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4D BIM-Based Master Scheduling for Giga-Projects: Improving Schedule Reliability and Stakeholder Alignment

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***Abstract-** Giga-projects operate under extreme conditions of scale, uncertainty, and interdependence. Their delivery is shaped by long supply chains, multi-package procurement, geographically dispersed teams, regulatory interfaces, and client ambitions that are often revised while construction is already underway. Under these conditions, master schedules frequently become static reporting documents rather than dynamic management instruments. Four-dimensional building information modeling (4D BIM), which links time information to three-dimensional digital models, has been increasingly positioned as a means of transforming master scheduling from a document-centered process into a visual, data-driven and collaborative control system. This review paper synthesizes recent literature published between 2020 and 2026 to examine how 4D BIM-based master scheduling contributes to schedule reliability and stakeholder alignment in giga-project environments. Following an evidence-led review procedure adapted from the structure and methodological logic of the sample article provided by the user, the paper analyzes recent studies on 4D BIM scheduling, megaproject integration, BIM-enabled stakeholder management, lean-BIM integration, progress monitoring, digital twins, and AI-supported schedule control. The review finds that 4D BIM improves schedule reliability through better work-package decomposition, improved constructability analysis, richer look-ahead planning, enhanced progress verification, earlier identification of spatial-temporal clashes, and stronger change-response capacity. It improves stakeholder alignment by creating a shared visual language, structuring information exchanges, clarifying interface dependencies, and supporting collaborative decision-making across owners, designers, contractors, consultants, and digital control teams. However, the literature also shows that these gains are not automatic. Their realization depends on model maturity, information governance, schedule coding standards, contractual alignment, staff capability, and integration with lean planning and real-time site data. The paper proposes a synthesized review framework that positions 4D BIM master scheduling as a socio-technical capability rather than a software feature. It concludes with implementation recommendations and future research priorities relevant to giga-project delivery organizations.*

***Keywords:** 4D BIM, Master Scheduling, Giga-Projects, Schedule Reliability, Stakeholder Alignment, Digital Twins, Lean Construction, Construction Planning, BIM Governance, Megaproject Delivery*

I. INTRODUCTION

The strategic significance of giga-projects has expanded rapidly in the last decade as governments and private investors have used them to pursue urban transformation, infrastructure renewal, industrial diversification, and flagship national development agendas. Yet giga-projects remain highly vulnerable to schedule slippage because they combine very large physical scope with complex contractual structures, long logistics chains, and unusually dense stakeholder networks. Research on megaproject performance continues to show that planning quality, process integration, and information integration are central determinants of project outcomes, especially when project complexity is high (Lin et al., 2024). In parallel, BIM-enabled integration management has been shown to improve megaproject performance by strengthening information sharing and cooperation behavior among participants (Wang et al., 2024). These findings have elevated the importance of digital planning methods capable of coordinating time, space, resources, logistics, safety, and interfaces in one environment.

Within this wider digital transformation, 4D BIM has emerged as one of the most practical and influential BIM applications for construction planning. The core principle is simple: schedule activities are linked to

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model objects so that the planned sequence of work can be visualized, interrogated, simulated, and communicated in time and space (Doukari et al., 2022; Mayouf et al., 2024). This capability is especially relevant to giga-projects, where master schedules must connect strategic milestone logic with thousands of sub-activities, work fronts, temporary works, logistics constraints, and changing interface conditions. Traditional Gantt charts and CPM networks remain essential, but on their own they often struggle to communicate constructability, spatial congestion, and cross-package interdependencies to the wide range of actors involved in giga-project delivery.

Recent scholarship indicates that BIM can positively influence planning and scheduling performance, improve coordination, and provide stronger decision support than traditional 2D-based planning approaches (Nawaz et al., 2021; Doukari et al., 2022). At the same time, new streams of research are expanding the 4D BIM field toward lean-integrated scheduling, AI-supported schedule generation, dynamic site layout planning, digital twins, automated progress monitoring, and enhanced stakeholder management (Awe et al., 2025; Chong et al., 2025; Ismail et al., 2025; Jiang et al., 2024). These developments suggest that 4D BIM is evolving from a visualization aid into a central scheduling infrastructure for complex projects.

Despite this momentum, the literature remains fragmented. Some studies focus on software workflows, others on progress monitoring, safety, immersive visualization, lean integration, or stakeholder collaboration. Relatively few studies consolidate these streams specifically around master scheduling in giga-projects. This creates a practical knowledge gap: project teams know 4D BIM can help, but they often lack a synthesized understanding of how it improves schedule reliability, what organizational conditions make it effective, and how it can align the large and heterogeneous stakeholder groups typical of giga-projects. This review paper addresses that gap.

II. REVIEW AIM, UNIQUE OBJECTIVES AND RESEARCH QUESTIONS

This paper aims to critically review how 4D BIM-based master scheduling can improve schedule reliability and stakeholder alignment in giga-projects. To keep the paper distinct from generic BIM or scheduling reviews, the study adopts the following unique objectives:

1. To synthesize recent evidence on the mechanisms by which 4D BIM improves master schedule reliability in giga-project settings.
2. To examine how 4D BIM supports alignment among owners, designers, contractors, subcontractors, consultants, and digital control teams across complex project interfaces.
3. To identify the technical, managerial, and governance conditions that determine whether 4D BIM becomes a live control system or remains a visualization artifact.
4. To integrate recent literature on lean planning, AI, digital twins, reality capture, and BIM-enabled collaboration into a unified review framework for giga-project master scheduling.
5. To propose an implementation-oriented conceptual model that can guide future research and professional practice.

These objectives are operationalized through three review questions:

RQ1: How does 4D BIM contribute to schedule reliability in giga-project master scheduling?
RQ2: How does 4D BIM improve stakeholder alignment across complex and multi-organizational project environments?
RQ3: What capabilities, enablers, and constraints shape successful 4D BIM-based master scheduling in giga-projects?

III. REVIEW METHODOLOGY

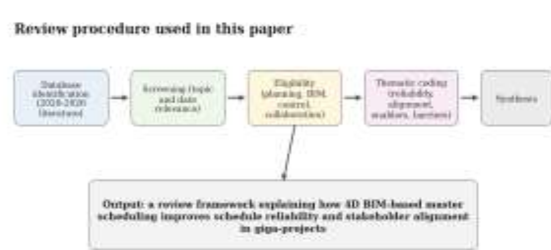

Figure 1. Review procedure adopted for the structured literature synthesis.

3.1. Review Design

This study is a structured review paper. Its methodological logic was designed by taking the user-provided sample article as a format reference, especially its stepwise progression from literature review to methodology, findings, discussion, conclusions, and future research directions. However, the present study remains fully distinct in topic, evidence base, and synthesis output. Because the objective was not to rank factors through a questionnaire but to synthesize recent evidence, a review methodology was selected instead of a survey-based design.

The review concentrated on publications from 2020 to 2026 to reflect the latest stage of development in 4D BIM, BIM-enabled collaboration, AI-supported scheduling, digital twins, and progress monitoring. The focus on this period is important because the literature after 2020 captures the transition of 4D BIM from isolated pilot implementations toward integrated digital planning ecosystems (Prebanić et al., 2021; Awe et al., 2025; Jiang et al., 2024).

3.2. Search Strategy

The review relied on a targeted academic search process using combinations of the following terms: “4D BIM”, “master scheduling”, “construction scheduling”, “giga-projects”, “megaproject performance”, “stakeholder management”, “schedule reliability”, “lean and BIM”, “digital twin construction”, “AI schedule management”, and “construction progress monitoring”. Priority was given to peer-reviewed journal articles and high-quality conference papers that were clearly relevant to planning, scheduling, stakeholder collaboration, or project control. Particular attention was paid to studies that demonstrated an explicit scheduling use of BIM rather than treating BIM only as a design coordination platform.

3.3. Inclusion and Exclusion Criteria

Studies were included when they met four conditions. First, they were published between 2020 and 2026. Second, they addressed 4D BIM directly or contributed closely related evidence on BIM-enabled planning, schedule control, project integration, stakeholder collaboration, lean-BIM workflows, or digital twins relevant to master scheduling. Third, they provided conceptual, empirical, case-based, or methodological insights useful for giga-project contexts. Fourth, they were accessible through reputable scholarly outlets.

Studies were excluded when they were outside the date window, focused solely on design authoring without time integration, or discussed BIM in ways that had no clear relevance to planning, project control, or stakeholder alignment. Commentary pieces without identifiable methods or practical insight were also excluded.

3.4. Synthesis Procedure

After screening, the selected literature was analyzed through thematic synthesis. Thematic coding was used because the reviewed papers were diverse in method, ranging from systematic reviews and case studies to framework papers, empirical surveys, and automation-focused research. Themes were not imposed a priori; instead, they were refined iteratively as the literature was read and compared. Five dominant synthesis themes emerged:

(a) 4D BIM and master schedule structuring,
(b) schedule reliability mechanisms,
(c) stakeholder alignment mechanisms,
(d) enabling capabilities and governance conditions, and
(e) future integrations with AI, digital twins, and reality capture.

3.5. Methodological Limitations

This review is limited by the current state of the literature. While many papers discuss “megaprojects” or “large projects”, relatively fewer studies focus explicitly on “giga-projects” as a distinct category. Therefore, this paper draws carefully from megaproject and large-scale project studies where the governance, scale, interface intensity, and planning challenges are comparable. A second limitation is that the rapid evolution of AI and digital twin applications means that some 2025-2026 publications are early-stage and may not yet represent mature industry-wide practice. Nonetheless, they are useful for indicating the frontier of development.

IV. FINDINGS AND ANALYSIS

4.1. 4D BIM as a Master Scheduling System

The literature consistently shows that 4D BIM is most valuable when it is treated as a scheduling system rather than a post hoc animation output. Doukari et al. (2022) demonstrated that effective 4D BIM creation requires clear scheduling objectives, information requirements, and workflow planning from the start of a project. Their comparison of conventional and more automated approaches showed that 4D BIM implementation often fails not because of software limitations, but because teams do not define the planning purpose, coding logic, or object-task relationships clearly enough. This finding matters for giga-projects, where master schedules are usually assembled from multiple contractor programs, package schedules, and design release plans.

Martins et al. (2022) further found that the applicability of 4D BIM tools depends on how efficiently they support planning decisions rather than how visually attractive the simulations are. For giga-projects, this means that a viable 4D BIM environment must support milestone decomposition, schedule-option testing, logistics sequencing, zone-based planning, and interface review across a hierarchy of time scales. In other words, 4D BIM adds value when it helps bridge executive-level milestone management with operationally meaningful work-package planning.

The literature also indicates that master scheduling in complex projects requires moving beyond purely object-based linking. In modular and industrialized contexts, Mayouf et al. (2024) showed that 4D BIM must capture constructability, operations, safety, and time as interacting considerations. This is highly transferable to giga-projects, where large-scale logistics, modular components, temporary works, and site-wide constraints make schedule logic inseparable from physical production logic. The master schedule must therefore be model-informed, not merely model-illustrated.

4.2. Mechanisms for Improving Schedule Reliability

Schedule reliability refers here to the extent to which planned work is made ready, executed in the intended sequence, and completed with minimal variance between planned and actual performance. Across the literature, six reliability mechanisms recur.

First, 4D BIM improves sequence transparency. Spatial-temporal simulation exposes sequence errors that may remain hidden in CPM networks or bar charts, especially when parallel work fronts or temporary works are involved (Doukari et al., 2022; Martins et al., 2022). This helps planners detect impossible overlaps, unrealistic handoffs, and conflicts between permanent and temporary elements.

Second, 4D BIM strengthens constructability assessment. In complex projects, sequence reliability is closely tied to physical buildability. By linking geometry and schedule, planners can test crane access, logistics paths, work-face congestion, and component installation order before construction begins. Ismail et al. (2025) showed that 4D BIM-based dynamic site layout planning can reduce cost and improve safety by adapting temporary facility arrangements to changing schedule needs. In giga-projects, where site layout and logistics are dynamic at district or corridor scale, this use is especially important.

Third, 4D BIM supports richer short- and medium-term planning. The literature on lean-BIM integration suggests that reliability gains are strongest when 4D BIM is connected to collaborative planning practices such as look-ahead planning, constraint removal, and Last Planner logic. Pérez et al. (2024) found that 4D construction planning and 4D analysis/optimization strongly influence the mitigation of delay factors in building projects, especially when combined with collaborative meetings and Last Planner System practices. Mayouf et al. (2024) similarly argued that lean-integrated 4D BIM can help remove unnecessary activities and rearrange work to reduce delays. For giga-projects, this implies that master schedules become more reliable when they are continuously translated into constraint-aware, visually supported near-term commitments.

Fourth, 4D BIM improves schedule risk anticipation. Rehman et al. (2020) argued that BIM can enhance project schedule risk management by making timing risks more visible, analyzable, and communicable. In giga-projects, schedule risk often emerges at interfaces between packages, authorities, utilities, procurement, and logistics. A 4D environment makes these interactions easier to simulate and discuss before they generate delay.

Fifth, 4D BIM facilitates progress verification. Reliability is not only about planning well; it is also about detecting deviation early. Vassena et al. (2023) demonstrated that integrating 4D BIM with SLAM-based mapping devices can support digital comparison between as-planned and as-built states. Similarly, Kavaliauskas et al. (2022) showed that IFC-based BIM integrated with point cloud data can automate significant aspects of progress monitoring. These developments matter greatly for giga-projects because progress is often reported through fragmented contractor narratives. Model-based verification creates a more objective basis for assessing whether the master schedule is holding.

Sixth, 4D BIM enhances adaptive control. The emergence of AI-supported schedule management and digital twin-enabled construction management suggests that 4D BIM is increasingly capable of functioning within continuous feedback loops. Chong et al. (2025) proposed a practical framework combining BIM and AI for dynamic schedule management, while Jiang et al. (2024) described a roadmap toward synchronized construction management using digital twins. Together, these studies indicate that schedule reliability in future giga-projects will depend on connecting the baseline 4D master schedule with real-time or near-real-time signals from the field.

4.3. 4D BIM and Stakeholder Alignment

The second major finding is that 4D BIM contributes to stakeholder alignment by functioning as a common cognitive and communication platform. Giga-projects involve clients, PMOs, designers, specialist engineers, package contractors, trade contractors, digital consultants, logistics planners, authorities, and operators. These actors often interpret the schedule differently because they rely on different drawings, codes, assumptions, and reporting formats. Alignment requires more than information sharing; it requires a shared understanding of what will happen, where, when, by whom, and under what constraints.

The literature shows that BIM enhances coordination and collaboration when it structures information exchange around a shared model. Mashali and El (2022) argued that BIM-based stakeholder information exchange workflows are particularly valuable during the planning phase of smart construction megaprojects. Their work highlights that stakeholder alignment improves when the exchange of planning information is designed intentionally rather than left to fragmented emails, disconnected reports, or discipline-specific software silos.

Wang et al. (2020) approached the issue from a social network perspective and showed that collaborative relationships in BIM project delivery are dynamic and structurally important. Their work is significant for giga-projects because alignment problems are often relational before they become technical. A 4D BIM environment can reveal interdependencies, but it can only improve outcomes if stakeholders are institutionally prepared to act on those insights. Zhang et al. (2022) reinforced this point by showing that stakeholder management mediates the relationship between BIM implementation and project performance. In other words, BIM alone does not produce alignment; alignment emerges when BIM is coupled with deliberate stakeholder management practices.

Other recent studies deepen this conclusion. Wang et al. (2024) found that BIM-based integration management influences megaproject performance through information sharing and cooperation behavior. Miao et al. (2024) showed that BIM-supported knowledge collaboration can help large highway projects handle diverse knowledge domains and stakeholder interactions more effectively. Prebanić et al. (2021) emphasized through a systematic review that digital transformation in construction stakeholder management remains underdeveloped, but digital systems can reshape how stakeholders engage and communicate. Together, these works indicate that 4D BIM contributes to alignment when it is used as a boundary object: a shared artifact around which different stakeholders negotiate timing, interfaces, responsibilities, and alternatives.

From a practical standpoint, the literature suggests four alignment functions of 4D BIM in giga-projects. The first is visual alignment, where the sequence of work becomes easier for non-planners to understand. The second is interface alignment, where package boundaries and handoffs become more explicit. The third is decision alignment, where options can be simulated before agreement is reached. The fourth is accountability alignment, where progress and deviation discussions are grounded in a visible and auditable schedule model rather than in isolated claims.

4.4. Integration with Lean Planning

One of the strongest patterns in the reviewed literature is the growing convergence between 4D BIM and lean construction. This convergence matters because schedule reliability problems in giga-projects are rarely caused by poor baseline scheduling alone. They also stem from work not being made ready, constraints not being removed, and information not flowing at the pace needed for production. Lean methods address these operational causes of unreliability, while 4D BIM adds the visualization and integration capability that helps teams see and coordinate the consequences of decisions.

Mayouf et al. (2024) demonstrated that lean-integrated 4D BIM can improve modular scheduling by foregrounding constructability, operations, safety, and time. Pérez et al. (2024) found that combining BIM uses with lean tools such as collaborative meetings and Last Planner practices can meaningfully reduce key delay factors. Likita et al. (2025) and Alnajjar et al. (2025) also show that the BIM-lean relationship is increasingly seen as a route toward more integrated, waste-aware project delivery. In giga-projects, this means 4D BIM should not be restricted to central planning departments. It should also support weekly and phase-based collaborative planning sessions where the master schedule is translated into executable commitments.

A key implication is that reliability should be managed as a layered system. The master schedule defines strategic logic and major interfaces. Phase plans and look-ahead plans translate that logic into more detailed and constraint-sensitive workflows. 4D BIM can connect these levels visually and analytically, helping teams test whether near-term commitments remain consistent with broader milestone logic. This layered integration is particularly important in giga-projects, where strategic deadlines are politically visible and operational disruptions can propagate quickly across interfaces.

4.5. Progress Monitoring, Reality Capture and Digital Twins

The reviewed studies show that the reliability benefits of 4D BIM become much stronger when the model is linked with field data. In older workflows, 4D BIM was often produced as a preconstruction exercise and then archived. Newer studies point toward a different model in which 4D BIM supports continuous or periodic comparison between plan and actual performance.

Vassena et al. (2023) linked 4D BIM with SLAM-based mapping devices for digital progress monitoring, while Kavaliauskas et al. (2022) used point cloud data with IFC-based BIM to automate object completion assessment. Hsieh et al. (2026) extended this frontier by integrating AI-based image recognition with BIM to automate construction progress monitoring and control. Camera placement itself has also become a research topic, with model-driven approaches improving the coverage and usefulness of monitoring systems (Houng et al., 2024). These advances are highly relevant to giga-projects because schedule slippage is often worsened by late or unreliable progress information. If field verification arrives too slowly, corrective action also arrives too late.

Digital twin literature adds a further layer. Jiang et al. (2024) argued that synchronized construction management requires dynamic integration of planning models and live production information. Su et al. (2025) likewise describe digital twins as an extension of BIM capable of supporting ongoing decision-making. In this trajectory, the 4D master schedule becomes the temporal backbone of a broader control ecosystem in which deviations can be detected, visualized, analyzed, and fed back into resequencing decisions. This does not eliminate uncertainty, but it increases the speed and quality of response.

4.6. Capability Requirements and Barriers

Although the literature is optimistic about 4D BIM, it also identifies persistent barriers. These can be grouped into technical, organizational, contractual, and human factors.

Technical barriers include inconsistent object breakdown structures, weak schedule coding, poor interoperability, excessive model detail that overwhelms planners, and insufficient data standards for linking packages and work fronts (Doukari et al., 2022; Awe et al., 2025). Organizational barriers include unclear ownership of the 4D process, lack of a common data environment, and separation between design teams, schedulers, and site teams. Contractual barriers arise when packages are procured in ways that discourage transparent schedule integration or shared digital workflows. Human barriers include uneven BIM literacy, planner resistance, and limited capability to interpret model-based simulations meaningfully (Martins et al., 2022; Oraee et al., 2021).

The literature on stakeholder management reinforces that barriers are not purely technical. Oraee et al. (2021) showed that collaboration in BIM-based construction networks is shaped by multiple influential factors, not just software availability. Tan et al. (2026) further suggest that BIM-enabled projects can still experience collaboration dilemmas when transaction costs, trust deficits, and fragmented incentives drive risk-averse behavior. This is a critical lesson for giga-projects: even a technically strong 4D BIM platform will fail to deliver alignment if project governance remains adversarial or fragmented.

Another recurring challenge is the gap between pilot success and institutionalization. Many organizations can create one impressive 4D simulation, but fewer can standardize the data structures, meeting routines, governance protocols, and skill development needed to maintain 4D BIM as a live project-control capability. From a giga-project perspective, this means adoption should be treated as organizational transformation rather than software procurement.

4.7. Implications for Giga-Projects

When the reviewed evidence is interpreted specifically for giga-projects, several implications stand out.

First, the value of 4D BIM rises with interface intensity. The more handoffs, work fronts, authority touchpoints, logistics dependencies, and package interfaces a project has, the more useful spatial-temporal coordination becomes. Giga-projects therefore stand to benefit disproportionately from 4D BIM compared with smaller, less interface-dense projects.

Second, 4D BIM is especially valuable where schedule decisions have reputational and strategic consequences. In giga-projects, delayed milestones often affect funding releases, public perception, political commitments, and downstream packages. A visually explicit and analytically rich scheduling environment helps leaders understand consequences earlier.

Third, giga-projects need federated rather than isolated 4D BIM. Package-level models and schedules must roll up into a master logic without losing local detail. This requires common coding structures, interface management protocols, and governance rules for how updates are validated and escalated.

Fourth, stakeholder alignment should be treated as a measurable scheduling outcome. If actors do not share understanding of sequence, responsibilities, and constraints, the master schedule will lose credibility and reliability. 4D BIM can improve this, but only if the project deliberately uses it during collaborative reviews, not just executive presentations.

V. DISCUSSION

5.1. A Synthesized Framework for 4D BIM-Based Master Scheduling

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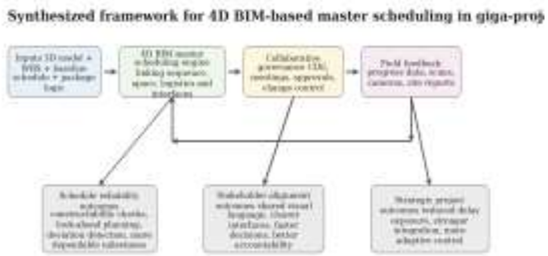

Figure 2. Synthesized framework for 4D BIM-based master scheduling in giga-projects.

The review suggests that 4D BIM-based master scheduling works best when understood as a socio-technical framework composed of five layers.

The first layer is data readiness. This includes model structure, work breakdown alignment, coding conventions, and a usable common data environment. Without this layer, the 4D model cannot function as a trustworthy scheduling instrument.

The second layer is planning integration. Here the 4D model is tied to milestone logic, phase planning, logistics planning, temporary works, and look-ahead processes. This layer converts the schedule from a static baseline into a coordinated planning system.

The third layer is collaborative governance. This includes meeting routines, decision rights, interface review protocols, and stakeholder information exchange workflows. This is where stakeholder alignment is either built or lost.

The fourth layer is field feedback. Progress monitoring, reality capture, AI-based recognition, and digital twin applications connect the plan to actual site conditions. This layer is crucial for maintaining schedule reliability over time.

The fifth layer is adaptive control. At this stage, deviations do not merely produce reports; they trigger model-informed resequencing, mitigation planning, and resource reallocation. This is the highest maturity level of 4D BIM-based master scheduling.

This layered understanding helps explain why some projects achieve substantial value from 4D BIM while others gain only limited visualization benefits. Value emerges when all or most layers are linked. Partial adoption may still help communication, but it does not fully transform schedule reliability.

5.2. Theoretical Contribution

The paper contributes to the literature by joining three conversations that are often treated separately: 4D BIM for planning, BIM for stakeholder management, and digital project control through AI and digital twins. The review indicates that schedule reliability and stakeholder alignment are mutually reinforcing, not independent outcomes. Reliable schedules require aligned stakeholders because commitments, interfaces, and information flows depend on collaboration. Aligned stakeholders require reliable schedules because shared confidence in the planning system shapes trust and decision quality. 4D BIM sits at the intersection of these two dynamics.

5.3. Managerial Implications

For project owners and PMOs, the review implies that 4D BIM should be specified early, with clear objectives tied to milestone assurance, package integration, and reporting governance. For contractors, the review suggests that schedulers, planners, construction managers, and BIM teams should not work in parallel silos; they need integrated routines and shared accountability. For consultants and digital delivery specialists, the key implication is that 4D BIM success depends as much on facilitation, data governance, and workflow design as on model production.

VI. CONCLUSIONS AND RECOMMENDATIONS

This review paper examined how 4D BIM-based master scheduling can improve schedule reliability and stakeholder alignment in giga-projects. Drawing on literature from 2020 to 2026, the study finds that 4D BIM improves reliability by making sequence logic visible, supporting constructability analysis, enabling stronger short-term planning, improving schedule risk communication, strengthening progress verification, and enabling adaptive control through integration with AI and digital twin systems. It improves stakeholder alignment by creating a shared

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temporal-spatial language, structuring information exchange, clarifying interfaces, and supporting collaborative decision-making across diverse project actors.

However, the review also shows that the effectiveness of 4D BIM is conditional. It depends on robust data structures, schedule-model alignment, governance routines, lean integration, field feedback mechanisms, and capability development. In giga-projects, the challenge is not merely to create 4D simulations, but to institutionalize 4D BIM as a live control architecture that links strategic milestones with operational production realities.

Based on the synthesis, the following recommendations are proposed:

1. Project clients should define 4D BIM requirements at project inception and link them to milestone assurance, package integration, and reporting protocols.
2. Project teams should adopt a common coding structure that links WBS, zones, packages, and model objects consistently.
3. 4D BIM should be used in collaborative planning forums, including phase planning and look-ahead sessions, not only in executive review meetings.

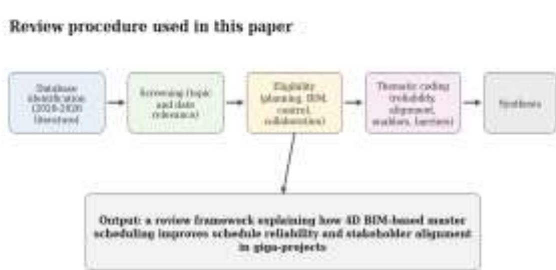

Figure 1. Review procedure adopted for the structured literature synthesis.

4. Progress monitoring systems should be integrated progressively with the 4D model using point clouds, SLAM, cameras, or AI-based recognition where feasible.
5. Giga-projects should establish explicit governance for model ownership, schedule updates, validation rules, and interface escalation.

VII. LIMITATIONS AND FUTURE RESEARCH

This paper has three main limitations. First, the literature on giga-projects remains smaller than the literature on megaprojects and large projects; therefore, some inferences were drawn from adjacent large-scale contexts. Second, because recent AI and digital twin studies are fast-evolving, their long-term practical maturity is still emerging. Third, the review synthesizes published studies rather than testing a framework empirically in one live giga-project.

Future studies should therefore examine live giga-project implementations longitudinally. There is a strong need for research on federated 4D BIM governance across multiple packages, quantitative measures of stakeholder alignment, and the relationship between 4D BIM maturity and schedule reliability performance indicators. Additional research should also investigate how AI-generated schedule updates can be governed ethically and contractually, how 4D BIM can support dispute avoidance in giga-projects, and how planners can balance model granularity with usability in large program environments.

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