Ingeniería y Competitividad
Vol 27 (1) 2025 doi: 10.25100/iyc.v27i1.14401

Vol 27 (1)

ISSN
0123-3033
e- 2027-8284

Review Article

Preliminary Projects Related to LC, BIM and AI in the Construction Industry

Proyectos preliminares relacionados con LC, BIM e IA en la industria de construcción

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How to cite?

Gómez-Rodrígez, G.N., Álvarez-Sanabria, A.F., Sarmiento-Rojas, J.A. Preliminary Projects Related to LC, BIM and AI in the Construction Industry Ingeniería y Competitividad, 2025, 27(1)e-30414401

https://doi.org/10.25100/iyc.v27i1.14401

Recibido: 29-08-24
Evaluado: 29-10-24
Aceptado: 11-02-25
Online: 26-02-25

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Abstract

Introduction: the adoption of Lean Construction (LC), Building Information Modeling (BIM), and Artificial Intelligence (AI) is significantly transforming construction management. However, research on the integration of these three approaches in the industry is still limited, which restricts the advancement of modernization in the construction sector.
Objective: this paper aims to systematically review 186 documents on the adoption of LC, BIM, and AI in construction projects. The research analyzes existing literature, identifies patterns and best practices, and provides recommendations for integrating these approaches into the industry.
Methodology: the PRISMA methodology was used, a structured guide for conducting systematic reviews and meta-analyses, which involved four main stages: identification, selection, eligibility assessment, and inclusion. This methodology ensures transparency and reproducibility of the review process. The review was conducted using the Scopus database, and tools, techniques, and strategies implemented in construction projects were evaluated, highlighting both project-specific and transversal characteristics.
Results: the review highlighted the synergies between LC, BIM, and AI, demonstrating how the combination of these technologies optimizes operational efficiency and reduces waste in construction projects. Furthermore, continuous improvement, more informed decision-making, and effective collaboration among project stakeholders throughout the project lifecycle were emphasized.
Conclusions: It is concluded that the adoption of LC, BIM, and AI has the potential to transform the construction sector by optimizing processes, improving sustainability, and allowing better integration of the stakeholders involved in projects. The need for greater adoption of these technologies to accelerate the modernization of the sector is emphasized.

Keywords: Lean Construction (LC); Building Information Modeling (BIM); Artificial Intelligence (AI), Systematic Re-view.

Resumen

Introducción: la adopción de Lean Construction (LC), Modelado de Información para la Construcción (BIM) e Inteligencia Artificial (IA) está transformando significativamente la gestión de la construcción. Sin embargo, la investigación sobre la integración de estos tres enfoques en el sector es aún limitada, lo que restringe el avance de la modernización en la industria de la construcción.
Objetivo: este artículo tiene como objetivo realizar una revisión sistemática de 186 documentos sobre la adopción de LC, BIM e IA en proyectos de construcción. La investigación analiza la literatura existente, identifica patrones y mejores prácticas, y ofrece recomendaciones para integrar estos enfoques en la industria.
Metodología: se utilizó la metodología PRISMA, una guía estructurada para realizar revisiones sistemáticas y meta-análisis, que permitió llevar a cabo cuatro etapas principales: identificación, selección, evaluación de elegibilidad e inclusión. Esta metodología garantiza la transparencia y reproducibilidad del proceso de revisión. La revisión se realizó usando la base de datos Scopus, y se evaluaron herramientas, técnicas y estrategias implementadas en proyectos de construcción, destacando tanto las características específicas de los proyectos como las transversales.
Resultados: la revisión destacó las sinergias entre LC, BIM e IA, mostrando cómo la combinación de estas tecnologías optimiza la eficiencia operativa y reduce el desperdicio en los proyectos de construcción. Además, se subrayó la mejora continua, la toma de decisiones más informadas y la colaboración efectiva entre los actores del proyecto a lo largo de su ciclo de vida.
Conclusiones: se concluye que la adopción de LC, BIM e IA tiene el potencial de transformar el sector de la construcción al optimizar procesos, mejorar la sostenibilidad y permitir una mejor integración de los actores involucrados en los proyectos. Se enfatiza la necesidad de una mayor adopción de estas tecnologías para acelerar la modernización del sector.

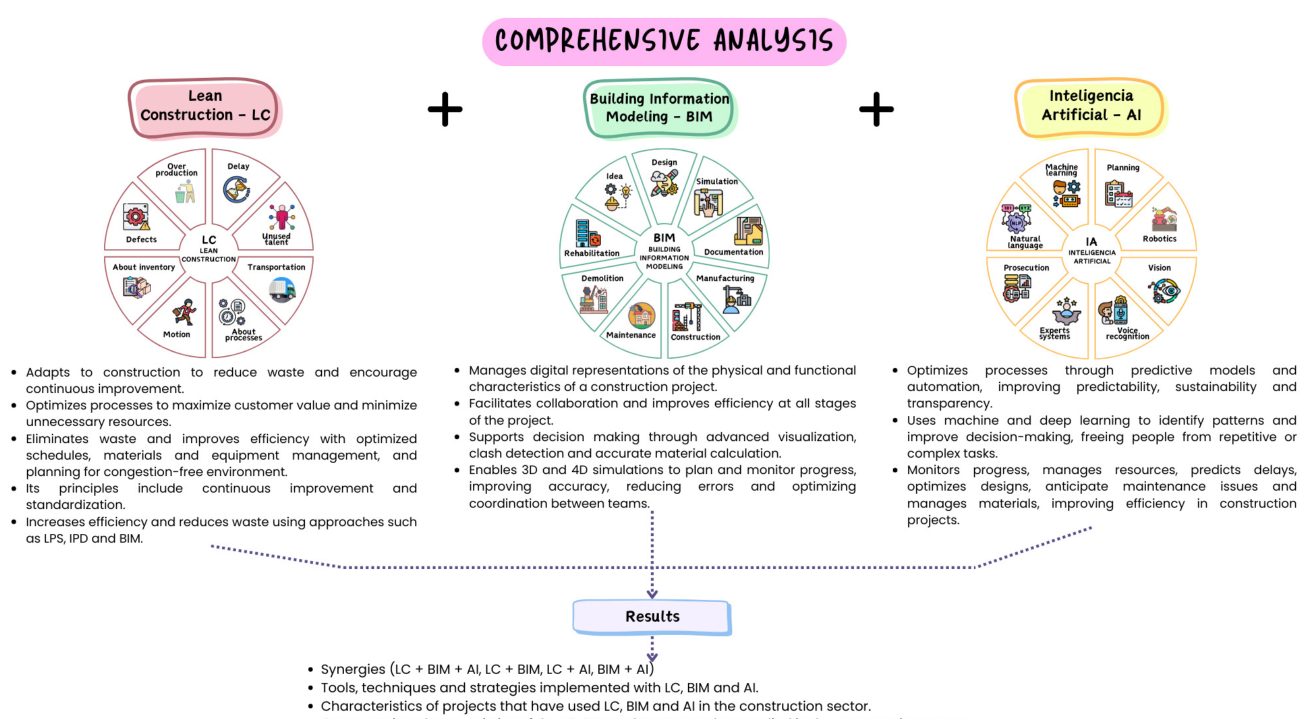
Palabras clave: Construcción Lean (LC); Modelado de información de construcción (BIM); Inteligencia Artificial (IA), Revisión Sistemática.

Contribution to the literature

Why was it conducted?
The construction industry is facing increasing complexity, requiring efficient management of tools, methodologies, and philosophies to meet project requirements. Despite the proven benefits of Lean Construction (LC), Building Information Modeling (BIM), and Artificial Intelligence (AI) in improving processes and decision-making, their integration remains a challenge. Many companies, especially SMEs, have limited financial, technological, and managerial resources, making it difficult to adopt these advanced approaches.

What were the most relevant results?
The study highlights that Lean Construction (LC), Building Information Modeling (BIM) and Artificial Intelligence (AI) offer significant advantages in construction project management. Furthermore, this research demonstrates that combining these approaches can provide benefits that exceed individual advantages, optimizing operational efficiency and reducing waste. LC eliminates activities that do not add value, BIM facilitates the visualization and coordination of projects, and AI analyzes large volumes of data and automates processes for more efficient execution.
The combination of BIM and AI provides powerful tools for informed decision-making. BIM visualizes all aspects of the project, while AI analyzes this data to identify patterns, predict problems, and suggest solutions. This allows project managers to make decisions based on concrete data and accurate simulations, improving quality and results.

What do these results contribute?
Implementing LC, BIM, and AI fosters a culture of innovation and continuous improvement in construction. LC establishes a solid basis for constantly improving processes, BIM offers a platform to implement these improvements visually and practically, and AI adds intelligence that allows automatic learning and continuous adaptation. This integration contributes significantly to the sustainability and efficient management of resources in construction projects, reducing costs and minimizing environmental impact, which is crucial to complying with environmental and social responsibility standards.
The theoretical evidence and case studies reviewed show that integrating LC, BIM, and AI improves the efficiency, quality, and sustainability of construction projects. The convergence of LC, BIM, and AI represents the future of construction project management, offering a holistic and efficient approach that enhances all aspects of the project life cycle. Adopting these technologies is not only a competitive advantage but a necessity to address current and future challenges in the industry.



doi: 10.25100/iycv.v27i1.14401

Introduction

Construction projects are becoming increasingly complex, requiring the efficient management of tools, methodologies, and philosophies integrated synergistically. Effective management is crucial to achieving objectives and meeting the increasingly demanding requirements of projects, which necessitate innovative solutions and in-depth knowledge (1). The construction industry faces persistent challenges related to efficiency, process optimization, and the adoption of advanced technologies. These challenges are exacerbated by limitations in resources and capacities, affecting the sector's productivity and competitiveness.

The individual application of LC, BIM, and AI has proven effective in improving construction processes and decision-making (2). However, there is a need to address the integration of these approaches, delving into various project management methodologies and technological tools to eliminate harmful practices resulting from incorrect decisions during the conception, planning, and execution of projects (3).

The BIM-Lean model is a technique that can significantly increase productivity in construction companies. This methodology allows for faster project progress in Colombia and optimizes resource utilization (4). Integrating LC and BIM with an AI approach aims to optimize construction processes. By combining their strengths, these technologies can enhance the efficiency, quality, safety, and sustainability of construction projects, benefiting all participants in the value chain (5).

Many companies are characterized by their limited access to financial, technological, innovation, and management resources (6). These limitations can complicate the adoption of advanced approaches that demand considerable investments in training and technology. Additionally, they operate in highly competitive environments with tight profit margins, making investments in these methodologies appear risky.

Although some companies manage their projects relatively effectively, there remains ample room for improvement in on-site management and planning quality, potentially leading to significant efficiency gains (7). The construction industry continues to face inefficiencies and challenges in project management due to financial and technical constraints, hindering the adoption of advanced technologies and efficient methodologies.

Companies often struggle with the efficient execution of construction projects, encountering slow, inefficient, and error-prone processes. However, implementing digital technologies can reduce operating costs by 20% to 25% (8). For instance, recent projects utilizing tools such as the Internet of Things (IoT) and automated management systems have optimized logistics, reduced machinery downtime, and improved materials delivery accuracy. This approach has significantly reduced costs while boosting productivity and safety. A notable example is Caterpillar, which used IoT sensors to connect and monitor equipment in real-time. This optimization in maintenance and scheduling resulted in a 22% reduction in operating costs for a large-scale infrastructure project (8). However, a lack of access to accurate, real-time data in some companies hinders decision-making during execution, affecting project efficiency, quality, and competitiveness. Failure to address these underlying issues could result in competitive difficulties, resource waste, delays, cost overruns, and limited capacity for innovation and adaptation, especially for MSMEs.

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LC is a production management approach that transforms the design and construction of buildings and infrastructure. It seeks to maximize value and minimize waste by implementing specific techniques throughout the project process (9), improving efficiency, and reducing costs by eliminating unnecessary activities and optimizing resource management.

BIM is a process that uses 3D digital modeling tools to generate and manage data for a building or project before, during, and after its execution, achieving significant savings in time, design, and resources (10). BIM increases efficiency and improves data management at all stages of a construction project, facilitating comprehensive coordination and management of information.

AI is a system that simulates human reasoning using mathematics and logic, allowing it to execute tasks and make decisions based on collected information (10). AI is a technology designed to complement and augment human capabilities, and it has proven beneficial across multiple sectors. Its application in construction offers significant benefits in efficiency, safety, and quality, making AI a strategic investment for the industry.

This underscores the need for a systematic and comprehensive review of the literature on the use of LC, BIM, and AI in construction projects. Such a review aims to identify patterns and good practices from successful case studies, describe cross-cutting characteristics and effective practices, and provide recommendations based on the study's findings and conclusions. This will address how advanced LC, BIM, and AI practices can enhance operational efficiency, informed decision-making, and quality in construction projects.

Methodology

A systematic review was conducted to identify and evaluate previous research on the implementation of Lean Construction (LC), Building Information Modeling (BIM), and Artificial Intelligence (AI) in the construction industry. The PRISMA methodology (11) was selected for its rigor in identifying and synthesizing empirical evidence, as it contributes to the clarity of data collection, systematization, and interpretation, and ensures transparency in the publication of scientific articles (12). This review allowed us to characterize the trends, practices, and outcomes of applying these methodologies in construction projects.

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology is an approach that outlines a minimum set of evidence-based items that must be included when reporting a systematic review and meta-analysis (13) in various disciplines. In the present study, PRISMA served as a key tool for collecting, analyzing, and synthesizing relevant information on the integration of LC, BIM, and AI in the construction sector.

Identification of Databases

The Scopus database was selected for the systematic review due to its broad scope and coverage in engineering and construction. Scopus is a comprehensive bibliographic database that encompasses various disciplines, including health, social and natural sciences, engineering, technology, and life sciences (14). It was chosen for its extensive coverage of scientific sources, reliable impact metrics, and advanced analytical tools that facilitate research search, analysis, and collaboration (15). Scopus offers advanced search options and valuable metrics for evaluating the impact and relevance of publications, providing a broader global perspective compared to other databases such as Web of Science and ScienceDirect.

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Search strategy

A search strategy was designed in Scopus using a combination of key terms to ensure that the selected articles included at least two keywords. This strategy enabled the identification of scientific articles, systematic reviews, meta-analyses, and relevant event reports. One hundred eighty-six publications were identified by applying the inclusion and exclusion criteria detailed in Table 1. During the analysis of the articles, those that did not meet the established requirements were discarded.

Table 1. Search and Selection Criteria

Criterion	Value
Source of information	Scopus database.
Period	2019 - 2024.
Types of publication	Scientific articles, systematic reviews, relevant meta-analyses, conferences, or event reports.
Languages	Spanish and English.
Search string	Article title, abstract, keywords: – "Lean Construction" AND "Building Information Modeling" AND "Artificial Intelligence". – "Lean Construction" AND "Building Information Modeling". – "Lean Construction" AND "Artificial Intelligence". – "Building Information Modeling" AND "Artificial Intelligence".
Inclusion	– Publications containing at least two of the specified keywords. – Publications available in open access. – Publications in English or Spanish.
Exclusion	– Non-peer-reviewed publications. – Publications not available in full text. – Publications outside the field of construction. – Publications that, although they include the keywords in their titles, summaries, or keywords, do not focus specifically on LC, BIM, and AI in construction.

Selection and Data Extraction Process

The article selection process was conducted in two stages. First, the titles and abstracts were reviewed to

doi: 10.25100/iyc.v27i1.14401

assess their initial relevance. Then, the full texts of the shortlisted articles were analyzed to determine their final inclusion in the review. Essential data were extracted from the final articles, including the title, author(s), year of publication, journal, methodologies used, and main findings.

Data Analysis

The extracted data was qualitatively analyzed using documentary content analysis to identify trends and patterns related to the integration of LC, BIM, and AI in construction. Tools such as VOSviewer were used to visualize and analyze key term networks. The bibliometric analysis evaluated scientific activity (16), focusing on publication dates, types of publications, geographical origins, media, and leading authors. The content analysis (16) concentrated on research methods, study topics, and content patterns, providing a qualitative interpretation of the meaning and context of the analyzed texts.

Validation and Reliability

To ensure the validity and reliability of the review process, a peer review was implemented. In this process, a second reviewer independently evaluated a random sample of the selected articles, checking for consistency in the selection and extraction of data. Additionally, a review was conducted to eliminate duplicates between the different database searches.

Limitations

The selected research method has two main limitations. First, although books were included in the discussion, the systematic review excludes grey literature and non-peer-reviewed sources such as blogs, websites, and social networks (17), which are popular among professionals and offer valuable information on the current application of LC, BIM, and AI in construction. Secondly, there is a possibility of omitting relevant articles that do not explicitly specify their relationship with the application or integration of LC, BIM, and AI in the sector in their titles, abstracts, or keywords.

Systematic Review

The method used is a systematic literature review of preliminary projects implementing LC, BIM, and AI in construction. This method allows for the location, evaluation, and synthesis of existing evidence (18). Researchers who conduct systematic reviews apply explicit and systematic methods designed to minimize bias, generating reliable results that support decision-making (19). Systematic reviews are essential for synthesizing and evaluating evidence, significantly contributing to advancing knowledge and informed decision-making in various fields, particularly in construction.

The review covers literature published between 2019 and 2024, a period chosen due to the exponential growth in the development and adoption of LC, BIM, and AI in the construction industry from 2019 onwards. During this time, significant progress has been observed in these technologies, especially in large-scale projects where data exchange between disciplines poses complex challenges. This challenge has encouraged the creation of collaborative innovations to minimize the fragmentation of information, consolidating the integration of these tools in projects of various scales (20). Thus, this interval allows for a precise analysis of the most recent

doi: 10.25100/iyc.v27i1.14401

and representative developments in these areas, as it also aims to evaluate the most relevant and current advancements. In addition, this review focuses on the key phases of research, tool development, and the implementation of these approaches. The review is structured in five main steps (17), as detailed in the methodology section Figure 1.

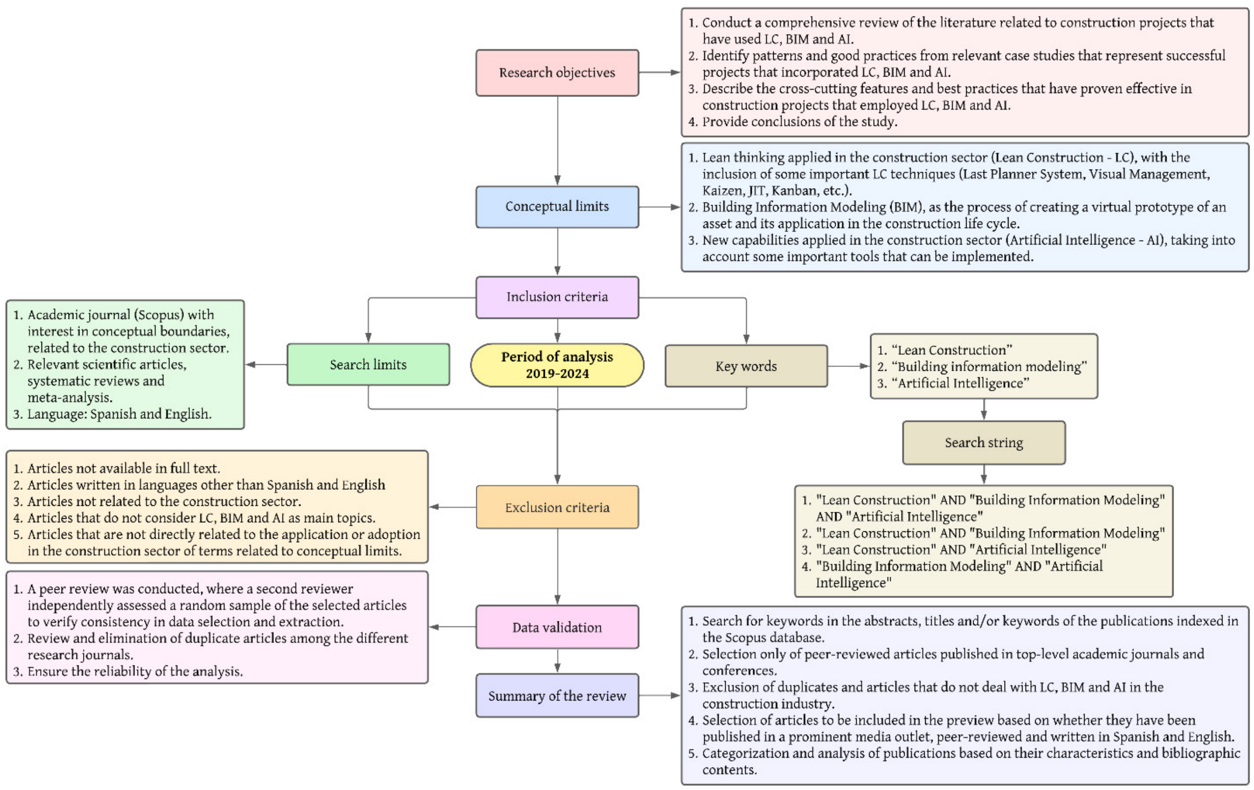

Figure 1. Details of the Systematic Literature Review on LC, BIM, and AI in the Construction Sector

Results and discussion

A set of publications classified according to different criteria is presented below to show the analysis results. To better understand the document, the numbers corresponding to quantity will be included in brackets and preceded by the abbreviation “q.,” which indicates “quantity.” For example, (q. 10) means that the corresponding quantity of the respective classification is 10.

When reviewing and classifying the publications according to their date and type, an increase was observed in the number of publications and in the interest in applying LC, BIM, and AI in the construction industry (Figure 2). The total number of publications on the integration of BIM and AI (q. 124) exceeds those focused on LC and BIM (q. 55) and LC and AI (q. 5) (Table 2). It is concluded that the growing interest in implementing these concepts in construction, especially since 2021, has been mainly driven by the integration of BIM and AI, coinciding with the increased interest in BIM in the sector. Most of the publications in this field are articles (q. 147).

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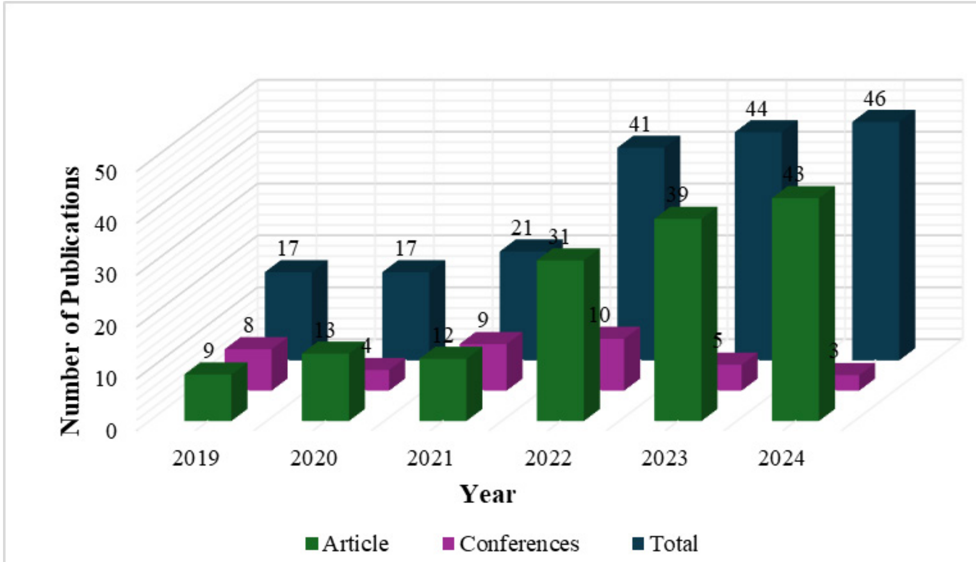

Figure 2. Quantity and Type of Publication by Year

According to Figure 3, academic institutions in the United Kingdom have led the way with the highest number of publications since 2019 (q. 27). Italy follows with (q. 22), China (q. 16), Australia (q. 9), Germany (q. 9), the United States (q. 7), and South Korea (q. 7). Interest in integrating some of these conceptual approaches is notable in certain countries. For example, academic institutions in South Korea, Hungary, and Austria have published work focusing on BIM and AI, which is not observed in publications considering LC and AI approaches.

Table 2. Publications by Year, Type, and Focus

Year	**Type of publication**	**Publication focus**				**Total**
		LC+BIM+AI	**LC+BIM**	**LC+AI**	**BIM+AI**	
2019	Article	0	5	0	4	9
	Conferences	0	7	0	1	8
2020	Article	1	7	0	5	13
	Conferences	0	2	0	2	4
2021	Article	0	3	0	9	12
	Conferences	0	5	1	3	9
2022	Article	0	4	1	26	31
	Conferences	0	5	2	3	10
2023	Article	1	10	0	28	39
	Conferences	0	2	0	3	5
2024	Article	0	5	1	37	43
	Conferences	0	0	0	3	3
Total		3	2	55	5	124
Total number of articles						147
Total number of conferences						39

doi: 10.25100/iyc.v27i1.14401

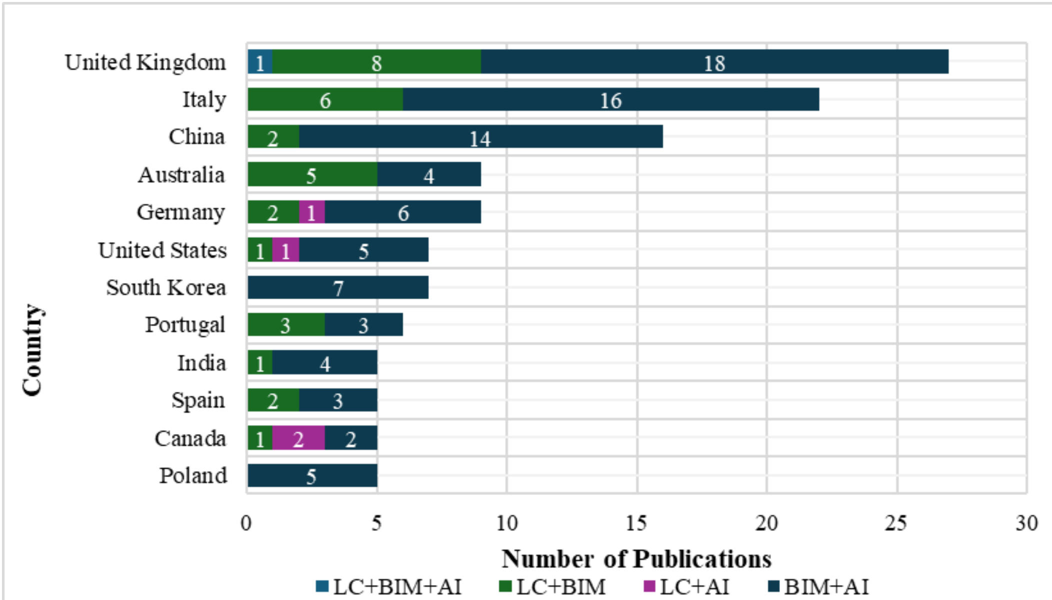

Figure 3. Publications by Country and Focus

According to Figure 4, The most common keywords among the 186 publications analyzed are "building information modeling," "artificial intelligence," "lean construction," "construction industry," "BIM," and "project management." The countries with the most publications are the United Kingdom, Italy, China, Australia, Germany, the United States, South Korea, Portugal, India, Spain, Canada, and Poland, coinciding with Figure 3. The authors with the most published documents include Di Giuda, Giuseppe Martino; Locatelli, Mirko; Koskela, Lauri; Tezel, Algan; Kassem, Mohamad; Matt, Dominik T; Schimanski, Christoph Paul; Brilakis, Ioannis; Sacks, Rafael; Drogemuller, Robin; Omrani, Sara; and Rashidian, Sara.

In terms of publication media, the journals "Data Centric Engineering" and "Developments in the Built Environment" are the only ones to have published articles focusing on LC, BIM, and AI (q. 2). The journal "Buildings" has been the medium with the most publications on LC and BIM (q. 9). For LC and AI, the 30th Annual Conference of the International Group for Lean Construction IGLC 2022 has been the primary medium (q. 2). The journal "Buildings" has also led in publications on BIM and AI (q. 24). The Table 3. presents a detailed classification of the primary means of publication, it should be noted that the majority of publications are in the "other" category, due to the diversity of journals in which they are published.

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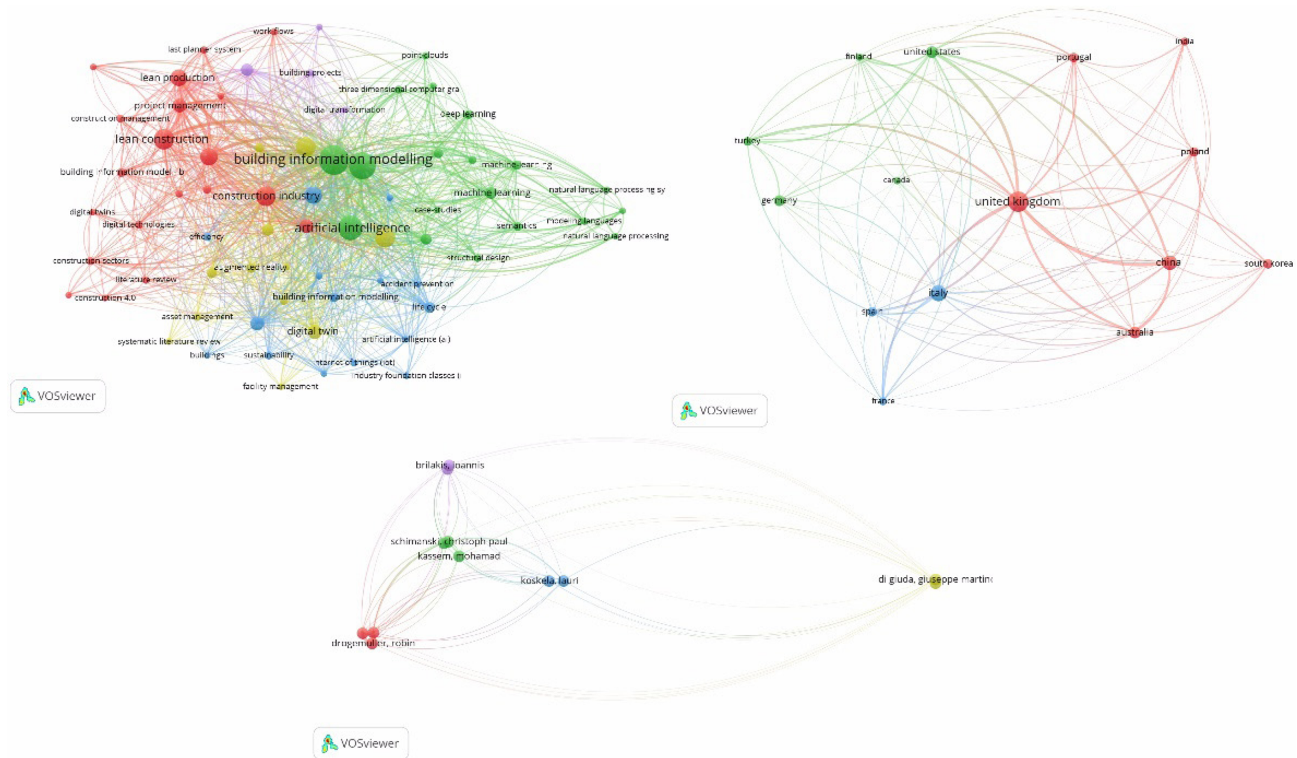

Figure 4. Co-occurrence of Keywords, Countries, and Authors with the Most Published Documents.

Table 3. Publications by Medium and Focus

Journal or conference	**Publication focus**			
	LC+BIM+AI	**LC+BIM**	**LC+AI**	**BIM+AI**
Data Centric Engineering	1			
Developments In the Built Environment	1			
Buildings		9		24
27th Annual Conference of The International Group for Lean Construction IGLC 2019		5		
30th Annual Conference of The International Group for Lean Construction IGLC 2022		5	2	
IGLC 2021 29th Annual Conference of The International Group for Lean Construction Lean Construction in Crisis Times Responding to The Post Pandemic AEC Industry Challenges		5		
Automation In Construction				13
Applied Sciences Switzerland				7
Journal Of Information Technology in Construction				5
IEEE Access				5
Others		31	3	70
Total	2	55	5	124

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Table 4. Prolific Authors by Number and Focus of Publication

Author	Publication focus			
	LC+BIM+AI	LC+BIM	LC+AI	BIM+AI
Matt, D.T.		4		
Schimanski, C.P.		3		
Rashidian, S.		3		
Omrani, S.		3		
Koskela, L.		3		
Drogemuller, R.		3		
Noueihed, K.			2	
Hamzeh, F.			2	
Locatelli, M.				3
Di Giuda, G.M.				3
Brilakis, I.				3
Others	9	169	21	181
Total	9	188	25	190

Table 5. Authors Most Cited by Publication Focus

Authors	Publication	Publication focus			
		LC+BIM+AI	LC+BIM	LC+AI	BIM+AI
Sacks, R., Brilakis, I., Pikas, E., Xie, H.S., Girolami, M.	(21)	346			
Pal, A., Lin, J.J., Hsieh, S.-H., Golparvar-Fard, M.	(22)	19			
Gbadamosi, A.-Q., Mahamadu, A.-M., Oyedele, L.O., ... Mahdjoubi, L., Aigbavboa, C.	(23)		111		
Ratajczak, J., Riedl, M., Matt, D.T.	(24)		87		
Sepasgozar, S.M.E., Hui, F.K.P., Shirowzhan, S., ...Yang, L., Aye, L.	(25)		84		
Meng, X.	(26)		70		
Arroyo, P., Schöttle, A., Christensen, R.	(27)			9	
Cisterna, D., Lauble, S., Haghsheno, S., Wolber, J.	(28)			3	
Boje, C., Guerriero, A., Kubicki, S., Rezgui, Y.	(29)				719
Baduge, S.K., Thilakarathna, S., Perera, J.S., ...Shringi, A., Mendis, P.	(30)				386
Wang, M., Wang, C.C., Sepasgozar, S., Zlatanova, S.	(31)				212
Forcael, E., Ferrari, I., Opazo-Vega, A., Pulido-Arcas, J.A.	(32)				201
Shahzad, M., Shafiq, M.T., Douglas, D., Kassem, M.	(33)				171
Çetin, S., De Wolf, C., Bocken, N.	(34)				168
Sacks, R., Girolami, M., Brilakis, I.	(35)				161

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Authors	Publication	Publication focus			
		LC+BIM+AI	LC+BIM	LC+AI	BIM+AI
You, Z., Feng, L.	(36)				143

Among the most prolific authors, Matt D.T. has the most articles on LC and BIM (q. 4). For LC and AI, the prominent authors are Noueihed, K., and Hamzeh, F. (q. 2 each). Locatelli, M., Di Giuda, G.M., and Brilakis, I. have written the most articles on BIM and AI (q. 3 each). Regarding LC, BIM, and AI, there is no dominant author. Table 4 offers a detailed classification of the most productive authors. Regarding the number of citations in Scopus, Boje C., Guerriero A., Kubicki S., and Rezgui Y. are the most cited authors (719 times) for their articles on BIM and AI. They are followed by Baduge S.K., Thilakarathna S., Perera J.S., Shringi A., and Mendis P. with 386 citations for their articles on the same subject. Table 5 provides a detailed ranking of the most cited authors, and Table 6 presents a list of the eight most cited publications.

Most of the research in this field is empirical, encompassing case studies, interviews, pilot implementations, and surveys (q. 58). In the field of LC, BIM, and AI, the predominant research method is the presentation of prototypes or models (q. 2). For publications focusing on LC and BIM, the most popular approach is literature review (q. 17), followed by the presentation of prototypes or models (q. 13) and case studies (q. 11). For articles on LC and AI, literature review is the preferred method (q. 4). For BIM and AI, the most common method is also literature review (q. 48), followed by the presentation of prototypes or models (q. 38). Figure 5 shows a detailed classification of publications according to research methods and preferred approaches in this field.

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Table 6. Most Cited Publications

Focus	Publication	Authors	Year	Contributions	Quotations
LC + BIM + AI	Construction with Digital Twin Information Systems	Sacks, R., Brilakis, I., Pikas, E., Xie, H.S., Girolami, M. (21)	2020	The adoption of Lean Construction (LC) improves efficiency and reduces waste in construction projects. Building Information Modeling (BIM) optimizes planning and coordination, reducing errors. Artificial Intelligence (AI) uses algorithms and data analysis to enhance decision-making and automate processes. These methodologies combined transform the construction industry, making it more efficient and precise.	346
	Automated Construction Progress Monitoring Based on Vision in a Built Environment through a Digital Twin	Pal, A., Lin, J.J., Hsieh, S.-H., Golparvar-Fard, M. (22)	2023	LC seeks smooth production flows and minimizes resource waste. BIM uses technology and workflows for the digital modeling of construction products and processes. AI employs advanced monitoring technologies and intelligent functions to analyze and optimize ongoing design, planning, and production.	19
LC + BIM	Off-Site Construction: Development of a BIM-Based Optimizer for Assembly	Gbadamosi, A.-Q., Mahamadu, A.-M., Oyedele, L.O., ... Mahdjoubi, L., Aigbavboa, C. (23)	2019	The integration of Design for Manufacture and Assembly (DFMA) with LC and BIM allows the evaluation and optimization of design through production metrics. This system considers factors such as ease and speed of assembly, handling, and waste generated during construction.	111
	BIM and AR-Based Application Combined with Location-Based Management System to Improve Construction Performance	Ratajczak, J., Riedl, M., Matt, D.T. (24)	2019	The AR4C application offers a unique tool that detects schedule deviations by visualizing construction progress in augmented reality (AR), providing daily progress and performance data, as well as specific information on scheduled tasks.	87

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Focus	Publication	Authors	Year	Contributions	Quotations
LC + AI	The Ethical and Social Dilemma of AI Uses in the Construction Industry	Arroyo, P., Schöttle, A., Christensen, R. (27)	2021	The adoption of LC has improved efficiency, reduced time and costs, and increased quality and customer satisfaction. AI in construction is used to automate tasks, perform predictive analysis, optimize designs, and manage risks. Studies highlight AI's potential to enhance decision-making and efficiency, though ethical and social concerns are also noted.	9
	Synergies between Lean Construction and Artificial Intelligence: AI-Driven Continuous Improvement Process	Cisterna, D., Lauble, S., Haghsheno, S., Wolber, J. (28)	2022	Combining LC and AI offers superior added value, integrating structured LC data to train AI models and leveraging AI to optimize LC techniques with predictions and automations. People are key to sustaining continuous improvement, but challenges like trust in models and data quality must be overcome.	3
BIM + AI	Towards a Semantic Digital Twin of Construction: Directions for Future Research	Boje, C., Guerriero, A., Kubicki, S., Rezgui, Y. (29)	2020	BIM offers procedures, technologies, and data schemes for a standardized representation of construction components and systems. AI is used for data analysis, machine learning, and systems optimization. By combining BIM and AI, more comprehensive and accurate digital models reflecting physical assets in real-time are created.	719
	Artificial Intelligence and Smart Vision for Construction 4.0: Machine Learning and Deep Learning Methods and Applications	Baduge, S.K., Thilakarathna, S., Perera, J.S., ...Shringi, A., Mendis, P. (30)	2022	BIM integrates and manages data throughout a project's lifecycle, from planning to operation. AI, including Machine Learning (ML) and Deep Learning (DL), enables machines to learn from data and perform complex tasks.	386

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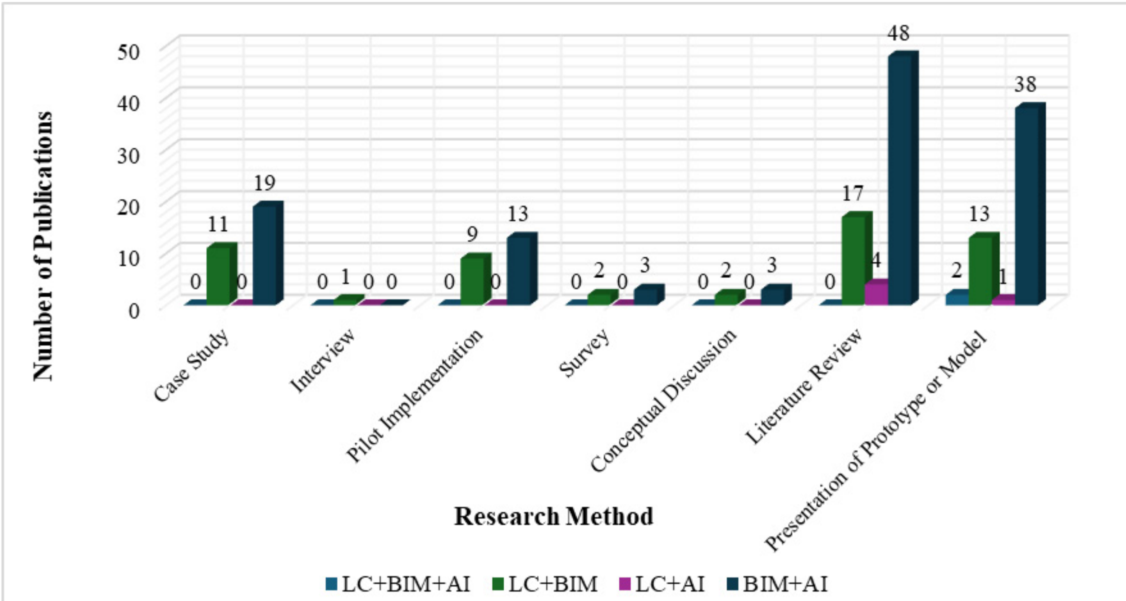

Figure 5. Classification of Publications by Research Methods and Focus.

Table 7. Publications by Focus and Content

Focus or content of the publication	No. of Pub.	Examples from the Literature
LC+BIM+AI	2	
Project Management	1	Pal, A., Lin, J.J., Hsieh, S.-H., Golparvar-Fard, M. (2023) (22)
Workflow	1	Sacks, R., Brilakis, I., Pikas, E., Xie, H.S., Girolami, M. (2020) (21)
LC+BIM	55	
Production planning and control	4	Haronian, E., Sacks, R. (2020) (37)
Digital construction	3	Ratajczak, J., Riedl, M., Matt, D.T. (2019) (24)
workflow	2	Schimanski, C.P., Monizza, G.P., Matt, D.T. (2021) (38)
Off-site construction	2	Marte Gómez, J.A., Daniel, E.I., Fang, Y., Oloke, D., Gyoh, L. (2021) (39)
Digital divices	2	Chen, C., Tang, L.C.M., Jin, Y. (2019) (40)
Project management	8	Peltokorpi, A., Seppänen, O. (2022) (41)
Lean Construction	19	Arayici, Y., Tokdemir, O.B., Kassem, M. (2023) (42)
BIM	15	Ybañez, R.S., De La Cruz, A.R. (2023) (43)
LC+AI	5	

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Focus or content of the publication	No. of Pub.	Examples from the Literature
Lean Production	3	Cisterna, D., Lauble, S., Haghsheno, S., Wolber, J. (2022) (28)
Decision making	2	Arroyo, P., Schöttle, A., Christensen, R. (2021) (27)
BIM+AI	124	
Architectural design	36	Abouelaziz, I., Jouane, Y. (2024) (44)
Information theory	19	Jang, S., Lee, G. (2024) (45)
Artificial intelligence	25	Wu, B., Maalek, R. (2023) (46)
Digital twin	13	Rafsanjani, H.N., Nabizadeh, A.H. (2023) (47)
Automation	9	Soman, R.K., Whyte, J.K. (2020) (48)
Mahcine learning	11	Erişen, S. (2023) (49)
Virtual reality	11	Sampaio, A.Z. (2019) (50)
Total	186	

Analysis of the articles revealed several content clusters in the publications focused on the construction industry (Table 7). In the LC, BIM, and AI focus, there is a total of one publication focused on project management and workflow, addressing the optimization of processes in construction. Regarding LC and BIM, the group with the most publications (q. 19) deals with the application of LC, followed by articles on BIM processes and factors (q. 15). Project management that implements LC and BIM is also prominent (q. 8). For LC and AI, Lean production and decision-making have respectively (q. 3) and (q. 2) publications, describing the application of LC techniques in construction with AI for decision-making. In the articles on BIM and AI, the group with the most publications (q. 36) is that of architectural design, showing how BIM facilitates the application of AI in construction. This is followed by publications that highlight the importance of AI in the construction sector (q. 25).

This systematic review has made a significant contribution to the field of construction project management through the implementation of LC, BIM, and AI. The research provides a comprehensive overview and detailed analysis of how combining these technologies and methodologies can improve operational efficiency, decision-making, collaboration, and sustainability in construction projects.

LC+BIM+AI

The systematic review demonstrates that integrating LC, BIM, and AI represents a significant advance in construction project management. This integration allows progress to be monitored and reported in real time, thanks to data collection and analysis (22). This method has evolved due to technological advances and the need for greater efficiency and precision in project monitoring. The synergy between LC, BIM, and AI optimizes design and construction processes, improving efficiency and reducing waste throughout the project life cycle.

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The combination of LC, BIM, and AI facilitates the early identification of problems and the implementation of efficient solutions. Digital tools automate construction progress monitoring, offering precise methods for supervising projects and addressing concerns (22). AI algorithms in BIM models detect conflicts and optimize work routes, enabling corrective measures (22) and optimizing resource use. The ability of AI to analyze large volumes of data and generate valuable insights complements LC practices and BIM's visual capabilities, resulting in more informed and accurate decisions backed by real-time data and predictive simulations, ultimately enhancing project planning and execution (21).

The implementation of LC fosters a culture of continuous improvement, which, when combined with BIM and AI, is further strengthened by data analysis and constant feedback. Lessons learned are quickly integrated into future projects, optimizing processes and results. This collaboration requires the participation of designers, consultants, contractors, suppliers, and public bodies. The completed projects allow existing information to be utilized and facilitate learning to improve the planning, estimation, and management of future projects (21).

LC+BIM

The combination of LC and BIM improves efficiency and reduces costs in construction projects. Numerous studies confirm that their integration increases productivity and reduces losses (51). BIM facilitates collaboration between teams and disciplines, while LC focuses on eliminating waste and improving processes. The importance of collaborative environments and open communication in BIM improves coordination and reduces errors, resulting in more coherent and better-executed projects (52).

Lean methodology enhances planning and scheduling accuracy by eliminating non-value-adding activities, seeking to maximize production (53). BIM allows for the visual assessment of the impact of design changes, which is complex with traditional 2D plans. Modeling and animating construction sequences in BIM 4D offer a unique visualization of processes and progress, identify resource conflicts, resolve constructability issues, optimize the process, and improve efficiency and safety (20). BIM's ability to visualize and simulate different scenarios complements detailed LC planning, allowing for quick and accurate adjustments to project changes.

The integration of LC and BIM enables more rigorous quality control by identifying potential problems early and applying preventive solutions. The fundamental principle of Lean is to reduce or eliminate waste, and BIM addresses these aspects in both the design and construction phases. With design development, teams can make decisions to avoid waste accumulation on-site. Traditional reviews of the construction process without BIM are time-consuming and costly (54). This integration significantly reduces waste and ensures more efficient use of resources.

The integration of LC with BIM technology is a key strategy for optimizing processes in construction projects. This synergy makes it possible to certify order in production, achieve adequate coordination of resources in each phase of the project, and significantly reduce waste, both in time and resources. Adopting this approach ensures that the final product meets the client's expectations and needs while maximizing the return for investors by minimizing waste and increasing operational efficiency (55). This combination transforms project management, aligning productivity with sustainability and customer satisfaction.

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Integrating BIM and LC methodologies in construction projects is essential to avoid schedule delays. BIM facilitates more efficient project management, improving design and engineering analysis, while Lean focuses on reducing waste and fostering collaboration among team members. By applying these methodologies, the factors that negatively impact construction are minimized, processes are optimized, and efficiency and profitability in residential projects are increased (56). Adopting these innovative methodologies represents a paradigm shift in the construction industry, positioning the companies implementing them at the forefront of competitiveness and sustainability.

LC+AI

Integrating LC with AI offers an innovative approach to optimizing the management of construction projects. Various AI algorithms are used to optimize design and projects (27). AI complements LC practices focused on efficiency and waste reduction by analyzing large volumes of data and generating recommendations based on patterns and trends. In construction, AI offers benefits such as supporting better decisions, optimizing schedules, and reducing environmental impact (27).

AI automates routine processes and optimizes workflows, aligning with the principles of Lean to eliminate activities that do not add value. Synergies include fail-safe quality, the 5S methodology, increased visualization and huddle meetings (28), improving product quality, promoting a culture of cleanliness and organization, facilitating decision-making, and enhancing communication and the effectiveness of meetings. Additionally, real-time data analysis with AI can identify bottlenecks and propose solutions to improve operational efficiency.

In the Last Planner® System (LPS), AI can quickly simulate multiple scenarios to assist in project planning, learn from historical data on common problems, and issue early alerts. It also uses information from previous projects to pass on knowledge and best practices, preventing the loss of information (28).

AI-driven predictive analytics make it possible to anticipate problems before they occur, which is crucial for improving LC, including predictive maintenance of equipment and machinery, reducing downtime, and enhancing resource availability. Continuous improvement is essential for performance in construction projects, and LC strengthens its position in the sector by focusing on resource optimization (57).

AI optimizes resource allocation by analyzing historical data and current conditions, improving the planning and use of materials and labor. In Takt planning and control, AI can estimate workload values and cadences based on historical data and environmental parameters, harmonizing the work cycles of machines and humans (28). Thus, AI and LC allow the definition of processes and work packages, automatically optimized zone sequences, and the actual duration of the project, resulting in optimal planning, cost reduction, and increased efficiency.

The transition to digitalization offers multiple benefits, including increased productivity, safety, and quality. These technologies empower professionals and strengthen organizations, driving them toward success when adequately implemented. However, irresponsible use or disruptive implementation can have adverse effects, leaving permanent consequences that could further damage the industry (58). Therefore, adopting a conscious and strategic approach to implementing digital technologies is essential, ensuring that they are integrated harmoniously with existing processes and that their adoption is supported by adequate training.

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Only in this way will it be possible to maximize their potential, mitigating risks and promoting sustainable development that benefits both organizations and the industry.

BIM+AI

The combination of BIM and AI offers a powerful approach to digitizing and optimizing construction projects. BIM enables collaborative decision-making and provides a unified platform for architects, engineers, and construction professionals to integrate and share project data, improving productivity, quality, and safety. AI, which has emerged in the last decade as a powerful tool, automates techniques and procedures in conventional construction processes (59), offering significant benefits in terms of accuracy, efficiency, and responsiveness. Predictive modeling and simulation can anticipate trends and evaluate possible outcomes in construction projects (60). BIM's ability to create accurate digital representations is enhanced by AI, which analyzes these models to detect problems and optimize designs, enabling advanced simulations that improve decision-making.

AI offers advanced data analysis capabilities that extract valuable information from BIM models. The growing use of AI techniques demonstrates high accuracy and the ability of AI models to learn, predict, and detect risk levels in real-time. Virtual and augmented reality provide fidelity, immersion, interaction, and visualization in facility management (61). This includes predicting construction times, costs, and potential problems, helping project teams make more informed decisions and mitigate risks.

The integration of BIM with AI in construction project management represents significant progress (62). The combination of AI with BIM allows real-time monitoring of construction projects through sensors and IoT devices that continuously collect data. Predictive analytics uses data, statistical algorithms, and machine learning techniques to predict future outcomes based on historical data. In the construction sector, capturing real-time data and converting it into useful information for forecasting has become revolutionary (63). This data is analyzed with AI algorithms to offer up-to-date information and instant recommendations, improving responsiveness and operational efficiency.

The synergy between technologies such as AI and BIM is revolutionizing architectural design and fostering interdisciplinary collaboration. Architects, engineers, and environmental scientists converge on common digital platforms to optimize each project stage, from conception to execution. This technological alliance reduces the environmental impact of buildings and drives innovation and efficiency, positioning different professionals as leaders in constructing a more sustainable and resilient urban environment (64). Thanks to this technological synergy, end users benefit from healthier, more energy-efficient spaces tailored to their needs.

Over the last decade, the construction industry has significantly transformed by adopting new technologies and methodologies. Specifically, Lean Construction (LC), BIM, and AI have become crucial tools for improving efficiency, reducing costs, and increasing quality in construction projects. Figure 6 summarizes the systematic review of LC, BIM, and AI adoption in construction. Figure

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7, Figure 8, Figure 9, Figure 10 y Figure 11, compile essential tools, techniques, and strategies, analyze the characteristics of projects that have implemented these methodologies, and establish the most relevant cross-cutting characteristics. Adopting LC, BIM, and AI has been crucial for modernizing and improving construction processes. This document provides a solid basis for understanding the effective implementation of these methodologies in various projects, enhancing the competitiveness of companies in the sector and contributing to sustainable development and innovation in construction.

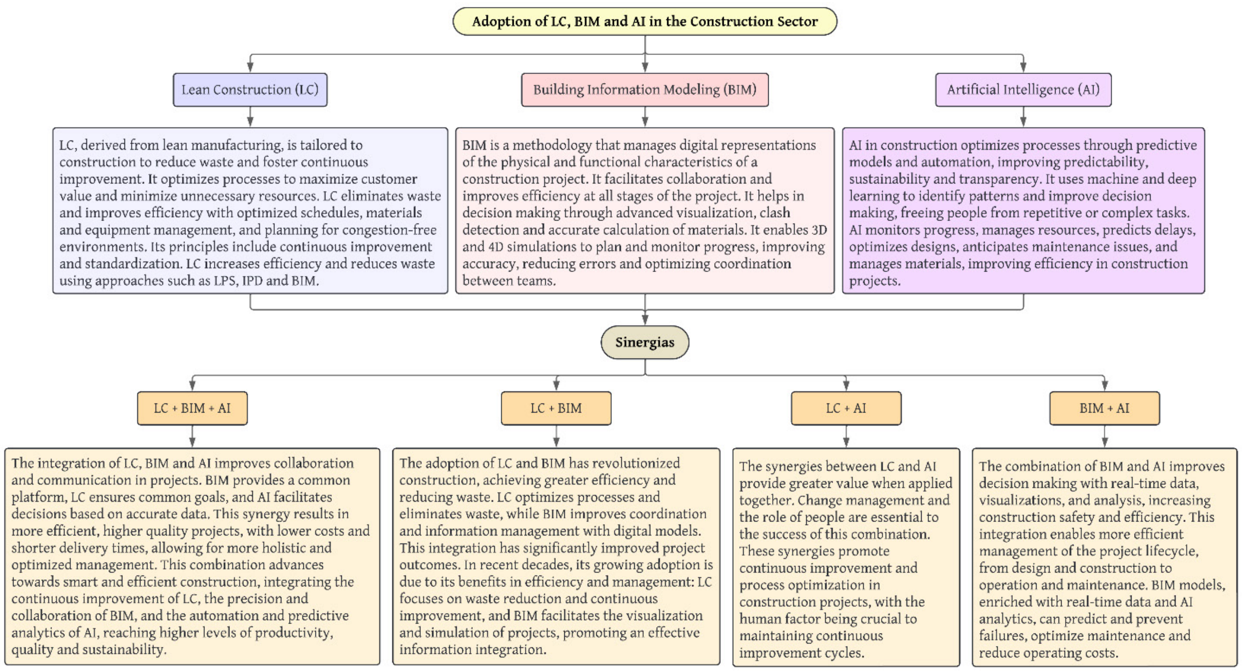

Figure 6. Adoption of LC, BIM and AI in the Construction Sector.

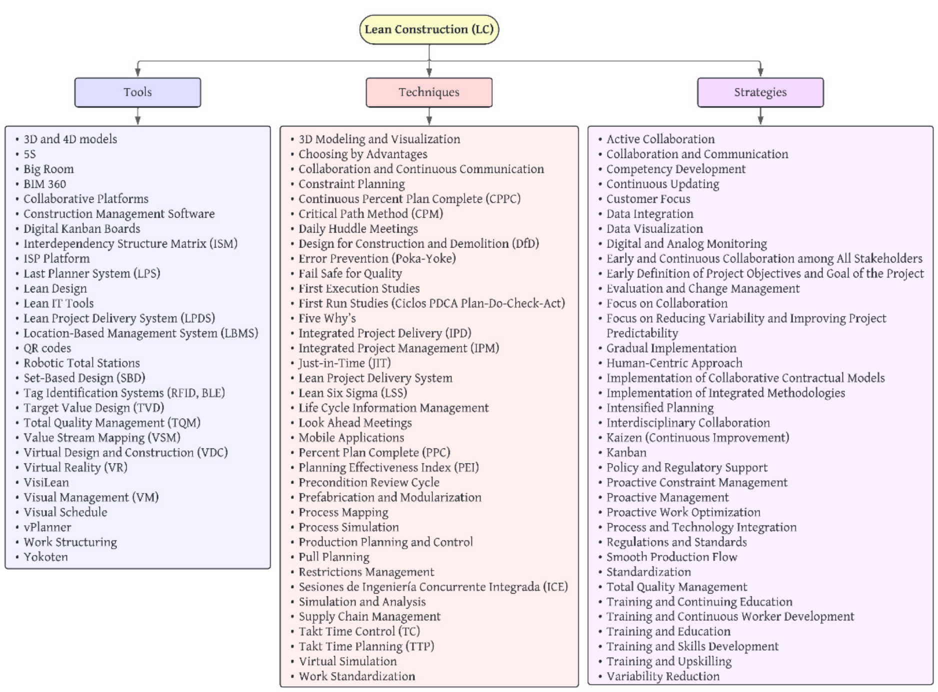

Figure 7. Tools, Techniques and Strategies Implemented with LC.

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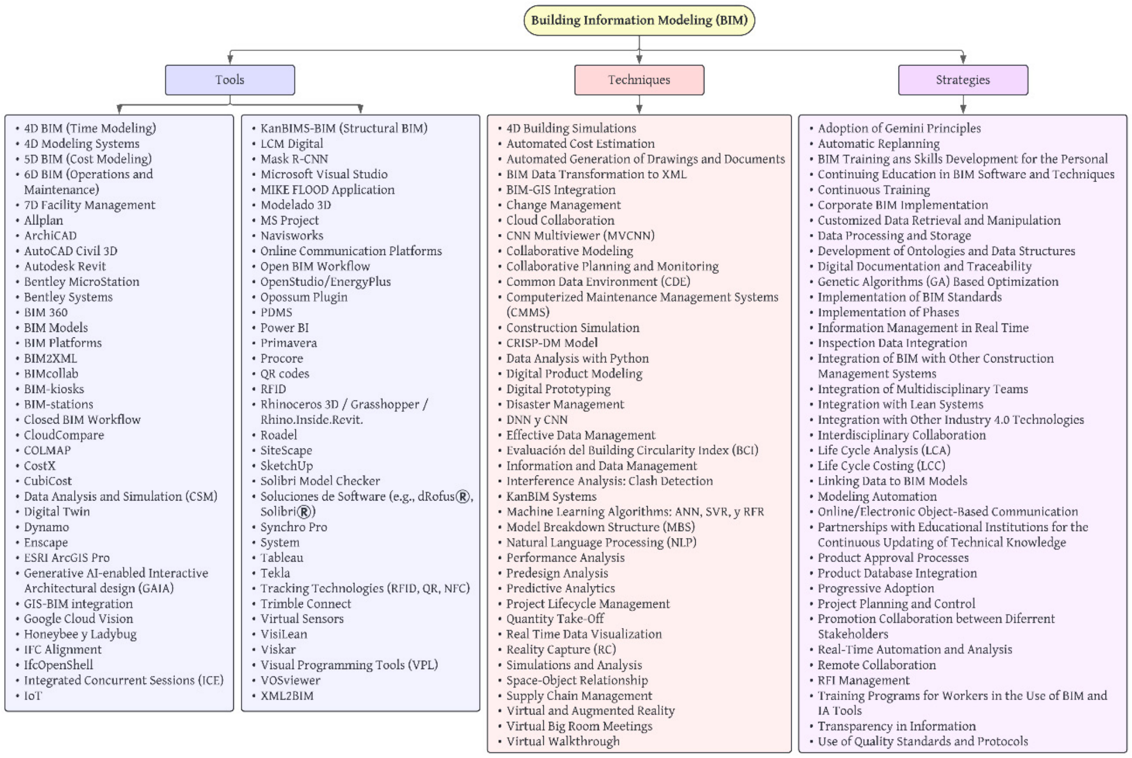

Figure 8. Tools, Techniques and Strategies Implemented with BIM.

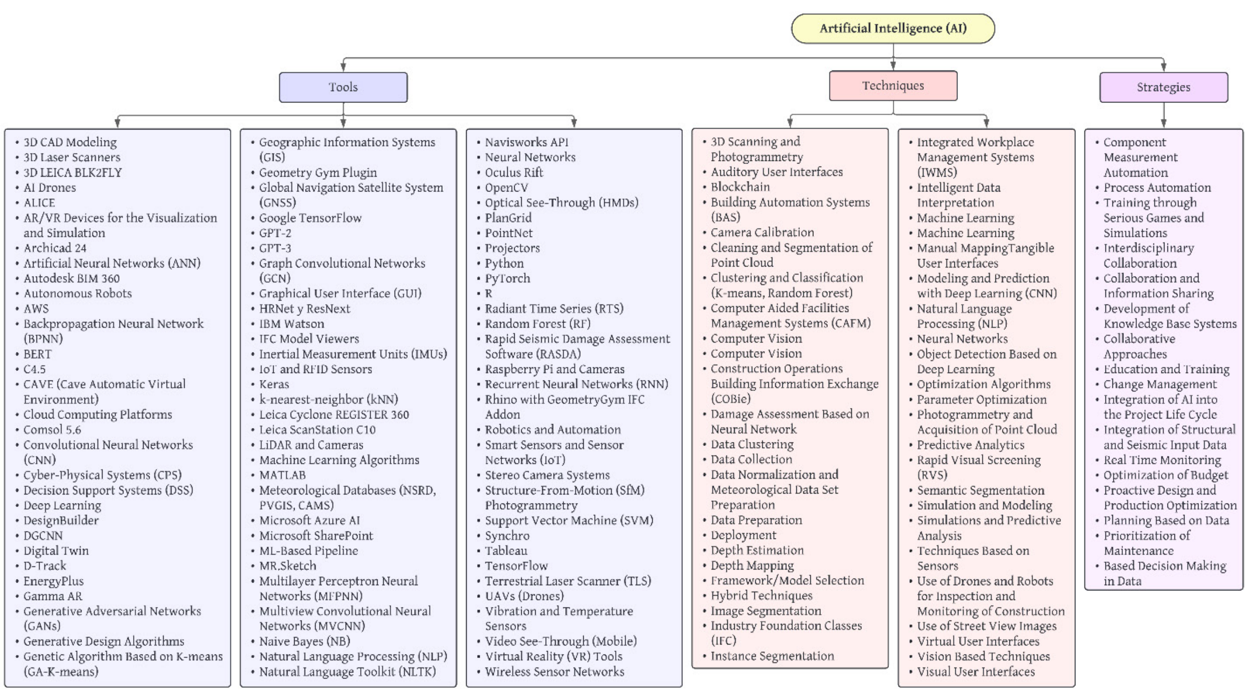

Figure 9. Tools, Techniques and Strategies Implemented with AI.

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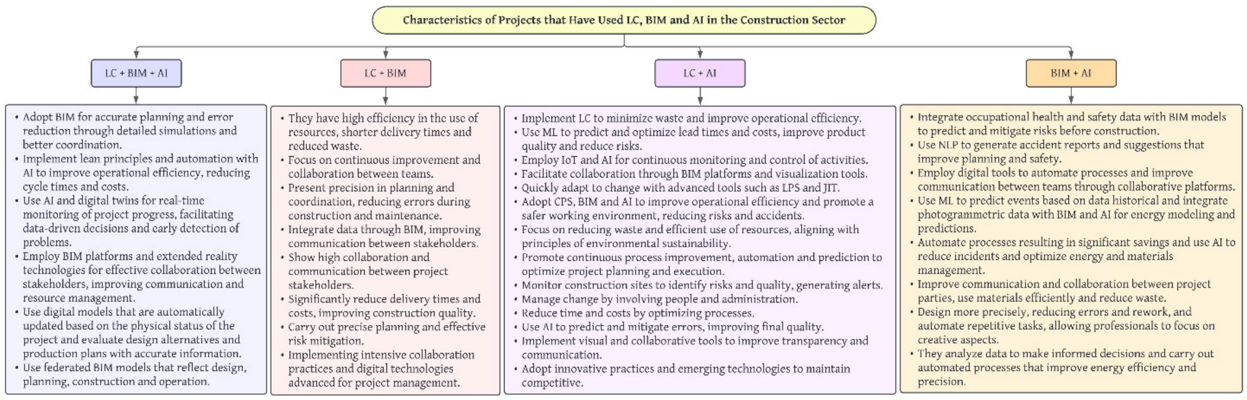

Figure 10. Characteristics of Projects that Have Used LC, BIM and AI in the Construction Sector.

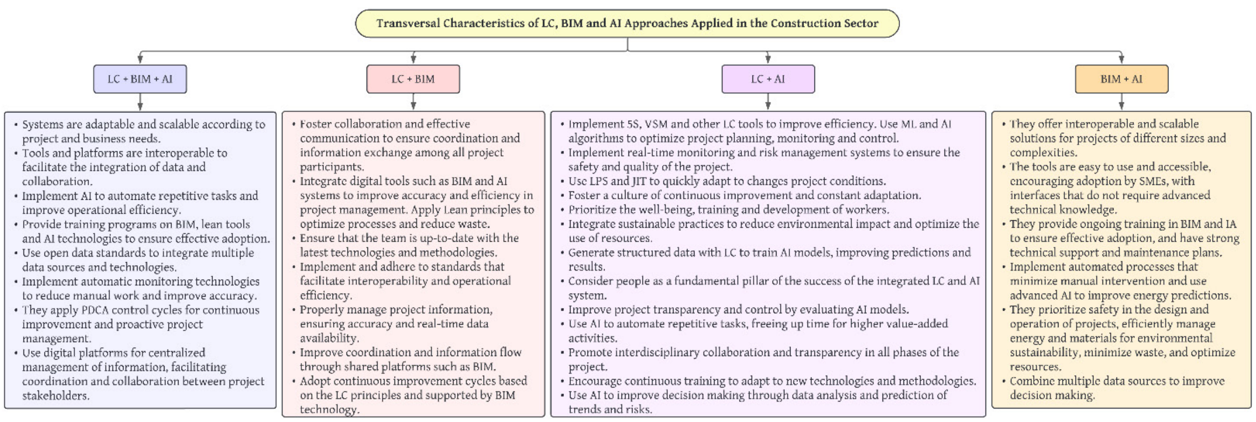

Figure 11. Transversal Characteristics of LC, BIM and AI Approaches Applied in the Construction Sector.

Conclusions

Integrating Lean Construction (LC), Building Information Modeling (BIM), and Artificial Intelligence (AI) in construction project management marks a significant evolution in the industry. Through a systematic review of 186 documents, this research demonstrates that combining these approaches can provide benefits that exceed individual advantages, optimizing operational efficiency and reducing waste. LC eliminates activities that do not add value, BIM facilitates the visualization and coordination of projects, and AI analyzes large volumes of data and automates processes for more efficient execution.

The combination of BIM and AI provides powerful tools for informed decision-making. BIM visualizes all aspects of the project, while AI analyzes this data to identify patterns, predict problems, and suggest solutions. This allows project managers to make decisions based on concrete data and accurate simulations, improving quality and results.

LC and BIM improve coordination and collaboration between teams and disciplines involved in a project. BIM acts as a common language, uniting the project's stakeholders, while the principles of LC promote agile

doi: 10.25100/iyc.v27i1.14401

and efficient work. The incorporation of AI reinforces this collaboration by automating communication and providing real-time information for collaborative decision-making.

Implementing LC, BIM, and AI fosters a culture of innovation and continuous improvement in construction. LC establishes a solid basis for constantly improving processes. BIM offers a platform to implement these improvements visually and practically, and AI adds intelligence that allows automatic learning and continuous adaptation. This integration contributes significantly to the sustainability and efficient management of resources in construction projects, reducing costs and minimizing environmental impact, which is crucial to complying with environmental and social responsibility standards.

The theoretical evidence and case studies reviewed show that integrating LC, BIM, and AI improves the efficiency, quality, and sustainability of construction projects. The convergence of LC, BIM, and AI represents the future of construction project management, offering a holistic and efficient approach that enhances all aspects of the project life cycle. Adopting these technologies is not only a competitive advantage but a necessity to address current and future challenges in the industry.

Future research that delves deeper into the integration and application of LC, BIM, and AI is highly recommended. This research will not only allow the findings obtained in this theoretical research to be empirically validated but will also provide a solid basis for evaluating its impact on improving construction processes. Additionally, it will help identify specific opportunities to optimize efficiency, reduce waste, and promote data-based decision-making in professional practice.

CRediT authorship contribution statement

Conceptualization - Ideas: Gisselle-Natalia Gómez-Rodríguez. Formal analysis: Gisselle-Natalia Gómez-Rodríguez. Investigation: Gisselle-Natalia Gómez-Rodríguez. Methodology: Gisselle-Natalia Gómez-Rodríguez. Project Management: Gisselle-Natalia Gómez-Rodríguez Andrés-Felipe Álvarez-Sanabria Jorge-Andrés Sarmiento-Rojas. Resources: Gisselle-Natalia Gómez-Rodríguez. Supervision: Gisselle-Natalia Gómez-Rodríguez, Andrés-Felipe Álvarez-Sanabria, Jorge-Andrés Sarmiento-Rojas. Validation: Gisselle-Natalia Gómez-Rodríguez, Andrés-Felipe Álvarez-Sanabria, Jorge-Andrés Sarmiento-Rojas. Visualization - Preparation: Gisselle-Natalia Gómez-Rodríguez, Andrés-Felipe Álvarez-Sanabria, Jorge-Andrés Sarmiento-Rojas. Writing - original draft - Preparation: Gisselle-Natalia Gómez-Rodríguez, Andrés-Felipe Álvarez-Sanabria, Jorge-Andrés Sarmiento-Rojas. Writing - revision and editing - Preparation: Gisselle-Natalia Gómez-Rodríguez, Andrés-Felipe Álvarez-Sanabria, Jorge-Andrés Sarmiento-Rojas.

Financing: not applicable
Conflicts of interest: the authors declare that they have no competing interests.
Ethical implications: not applicable.

doi: 10.25100/iyc.v27i1.14401

References

1. Lara-García AM, Nieto-Vargas JA. Sinergias y Aplicación de las Metodologías y Principios de Lean Construction, BIM y Construcción Sostenible, para la Mejora y Progreso de la Industria de la Construcción [Internet]. [Bogotá D.C.]: Universidad Católica de Colombia; 2021 [cited 2023 Aug 14]. Available from: https://hdl.handle.net/10983/26938

2. Latorre Uriz A, Sanz C, Sánchez B. Aplicación de un Modelo Lean-BIM para la Mejora de la Productividad en Redacción de Proyectos de Edificación. Informes de la Construcción [Internet]. 2019 Dec 30 [cited 2024 Jun 19];71(556):1-9. https://doi.org/10.3989/ic.67222

3. Borda Zambrano MA. Interacción Lean-BIM para el Diseño de Metodología de Gestión de Proy-ectos de Construcción en Etapa de Planificación y Ejecución. Gerencia Integral de Proyectos [In-ternet]. 2022 Nov 5 [cited 2023 Aug 14];1-22. Available from: https://repository.umng.edu.co/server/api/core/bitstreams/5fe8e658-67ba-42d3-b5a2-69e885580be0/content

4. Morán Muñoz V de D, Pinilla Díaz L. Sistema de Gestión Bim - Lean: Efectos de su Aplicación en el Desarrollo de Proyectos de Construcción Civil [Internet]. [Cartagena de Indias, D. T. y C.]: Universidad de Cartagena; 2022 [cited 2023 Aug 14]. Available from: https://hdl.handle.net/11227/15529

5. Mendoza JG, Quispe MB, Muñoz SP. Una Revisión Sobre el Rol de la Inteligencia Artificial en la Industria de la Construcción. Ingeniería y Competitividad [Internet]. 2022 Jan 28 [cited 2024 Jun 19];24:1-23. https://doi.org/10.25100/iyc.v0i00.11727

6. Sarmiento Rojas JA, Hernández Carrillo CG, Rueda Varón MJ. Factores de Permanencia Empre-sarial del Sector de la Construcción en Colombia [Internet]. 1st ed. Editorial UPTC, editor. Fac-tores de permanencia empresarial del sector de la construcción en Colombia. Tunja: Editorial UPTC; 2022 [cited 2024 Dec 28]. 1-398 p. https://doi.org/10.19053/9789586607117

7. Romano FG. Viabilidad del Despliegue de la Filosofía Lean Construction a Pie de Obra Mediante su Digitalización a Través de una BIM-Station [Internet]. [Barcelona]: Universidad Politécnica de Cataluña UPC; 2023 [cited 2023 Aug 14]. Available from: http://hdl.handle.net/2117/384728

8. Rusch Reichhard J. GrupoTusMaquinas. 2023 [cited 2024 Jun 19]. Transformación Digital en la Logística del Sector Construcción. Available from: https://blog.grupotusmaquinas.com/transformacion-digital-en-la-logistica-del-sector-construccion/

9. Ayerra Linares M. Integrated Project Delivery, Modelo de Gestión en la Edificación. Claves para la Implantación y el Desarrollo de los Procesos Colaborativos en el Sector de la Construcción en España [Internet]. [Madrid]: Universidad Politécnica de Madrid; 2021 [cited 2023 Sep 16]. Avail-able from: https://oa.upm.es/66828/

10. Campos Carballo C. Metaverso y BIM: Entornos Virtuales [Internet]. [Madrid]: Universidad Politécnica de Madrid; 2023 [cited 2023 Aug 14]. Available from: https://oa.upm.es/id/eprint/72658

11. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. Declaración PRISMA 2020: Una Guía Actualizada para la Publicación de Revisiones Sistemáticas. Rev Esp Cardiol [Internet]. 2021 May 21 [cited 2024 Jun 19];74(9):790-9. https://doi.org/10.1016/j.recesp.2021.06.016

12. Zabalza Navarro V, González Torres A. Estudio del Proceso Indagatorio Inherente A Una Revi-sión Sistemática Documental Prisma 2020 Con Empleo De Metaanálisis. RIDE Revista Iberoamericana para la Investigación y el Desarrollo Educativo [Internet]. 2024 May 9 [cited 2024 Nov 16];14(28):1-24. https://doi.org/10.23913/ride.v14i28.1904

13. Universidad de Navarra. Revisiones Sistemáticas: PRISMA 2020: Guías Oficiales Para Informar (Redactar) Una Revisión Sistemática [Internet]. 2024 [cited 2024 Nov 16]. Available from: https://biblioguias.unav.edu/revisionessistematicas/guias_oficiales

doi: 10.25100/iyc.v27i1.14401

14. Universidad Distrital Francisco José de Caldas. Biblioteca Digital - Recursos Electrónicos. 2023 [cited 2024 Apr 27]. Fuentes de Información Confiables - Available from: https://bibliotecas.udistrital.edu.co/ud/bdigital2/subjects/guide.php?subject=fuentes_informacion

15. Codina L. Scopus: El Mejor Navegador Científico de la Web. El Profesional de la Información [Internet]. 2005 Feb [cited 2024 Jun 19];14(1):44-9. https://doi.org/10.3145/epi.2005.feb.07

16. Arbeláez Gómez MC, Onrubia Goñi J. Análisis Bibliométrico y de Contenido. Dos Metodologías Complementarias para el Análisis de la Revista Colombiana Educación y Cultura. Revista de In-vestigaciones [Internet]. 2016 Aug 23 [cited 2024 Jul 5];14(23):14-31. https://doi.org/10.22383/ri.v14i1.5

17. Tezel A, Taggart M, Koskela L, Tzortzopoulos P, Hanahoe J, Kelly M. Lean Construction and BIM in Small and Medium-Sized Enterprises (SMEs) in Construction: A Systematic Literature Review. Canadian Journal of Civil Engineering [Internet]. 2020 Mar 27 [cited 2024 Jul 6];47(2):186-201. https://doi.org/10.1139/cjce-2018-0408

18. Petticrew M. Systematic Reviews from Astronomy to Zoology: Myths and Misconceptions. Br Med J [Internet]. 2001 Jan 13 [cited 2024 Mar 17];322(7278):98-101. https://doi.org/10.1136/bmj.322.7278.98

19. Cochrane. Sobre las revisiones Cochrane. 2020 [cited 2024 Mar 17]. ¿Qué es una revisión sis-temática? Available from: https://www.cochranelibrary.com/es/about/about-cochrane-reviews

20. Rashidian S, Drogemuller R, Omrani S. Building Information Modelling, Integrated Project De-livery, and Lean Construction Maturity At-tributes: A Delphi Study. Buildings [Internet]. 2023 Jan 18 [cited 2024 May 30];13(2):1.https://doi.org/10.3390/buildings13020281

21. Sacks R, Brilakis I, Pikas E, Xie HS, Girolami M. Construction With Digital Twin Information Systems. Data-Centric Engineering [Internet]. 2020 Nov 27 [cited 2024 May 30];1(e14):1-26. Available from: https://www.cambridge.org/core/journals/data-centric-engineering/article/construction-with-digital-twin-information-systems/C88A0AE68BBA09517D7534B9DBE24FEF

22. Pal A, Lin JJ, Hsieh SH, Golparvar-Fard M. Automated Vision-Based Construction Progress Monitoring in Built Environment Through Digital Twin. Developments in the Built Environ-ment [Internet]. 2023 Dec 1 [cited 2024 May 30];16:1. https://doi.org/10.1016/j.dibe.2023.100247

23. Gbadamosi AQ, Mahamadu AM, Oyedele LO, Akinade OO, Manu P, Mahdjoubi L, et al. Offsite Construction: Developing a BIM-Based Optimizer for Assembly. J Clean Prod [Internet]. 2019 Apr 1 [cited 2024 Dec 27];215:1180-90. https://doi.org/10.1016/j.jclepro.2019.01.113

24. Ratajczak J, Riedl M, Matt DT. BIM-based and AR Application Combined with Location-Based Management System for the Improvement of the Construction Performance. Buildings [Inter-net]. 2019 May 9 [cited 2024 Dec 28];9(5):1-17. https://doi.org/10.3390/buildings9050118

25. Sepasgozar SME, Hui FKP, Shirowzhan S, Foroozanfar M, Yang L, Aye L. Lean Practices Using Building Information Modeling (BIM) and Digital Twinning for Sustainable Construction. Sus-tainability (Switzerland) [Internet]. 2020 Dec 25 [cited 2024 Dec 28];13(1):1-22. https://doi.org/10.3390/su13010161

26. Meng X. Lean Management in the Context of Construction Supply Chains. Int J Prod Res [In-ternet]. 2019 Jun 16 [cited 2024 Dec 28];57(11):3784-98. https://doi.org/10.1080/00207543.2019.1566659

27. Arroyo P, Schöttle A, Christensen R. The Ethical and Social Dilemma of AI Uses in the Con-struction Industry. In: 29th Annual Conference of the International Group for Lean Construction (IGLC) [Internet]. Lima: Department of Engineering, Civil Engineering Division, Pontificia Uni-versidad Catolica del Peru; 2021 [cited 2024 May 30]. p. 227-36. https://doi.org/10.24928/2021/0188

doi: 10.25100/iyc.v27i1.14401

28. Cisterna D, Lauble S, Haghsheno S, Wolber J. Synergies Between Lean Construction and Artifi-cial Intelligence AI Driven Continuous Improvement Process. In: 30th Annual Conference of the International Group for Lean Construction (IGLC) [Internet]. Alemania: Department of Engi-neering, Civil Engineering Division, Pontificia Universidad Catolica del Peru; 2022 [cited 2024 May 30]. p. 199-210. https://doi.org/10.24928/2022/0122

29. Boje C, Guerriero A, Kubicki S, Rezgui Y. Towards a semantic Construction Digital Twin: Direc-tions for future research. Autom Constr [Internet]. 2020 Jun 1 [cited 2024 Dec 28];114:1-16. Available from: https://www.sciencedirect.com/science/article/pii/S0926580519314785?via%3Dihub

30. Baduge SK, Thilakarathna S, Perera JS, Arashpour M, Sharafi P, Teodosio B, et al. Artificial In-telligence and Smart Vision for Building and Construction 4.0: Machine and Deep Learning Methods and Applications. Autom Constr [Internet]. 2022 Sep 1 [cited 2024 Dec 27];141:1-26. https://doi.org/10.1016/j.autcon.2022.104440

31. Wang M, Wang CC, Sepasgozar S, Zlatanova S. A Systematic Review of Digital Technology Adoption in Off-Site Construction: Current Status and Future Direction Towards Industry 4.0. Buildings [Internet]. 2020 Nov 13 [cited 2024 Dec 28];10(11):1-29. https://doi.org/10.3390/buildings10110204

32. Forcael E, Ferrari I, Opazo-Vega A, Pulido-Arcas JA. Construction 4.0: A Literature Review. Sustainability (Switzerland) [Internet]. 2020 Nov 23 [cited 2024 Dec 28];12(22):1-28. https://doi.org/10.3390/su12229755

33. Shahzad M, Shafiq MT, Douglas D, Kassem M. Digital Twins in Built Environments: An Inves-tigation of the Characteristics, Applications, and Challenges. Buildings [Internet]. 2022 Jan 25 [cited 2024 Dec 27];12(2):1-19. https://doi.org/10.3390/buildings12020120

34. Çetin S, De Wolf C, Bocken N. Circular Digital Built Environment: An Emerging Framework. Sustainability (Switzerland) [Internet]. 2021 Jun 3 [cited 2024 Dec 27];13(11):1-34. https://doi.org/10.3390/su13116348

35. Sacks R, Girolami M, Brilakis I. Building Information Modelling, Artificial Intelligence and Con-struction Tech. Developments in the Built Environment [Internet]. 2020 Nov 1 [cited 2024 Dec 27];4:1-9. Available from: https://www.sciencedirect.com/science/article/pii/S2666165920300077?via%3Dihub

36. You Z, Feng L. Integration of Industry 4.0 Related Technologies in Construction Industry: A Framework of Cyber-Physical System. IEEE Access [Internet]. 2020 Jul 6 [cited 2024 Dec 27];8:122908-22. https://doi.org/10.1109/ACCESS.2020.3007206

37. Haronian E, Sacks R. Roadels: Discrete Information Objects for Production Planning and Control of Road Construction. Journal of Information Technology in Construction [Internet]. 2020 Apr 1 [cited 2024 Dec 27];25:254-71. https://doi.org/10.36680/j.itcon.2020.015

38. Schimanski CP, Monizza GP, Matt DT. The Role of Common Data Environments as Enabler for Reliable Digital Lean Construction Management. In: 29th Annual Conference of the Internation-al Group for Lean Construction (IGLC) [Internet]. Lima: Department of Engineering, Civil En-gineering Division, Pontificia Universidad Catolica del Peru; 2021 [cited 2024 Dec 27]. p. 97-106. https://doi.org/10.24928/2021/0110

39. Marte Gómez JA, Daniel EI, Fang Y, Oloke D, Gyoh L. Implementation of Bim and Lean Con-struction in Offsite Housing Construction: Evidence from the UK. In: 29th Annual Conference of the International Group for Lean Construction (IGLC) [Internet]. Lima: Department of Engi-neering, Civil Engineering Division, Pontificia Universidad Catolica del Peru; 2021 [cited 2024 Dec 27]. p. 955-64 https://doi.org/10.24928/2021/0122

40. Chen C, Tang LCM, Jin Y. Development of 5D Bim-Based Management System for Pre-Fabricated Construction in China. In: International Conference on Smart Infrastructure and Con-struction 2019 (ICSIC) [Internet]. ICE Publishing. https://doi.org/10.1680/icsic.64669.215

doi: 10.25100/iyc.v27i1.14401

41. Peltokorpi A, Seppänen O. Managing Product Information for Lean Construction: Use Cases and A Proposed Process. In: 30th Annual Conference of the International Group for Lean Construc-tion (IGLC) [Internet]. Edmonton: Department of Engineering, Civil Engineering Division, Pon-tificia Universidad Catolica del Peru; 2022 [cited 2024 Dec 27]. p. 388-98. https://doi.org/10.24928/2022/0142

42. Arayici Y, Tokdemir OB, Kassem M. A Quantitative, Evidence-based Analysis of Correlations Between Lean Construction and Building Information Modelling. Smart and Sustainable Built Environment [Internet]. 2023 Nov 21 [cited 2024 Dec 27];12(5):975-1001. https://doi.org/10.1108/SASBE-03-2022-0052

43. Ybañez RS, De La Cruz AR. Related Literature Review 5D Model for Project and Opera-tion/Maintenance Remote Monitoring of Equipment and Piping System. Journal Europeen des Systemes Automatises [Internet]. 2023 Jun 30 [cited 2024 Dec 27];56(3):355-64. https://doi.org/10.18280/jesa.560301

44. Abouelaziz I, Jouane Y. Photogrammetry and Deep Learning for Energy Production Prediction and Building-Integrated Photovoltaics Decarbonization. Build Simul [Internet]. 2023 Dec 7 [cited 2024 Dec 27];17(2):189-205. https://doi.org/10.1007/s12273-023-1089-y

45. Jang S, Lee G. Interactive Design by Integrating a Large Pre-Trained Language Model and Build-ing Information Modeling. In: ASCE International Conference on Computing in Civil Engineer-ing 2023: Visualization, Information Modeling, and Simulation, i3CE 2023 [Internet]. Corvallis: Computing in Civil Engineering 2023 https://doi.org/10.1061/9780784485231.035

46. Wu B, Maalek R. Renovation or Redevelopment: The Case of Smart Decision-Support in Aging Buildings. Smart Cities [Internet]. 2023 Aug 10 [cited 2024 Dec 27];6(4):1922-36. https://doi.org/10.3390/smartcities6040089

47. Rafsanjani HN, Nabizadeh AH. Towards Digital Architecture, Engineering, and Construction (AEC) Industry Through Virtual Design and Construction (VDC) and Digital Twin. Energy and Built Environment [Internet]. 2023 Apr 1 [cited 2024 Dec 27];4(2):169-78. https://doi.org/10.1016/j.enbenv.2021.10.004

48. Soman RK, Whyte JK. Codification Challenges for Data Science in Construction. J Constr Eng Manag [Internet]. 2020 Apr 27 [cited 2024 Dec 27];146(7):1-47. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001846

49. Erişen S. A Systematic Approach to Optimizing Energy-Efficient Automated Systems with Learning Models for Thermal Comfort Control in Indoor Spaces. Buildings [Internet]. 2023 Jul 19 [cited 2024 Dec 27];13(7):1-29. https://doi.org/10.3390/buildings13071824

50. Sampaio AZ. BIM Capacities Improved with VR Technology in The Building Project. In: Inter-national Conferences Big Data Analytics, Data Mining and Computational Intelligence 2019 [In-ternet]. Theory and Practice in Modern Computing 2019 https://doi.org/10.33965/tpmc2019_201907C028

51. Uvarova SS, Orlov AK, Kankhva VS. Ensuring Efficient Implementation of Lean Construction Projects Using Building Information Modeling. Buildings [Internet]. 2023 Mar 15 [cited 2024 May 30];13(3):1-24. https://doi.org/10.3390/buildings13030770

52. Patching A, Skitmore M, Rusch R, Lester D. Case Study of The Collaborative Design of an Inte-grated BIM, IPD and Lean University Education Program. International Journal of Construction Management [Internet]. 2024 May 22 [cited 2024 May 30];24(7):799-808. https://doi.org/10.1080/15623599.2023.2215107

53. Karatas I, Budak A. Investigating the Impact of Lean-BIM Synergy on Labor Productivity in the Construction Execution Phase. Journal of Engineering Research (Kuwait University) [Internet]. 2023 Oct 17 [cited 2024 May 30];11(4):322-33. https://doi.org/10.1016/j.jer.2023.10.021

54. Garcés G, Peña C. A Review on Lean Construction for Construction Project Management. Re-vista Ingeniería de Construcción RIC [Internet]. 2023 Apr 2 [cited 2024 May 30];38(1):43-60. https://doi.org/10.7764/RIC.00051.21

doi: 10.25100/iyc.v27i1.14401

55. Ngoc NM, Dung NA, Hung TD, Thang TN. Challenges of BIM Technology and Lean Theory in the Construction Industry in Vietnam. Engineering, Technology and Applied Science Research [Internet]. 2024 Jun 20 [cited 2024 Dec 25];14(5):17548-54. https://doi.org/10.48084/etasr.7810

56. Pérez Y, Ávila J, Sánchez O. Influence of BIM and Lean on Mitigating Delay Factors in Building Projects. Results in Engineering [Internet]. 2024 Jun 1 [cited 2024 Dec 27];22:1-18. https://doi.org/10.1016/j.rineng.2024.102236

57. Velezmoro-Abanto L, Cuba-Lagos R, Taico-Valverde B, Iparraguirre-Villanueva O, Cabanillas-Carbonell M. Lean Construction Strategies Supported by Artificial Intelligence Techniques for Construction Project Management - A Review. International Journal of Online and Biomedical Engineering [Internet]. 2024 Feb 27 [cited 2024 May 30];20(3):99-114. https://doi.org/10.3991/ijoe.v20i03.46769

58. Noueihed K, Hamzeh F. Envisioning a Human Centric Approach to C4.0 Technologies. Lean Construction Journal [Internet]. 2022 Nov 16 [cited 2024 Dec 27];2022:156-70. https://doi.org/10.60164/30b5h6i2c

59. Khan N, Nadeau S, Xuan-Tan P, Boton C. Exploring Associations Between Accident Types and Activities in Construction Using Natural Language Processing. Autom Constr [Internet]. 2024 May 11 [cited 2024 May 30];164:1-15. https://doi.org/10.1016/j.autcon.2024.105457

60. Chashyn D, Khurudzhi Y, Daukšys M. Directions for the Formation of «City Intelligent Models» Using Artificial Intelligence for the Post-war Reconstruction of Historical Buildings. Budownic-two i Architektura [Internet]. 2024 Mar 29 [cited 2024 May 30];23(1):73-86. https://doi.org/10.35784/bud-arch.5560

61. Pedral Sampaio R, Aguiar Costa A, Flores-Colen I. A Systematic Review of Artificial Intelligence Applied to Facility Management in the Building Information Modeling Context and Future Re-search Directions. Buildings [Internet]. 2022 Nov 10 [cited 2024 May 30];12(11):1-23. https://doi.org/10.3390/buildings12111939

62. Tran T Van, Tran HVV, Nguyen TA. A Review of Challenges and Opportunities in BIM Adop-tion for Construction Project Management. Engineering Journal [Internet]. 2024 Aug 31 [cited 2024 Dec 27];28(8):79-98. https://doi.org/10.4186/ej.2024.28.8.79

63. Igwe US, Mohamed SF, Dzahir Azwarie MBM, Ugulu RA, Ajayi O. Acceptance of Contempo-rary Technologies for Cost Management of Construction Projects. Journal of Information Tech-nology in Construction [Internet]. 2022 Oct [cited 2024 May 30];27:864-83. https://doi.org/10.36680/j.itcon.2022.042

64. Płoszaj-Mazurek M, Ryńska E. Artificial Intelligence and Digital Tools for Assisting Low-Carbon Architectural Design: Merging the Use of Machine Learning, Large Language Models, and Build-ing Information Modeling for Life Cycle Assessment Tool Development. Energies (Basel) [Inter-net]. 2024 Jun 18 [cited 2024 Dec 27];17(12):1-21. https://doi.org/10.3390/en17122997

doi: 10.25100/iyc.v27i1.14401