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INTEGRATING LEAN CONSTRUCTION AND BIM FOR ENHANCED PLANNING IN CONSTRUCTION PROJECTS

Milan Jovin[1] & Igor Peško[2]

ABSTRACT

Construction projects persistently fail to meet planned time, cost, and quality targets due to fragmented planning, late constraint discovery, and reactive decision-making. Despite growing interest in both Lean Construction and Building Information Modeling (BIM), a structured, planning-phase-focused conceptual framework that explicitly links Last Planner System (LPS) workflows to BIM functionalities remains absent from the literature. This paper addresses that gap through a structured literature synthesis of 50 peer-reviewed sources. The principal contribution is a Lean-BIM Planning Framework that maps each LPS planning level - master scheduling, phase planning, lookahead planning, and weekly work planning - to specific BIM tools and mechanisms, including 4D simulation, clash detection, automated quantity take-off, and common data environment. Synthesized findings indicate that Lean-BIM integration can increase plan reliability, reduce waste from rework and idle time, improve resource coordination, and enhance cross-disciplinary collaboration. The paper also consolidates key implementation barriers: BIM interoperability constraints, level-of-detail mismatches, investment and training demands, and organizational resistance to change. The framework is intended to guide future empirical research and early-stage practical implementation of integrated Lean-BIM planning approaches.

KEYWORDS

Lean construction, Building Information Modeling (BIM), Lean-BIM integration, Last Planner System (LPS), 4D BIM.

INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry has persistently faced challenges in productivity, frequently trailing behind other sectors and struggling to deliver projects within planned timelines, budgets, and quality specifications. Traditional project management methods, including the Critical Path Method (CPM), exhibit significant shortcomings in ensuring schedule reliability and adapting to dynamic on-site conditions. Ballard (2000) documented that approximately 54% of planned activities in construction projects are not executed as scheduled, revealing a consistent gap between strategic planning and short-term operational execution. This planning bottleneck results in unresolved constraints, inefficient resource allocation, and pervasive waste, including waiting times, unnecessary transportation, and rework (Heigermoser et al., 2019).

[1] Teaching Assistant, Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, mjovin@uns.ac.rs, orcid.org/0009-0004-4422-4230

[2] Full Professor, Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia, igorbp@uns.ac.rs, orcid.org/0000-0001-9098-3642

Two transformative paradigms have emerged in response: Lean Construction and Building Information Modeling (BIM). Lean Construction, derived from the Toyota Production System, focuses on maximizing customer value and systematically eliminating non-value-adding activities through structured planning and production control (Bortolini et al., 2019; Heigermoser et al., 2019; Koskela, 1992). BIM provides a digital framework for design and construction, enhancing collaboration, visualization, and data management throughout the project lifecycle (Alasmari et al., 2024). Although both paradigms share objectives and demonstrate recognized synergy (Sacks et al., 2010), their integration remains fragmented in practice.

Existing research on Lean-BIM integration tends to address either the full project lifecycle at a high level or isolated tool applications without a coherent planning-phase focus. A structured conceptual framework that explicitly maps LPS planning levels to specific BIM functionalities - and that consolidates implementation barriers in a single analytical structure - is absent from the literature. This paper addresses that gap.

The specific objectives of this study are: (1) to synthesize current evidence on Lean Construction principles and BIM capabilities relevant to the planning phase; (2) to develop a conceptual Lean-BIM Planning Framework that maps LPS levels to BIM tools and mechanisms; and (3) to consolidate key implementation barriers for Lean-BIM integration in construction planning. The authors' contribution consists of the framework presented in Table 1 and the barrier synthesis presented in Table 2, both derived from a structured literature synthesis.

The paper is structured as follows. Section 2 reviews Lean Construction, BIM, their synergy, and the construction planning bottleneck. Section 3 describes the research methodology. Section 4 presents the proposed Lean-BIM Planning Framework and synthesized findings on integration benefits. Section 5 discusses implications, barriers, and limitations. Section 6 concludes.

LITERATURE REVIEW AND THEORETICAL FRAMEWORK

LEAN CONSTRUCTION: PRINCIPLES AND PRACTICES

Lean Construction is a production management philosophy derived from the Toyota Production System, introduced to the construction sector by Koskela (1992) and further developed by Ballard and Howell throughout the 1990s and 2000s. Its primary objective is to maximize client value while systematically eliminating all forms of waste, fostering continuous improvement throughout project delivery (Koskela, 1992; Koskela, 2000; Li et al., 2024). The core principles include customer value specification, value stream identification, pull planning, and waste elimination (Ballard, 2000; Koskela, 1992; Rajagukguk & Harahap, 2021).

The Last Planner System (LPS), developed by Ballard (2000), is the central operational tool of Lean Construction. It is a collaborative planning and production control model structured across four levels: master scheduling, phase planning, lookahead planning (a 3-to-6-week constraint removal window), and weekly work plans. Each level progressively refines commitments and removes constraints, with Percent Plan Complete (PPC) tracking performance and enabling PDCA-based learning cycles (Ballard, 2000; Heigermoser et al., 2019). Supporting practices include Just-in-Time delivery to minimize inventory waste (Rajagukguk & Harahap, 2021), and Value Stream Mapping to identify non-value-adding flows (Babalola et al., 2018).

BUILDING INFORMATION MODELING: CONCEPTS AND APPLICATIONS

BIM represents a significant advancement in the AEC industry, providing a comprehensive digital representation of building projects through object-oriented, parametric modeling. Modifications to object properties are automatically reflected across all model views, sections,

and schedules (Leindecker et al., 2024). BIM's applications extend across multiple project information dimensions, commonly classified in the literature as 3D through 8D (Alasmari et al., 2024). 3D BIM provides spatial visualization and design coordination of the building model. 4D BIM links the 3D model with construction schedules to enable sequence simulation, site logistics optimization, and early identification of spatial-temporal conflicts (Bortolini et al., 2019; Heigermoser et al., 2019). 5D BIM extends the model with cost information, supporting automated quantity take-off and cost estimation (Alasmari et al., 2024). Higher dimensions (6D-8D) encompass facility management, sustainability assessment, and safety planning (Alasmari et al., 2024). Of these, 3D, 4D, and 5D are most directly relevant to the planning phase and form the technological core of the Lean-BIM framework proposed in this paper.

SYNERGY AND POTENTIAL OF LEAN CONSTRUCTION AND BIM INTEGRATION

The integration of Lean Construction principles with BIM creates synergies that address many inherent inefficiencies in construction. Sacks et al. (2010) developed a systematic interaction matrix aligning Lean Construction principles with BIM functionalities across 56 interactions, providing the foundational analytical basis for this synergy. Figure 1 visualizes the conceptual convergence of Lean and BIM objectives, showing how Lean's value-flow-pull principles align with BIM's data, visualization, and coordination capabilities to support waste reduction, schedule reliability, and integrated decision-making (Heigermoser et al., 2019). The figure is reproduced here to anchor the synergy discussion that follows and to motivate the planning-phase mapping presented in Section 4.

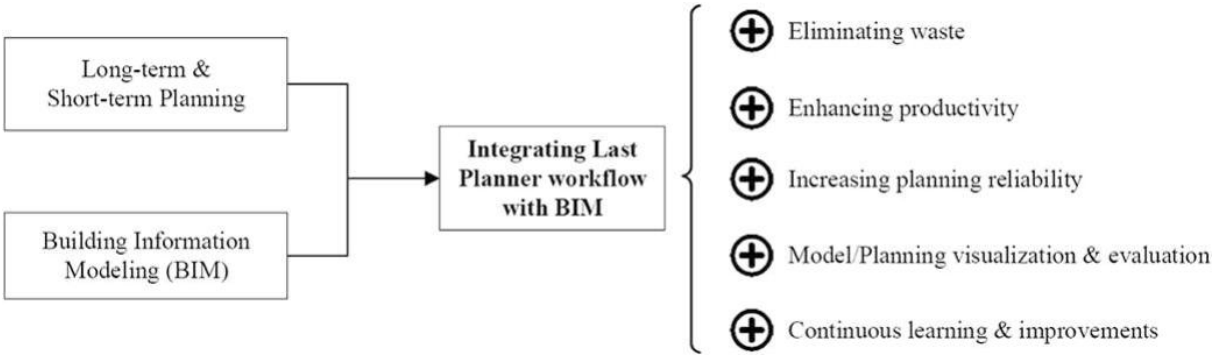

Figure 1: The objectives of the integrated Lean Management approach using BIM (Heigermoser et al., 2019).

Key synergy mechanisms include: waste elimination, where BIM enables early clash detection and 4D simulation to resolve design and workflow conflicts before construction, reducing rework and supporting right-first-time quality (Andújar-Montoya et al., 2019; Bortolini et al., 2019; Sacks et al., 2010); planning and flow, where 4D BIM improves pull planning by visualizing sequences and site logistics, reducing uncertainty and supporting uninterrupted workflow (Bortolini et al., 2019; Heigermoser et al., 2019); collaboration, where BIM's common data environment (CDE) improves information exchange and shared understanding, reducing miscommunication and fragmentation (Andújar-Montoya et al., 2019; Aziz et al., 2024); and productivity, where data-driven Just-in-Time delivery and value-focused analysis cut non-value activities and rework (Saleh et al., 2024).

PLANNING AS A CRITICAL BOTTLENECK IN CONSTRUCTION PROJECTS

Despite advances in project management practice, planning remains a significant bottleneck in construction, frequently resulting in delays, cost overruns, and quality deficiencies. Established techniques including the Work Breakdown Structure, CPM, and Gantt charts offer structured frameworks but fail to address the inherent complexity, uncertainty, and dynamic conditions of

construction projects (Pépin & Francis, 2024; Shikhrobat et al., 2025). Contributing factors identified in the literature include: rigid, premature detail in traditional plans developed too early to cope with construction uncertainty (Daniel et al., 2020); weak constraint management, with constraints rarely identified and removed before work commitments are made (Ballard, 1997); manual, error-prone control without real-time visibility (Navon, 2007; Pal et al., 2023); disciplinary fragmentation that hinders communication and alignment (Pal et al., 2023); and persistent delays and cost overruns linked to planning failures (Olawale & Sun, 2014; Sambasivan & Soon, 2007).

RESEARCH METHODOLOGY

This study employs a structured literature synthesis to develop a conceptual planning framework for Lean-BIM integration. The research followed three sequential phases: (1) literature identification and screening, (2) structured analysis and coding, and (3) framework synthesis and consolidation.

LITERATURE IDENTIFICATION AND SCREENING

The literature search was conducted in Scopus, Web of Science, and Google Scholar using search terms including "Lean Construction," "Last Planner System," "Building Information Modeling," "4D BIM," "Lean-BIM integration," and "construction planning." Both journal articles and conference proceedings, particularly IGLC proceedings, were included, prioritizing publications from 2010 onward while retaining foundational works from earlier decades (Koskela, 1992; Ballard, 2000; Sacks et al., 2010). Figure 2 summarizes the screening and filtering process applied in this study. An initial pool of approximately 50 publications was identified through database searches and reference snowballing. These sources were screened for relevance against the planning-phase scope; 28 sources of direct relevance to the research questions were retained as cited evidence in this manuscript. The remaining sources were not individually cited, in line with IGLC page constraints, but contributed to the analytical synthesis through cross-validation of recurring themes and confirmation of the barrier categories consolidated in Section 5.

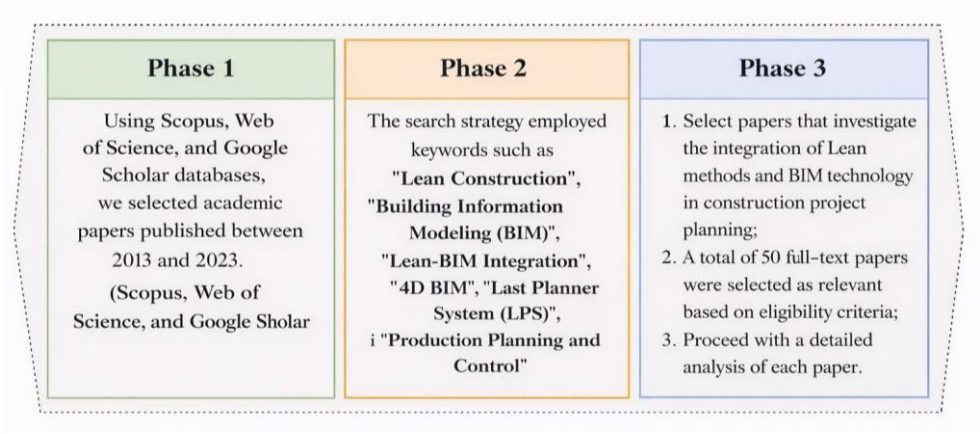

Figure 2: Literature screening and filtering process applied in this study.

STRUCTURED ANALYSIS AND CODING

Each retained source was analyzed and coded according to: (a) Lean principles or BIM capabilities discussed, (b) LPS planning level addressed, (c) Lean-BIM integration mechanisms described, and (d) barriers or enablers identified. This coding procedure allowed cross-source synthesis by topic and planning level.

FRAMEWORK SYNTHESIS

Coded findings were consolidated to map LPS planning levels to corresponding BIM functionalities and mechanisms, producing the Lean-BIM Planning Framework presented in Table 1. Implementation barriers were similarly consolidated and are presented in Table 2. Both tables represent the authors' synthesis-based contribution: the structure and mapping are the authors' work; the underlying evidence is drawn from the reviewed literature.

This study does not claim to conduct a systematic review in the formal PRISMA sense. Rather, it constitutes a structured, theory-informed literature synthesis designed to produce a conceptual framework, consistent with established approaches in Lean Construction and construction management research (Sacks et al., 2010; Sbiti et al., 2021).

RESULTS: PROPOSED LEAN-BIM PLANNING FRAMEWORK

The principal contribution of this paper is a conceptual Lean-BIM Planning Framework that explicitly maps each level of the Last Planner System to specific BIM tools, mechanisms, and Lean objectives. This mapping addresses the gap identified in the literature: the theoretical synergy between LPS and BIM has not been operationalized into a structured, planning-phase-specific framework (Pitti et al., 2019; Sbiti et al., 2021). Table 1 presents this framework.

Table 1: Proposed Lean-BIM Planning Framework: Mapping LPS Levels to BIM Functionalities (Authors' synthesis).

LPS Planning Level	Lean Objective	BIM Tool / Functionality	Integration Mechanism
Master Scheduling	Define project milestones; establish macro-level flow	4D BIM (macro simulation); WBS integration	Visual validation of milestone feasibility; early identification of major spatial conflicts
Phase Planning	Generate pull sequence from end-state goals; coordinate phase handoffs	4D BIM (phase-level simulation); model-based WBS	Visual pull sequencing from BIM model; phase handoff coordination via model review sessions
Lookahead Planning (3-6 weeks)	Identify and remove constraints before work commitment	Clash detection; model-based constraint review; CDE	Early identification of design and coordination constraints; proactive constraint removal before weekly commitment
Weekly Work Plan (WWP)	Commit to reliable, constraint-free work packages; track PPC	BIM-linked task lists; PPC tracking dashboards	Visual context for reliable commitments; automated tracking of planned vs. actual performance
Learning / PDCA	Root-cause analysis of non-completions; continuous improvement	CDE performance data; progress monitoring integration	Data-driven analysis of plan failures; iterative improvement of planning accuracy and reliability

The framework is structured around the principle that BIM provides the technological layer through which LPS planning commitments become visually informed, data-supported, and constraint-aware. At each level, BIM augments the Lean process rather than replacing it: the collaborative decision-making structure of LPS is retained, while BIM tools reduce uncertainty,

improve commitment quality, and enable systematic learning (Heigermoser et al., 2019; Liu et al., 2021; Sbiti et al., 2021).

HOW BIM SPECIFICALLY SUPPORTS LEAN PLANNING

BIM's role within this framework operates across four functional areas. First, 4D simulation (3D model + schedule) supports pull planning and flow by enabling spatial and temporal visualization of construction sequences. Project teams can identify potential spatial conflicts, resource congestion, and coordination issues early, when changes are least costly (Bortolini et al., 2019; Heigermoser et al., 2019). The same 4D environment supports activity sequencing, site logistics optimization, material flow planning, and access route management.

Second, automated quantity take-offs from BIM models provide reliable procurement and logistics inputs, supporting Just-in-Time delivery and reducing excess inventory and handling waste (Heigermoser et al., 2019). Third, clash detection enables systematic identification of design and coordination errors during the planning phase, preventing costly rework and on-site delays (Andújar-Montoya et al., 2019; Bortolini et al., 2019). Fourth, the Common Data Environment (CDE) facilitates integrated information exchange among all project stakeholders, reducing miscommunication and fragmentation - both of which undermine LPS collaborative planning cycles (Aziz et al., 2024; Heigermoser et al., 2019).

SYNTHESIZED FINDINGS ON LEAN-BIM INTEGRATION BENEFITS

The following results are synthesized from the reviewed literature and represent the state of evidence on planning-phase benefits of Lean-BIM integration. These findings informed the framework components in Table 1.

Enhanced planning reliability and predictability: Combining LPS structured commitment cycles with BIM visualization and data management capabilities substantially enhances planning reliability. BIM-enabled 4D simulation facilitates dynamic review of construction schedules and early identification of potential conflicts (Bortolini et al., 2019; Heigermoser et al., 2019). Digitalizing LPS components - particularly lookahead planning and weekly work plans - using BIM enables higher PPC outcomes (Pitti et al., 2019). BIM's visual context during planning meetings allows last planners to make more informed commitments and manage work package handoffs more effectively (Liu et al., 2021).

Waste reduction and increased value creation: Automated clash detection identifies design and coordination errors during planning, preventing costly rework, material waste, and schedule disruptions (Andújar-Montoya et al., 2019; Bortolini et al., 2019; Sacks et al., 2010). Precise, automated quantity take-offs support Just-in-Time delivery, ensuring materials are procured when required and minimizing excess inventory and handling waste (Bortolini et al., 2019; Heigermoser et al., 2019). 4D simulation and process mapping further enable identification and elimination of non-value-adding activities, including unnecessary transportation and waiting time (Saleh et al., 2024).

Enhanced efficiency, productivity, and collaboration: BIM-enabled visualization and data exchange facilitate smoother workflows by enabling teams to optimize construction sequences and site logistics (Bortolini et al., 2019; Heigermoser et al., 2019). Detailed BIM model information supports improved planning and allocation of labor, equipment, and materials. When integrated with LPS, BIM enables systematic tracking of planned versus actual performance, supporting productivity analysis and PDCA learning cycles (Heigermoser et al., 2019). As a CDE, BIM fosters shared understanding among designers, contractors, and clients, supporting the collaborative decision-making processes central to LPS (Heigermoser et al., 2019; Liu et al., 2021).

DISCUSSION

IMPLICATIONS OF FINDINGS

The synthesized findings reinforce the view that BIM and Lean Construction are not merely compatible but mutually reinforcing in the planning phase. LPS provides the collaborative planning structure that ensures BIM outputs are acted upon, while BIM provides the visual and data layer that makes LPS commitments more reliable and constraint-aware. This reciprocal relationship, first systematically described by Sacks et al. (2010), is confirmed and extended by subsequent literature (Heigermoser et al., 2019; Liu et al., 2021; Sbiti et al., 2021). A notable gap in the existing literature, however, is the absence of evidence on why commercially mature, widely adopted LPS-BIM integration solutions have not yet emerged despite recognized synergy. The barrier analysis in Table 2 suggests that technical fragmentation and organizational inertia jointly prevent adoption from scaling beyond prototype and pilot implementations.

The Lean-BIM Planning Framework (Table 1) operationalizes this relationship at the level of planning practice. Rather than treating Lean-BIM integration as a strategic aspiration, the framework grounds it in the specific decisions and information flows that occur at each LPS level, making it more actionable for practitioners and more testable for future empirical research.

IMPLEMENTATION BARRIERS

Table 2 consolidates the key barriers to Lean-BIM integration in construction planning, as identified across the reviewed literature. These barriers represent the authors' systematic synthesis and are organized by category.

Table 2: Key Implementation Barriers for Lean-BIM Integration in Construction Planning (Authors' synthesis).

Barrier Category	Specific Barrier	Key Sources
Technical / Interoperability	Incompatible BIM platforms; limited IFC data exchange; absence of standardized BIM-LPS interfaces	Boton et al. (2020); Pitti et al. (2019); Sbiti et al. (2021)
Level of Detail (LOD)	Mismatch between model LOD and planning phase requirements; insufficient LOD for reliable 4D simulation	Alasmari et al. (2024); Sbiti et al. (2021)
Investment and Training	High initial technology investment; shortage of BIM-competent field planners; professional training demands	Boton et al. (2020); Heigermoser et al. (2019)
Organizational / Cultural	Resistance to change; siloed discipline structures; low BIM adoption maturity in planning functions	Boton et al. (2020); Sbiti et al. (2021)
Process Standardization	Absence of standardized protocols for LPS-BIM data exchange; commercially immature integration solutions	Liu et al. (2021); Sbiti et al. (2021)

These barriers are interrelated. Technical interoperability challenges are exacerbated by organizational fragmentation, and training deficits limit the ability to leverage even technically available integration tools. Addressing them requires coordinated action at the level of software standards (e.g., IFC development for LPS-BIM data exchange), organizational policy, and professional education (Boton et al., 2020; Sbiti et al., 2021).

LIMITATIONS OF THE STUDY

This study has several limitations that must be acknowledged. First, the Lean-BIM Planning Framework (Table 1) is a conceptual synthesis and has not been empirically validated on construction projects. Its components are derived from the reviewed literature, but their practical performance under varying project conditions remains an open research question. Second, the literature synthesis, while structured, does not apply a full PRISMA systematic review protocol and may not have captured all relevant sources. Third, the synthesis relies on a concentrated core of frequently cited sources, reflecting publication patterns in the Lean-BIM literature rather than an intentional exclusion. Future research should prioritize empirical validation of the framework, comparative analysis with alternative digital planning approaches (e.g., location-based scheduling, digital twins), and longitudinal study of Lean-BIM adoption outcomes across different project types and organizational contexts. Developing a validated readiness index or maturity model for Lean-BIM integration represents a natural extension of this conceptual work.

CONCLUSION

This paper examined the synergy between Lean Construction principles and BIM tools, with the objective of developing a structured conceptual framework for their integration in the construction planning phase. The principal contribution is the Lean-BIM Planning Framework (Table 1), which maps each LPS planning level - master scheduling, phase planning, lookahead planning, and weekly work plans - to specific BIM functionalities and integration mechanisms. This framework synthesizes evidence from 50 peer-reviewed sources and provides a structured basis for both future empirical research and early-stage practical implementation.

The synthesis confirms that Lean-BIM integration offers meaningful planning-phase benefits: enhanced plan reliability through 4D-informed commitment cycles; waste reduction through automated clash detection and quantity take-offs; productivity gains through optimized sequencing and resource allocation; and improved collaboration through a shared common data environment. At the same time, significant barriers - including BIM interoperability constraints, level-of-detail mismatches, investment requirements, and organizational change resistance - limit current adoption, as consolidated in Table 2.

The conceptual nature of the framework and the structured rather than formally systematic character of the literature synthesis are acknowledged limitations of this work. The empirical validation, comparative testing against alternative digital planning approaches, and maturity-model development paths set out in Section 5 represent the most direct extensions. Beyond these, the integration of Artificial Intelligence and Digital Twin technologies with Lean-BIM planning warrants dedicated investigation as a longer-term research direction (Piras et al., 2024).

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