

Implications for Practice and Research Agenda

For practitioners, the review suggests a pragmatic sequencing logic for organisations weighing where to invest first. BIM-P6 integration offers the most mature evidence base and the clearest near-term return for programmes with significant spatial coordination risk (dense MEP routing, multi-trade sequencing, or brownfield/occupied-site constraints). AI/ML integration offers value primarily where an organisation already has a substantial archive of completed, well-structured P6 schedules to train or calibrate models against; the UK study's reliance on 302 valid files out of 560 collected illustrates how much historical data quality matters, and organisations with sparse or inconsistently maintained schedule archives should expect this to be a binding constraint before software capability is. UAV integration offers the fastest standalone implementation and the most directly interpretable output (a visual as-built record) but currently delivers the least schedule-native value unless deliberately connected back into progress reporting workflows rather than used purely for stakeholder communication.

For researchers, this review identifies three specific gaps meriting dedicated study. First, the near-complete absence of peer-reviewed, as opposed to vendor-authored, empirical evaluation of UAV-P6 integration outcomes represents the most immediately addressable gap, given that the underlying photogrammetric and data-synchronisation technologies are already mature and deployed at scale in industry. Second, no identified source in this review reports a controlled or comparative study of BIM-P6 integration outcomes across multiple projects; the field currently rests on single-case evidence that, while directionally consistent, cannot support strong causal claims about the magnitude of benefit. Third, and most significantly, the complete absence of documented tri-integrated implementations combining BIM, AI, and UAV streams around a shared P6 backbone, the gap the TCSF framework is intended to address conceptually, represents an open empirical frontier: even a single well-instrumented pilot project reporting on such an integration would materially advance the field beyond its current state of three parallel, non-communicating literatures.

CONCLUSION

Oracle Primavera P6 remains, more than four decades after its origins as Primavera Systems, the dominant CPM scheduling backbone for major construction and infrastructure programmes, valued precisely for the disciplined, activity-and-logic-centred data model that has proven durable across generations of software revision. That same data model, architected for time, cost, and resource logic rather than for geometric, probabilistic, or image-based data, is also the source of the interoperability gap this review has traced across three otherwise distinct technology streams: BIM, AI/ML, and UAV-based reality capture. In each case, the construction industry has

responded not by waiting for native platform integration but by constructing bridging infrastructure, Navisworks pipelines, scripted data-extraction workflows, and vendor middleware, around P6's proprietary export formats.

This review has synthesised what is currently known, and not known, about each of these three streams, and has proposed the Tri-Layer Convergent Scheduling Framework as a conceptual scaffold for thinking about their deliberate combination rather than their continued parallel, siloed development. The framework's central and untested proposition, that UAV-verified physical progress should feed directly into AI-driven predictive recalibration rather than each data stream connecting only to the schedule in isolation, is offered as a specific, falsifiable direction for future empirical work. As the underlying technologies, generative AI-based schedule optimisation, increasingly capable drone photogrammetry, and cloud-native BIM authoring, continue to mature, the practical and academic case for closing this interoperability gap, rather than continuing to manage it through point-to-point workarounds, is likely to strengthen.

The pace of change across all three underlying technology domains makes this an opportune moment for the construction management research community to move from parallel, single-stream investigation toward the kind of deliberately integrated empirical work this review has argued is currently absent, before the interoperability gap identified above hardens further into permanent, single-purpose middleware built around each pairwise combination alone.

REFERENCES

- Advexure. (2025). *Drone progress monitoring & documentation*. <https://advexure.com/pages/progress-monitoring-and-documentation-drones>
- ALICE Technologies / Dan Cumberland Labs. (2026). *AI construction scheduling: From reactive to predictive*. <https://dancumberlandlabs.com/blog/ai-construction-scheduling/>
- Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for firms and stakeholders. *Leadership and Management in Engineering*, 2(3), 139–147.
- Construction Briefing. (2025). *The 2025 construction outlook: Digital twins, automation and interoperability*. <https://www.constructionbriefing.com/news/digital-twins-automation-and-interoperability-t/8050154.article>
- Datagrid. (2025). *Maximize construction efficiency with AI in Primavera P6 & Smartsheet*. <https://datagrid.com/blog/automate-primavera-p6-smartsheet-scheduling-construction>
- Discover Civil Engineering / Springer Nature. (2026). *Integrating building information modeling and Primavera P6 to mitigate delays and optimize costs in public housing projects in India*. <https://doi.org/10.1007/s44290-026-00511-0>
- Drone as a Service. (2026). *Drones in construction: Safety, monitoring & project control guide 2026*. <https://www.droneasaservice.com/blog/drones-construction-guide/>
- Eagleview. (2025). *Drone construction monitoring: How to keep projects on track*. <https://www.eagleview.com/eagleview/drone-construction-monitoring/>
- Emerald Publishing. (2025). A machine learning-based buffer estimation for construction schedules under uncertainty. In *The Role of Artificial Intelligence Applications in Business*. <https://www.emerald.com/books/edited-volume/17073/chapter-abstract/94353177>
- Global PM. (2025). *XER vs. XML files in Primavera P6: Which one should you use?* <https://globalpm.com/xer-vs-xml-files-in-primavera-p6-which-one-should-you-use/>
- IJAIDR. (2025). *Critical path method vs EVM: A comparative analysis*. <https://www.ijaidr.com/papers/2025/1/1409.pdf>
- IJFMR. (2026). *Project management in construction using Primavera P6*. <https://www.researchgate.net/publication/391418739>
- IJSAT. (2025). *How P6 can optimize planning and project control*. <https://www.ijstat.org/papers/2025/2/5264.pdf>
- IJSRET. (2026). *BIM-integrated project planning and scheduling using Primavera*. <https://ijsret.com/2026/03/18/bim-integrated-project-planning-and-scheduling-using-primavera/>
- Innovative Construction and Petrochemical Technologies. Mohammed, N. J. (2025). BIM and Primavera integration in structural project planning: *A simulation based study*. 2(1), 26–38. <https://doi.org/10.71285/icpt.v2i1.10>
- MDPI Buildings. (2025). *AI-driven digital twins in industrialized offsite construction: A systematic review*. <https://doi.org/10.3390/buildings15172997>
- Nomic AI. (2026). *AI for Primavera P6* (AI for AEC glossary). <https://www.nomic.ai/glossary/ai-for-primavera>
- Oracle. (2026). *Primavera P6 Enterprise Project Portfolio Management*. <https://www.oracle.com/construction-engineering/primavera-p6/>
- Oracle Primavera Cloud Documentation. (2026). *Import/export to P6 overview*. <https://primavera.oraclecloud.com/help/en/user/95912.htm>
- Pinnacle Infotech. (2025). *Do digital twins and generative AI make the perfect duo?* <https://pinnacleinfotech.com/digital-twins-and-generative-ai/>
- Planning Engineer FZE. (2025). *Primavera P6 export file types explained*. <https://planningengineer.net/primavera-p6-export-file-types-explained/>
- ProjectManager.com. (2025). *What is Oracle Primavera P6? Uses, features & pricing*. <https://www.projectmanager.com/blog/what-is-primavera-p6>
- ProjeX Consult. (2025). *Construction schedule risk assessment with Primavera P6*. <https://projexconsult.com/construction-schedule-risk-assessment/>
- ResearchGate. (2022). *Construction schedule risk analysis – A hybrid machine learning approach*. <https://www.researchgate.com/publication/3544290-026-00511-0>

- researchgate.net/publication/357809528
- ResearchGate. (2025). *A comparative analysis of Primavera P6 and Microsoft Project in construction management*. <https://www.researchgate.net/publication/398600860>
- ResearchGate. (2026). *The role of machine learning in predicting project delays*. <https://www.researchgate.net/publication/400406484>
- RoboticsTomorrow. (2026). *How drone-based construction progress monitoring is driving smarter industrial workflows*. <https://www.roboticstomorrow.com/article/2026/03/>
- ScheduleLens. (2026). *XER file analysis: How to review P6 schedules without P6*. <https://schedulelens.com/blog/xer-file-analysis/>
- ScienceDirect. (2026). *Digital twins in offsite construction: Current implementations, challenges, and future pathways*. <https://www.sciencedirect.com/science/article/pii/S0926580526000610>
- Taylor & Francis / International Journal of Construction Management. (2026). *Artificial intelligence for construction planning and scheduling: An empirical PLS-SEM analysis of opportunities and barriers*. <https://doi.org/10.1080/15623599.2026.2636005>
- Taylor & Francis. (2025). *A comprehensive review of digital twin implementation in construction: Current trends and future directions*. <https://doi.org/10.1080/13467581.2025.2517242>
- The Skills Age. (2026). *What export file formats does Primavera P6 support?* <https://theskillsage.com/what-export-file-formats-does-primavera-p6-support/>