International Journal of BIM and Engineering Science

♦ ISSN: 2571-1075 Vol: 12, No. 02, 2026 ♦ PP. 11–18

Article DOI: https://doi.org/10.54216/IJBES.120202

FULL LENGTH ARTICLE

Quantifying Geospatial Logistics Risks in Construction Supply Chains through an Integrated GIS-4D BIM Framework

Batoul Hasanin[1,*] **Youssef Aris**[2] **Sonia Ahmad**[3] **Amarnath CB**[4]

[1] PhD Student in Architectural Design, Damascus University, Syria
[2] Master in BIM Management, Syrian Virtual University, Syria
[3] Director of the Master's Program in BIM and Management, Syrian Virtual University, Syria
[4] President, India BIM Association, India

Emails: Arch.alaa.has@gmail.com; youssef_247970@svuonline.org; sonia.ahmad@bankskelly.co.uk; info@ibima.co.in

Received: November 19, 2025 Revised: January 09, 2026 Accepted: February 10, 2026 ⋆ Corresponding author

ABSTRACT

Construction supply chains are inherently sensitive to spatial and logistical disruptions, yet conventional project planning approaches, including standalone 4D BIM, rarely incorporate geospatial risk factors. This study proposes an integrated GIS-MCDM-4D BIM framework to quantify, simulate, and operationalize geospatial logistics risks within construction supply chains. The framework systematically translates GIS-derived spatial risk indicators, such as supplier accessibility, transportation network variability, and route vulnerability, into temporal constraints embedded in 4D BIM simulations. A real-world case study of a reinforced concrete project in Syria, involving multiple suppliers and a heterogeneous transportation network, is employed to validate the approach. Findings indicate that even minor spatial disruptions can cascade through interdependent construction activities, resulting in significant schedule delays. The integration of GIS and 4D BIM enables proactive, risk-informed planning, demonstrating that geospatial conditions exert a substantial influence on construction timelines. This framework advances beyond descriptive GIS applications by providing a quantitative, operational tool for enhancing schedule reliability, supplier selection, and decision-making in complex and unstable construction environments. The proposed methodology offers a transferable solution for managing geospatial logistics risks in diverse construction contexts.

Keywords: GIS-BIM integration ▪ 4D BIM ▪ Construction supply chain ▪ Geospatial logistics risks ▪ Multi-criteria decision-making (MCDM) ▪ Schedule simulation ▪ Risk-informed planning

1. INTRODUCTION

Construction supply chains are inherently complex and highly sensitive to external disruptions, particularly those related to logistics and material transportation [1]. Traditional project planning approaches, even when supported by Building Information Modelling (BIM), often struggle to capture the spatial dynamics that govern supply chain performance [2]. Although BIM provides robust capabilities for modelling building components and construction schedules, it remains limited in representing geospatial variability, such as the spatial distribution of suppliers, transportation network conditions, and route-specific constraints [3].

In parallel, Geographic Information Systems (GIS) offer advanced spatial analytical capabilities; however, they are typically applied independently of time-based project planning processes. In prevailing practice, GIS is mainly used for mapping supplier locations, assessing network accessibility, or visualizing logistics conditions, with limited integration into BIM-based schedule simulations [4]. This separation between spatial analysis and temporal planning is critical because construction delays and cost overruns frequently arise from spatially driven logistical risks that are not explicitly reflected in project schedules [5].

Despite extensive research on BIM, GIS, and 4D BIM applications, GIS continues to function largely as a descriptive analytical tool, while 4D BIM serves primarily as a schedule visualization environment, with few frameworks operationally integrating quantified geospatial risks into time-based simulations [6]. Moreover, the absence of a measurable linkage between spatial risk factors and their cumulative impact on construction timelines restricts predictive and risk-informed planning for complex construction supply chains [7].

To address these limitations, this research proposes and validates an integrated GIS-multi-criteria decision-making (MCDM)-4D BIM framework that systematically transforms GIS-derived spatial risk indicators into temporal constraints within 4D BIM simulations. By elevating GIS from a static mapping tool to an operational analytical component and establishing a quantitative relationship between geospatial logistics risks and construction schedule delays, the proposed framework enables proactive risk management, improves schedule reliability, and supports data-driven decision-making in construction supply chains operating under complex logistical conditions.

2. LITERATURE REVIEW

2.1 BIM-GIS Integration in Construction

The integration of BIM and GIS has progressed through multiple conceptual and operational paradigms, generally classified into BIM-driven, GIS-driven, and bidirectional or balanced integration [8]. In BIM-driven approaches, GIS datasets are typically simplified and embedded within BIM environments to enhance visualization and contextual awareness, often at the expense of GIS analytical capabilities. Conversely, GIS-driven approaches prioritize geospatial analysis while using BIM models largely as static reference data, which constrains dynamic construction-phase decision-making [9].

Balanced or bidirectional integration seeks to exploit the complementary strengths of both platforms by enabling reciprocal data exchange and coordinated spatial-temporal analysis [10]. Nonetheless, effective bidirectional integration remains technically challenging. Persistent obstacles include interoperability, particularly when transforming IFC-based BIM models into CityGML-compliant GIS representations [11]. Variations in data structures, semantic definitions, levels of detail, and coordinate reference systems can result in data loss, geometric inconsistencies, and reduced reliability in downstream analyses [12]. These limitations have confined many BIM-GIS studies to conceptual frameworks or visualization-oriented applications rather than operational decision-support systems [13].

2.2 GIS in Construction Logistics and Transportation

GIS has been extensively applied to transportation and logistics analyses in construction due to its spatial analytical capabilities [4]. Network-based methodologies, including accessibility analysis, shortest-path computation, and service-area evaluation, are commonly employed to assess supplier reachability, route efficiency, and logistical coverage [14]. GIS also supports risk assessment by identifying vulnerable routes, service gaps, and potential bottlenecks within transportation networks [15]. Despite this analytical rigor, GIS outputs are often treated as independent decision-support indicators rather than being systematically integrated into time-based project simulations [16,17].

2.3 4D BIM in Schedule Risk Analysis

4D BIM extends traditional 3D modelling by incorporating temporal data, enabling visualization of construction sequences and improved schedule management [18]. Through 4D BIM, planners can detect task sequencing conflicts, evaluate alternative construction strategies, and optimize internal workflows [19]. However, current 4D BIM applications predominantly address internal project risks, including resource allocation, productivity variability, and sequencing constraints. External factors related to supplier accessibility, transportation network reliability, and spatial disruptions are frequently excluded or considered qualitatively [20]. Consequently, schedules may be internally optimized but insufficiently resilient to real-world logistical uncertainty [21,22].

2.4 Identified Research Gap

A systematic review of the literature reveals a methodological disconnect between geospatial risk assessment and temporal schedule management. While GIS quantifies transportation and logistical risks, 4D BIM excels in temporal simulation and construction sequence analysis. Yet these domains often operate in isolation. Existing approaches generally fail to translate quantified geospatial logistics risks into explicit temporal inputs within 4D BIM environments. This study addresses that gap by integrating GIS-derived logistical risk metrics directly into 4D BIM simulations, enabling risk-informed and resilient construction planning. The literature synthesis is presented in Figure (1).

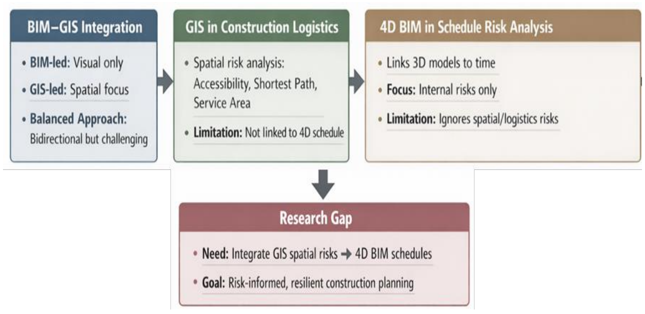

Figure 1. Literature review synthesis for BIM-GIS integration and 4D BIM in construction logistics.

3. BIBLIOMETRIC ANALYSIS

3.1 Inclusion and Exclusion Criteria

The selection of literature was guided by inclusion and exclusion criteria to ensure methodological rigor and topical relevance. Included sources comprised peer-reviewed journal articles and conference proceedings explicitly addressing BIM, GIS, and transportation or logistics management within construction. Studies were excluded if they were not available in full-text format, lacked relevance to the research objectives, or relied on non-verified sources.

3.2 Bibliometric Analysis of Previous Studies

3.2.1 Publications per Year

A total of 66 studies on BIM-GIS integration, published between 2013 and 2025, were analysed. The annual distribution reveals a pronounced upward trajectory in publication volume, particularly from 2018 onward. This growth reflects advances in geospatial data processing, enhanced BIM functionalities, and growing recognition of the benefits of combining spatial and digital construction information, as shown in Figure (2).

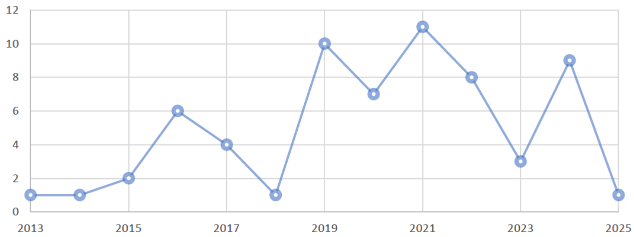

Figure 2. Number of studies published between 2013 and 2025.

3.2.2 Most Cited Authors

The list of most cited researchers highlights leading contributors to BIM-GIS integration. Authors such as J. Irizarry and X. Liu have made sustained contributions to foundational theories and methodologies, as summarized in Table (1).

Table 1. Most cited researchers.

Cites	Author	Research focus
661	J. Irizarry	BIM-GIS integration for construction supply chain monitoring
507	X. Liu	State-of-the-art BIM-GIS integration review
424	H. Wang	BIM-GIS integration in sustainable built environments
361	Y. Deng	BIM and 3D GIS mapping across levels of detail

3.2.3 Most Cited Articles

The most cited articles indicate the influence of studies supporting BIM-GIS applications in construction supply chains, as shown in Table (2).

Table 2. Most cited articles adapted from the bibliometric analysis.

Cites	Authors	Title	Year
661	J. Irizarry	Integrating BIM and GIS to improve visual monitoring of construction supply chain management	2013
507	X. Liu	A state-of-the-art review on BIM-GIS integration	2017
424	H. Wang	Integration of BIM and GIS in sustainable built environment	2019
361	Y. Deng	Mapping between BIM and 3D GIS in different levels of detail	2016
298	Y. Song	Trends and opportunities of BIM-GIS integration in AEC	2017
238	Z. Ma	Integrated application of BIM and GIS: an overview	2017
212	V. J. L. Gan	Integrating 4D BIM and GIS for construction supply chain management	2019

3.2.4 Most Cited Journals

Automation in Construction ranked first in terms of citation count, followed by the International Journal of Geo-Information, as illustrated in Figure (3).

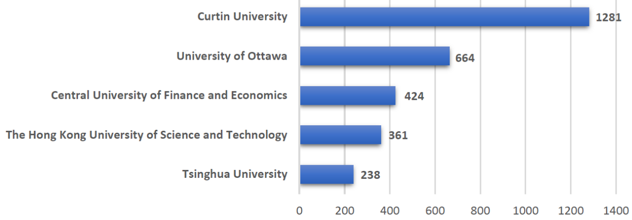

Figure 3. Most cited journals adapted by the author.

3.2.5 Most Cited Universities

Curtin University and the University of Ottawa were among the most influential institutions, as shown in Figure (4).

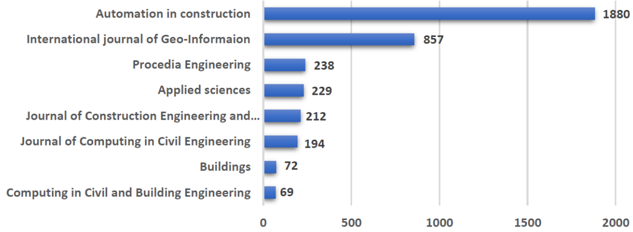

Figure 4. Most cited universities.

3.2.6 Most Cited Countries

At the country level, China and Australia represented major centers of research productivity in BIM-GIS integration, as presented in Figure (5).

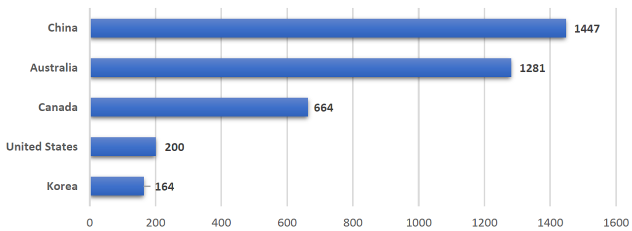

Figure 5. Most cited countries.

3.3 Qualitative Analysis of Previous Studies

Previous studies have focused on integrating BIM and GIS technologies to enhance supply chain management in construction projects, with variations in application types and target domains. These studies demonstrate that combining BIM and GIS provides advanced capabilities for visual monitoring, spatial data analysis, process optimization, cost reduction, and improved decision-making efficiency.

Previous studies have extensively explored the integration of BIM and GIS technologies to enhance various aspects of construction management, particularly supply chain optimization, logistical efficiency, and risk reduction. For instance, Irizarry et al. conducted a case study at the Nursing College building of West Georgia University, demonstrating that BIM-GIS integration significantly improved visual monitoring of material flows and quantity estimation, while highlighting the importance of semantic interoperability between the two systems. Similarly, Liu et al. and Wang et al. provided comprehensive literature reviews and bibliometric analyses on BIM-GIS integration, identifying information loss during data conversion and the need for standardized technical solutions.

In a practical application, Deng et al. examined a five-story building, developing a 4D model to optimize supplier selection, schedule material deliveries, and allocate assembly locations. The study confirmed that such modeling can reduce costs and improve logistical efficiency. Addressing urban construction waste management, Al-Saggaf and Jrade developed a virtual model combining BIM and GIS to sort demolition waste and analyze transport distances and time, reducing the number of required trucks. Moreover, Di Graziano et al. applied BIM-GIS integration to manage construction sites at Catania Airport, emphasizing 3D simulations, real-time tracking, and risk mitigation. Khan et al. developed a 3D geological model using GIS and BIM to support construction planning and structural safety, while Mohammed conducted a systematic review on improving construction material supply chains through BIM and GIS integration.

Collectively, these studies confirm that BIM-GIS integration offers substantial advantages in visual monitoring, logistical optimization, cost reduction, and risk management. However, they also indicate persistent technical challenges, emphasizing the need for standardization, interoperability, and adaptation to diverse geographic and operational contexts. Table (3) provides the qualitative comparison of the reviewed studies.

Table 3. Qualitative analysis of previous studies.

Study	Variables and Objective	Key findings	Recommendations
Irizarry et al.	BIM-GIS integration; weak visual monitoring and supply-chain management; enhance visual monitoring and supply chain	Developed an integrated BIM-GIS model and improved material-flow visualization	Study semantic interoperability and apply additional case studies
Liu et al.	BIM-GIS integration; technical gaps; comprehensive review of BIM-GIS applications	Identified three integration approaches and highlighted information loss	Develop bidirectional conversion methods and standardized building models
Wang et al.	BIM-GIS integration; technical gaps; analyse trends and practical applications	Identified three integration approaches and increased research attention	Develop data conversion methods and refine modelling approaches
Deng et al.	4D BIM-GIS integration for supplier selection; supply-chain improvement and cost reduction; decision-support framework	Improved supplier selection, reduced costs, and optimized delivery allocation	Expand study scope, include additional variables, and study uncertainty impact
Al-Saggaf and Jrade	BIM-GIS integration; demolition waste management; improve waste management in large projects	Estimated waste volumes, sorted and classified waste, and reduced trucks	Increase automation level and enhance BIM-GIS integration
Di Graziano et al.	BIM-GIS integration for site management; operational and risk management; manage complex areas	Effective simulation, real-time tracking, and risk reduction	Expand integration and practical applications in AEC
Khan et al.	GIS-BIM integration; lack of geotechnical data; model geotechnical properties and safe construction zones	Accurate geological model, field-data alignment, and soil classification	Expand methodology and develop integrated platform
Mohammed	Supply-chain integration using BIM, GIS, IoT, and AI; performance and efficiency; improve supply-chain efficiency	Improved decision-making, reduced duration, and enhanced stakeholder communication	Develop standard frameworks, training programs, and practical case studies

3.3.1 Similarities and Differences among Previous Studies

The previous studies exhibit notable similarities in their theoretical framework, objectives, methodological tools, and findings. Conceptually, all studies assume that BIM provides detailed project information, including engineering, material, and temporal data, while GIS contributes spatial and geographical context. The integration of these two technologies creates added value that neither can achieve independently. Most studies share the overarching goal of leveraging BIM-GIS integration to enhance efficiency in the construction sector, whether operational, logistical, financial, or related to safety and sustainability. Commonly used tools include Revit for BIM, ArcGIS for GIS, and Synchro 4D Pro for schedule management. Collectively, the findings underscore that BIM-GIS integration improves visual representation, enhances material and logistics management, and facilitates decision-making and interdisciplinary coordination.

Despite these similarities, the studies differ in several respects. In terms of application focus, Irizarry, Deng, and Mohammed concentrate on logistics and supply chain management, while Di Graziano and Khan specialize in operational and geotechnical risk management. Al-Saggaf and Jrade uniquely address sustainability in urban construction, whereas Liu and Mohammed provide broad literature reviews rather than specific applications. Depth of integration also varies: some studies focus primarily on visual and informational integration to aid decision-making, while others offer analytical models and automated solutions for specific challenges such as supplier selection or sustainable waste quantification. The maturity of the studies ranges from initial explorations of potential benefits to advanced and complex methodological developments.

3.3.2 Similarities and Differences between Previous Studies and the Current Study

The current study aligns with previous research in its theoretical foundation and general objective, emphasizing the importance of BIM-GIS integration to enhance supply chain management. Methodologically, it adopts a practical, experimental approach similar to previous case studies, applying BIM and GIS tools to a specific scenario. Tools such as Revit and ArcGIS remain consistent with those used in earlier applied studies, and expected outcomes such as improved material tracking, cost reduction, and enhanced transport efficiency mirror those reported by previous work.

However, the current study diverges in several critical aspects. Geographically and socially, previous research was conducted in technologically advanced and stable environments, such as the United States, South Korea, China, and Italy, where digital infrastructure and organized supply chains are readily available. In contrast, the current study focuses on Syria, a context characterized by fragile infrastructure and highly complex logistical challenges, making it the first study to implement such integration in a vulnerable, post-conflict setting. Methodologically, earlier studies relied on bibliometric analyses, theoretical reviews, or case studies of completed projects, whereas the current research employs an applied experimental approach, integrating BIM and GIS with Synchro 4D Pro to simulate real-world transport management in reconstruction projects using data suitable for resource-limited environments.

The primary focus also differs: previous studies aimed at improving general construction management efficiency, such as visual representation, sustainability, or interdisciplinary coordination, while the current study specifically targets transport management within the construction supply chain, a critical issue in contexts such as Syria where transportation costs and road safety are major concerns. The variables examined are broader, encompassing practical logistics and real-world factors such as distances and transport costs, in addition to technical considerations such as model LOD, IFC-CityGML integration, and schedule management. Furthermore, the current study adopts a more holistic approach by integrating economic aspects into the analysis and emphasizing improved transport efficiency within supply chains. As a result, while previous studies reported efficiency gains, cost reduction, and enhanced safety, the current study expects practical outcomes such as reduced material waste, optimized shipment scheduling, and a transferable model for similar constrained environments.

4. RESEARCH METHODOLOGY

This research employs an applied, data-driven methodology designed to operationalize BIM-GIS integration for optimizing transportation management within construction supply chains. The methodology follows a structured workflow combining spatial analysis, MCDM, and 4D BIM simulation to translate geospatial risks into measurable schedule impacts.

4.1 Research Design

An applied case-study approach was adopted to validate the proposed framework under realistic logistical conditions. A descriptive-analytical methodology was used to examine spatial, operational, and temporal variables governing concrete supply chains. This analysis is complemented by digital simulation, enabling dynamic assessment of transportation risks and their cumulative effects on project scheduling.

4.2 Data Preparation and Geodatabase Development

A geospatial database was constructed to represent concrete suppliers and the regional transportation network. Spatial data were integrated with operational attributes, including unit price, production capacity, and delivery time. Network connectivity was enhanced by adding nodes to ensure realistic route modelling. This database served as the analytical backbone for subsequent GIS-based evaluations.

4.3 GIS-Based Spatial Analysis

Network-based GIS tools were applied to quantify logistical performance and risks. Closest Facility Analysis identified optimal delivery routes between suppliers and the project site while considering travel time and network constraints. Service Area Analysis evaluated supplier accessibility and logistical coverage within defined time thresholds. The outputs provided quantitative spatial risk indicators reflecting transportation reliability and vulnerability.

4.4 Multi-Criteria Decision Making

An MCDM model was implemented to evaluate suppliers holistically. Relative weights were assigned to spatial and operational criteria according to strategic significance. A composite score was calculated for each supplier, facilitating selection of the strategically optimal supplier that balances cost, time, productivity, and spatial risk rather than simply choosing the fastest option.

4.5 BIM Modeling and 4D Simulation

Concrete structural elements were modeled in Autodesk Revit, and material quantities were extracted and linked to the selected supplier. The BIM model and construction schedule were imported into Synchro Pro to develop a 4D BIM simulation. Spatial risks quantified through GIS analysis were incorporated as time-based constraints within the simulation, enabling assessment of how geographically induced disruptions propagate through the construction schedule. The full research workflow is shown in Figure (6).

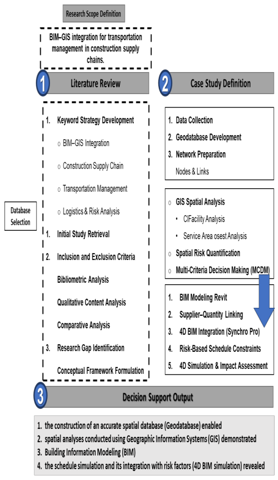

Figure 6. Research workflow.

5. CASE STUDY AND RESULTS

5.1 Case Study Description

The proposed GIS-MCDM-4D BIM framework was validated through an applied case study of a real construction project featuring a reinforced concrete structural system and a multi-supplier concrete supply chain. Concrete was selected due to its critical role in structural execution and its dependency on timely and continuous delivery. The case study involves multiple ready-mix concrete suppliers located at varying distances from the construction site and connected through a heterogeneous transportation network. Each supplier exhibits unique operational characteristics, including production capacity, unit cost, and dispatch efficiency.

The transportation network incorporates roads of differing functional classifications, connectivity levels, travel distances, and potential bottlenecks. These conditions introduce varying levels of geospatial risk that directly affect delivery reliability and construction continuity. Figure (7) locates the project site and concrete suppliers within the transportation network.

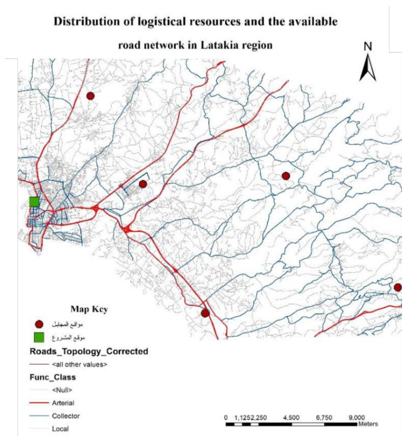

Figure 7. Geographic distribution of the construction site and concrete suppliers within the transportation network.

5.2 GIS-Based Spatial Analysis and Results

A comprehensive GIS-based analysis was conducted to evaluate supplier logistics performance.

A geodatabase incorporated supplier locations, road network attributes, and operational data, including delivery time, unit cost, and production capacity. Network analysis techniques quantified spatial accessibility and transportation efficiency. The results revealed notable variations in accessibility and service efficiency among suppliers. Some suppliers demonstrated short travel times but limited service areas, increasing vulnerability to network disruptions. Others exhibited broader service coverage but longer delivery durations.

Figures (8), (9), and (10) illustrate supplier classification by arrival time, price per cubic meter, and productivity, respectively. These visualizations highlight spatial risk patterns that are not apparent when using conventional non-spatial metrics.

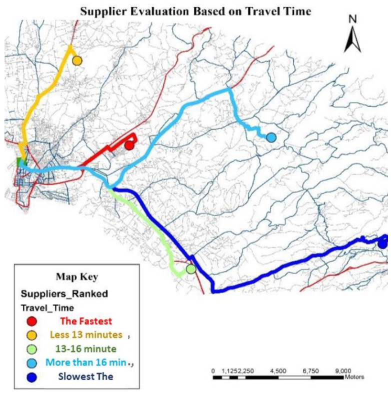

Figure 8. Supplier classification map by arrival time.

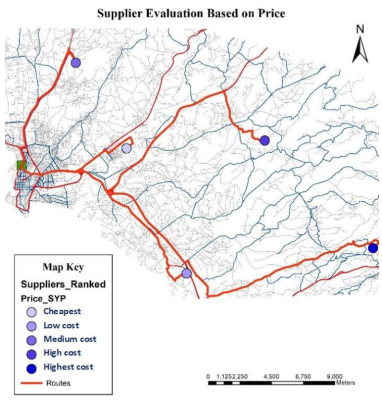

Figure 9. Map classifying suppliers by price per cubic meter.

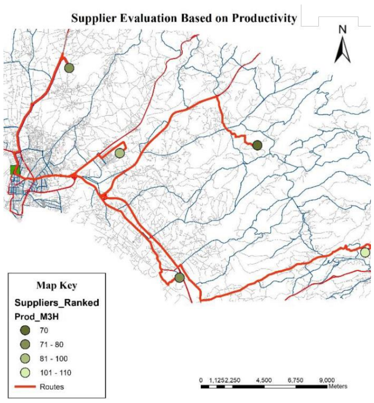

Figure 10. Supplier classification map by productivity.

5.3 Integration with 4D BIM and Simulation Results

To assess the temporal implications of geospatial logistics risks, GIS analysis results were integrated into a 4D BIM environment. A detailed BIM model of concrete structural elements was developed, with quantity take-offs extracted to define material demand over time. The construction schedule was linked to the BIM model to produce a baseline 4D simulation reflecting conventional planning assumptions.

In the baseline scenario, material deliveries were assumed stable and unaffected by external spatial conditions. Quantified spatial risk indicators, including extended travel times, limited service coverage, and network vulnerabilities, were incorporated as temporal constraints within the 4D BIM model. The revised simulation revealed deviations from the baseline schedule. While individual spatial disruptions appeared minor in isolation, their cumulative effect resulted in measurable schedule delays across multiple construction phases, as shown in Table (4).

Table 4. Schedule delay after adding risks to Synchro.

Item	Before risks	After risks
Project completion date	31/10/2026	11/11/2026
Project duration	473 days	480 days

These results demonstrate that neglecting geospatial logistics risks during schedule planning can lead to systematic underestimation of project duration. By integrating GIS-derived risk data into 4D BIM simulations, schedules become more realistic, resilient, and reflective of actual construction conditions.

6. DISCUSSION

6.1 Amplification of Minor Spatial Disruptions into Significant Schedule Delays

The results reveal that seemingly minor geospatial disruptions can trigger disproportionately large impacts on construction schedules. This amplification stems from the cumulative and sequential nature of construction operations. Concrete delivery, a time-sensitive repetitive task, serves as a critical input for multiple downstream activities. Any delay at this stage propagates through dependent tasks, magnifying temporal consequences.

Spatial disruptions, such as marginal increases in travel time, limited service coverage, or reduced network redundancy, may appear negligible when assessed individually using GIS analysis. However, when introduced into 4D BIM simulation, their repeated occurrence across multiple delivery cycles leads to cumulative schedule slippage. This finding highlights that traditional planning approaches often underestimate temporal risk by treating logistical variability as an exception rather than as an intrinsic feature of construction environments.

6.2 Comparison with Previous BIM-GIS and 4D BIM Studies

This research extends prior work on BIM-GIS integration and construction logistics. Deng et al. proposed a conceptual linkage between GIS-based logistics analysis and 4D BIM for construction supply chain management, focusing primarily on information integration and visualization. Irizarry et al.

demonstrated the benefits of integrating BIM and GIS for construction visualization and decision support. In contrast, this study advances beyond conceptual integration by establishing a measurable workflow in which GIS-derived logistics risks are transformed into temporal constraints within 4D BIM simulation.

6.3 Value of GIS-4D BIM Integration in Unstable Environments

The integration of GIS with 4D BIM demonstrates particular value in unstable or high-risk environments where transportation networks are frequently disrupted. In such contexts, reliance on static schedules or internally focused planning models is insufficient. By incorporating spatial risk indicators into schedule simulations, the framework enhances decision-making and schedule resilience. This capability is especially relevant for construction projects in regions with fragmented infrastructure, limited network redundancy, or unpredictable logistical conditions. In these environments, spatial risks are not exceptions but persistent characteristics of the operating context.

6.4 Implications for Real-World Construction Supply Chain Planning

Supplier selection processes that emphasize cost and production capacity while ignoring spatial risk exposure may produce suboptimal decisions. Even suppliers with strong economic profiles may pose substantial schedule risks due to their geospatial context. Integrating GIS-based logistics analysis with 4D BIM scheduling facilitates risk-informed planning that reflects real-world operating conditions. This approach supports more accurate schedule forecasting, better supplier evaluation, and improved alignment between logistical planning and construction execution. Ultimately, this research underscores that construction schedules are not purely temporal artifacts but are deeply shaped by spatial conditions. Recognizing and operationalizing this relationship represents a critical step toward more reliable and resilient construction supply chain planning. The integrated decision-support logic is summarized in Figure (11).

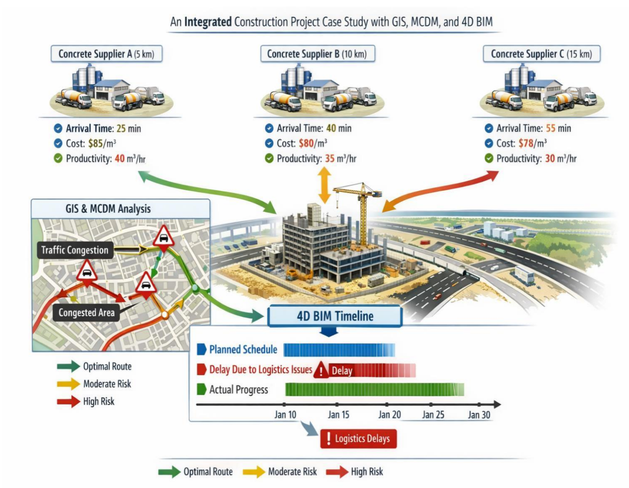

Figure 11. GIS-MCDM-4D BIM integration for concrete supply chain: supplier performance, spatial risk, and schedule impact visualization.

7. CONCLUSION

This study established a measurable and operational link between geospatial conditions and construction schedule performance. The results confirm that spatial logistics risks, often considered secondary or external, can produce significant cumulative effects on project timelines when systematically propagated through construction schedules. By quantifying these impacts, the research moves beyond descriptive assessment toward evidence-based evaluation of time-related risks.

The findings demonstrate that GIS should no longer be viewed merely as a spatial mapping or descriptive tool, nor should 4D BIM be treated solely as a visualization environment. When integrated within a unified analytical framework, GIS acts as a dynamic risk assessment engine that directly informs 4D BIM simulations, transforming construction schedules into responsive, risk-aware planning instruments.

The proposed GIS-MCDM-4D BIM framework supports proactive planning by enabling early identification of logistical vulnerabilities and their temporal consequences. This approach enhances schedule reliability and provides decision-makers with a more realistic understanding of construction execution under complex and variable spatial conditions. The framework can be adapted to other construction projects and infrastructure developments characterized by complex supply chains, transportation dependencies, or unstable logistical environments. Future research may incorporate additional spatial risk factors or dynamic data sources to strengthen predictive planning and risk management capabilities.

REFERENCES

[1] S. Deep et al., "Disruption to construction supply chains during COVID-19 in developing economies: A strategic framework for sustainable and resilient logistics," 2025, Art. no. 100235.

[2] J. A. Carbone and F. Economics, "Food supply chains: Coordination, governance and other shaping forces," vol. 5, no. 1, p. 3, 2017.

[3] S. Metvaei et al., "A GPS-integrated IoT framework for real-time monitoring of prefabricated building modules during transportation," vol. 15, no. 23, p. 4242, 2025.

[4] J. Irizarry, E. P. Karan, and F. Jalaei, "Integrating BIM and GIS to improve the visual monitoring of construction supply chain management," *Automation in Construction*, vol. 31, pp. 241–254, 2013.

[5] F. Ardila and A. Francis, "Spatiotemporal planning of construction projects: A literature review and assessment of the state of the art," vol. 6, Art. no. 550305, 2020.

[6] O. Olaseni, "Optimizing construction project delivery using BIM for real-time design, scheduling, and cost integration," 2022.

[7] Zhasmukhambetova, H. Evdorides, and R. J. Davies, "Integrating risk assessment and scheduling in highway construction: A systematic review of techniques, challenges, and hybrid methodologies," vol. 5, no. 3, p. 85, 2025.

[8] R. Fosu et al., "Integration of building information modeling (BIM) and geographic information systems (GIS): A literature review and future needs," in *Proc. 32nd CIB W78 Conf.*, Eindhoven, The Netherlands, 2015.

[9] Z. Ning, M. Jia, and J. Li, "From smart cities to digital twin cities: A GIS-driven review of urban refined governance models and paradigm transformation," vol. 5, pp. 3–35, 2026.

[10] S. Wang, Y. Zhong, and E. Wang, "An integrated GIS platform architecture for spatiotemporal big data," *Future Generation Computer Systems*, vol. 94, pp. 160–172, 2019.

[11] Borrmann et al., "Multi-scale geometric-semantic modeling of shield tunnels for GIS and BIM applications," vol. 30, no. 4, pp. 263–281, 2015.

[12] R. J. Li, "Data structures and application issues in 3-D geographic information systems," vol. 48, no. 3, pp. 209–224, 1994.

[13] F. Jalaei, A. Jrade, and M. Nassiri, "Integrating decision support system (DSS) and building information modeling (BIM) to optimize the selection of sustainable building components," *Journal of Information Technology in Construction*, vol. 20, pp. 399–420, 2015.

[14] G. F. et al., "A GIS-supported methodology for the functional classification of road networks," vol. 69, pp. 368–375, 2023.

[15] B. Inanloo et al., "A decision-aid GIS-based risk assessment and vulnerability analysis approach for transportation and pipeline networks," vol. 84, pp. 57–66, 2016.

[16] Ahsan, *Integration of BIM and GIS for Smart Construction Management*. Politecnico di Torino, 2024.

[17] C. Guerrero, *Modelling and Dynamic Assessment of Space Project Cost and Schedule Performance: Simulation and Review of Policy Implications Using System Dynamics*. UCL, 2024.

[18] Romigh, J. Kim, and A. Sattineni, "4D scheduling: A visualization tool for construction field operations," in *Building Information Modeling in Pedagogy and Practice*. Routledge, 2017, pp. 178–188.

[19] S. S. Martins et al., "Evaluation of 4D BIM tools applicability in construction planning efficiency," vol. 22, no. 15, pp. 2987–3000, 2022.

[20] M. Awe et al., "Towards 4D BIM: A systematic literature review on challenges, strategies and tools in leveraging AI with BIM," vol. 15, no. 7, p. 1072, 2025.

[21] Whitlock et al., "4D BIM for construction logistics management," vol. 2, no. 2, pp. 325–348, 2021.

[22] Elhendawi, "Leadership and change management in adopting ISO 19650 standards as a catalyst for digital transformation in construction organisations," MBA thesis, Horizons University, Paris, France, 2025.