infrastructures

MDPI

Review

The Application of BIM and Digital Twins in Sustainable Supply Chain Management: A Systematic Literature Review

Foad Zahedi and Ricardo Mateus *

Department of Civil Engineering, ARISE, ISISE, University of Minho, 4800-058 Guimarães, Portugal; f.zahedi@srbiau.ac.ir
* Correspondence: ricardomateus@civil.uminho.pt

Abstract

The construction industry faces persistent challenges in achieving sustainable and circular supply chain management due to fragmented material flows, limited information continuity, and weak coordination among stakeholders. Building Information Modelling (BIM) and Digital Twins offer complementary capabilities for addressing these challenges, yet their roles in sustainable and circular supply chains remain insufficiently integrated. This study critically reviews the literature on BIM and Digital Twins in Sustainable Supply Chain Management (SSCM) and the Circular Economy (CE) in construction. A structured literature review was conducted to identify major research trends, knowledge structures, thematic developments, implementation mechanisms, and research gaps. The analysis synthesizes the literature around key thematic areas, including material passports, reverse logistics (RL), off-site construction (OSC), artificial intelligence (AI), technology integration, construction and demolition waste (CDW), and decision-making. The findings indicate that BIM primarily supports structured lifecycle information, material traceability, and information continuity, while Digital Twins extend these capabilities through dynamic data integration, monitoring, and decision support. However, fragmented technological applications, interoperability limitations, insufficient data, organisational barriers, and limited integration across supply chain processes continue to constrain implementation. Based on these findings, a Digital–Circular Supply Chain Framework is proposed to conceptualize how BIM and Digital Twins can connect information, material flows, and decision-making to support SSCM and CE throughout the construction life cycle.

Keywords: building information modelling (BIM); digital twins; circular economy; supply chain management; sustainability; material passports; reverse logistics

Check for updates

Academic Editor: Lucía Díaz-Vilariño

Received: 4 September 2026
Revised: 25 October 2026
Accepted: 26 October 2026
Published: 29 October 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

The construction industry contributes substantially to resource depletion, construction and demolition waste, and greenhouse gas emissions [1]. These impacts are reinforced by fragmented material flows and discontinuous information across the building life cycle. Procurement, design, construction, operation, refurbishment, and end-of-life (EOL) activities are often managed by different actors and systems, making it difficult to maintain reliable information about material composition, quantity, condition, location, and recovery potential. Sustainable and circular supply chain management therefore requires coordination not only of physical material flows but also of the information and decisions that connect them.

This challenge is particularly visible in the transition from linear construction practices to a Circular Economy (CE). Rather than treating materials as waste at the end of a building's service life, circular approaches seek to retain their value through reuse, repair, recovery, and recycling [2–5]. RL is important to this transition because recovered materials must be directed back into appropriate supply-chain processes. Yet, construction Reverse Logistics (RL) is complicated by inconsistent deconstruction practices, uncertain secondary-material markets, variation in recovered-material quality, and fragmentation among demolition, recycling, manufacturing, and other actors [6]. Material passports can help preserve and communicate information about building materials and components, but their usefulness depends on data reliability, standardisation, interoperability, and willingness to share information [7–9]. These requirements make information continuity a central issue in sustainable and circular supply chain management.

BIM can provide a structured information environment for addressing part of this challenge. Beyond geometric representation, BIM can organize and exchange asset and material information across life cycle stages [10,11]. In circular construction, BIM-based approaches have been applied to deconstruction planning, material recovery, sustainability assessment, the identification of reusable components, and the integration of secondary materials into design and manufacturing [11–15]. When linked to material-passport information, BIM can help record characteristics relevant to future reuse and recovery. However, model-based information does not automatically remain current as asset conditions, material availability, logistics, and operational circumstances change. Nor does a digital model, by itself, ensure that information is exchanged among supply-chain partners or used in coordinated decisions.

Digital Twins offer a complementary capability by connecting digital representations with data generated by physical assets and processes. Their integration with BIM can extend structured life cycle information through dynamic data integration, monitoring, updating, and decision support [16]. In principle, this combination can improve material traceability and information transparency, support coordination between forward and reverse flows, and help align recovery opportunities with supply-chain requirements. Nevertheless, these outcomes are not produced by technology alone: they depend on interoperability, appropriate data, governance arrangements, stakeholder collaboration, and integration with the processes through which supply-chain decisions are made. The key issue is therefore how BIM and Digital Twins can be connected with circular material strategies and supply-chain processes, rather than considering each technology or application in isolation.

The literature also indicates that significant barriers remain between the potential of digital technologies and their practical application in circular construction. BIM implementation can be constrained by high implementation costs, limited digital skills, and unclear regulatory frameworks [17]. Material passport implementation faces additional challenges related to data standardisation, interoperability, information availability, intellectual-property concerns, and data privacy [8,9]. Digital Twin implementation similarly involves challenges associated with computational requirements; interoperability between BIM, IoT, and supply chain systems; and the availability of appropriate digital expertise [16]. Organisational barriers, including resistance to change, difficulties in multidisciplinary collaboration, and insufficient training and support, can further restrict the implementation of circular strategies [18]. These observations suggest that the effectiveness of digitalisation cannot be explained solely by the capabilities of individual technologies. Rather, technological capabilities need to be considered in relation to information governance, stakeholder collaboration, organisational readiness, and the processes through which circular supply chain decisions are made.

Accordingly, an important issue is not whether BIM, Digital Twins, material passports, RL, or other digital technologies can individually support sustainability or CE, but how their capabilities can be connected across the construction supply chain to enable continuity between information, material flows, and decisions. Existing literature has addressed several parts of this relationship. BIM has been examined as an enabler of CE-related applications [12–15], while material passports have been proposed as mechanisms for retaining and communicating material information [7,8]. RL research has highlighted the organisational and market conditions required for recovering materials [6], and research on Digital Twins has identified their potential as dynamic digital representations alongside challenges to their implementation [16]. However, these streams of research have largely developed around different technological, organisational, and application perspectives. The resulting knowledge base therefore provides evidence of individual capabilities but offers less clarity regarding the mechanisms through which these capabilities can be integrated into sustainable and circular supply chain management.

Recent review studies reinforce this need for a more integrated perspective. Aljaber et al. [15] identified the broad range of ways in which BIM can support CE while also highlighting limitations in comprehensive implementation and industrial evidence. Research examining BIM and Digital Twin integration has similarly identified considerable sustainability potential while emphasising the need for further academic and practical validation [19]. Theeraworawit et al. [20] examined sustainable supply chains in the context of CE, but their focus was not on an integrated BIM–Digital Twin perspective. Nguyen and Adhikari [21] provided a broad review of emerging digital technologies, yet their synthesis primarily considered individual technologies and future developments rather than the mechanisms connecting digital technologies with sustainable and circular supply chain performance. Taken together, these studies suggest that the existing knowledge remains distributed across technology-specific, life cycle, and supply chain perspectives, leaving the systemic relationship between BIM, Digital Twins, Sustainable Supply Chain Management (SSCM), and CE insufficiently conceptualised.

This gap is particularly important because sustainable and circular supply chain performance depends on the interaction of material flows, information flows, and decision processes rather than on the isolated adoption of a particular technology. A more integrated understanding is therefore required to explain how digital technologies can support material identification and traceability, connect forward and reverse flows, facilitate collaboration among stakeholders, improve decision-making, and maintain information continuity throughout the construction life cycle. Such an understanding can also clarify the conditions under which digital technologies contribute to sustainability and circularity rather than merely digitising existing fragmented processes.

In this context, this paper aims to explore the application of BIM/Digital Twins in SSCM and CE through an in-depth literature review, focusing on the most cited papers since January 2019. The time span stems from the rapid pace of advancements and the potential obsolescence of older findings. This ensures the research is grounded in the most current knowledge and methodologies, relevant to contemporary understanding and addressing current challenges. The study emphasizes the promotion of sustainable material procurement through CE principles and proposes future research directions. The paper aims to investigate whether BIM and Digital Twin can contribute to implementing a circular supply chain in the construction industry, addressing current needs by answering the following research questions:

What are the major research trends, knowledge structures, and thematic developments concerning BIM and Digital Twins for sustainable and circular supply chain management in the construction industry?

How do BIM and Digital Twins individually and jointly contribute to sustainable and circular supply chain management throughout the construction life cycle?

What knowledge gaps, research challenges, and future directions remain in integrating BIM and Digital Twins for SSCM and CE?

How can the findings of the review be synthesized into a conceptual Digital–Circular Supply Chain Framework that supports the implementation of SSCM and CE principles?

Accordingly, this review focuses specifically on the role of BIM and Digital Twins in SSCM within the construction context, rather than examining their general applications across the construction lifecycle. Particular attention is given to supply chain mechanisms such as information exchange, material traceability, procurement, forward and reverse logistics, circular resource flows, and decision-making.

To bridge the gap in understanding how integrated BIM and Digital Twins function within SSCM, this study introduces a novel Digital–Circular Supply Chain Framework. By synthesizing insights from the reviewed thematic clusters, the proposed framework delineates the specific mechanisms through which these digital technologies drive circularity, sustainability, and resilience throughout the construction supply chain.

2. Materials and Methods

The literature review involves several steps, including identifying relevant databases and keywords, analysing correlations between keywords, searching the literature within databases, screening results, conducting in-depth analysis, and exploring knowledge gaps.

2.1. Research Methodology

A systematic literature review is conducted to bring previous efforts into light [22,23], utilizing the PRISMA checklist, provided in supplementary material, which explores current research trends and enhances the understanding of existing knowledge [24]. The literature identification and selection process is presented in Figure 1. The process consisted of database identification, database-level screening, citation-based selection, relevance assessment, and forward and backward snowballing. The reference lists of the 50 core studies were subsequently examined through backward snowballing. Retrieved papers were assessed against the same predefined eligibility criteria to exploit only those meeting the criteria were retained, none of the identified papers through snowball sampling met the criterion, specifically due to previously selection as core study and the publication year. Consequently, through Scientometric analysis, bibliographic networks are developed, and the application of BIM and Digital Twin in sustainable CE-oriented supply chains is discussed.

To ensure consistency in study selection, predefined inclusion and exclusion criteria were applied during screening. Studies were included when they (1) were published in English; (2) were classified as journal articles, conference papers, or review papers; (3) were published between January 2019 and 20 July 2025; (4) were indexed within the Engineering subject area; and (5) addressed BIM, Digital Twin, or their application in relation to procurement, materials, logistics, or supply chain management within the scope of the research questions. Studies were excluded when they were book chapters, published in languages other than English, duplicates, outside the research scope through title, abstract and full-text assessment, or focused primarily on non-construction applications such as manufacturing or healthcare. Relevance was assessed against the research questions and the construction-oriented scope of SSCM and CE. The screening and eligibility assessment were conducted by authors through discussion and consensus, with disagreements resolved through joint review. To identify influential studies while mitigating the potential exclusion of emerging research, the primary dataset was based on highly cited peer-reviewed

studies and complemented by backward and forward snowballing. However, the backward snowballing returned no result that satisfies initial selection criteria. So, the number of publications selected for the critical analysis was reduced to 50 from the 2395 initially explored papers. Supplementary documents were also identified to explore emerging research published in 2024 and 2025 that considers time constraints to identify the citation number criteria: 14 relevant papers relevant to the paper's objective, with one or more citations, and all 6 2025 relevant papers were added to the repository. Also, forward snowballing was applied, which resulted to 13 more papers. Eventually, 83 publications were selected for the review.

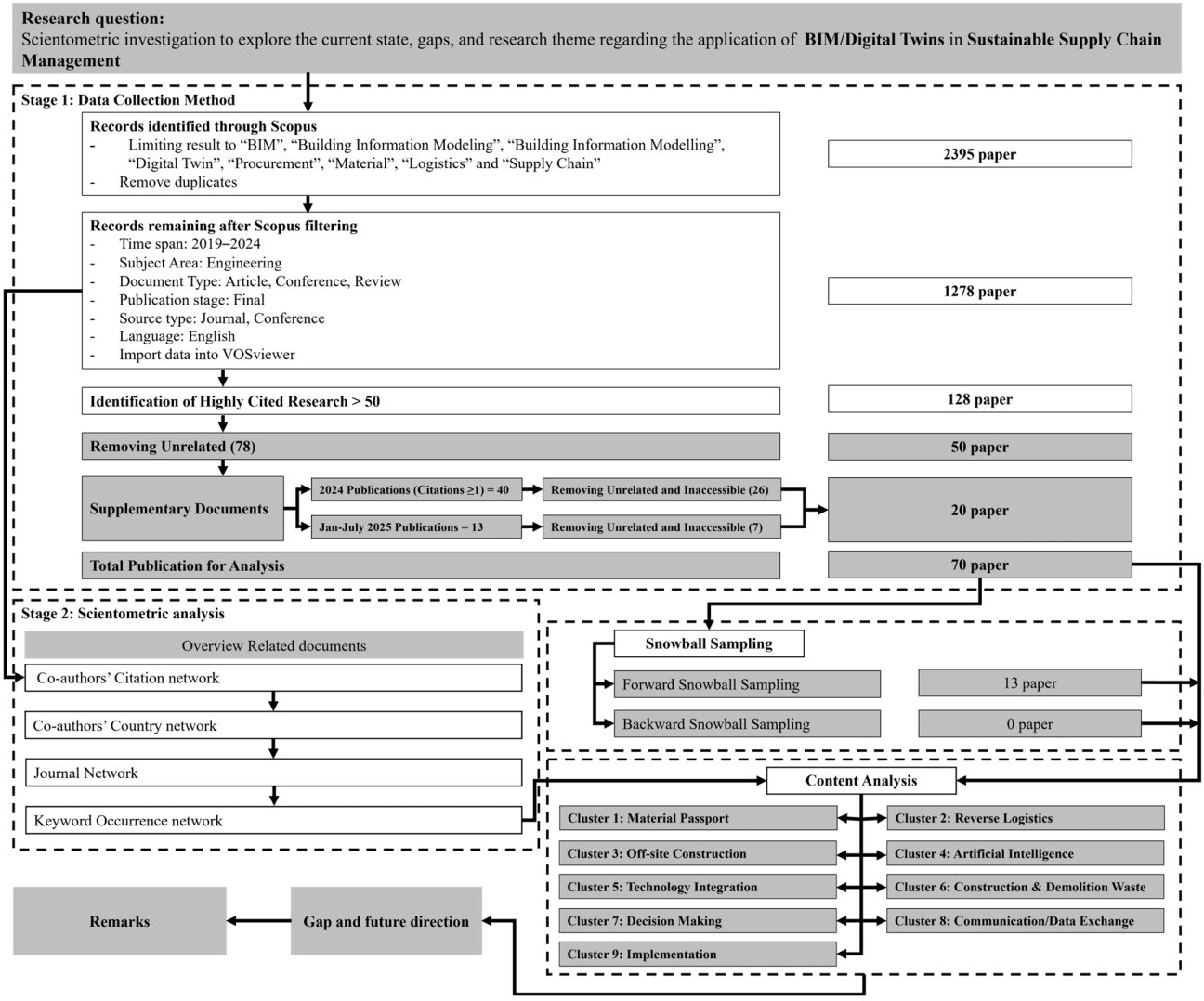

Figure 1. Scientometric analysis flowchart.

This study adopts an integrated review approach combining scientometric analysis and systematic thematic review, with the two stages serving different analytical purposes. The scientometric analysis was conducted on the bibliographic dataset to identify publication trends, influential sources, collaboration networks, co-citation structures, and keyword evolution. In contrast, the thematic analysis was applied to the selected publications to examine their substantive contributions, recurring research problems, knowledge gaps, technological relationships, and future research directions. Finally, insights from both analytical stages were synthesized to provide an overview of the structure and evolution of the field, while the thematic analysis provided the conceptual interpretation needed to explain the significance

of the identified research patterns. The findings from both stages were then synthesized to develop the proposed Digital–Circular Supply Chain Framework. This integrated methodology combines the strengths of quantitative knowledge mapping with qualitative conceptual interpretation, thereby providing a more comprehensive understanding of the field.

Given the mixed nature of the reviewed literature, which includes empirical studies, case studies, conceptual frameworks, review papers, and technology-oriented studies, no single standardized methodological quality assessment instrument was applied across all included publications. Instead, methodological rigor was addressed through predefined eligibility and screening criteria, including peer-review status, language, relevance to the research agenda, disciplinary relevance, and removal of duplicate and irrelevant records. The citation threshold was used as a selection strategy to identify influential studies rather than as a direct measure of methodological quality. The absence of a formal study-level quality appraisal is recognized as a methodological limitation of the present review.

The nine thematic clusters were developed inductively from the substantive focus of the reviewed studies rather than being treated as statistically independent bibliometric clusters. Each publication was examined according to its main research problem, technological focus, construction supply chain application, and contribution to sustainable or circular supply chain practices. Studies addressing more than one topic were considered across the relevant thematic relationships, reflecting the interconnected nature of the research field. Through this process, nine interconnected clusters were identified as Material Passport, Reverse Logistics, Off-site Construction, Artificial Intelligence, Technology Integration, Construction and Demolition Waste, Decision Making, Communication/Data Exchange, and Implementation. The clusters were subsequently compared to identify recurring problems, digital capabilities, implementation barriers, and relationships among BIM, Digital Twins, and complementary technologies.

The thematic analysis focused on identifying recurring problems, technological capabilities, implementation barriers, and research gaps across the selected studies. For each publication, attention was given to the supply chain problem addressed, the role of BIM and/or Digital Twins, complementary technologies employed, the construction life cycle stage considered, reported benefits, and identified limitations or implementation barriers. Related observations were then grouped into broader thematic categories, which were refined through comparison across the selected publications. The purpose of this analysis was not merely to summarize individual studies, but to identify relationships and recurring patterns across the literature and to use these patterns as the basis for the subsequent conceptual synthesis. The purpose of the thematic analysis was therefore not limited to summarizing individual publications. Instead, the analysis sought to identify common research concerns, relationships among digital technologies, and persistent implementation challenges across the literature. The resulting themes were subsequently synthesized to identify research gaps and to inform the development of the proposed Digital-Circular Supply Chain Framework.

2.2. Data Collection

The Scopus database was selected as the source for conducting the literature review. The reasoning for this choice is that Scopus is a robust and comprehensive database that supports a wide range of research activities, making it an excellent source for review papers. Scopus was chosen as the primary database for this review because of its comprehensive coverage of peer-reviewed publications and its rigorous indexing standards. It contains more than 100 million records from over 19.5 million authors spanning more than 330 academic disciplines, making it one of the most comprehensive bibliographic databases. Its systematic indexing process and broad disciplinary coverage improve the reliability, transparency, and

reproducibility of systematic literature reviews. Its extensive coverage, accurate document type assignment, and global reach contribute to its reputation as a reliable resource for academic research. Specifically, the search string was ("BIM" OR "building information modelling" OR "building information modeling" OR "digital twin") AND ("procurement" OR "material" OR "logistics" OR "supply chain"). This structure allowed studies addressing BIM, Digital Twins, or both technologies to be retrieved, provided that they also addressed at least one of the specified supply chain-related concepts.

The search strategy focused on the established BIM terminology, including "BIM", "building information modelling", and "building information modeling", together with "digital twin". The term "digital model" was not included because of its broad meaning and potential to retrieve studies outside the BIM and Digital Twin scope. Similarly, "building information model" was not used as a separate search term because the search strategy was designed around BIM as the established technology/process terminology rather than individual building information models.

An initial search using this strategy identified 2395 records. The results were subsequently screened using predefined database filters, including publication period, subject area, document type, publication stage, source type, and language. After applying these filters, 1278 records remained for further screening. The search covered publications available from January 2019 to 20 July 2025, as summarized in Table 1.

Table 1. Bibliometric Search Criteria and Results.

Stage	Filter		No of Docs
Search Strategy Title and Keywords	("BIM" **OR** "building information modelling" **OR** "building information modeling" **OR** digital twin") **AND** ("procurement" **OR** "material" **OR** "logistics" **OR** "supply chain")		2395
Screening	Date Subject area Document type Publication stage Source type Language	January 2019–July 2025 Engineering Article, Conference, Review Final Journal, Conference English	1278
Identification of highly cited research	Number of citations	Over or equal to 50 times	128
Removing unrelated (78)			50
Supplementary search for recent studies	Date Number of citations	January–December 2024 More than or equal to 1	14
	Date	January–July 2025	6

A citation threshold of 50 citations was applied to identify a core set of highly cited publications for the subsequent in-depth thematic analysis. The threshold was adopted as a pragmatic screening strategy to reduce the large number of retrieved records and focus the detailed qualitative analysis on studies that had received substantial scholarly attention. It was not used as an indicator of methodological quality. This approach inevitably introduces a temporal bias because older publications have had a longer period in which to accumulate citations, whereas recent publications, particularly those published in 2024 and 2025, may be underrepresented despite their potential relevance. The subsequent forward snowballing of the retained studies was therefore used to complement, rather than eliminate, this limitation by identifying additional conceptually relevant publications. Emerging papers published in 2024 and 2025 that reduce the temporal bias are also considered, with all 2024 related

papers with one or more citations and all relevant 2025 papers being entered into the content analysis.

2.3. Data Statistical Analysis

VOSViewer 1.6.20, a software tool for statistical analysis and Scientometric mapping, was employed to generate Scientometric maps by analysing the data. This research includes maps and analyses of the countries, resources, and co-citation occurrences of co-authors.

2.4. Publication Analysis Through Time Distribution

As depicted in Figure 2, the use of BIM and Digital Twins in supply chain management has seen rapid growth since January 2019. Scopus data shows a steady rise in related publications, increasing from 44 articles in 2019 to 175 in 2024, nearly a fourfold growth in just five years.

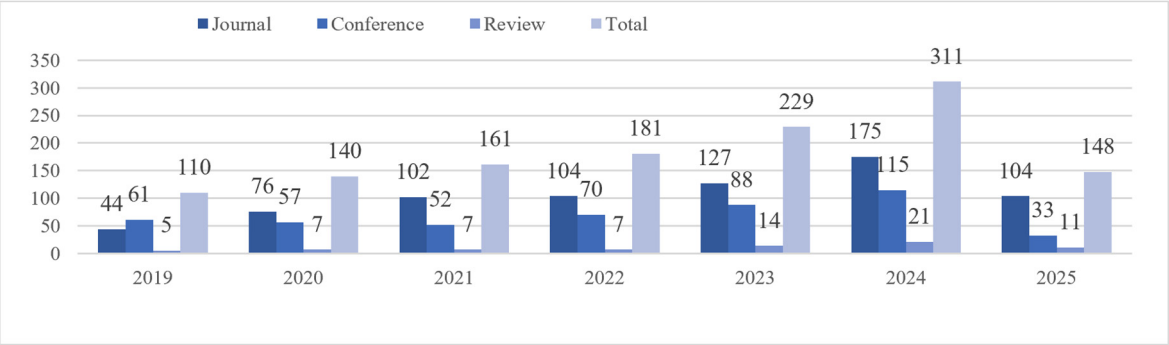

Figure 2. BIM and Digital Twins in supply chain management publications divided by year and type.

The distribution of the identified themes, presented in Table 2, suggests a gradual shift in the research landscape from BIM toward Digital Twin-oriented approaches. While BIM occurrences remained relatively stable between 2019 and 2024 (54–63 occurrences), Digital Twin occurrences increased substantially from 23 in 2019 to 156 in 2024. The increase suggests that Digital Twins have progressively gained prominence as a mechanism for extending lifecycle information and enabling more dynamic and data-driven construction processes.

Table 2. Keyword occurrences by date.

Year	BIM	Digital Twin	Circular Economy	AI	Material Passport	Reverse Logistics	Digital Technologies
2019	61	23	2	4	1	1	1
2020	54	58	4	3	3	0	1
2021	55	80	8	5	2	1	0
2022	59	101	5	4	2	0	0
2023	58	141	9	10	2	0	3
2024	63	156	10	5	3	3	1
2025	2	2	0	0	0	0	0

At the same time, CE themes increased from 2 occurrences in 2019 to 10 in 2024, indicating a gradual incorporation of circularity into the digital construction research agenda. AI-related themes also became more visible, although their occurrence remained comparatively limited. In contrast, Material Passports and RL remained relatively underrepresented, suggesting that the application of digital technologies to specific circular supply chain mechanisms is still at an emerging stage.

Several factors may explain the observed evolution of the research landscape. First, the increasing digitalization of the construction industry has expanded the role of digital technologies from information modelling toward continuous lifecycle information management. Second, the growing availability of real-time data, sensing technologies, and data analytics has created conditions for Digital Twins to extend the static information capabilities traditionally associated with BIM. Third, paying increasing attention to CE and resource efficiency has encouraged researchers to explore digital approaches for material traceability, lifecycle management, and circular decision-making. The emergence of AI-related research further indicates a gradual movement toward more intelligent and data-driven construction processes.

These factors provide acceptable explanations for the observed thematic evolution, although the bibliometric analysis does not establish direct causal relationships.

Together, the patterns suggest a gradual paradigm shift from BIM-centred digitalization toward Digital Twin-enabled, data-driven, and increasingly circular construction supply chains. However, the relatively limited occurrence of Material Passports and RL indicates that the integration of digital technologies with specific circular supply chain mechanisms remains comparatively underdeveloped.

2.5. Co-Authors' Country Analysis

Figure 3 illustrates the global distribution of publications in this field, where larger circles denote higher research output and color-coded clusters reflect international collaboration. Also, the line thickness advocates the higher strength of collaboration between two countries. Overall, 55 countries were analysed, with inclusion criteria requiring each paper to have at least five citations.

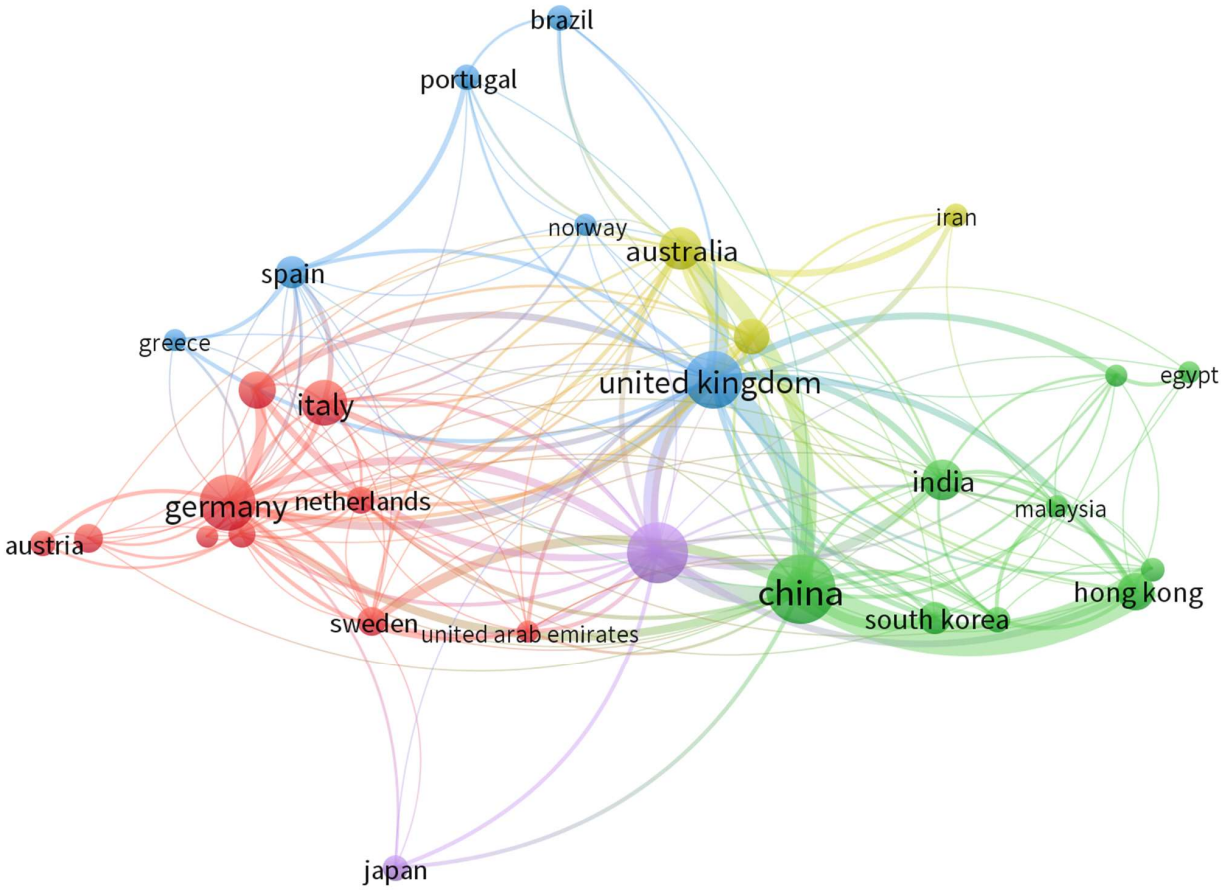

Figure 3. Country-level co-authorship network of the reviewed research field.

Table 3 and Figure 4 rank country contributions by co-authors, showing China as the top producer with 240 publications, 5215 citations, and 125 links. The United States follows with 170 papers, 3,211 citations, and 103 links, while the United Kingdom ranks third with 153 papers, 4403 citations, and 127 links. Germany stands out for the highest citation count (5653) across 144 papers and 66 links, and Italy contributed 92 publications, 1691 citations, and 37 links, indicating that citation impact and international collaboration strength represent distinct dimensions of the research landscape.

Table 3. Co-authors' countries: detailed information.

Id	Country	Documents	Citations	Total Link Strength
1	China	240	5215	125
2	United States	170	3211	103
3	United Kingdom	153	4403	127
4	Germany	144	5653	66
5	Italy	92	1691	37
6	Australia	73	2842	73
7	India	64	705	38
8	France	53	2067	35
9	Hong Kong	52	1744	55
10	Canada	47	1129	35
11	Spain	41	468	31
12	South Korea	39	452	30
13	Sweden	30	641	32
14	Russian Federation	29	599	10
15	Switzerland	27	410	29

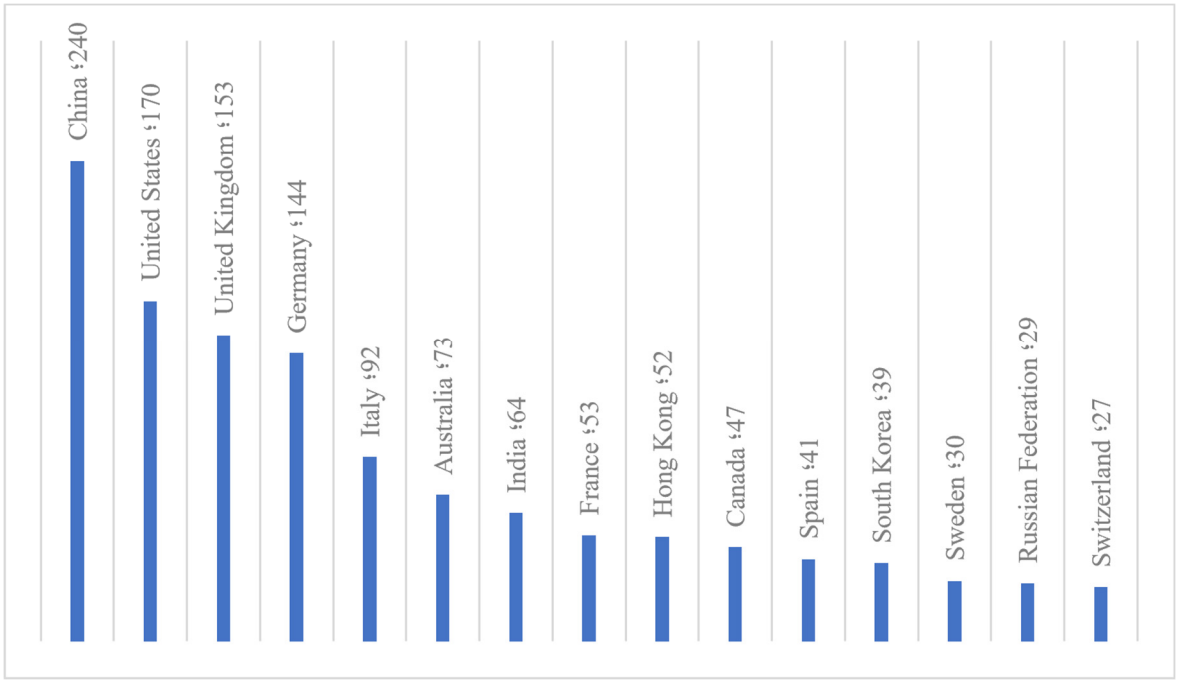

Figure 4. Co-authors' country contribution.

Table 4 shows that Jinan University, China, leads institutional contributions to the BIM/Digital Twins–Supply Chain Management field with 36 publications and 358 citations. The Hong Kong Polytechnic University follows with 16 papers and 149 citations. Other key contributors include Beihang University, China (15 papers, 512 citations); Fraunhofer

Institute, Germany (9 papers, 60 citations); and Chongqing University, China (8 papers, 132 citations).

Table 4. University contribution to the research field.

Rank	Organization	Documents	Citations
1	Jinan University, China	36	358
2	The Hong Kong Polytechnic University, China	16	149
3	Beihang University, China	15	512
4	Fraunhofer Institute, Germany	9	60
5	Chongqing University, China	8	132

In addition, the top five most cited articles are listed in Table 5. As shown, all the papers are published in journals. These articles were published between 2019 and 2022, with the most cited paper being "*A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0*." This Article, published in Production Planning and Control in 2021, has been cited 839 times. Although this paper addresses supply chain management broadly within Industry 4.0 rather than focusing exclusively on construction, its discussion of digital supply chain integration and disruption management provides relevant conceptual insights into digital technology applications in construction supply chains. Therefore, it was considered relevant to this review.

Table 5. The five most cited papers.

Authors	Title	Year	Source Title	Cited By	Type	Refs.
Ivanov & Dolgui	A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0	2021	Production Planning and Control	839	Article	[25]
Baduge et al.	Artificial intelligence and smart vision for building and construction 4.0: Machine learning and deep learning methods and applications	2022	Automation in Construction	586	Review	[26]
Sacks et al.	Construction with digital twin information systems	2020	Data-Centric Engineering	430	Article	[27]
Li J.; Kassem M.	Applications of Distributed Ledger Technology (DLT) and Blockchain-Enabled Smart Contracts in Construction	2021	Automation in Construction	199	Article	[28]
Bortolini R.; Formoso C.T.; Viana D.D.	Site Logistics Planning and Control for Engineer-to-Order Prefabricated Building Systems Using BIM 4D Modeling	2019	Automation in Construction	177	Article	[29]

2.6. Source Analysis

The development of BIM/Digital Twin in SSCM is supported by both journals and conference proceedings. Figure 5 and Table 6 highlights the most active sources between January 2019 and July 2025. Procedia CIRP and IFAC-PapersOnLine are the leading confer-

ence outlets, publishing 41 (3.21%) and 36 (2.82%) papers, respectively. Among journals, Automation in Construction contributed the most with 42 papers (3.29%), followed by Buildings with 36 papers (2.82%), Applied Sciences with 27 papers (2.11%), and the International Journal of Advanced Manufacturing Technology with 25 papers (1.96%). Table 6 lists the top 12 sources overall, with colour coding indicating publication periods, with yellow for recent and purple for earlier contributions.

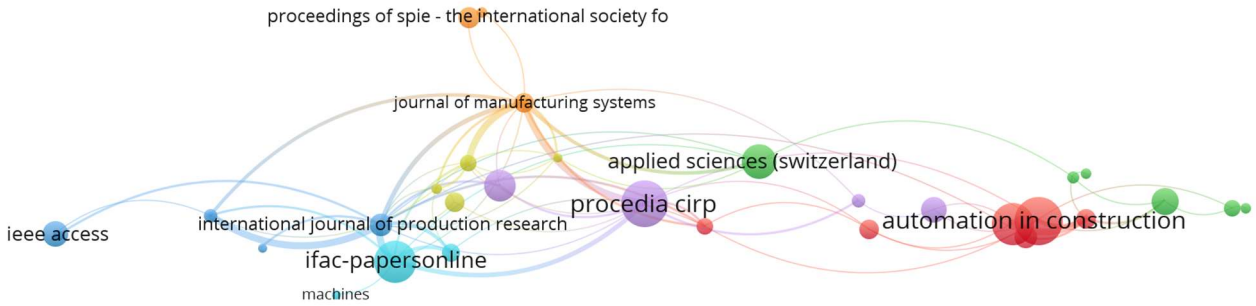

Figure 5. Publication source network.

Table 6. Publication source analysis.

Row	Source	Country	Documents	Percentage	H-Index
Journal Publications (Total)			***237***	***18.55%***	
1	Automation in Construction	The Netherlands	42	3.29%	219
2	Buildings	Switzerland	36	2.82%	85
3	Applied Sciences (Switzerland)	Switzerland	27	2.11%	197
4	International Journal of Advanced Manufacturing Technology	United Kingdom	25	1.96%	188
5	Journal of Building Engineering	The Netherlands	20	1.56%	139
6	IEEE Access	United States	19	1.49%	338
7	Journal of Cleaner Production	United Kingdom	19	1.49%	397
8	Sensors	Switzerland	18	1.41%	303
9	International Journal of Production Research	United Kingdom	16	1.25%	217
10	Journal of Construction Engineering and Management	United States	15	1.17%	158
Conference Proceeding (Total)			***77***	***6.03%***	
1	Procedia CIRP	The Netherlands	41	3.21%	125
2	IFAC-PapersOnLine	The Netherlands	36	2.82%	105
Others (Number of publications < 15)			***954***	***75.43%***	

H-Index extracted from Scimago Journal & Country Rank "https://www.scimagojr.com/" (accessed on 1 October 2026).

2.7. Research Theme and Keyword Relationships

Figure 6 illustrates the keyword co-occurrence network restored from the preliminary research dataset, highlighting the most frequently mentioned keywords in the literature. The top five most recurring keywords are *Digital Twin* and *Digital Twins* (593 occurrences), followed by *BIM*, *Building Information Modelling*, *Building Information Modeling (BIM)*, *Building Information Modelling*, and *Building Information Modelling (BIM)* (309); *supply chain* and *supply chain management* (78); *Industry 4.0* (68); and *Sustainability* (61).

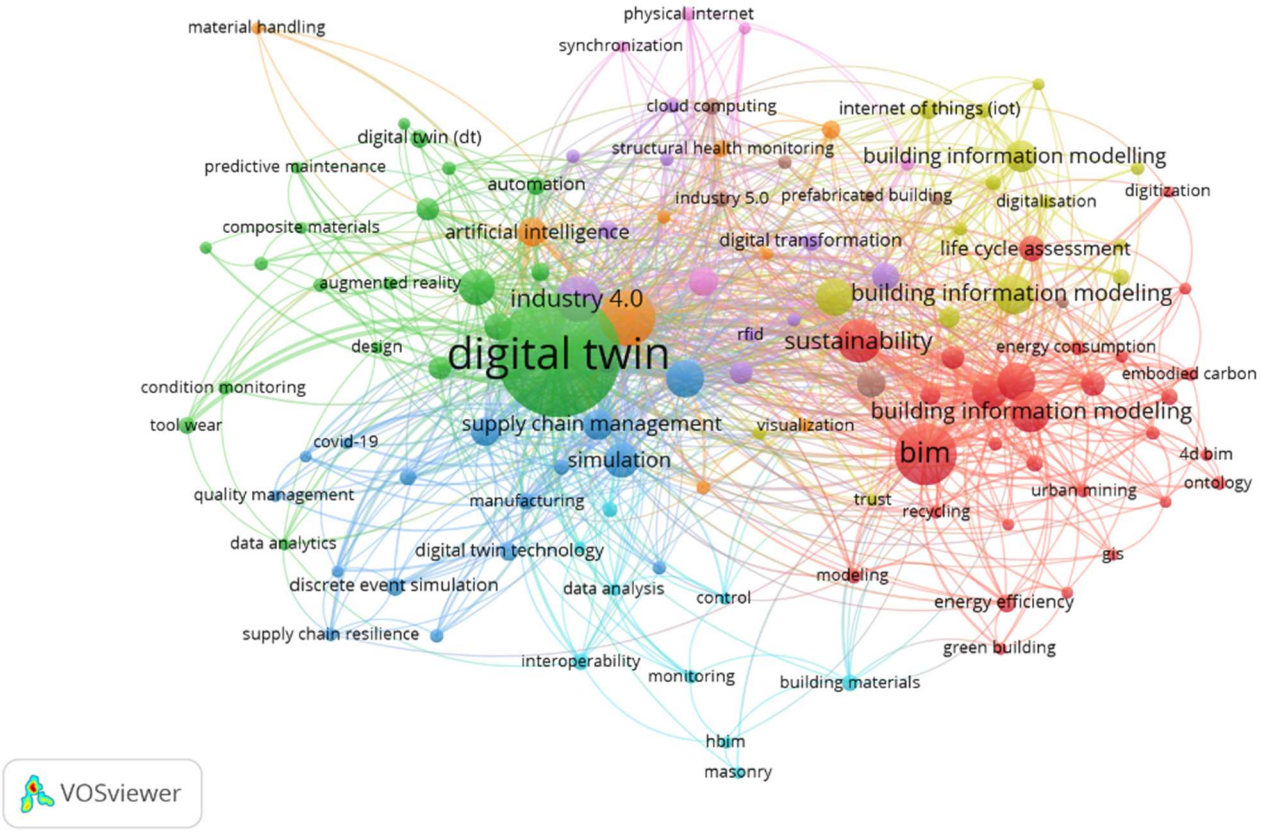

Figure 6. Keyword co-occurrence network.

Table 7 highlights that the relationship between BIM and Digital Twins in SSCM is a central research focus. It also shows increasing interest in integrating emerging technologies with BIM to enhance supply chain practices.

Figure 6 reveals four main interconnected but distinguishable research orientations within the literature, separated by colors. One group, the Orange, is built upon AI and automation, indicating use of computational methods and intelligent systems for predicting, optimizing, and decision-making. The second group, the Red, connects sustainability-related concepts with BIM, reflecting the role of structured life cycle information in environmental assessment and construction-related sustainability applications. The other group, the Blue, links supply chain concepts with simulation, highlighting the use of modelling and analytical approaches to examine operational processes and supply chain performance. The IoT and digitalization in the Light Green group reflects the growing attention to connected technologies, data acquisition, and the integration of digital systems. The last group, the Dark Green, centres the application of dynamic information flow of information of the built environment information, emphasizing on digital twin. The attention to the area reveals the attraction of practitioners to the real-time monitoring and seamless flow information that updates the current information immediately. Condition monitoring and predictive maintenance are some of the research grounds of the group.

Table 7. Keywords by occurrence order.

Rank	Keyword	Occurrences
1	digital twin & digital twins	593
2	BIM & building information modelling & building information modeling (BIM) & building information modelling & building information modelling (BIM)	309
3	supply chain & supply chain management	78
4	industry 4.0	68
5	sustainability	61
6	blockchain	45
7	machine learning	44
8	circular economy	41
9	simulation	39
10	artificial intelligence	28
11	optimization	27
12	internet of things	26
13	resilience	26
14	additive manufacturing	24

The coexistence of these groups suggests that research is developing across complementary technological and application domains rather than around a single unified approach. BIM and Digital Twins provide potential points of connection between life cycle information, dynamic data, analytical capabilities, and supply chain processes. However, the presence of related keywords within the same network does not in itself demonstrate that these capabilities have been integrated in operational construction supply chains. Instead, the network highlights the need to examine how technological developments are translated into coordinated processes for material traceability, procurement, forward and reverse logistics, and circular decision-making.

From an SSCM perspective, the key insight is therefore not simply that BIM and Digital Twins are related, but that the research landscape combines relatively technology-oriented themes with sustainability and supply chain applications that are not yet consistently connected. This interpretation is consistent with the thematic review that follows, which examines the mechanisms, implementation barriers, and research gaps across the nine clusters.

Notably, keyword occurrence is measured through merging similar keywords, including "digital twin and digital twins"; "BIM, building information modelling, building information modeling (BIM), building information modelling, and building information modelling (BIM)"; and "supply chain and supply chain management". Digital Twins was the most frequently occurring keyword during the period under study, with 593 occurrences, followed by BIM, with 309. This finding indicates growing research interest in the use of structured digital information in the construction industry, with increasing attention being paid to the dynamic flow of information enabled by Digital Twins, compared with the more static information structures traditionally associated with BIM.

3. Content Analysis

Considering that 1278 papers were explored based on the criteria defined in the database, with those cited 50 times or more, 128 papers were selected for further analysis. These were then reduced to 50 after removing unrelated entries. Following the relevance screening of the highly cited publications, the reference lists of the 50 retained studies were examined using forward snowballing. To address the bias of neglecting 2024 and 2025 review, due to shorter time to be considered and cited, a supplementary condition is defined with the 2024 published paper with equal and more than 1 time (14 papers),

and all the related 2025 related publications (6 papers), and all related Thirteen additional publications were identified as directly relevant to the research objectives and were therefore included in the thematic review, resulting in a final set of 83 publications. Additionally, using forward Snowball Sampling method [30], 13 more papers have been selected for review. Therefore, the number of documents analyzed increased to 83 articles.

To identify research gaps relevant to SSCM and CE, the selected literature was thematically analysed and categorized into the clusters. Although these clusters represent different technological and application domains, each was examined based on its contribution to information continuity, material traceability, procurement, logistics, reverse logistics, decision-making, coordination, and implementation within sustainable and circular construction supply chains.

Cluster 1: Material Passport

Material Passports can connect building component information with decisions about disassembly, recovery, and reuse. The studies show a progression from documenting material characteristics towards using structured information to support circular decisions. BIM-based approaches have been developed to enrich material information with recovery potential and disassembly requirements [31], support life cycle assessment (LCA) and material management [32,33], and connect deconstruction information with subsequent reuse opportunities [34]. Related research has also identified the potential for combining BIM and Material Passports with AI, machine learning (ML), Radio Frequency Identification (RFID), and blockchain to improve data collection and resource recovery [35]. Taken together, these studies indicate that the value of a Material Passport depends less on the volume of information stored than on whether that information can inform decisions at later stages of the material life cycle.

However, the reviewed studies also reveal a gap between information availability and its effective use across the supply chain. Incomplete design-stage information, fragmented databases, limited interoperability, and insufficient economic indicators constrain the use of Material Passports for reliable recovery and reuse decisions [32–35]. These limitations suggest that material information cannot independently guarantee circular outcomes. Its value depends on whether information is sufficiently reliable, transferable, and relevant to the requirements of designers, contractors, procurement teams, and recovery actors.

From an SSCM perspective, Material Passports should therefore be understood as an information mechanism linking design-stage decisions with procurement, material allocation, and reverse logistics. The central research challenge is to move beyond documenting material properties towards connecting this information with practical decisions about the availability, suitability, economic feasibility, and recovery of secondary materials. This requires stronger alignment between information standards, data governance, and supply chain processes so that Material Passports function as active decision-support mechanisms rather than isolated repositories.

Cluster 2: Reverse Logistics

The studies in this cluster examine how digital technologies can support the identification, assessment, movement, and reuse of recovered construction materials. BIM-based optimization approaches combine material information with environmental assessment to compare new and reclaimed materials [36], while BIM-based tools and proposed integrations with augmented reality (AR), RFID, and Geographic Information Systems (GIS) aim to improve information capture and recovery planning [37]. Research on reclaimed timber further demonstrates how 3D scanning, BIM, computational design, ML, and robotic fabrication can connect the physical characteristics of recovered components with downstream design and manufacturing decisions [38,39]. Collectively, these studies show that digital

support for RL extends beyond locating recoverable materials: it can also help determine whether recovered components can be incorporated into new construction activities.

Nevertheless, the evidence indicates that technological capability alone does not resolve the operational uncertainty associated with RL. Recovery depends on the condition and geometry of salvaged materials, the availability of reliable information, the cost of inspection and processing, and the existence of suitable markets and distribution arrangements. Although digital tools have been proposed to address individual information and coordination problems, the practical effectiveness and scalability of integrated systems remain insufficiently demonstrated [37]. Moreover, RL is often treated separately from conventional procurement and distribution, despite the need to coordinate deconstruction, storage, transportation, and the subsequent use of recovered materials [40].

The main implication for SSCM is that RL should not be treated as an isolated EOL activity. It needs to be coordinated with forward supply chain decisions so that recovered materials can be assessed against future demand, technical requirements, and procurement needs. OSC may offer favourable conditions for such coordination because component standardization can facilitate identification, handling, and reuse. However, the extent to which these benefits can be achieved depends on practical infrastructure, cost-effectiveness, market coordination, and validated procedures. Future research should therefore evaluate integrated forward and reverse logistics systems under real project conditions rather than assuming that the adoption of digital tools will automatically improve recovery performance.

Cluster 3: Off-site Construction

OSC provides an important context for examining how digital technologies can coordinate production, transportation, assembly, and material management across construction supply chains. The reviewed literature identifies the use of BIM and complementary technologies to improve production coordination, information flow, logistics, and resource efficiency in prefabricated construction [41]. BIM-based approaches have also been applied to assess carbon emissions across construction stages [42] and to improve material selection, assembly planning, waste reduction, and handling [43]. Digital Twin applications in modular construction have similarly indicated potential benefits for scheduling and supply chain visibility [44]. Together, these studies suggest that OSC can provide a structured setting in which digital information supports coordination between off-site production and on-site construction.

However, the sustainability contribution of OSC remains unevenly assessed. Several studies emphasize productivity, time savings, assembly efficiency, or carbon emissions, while giving less attention to broader life cycle performance, including cost, quality, component recovery, and reuse [41–44]. The scope of individual applications is also sometimes restricted to particular geographical contexts or building components, limiting the extent to which their findings can be generalized. Consequently, improved production efficiency should not automatically be interpreted as evidence of circularity or overall sustainability. These outcomes need to be evaluated using broader performance criteria that consider both immediate construction activities and the subsequent use or recovery of components.

The relationship between OSC, Material Passports, and RL is particularly important for circular supply chains. Standardized components and better information continuity may facilitate material identification, maintenance, disassembly, and reuse, but these benefits depend on whether such requirements are incorporated into design, procurement, and logistics planning. BIM and Digital Twins could support this coordination by linking component information with production status, transportation, assembly, and EOL requirements. The principal research opportunity is therefore to evaluate OSC as a potential setting for integrating digital information with design for disassembly, recovery planning, and life

cycle sustainability assessment, rather than treating prefabrication primarily as a means of increasing productivity.

Cluster 4: Artificial Intelligence

AI is increasingly considered a means of extending BIM and Digital Twin capabilities from information management and monitoring towards prediction and adaptive decision-making. The reviewed studies describe intelligent Digital Twins that combine human input and AI algorithms to monitor supply chains, anticipate disruptions, and support continuous learning [45]. Other work integrates BIM, automated data acquisition, lean production, and AI to support construction project management [27], while AI-based methods have been investigated for predicting material properties and supporting sustainable material selection [26]. These applications indicate that AI can contribute to SSCM when data generated across construction activities are converted into information that supports timely operational and strategic decisions.

However, the reviewed evidence also identifies limitations that constrain this potential. The reliability of AI-supported decisions depends on data quality, model performance, interoperability, and the ability to interpret changing operational conditions. The literature further highlights the influence of algorithm aversion and users' responses to algorithmic errors, indicating that technically sophisticated systems may not be adopted or trusted in practice [46,47]. In addition, concerns about overfitting, the integration of data from different project elements, and the commercial implementation of proposed systems remain unresolved [27]. The challenge is therefore not simply to improve predictive accuracy, but to establish conditions under which AI recommendations can be assessed, understood, and incorporated into real supply chain decisions.

For SSCM, the most relevant contribution of AI-enabled Digital Twins lies in connecting prediction with actionable decisions about procurement, material allocation, logistics, and disruption response. This requires reliable and interoperable data as well as appropriate human oversight and organizational learning. The reviewed studies provide a basis for this potential, but further empirical investigation is needed to establish how AI-supported decisions perform under real project conditions and whether they produce measurable improvements in sustainability, circularity, or supply chain resilience. Future work should consequently move beyond conceptual demonstrations towards validated applications that account for data integrity, human–algorithm interaction, and implementation constraints.

Cluster 5: Technology Integration

Technology integration research examines how BIM and Digital Twins can work with complementary technologies, including blockchain, IoT, RFID, GIS, and data analytics, to improve information exchange, traceability, procurement, logistics, and supply chain coordination. The reviewed literature indicates that digital technologies have been applied more extensively during design and construction than during later stages, such as existing building management and EOL recovery [48]. BIM–blockchain approaches have been proposed to improve procurement transparency, data security, traceability, and the execution of smart contracts [49–55]. Other studies investigate combinations of BIM with IoT, GIS, RFID, and Digital Twins to support logistics, vendor selection, material-flow management, monitoring, and risk management [56–64]. These applications collectively suggest that technology integration can connect information generated by different systems and stakeholders across construction supply chain activities.

Despite this breadth of proposed applications, the evidence is uneven in terms of implementation and validation. Several frameworks remain conceptual, while practical adoption is constrained by interoperability problems, cybersecurity risks, regulatory uncertainty, cost, legacy systems, and limited stakeholder acceptance [28,49–55]. Research on Digital Twins also indicates that digital representation and monitoring do not necessarily translate

into sustainability outcomes unless the resulting information supports intervention and decisions across the life cycle [56]. Similarly, the availability of integrated technologies does not by itself resolve organizational barriers or guarantee that information will be used consistently by different supply chain actors [65,66].

This cluster pinpoints that technological integration should be distinguished from effective supply chain integration. Connecting systems technically is only one part of the challenge; data must also be consistent, accessible, trusted, and relevant to the decisions of participating organizations. This cluster also provides enabling capabilities for Material Passports, OSC, RL, and circular resource management, but the practical value of these capabilities depends on common information requirements, governance arrangements, implementation guidance, and economic feasibility. Future research should therefore assess integrated digital systems in operational settings and investigate how technical interoperability can be translated into reliable information exchange, coordinated decisions, and measurable supply chain outcomes.

Cluster 6: Construction & Demolition Waste

Research on CDW examines how digital tools can support material assessment, waste prediction, environmental evaluation, and the identification of opportunities for reuse and recycling. BIM has been applied to support environmentally informed material selection and waste reduction [16], while BIM-based sustainability assessment frameworks have been proposed to compare material alternatives [67]. BIM-LCA studies further demonstrate how material choices can be assessed in terms of environmental impacts [68], and design-stage quantification can provide information about expected waste streams [69]. Other research develops material-level circularity frameworks [70], applies AI-based models to waste prediction [71], and investigates BIM- and virtual-reality-based approaches to visualizing circularity strategies and assessing material recovery potential [72]. Additional studies propose broader BIM-supported systems for tracking material availability, simulating deconstruction, recognizing waste, and supporting urban-scale circular economy activities [73–75].

Taken together, these studies show that digital technologies can improve the visibility and assessment of CDW-related material flows. However, their contributions are often limited by incomplete environmental or economic indicators, insufficient standardization, limited availability of reliable material data, and the need for validation in different construction contexts [16,67–70,76]. The literature also identifies implementation barriers related to regulation, training, digital infrastructure, and the expertise of demolition-phase stakeholders [77,78]. These findings reveal a persistent gap between the ability to predict or classify waste and the ability to ensure that materials are actually recovered and returned to productive use.

From an SSCM and CE perspective, CDW management should not be assessed only through waste quantities or recycling rates. Digital information has greater circular value when it supports decisions about waste prevention, material reuse, recovery, transportation, and subsequent demand. This requires continuity between design-stage information and EOL activities, as well as coordination between designers, contractors, demolition teams, material recovery organizations, and procurement actors. The principal research need is therefore to connect digital waste assessment with practical recovery processes and wider economic, institutional, and organizational conditions. Large-scale pilots, standardized material information, and consistent circularity indicators could help establish whether the proposed digital approaches deliver benefits beyond improved waste monitoring.

Cluster 7: Decision Making

The studies in this cluster examine how BIM and related analytical methods can support decisions concerning material quantities, design alternatives, procurement, logistics, and life

cycle sustainability. BIM-based quantity surveying and 4D planning approaches have been used to improve the accuracy of material take-offs, production planning, and transportation arrangements [29,79]. Other studies integrate BIM with environmental assessment and multi-criteria methods to compare design and material alternatives [80–86]. BIM-based procurement optimization further illustrates how model-derived quantities and project schedules can inform decisions about purchasing timing and quantities [87]. Research combining BIM with lean construction also highlights the potential to improve process coordination and productivity, although organizational and implementation barriers remain, particularly for smaller firms [88–90]. Collectively, these studies indicate a shift from using BIM primarily to represent project information towards using it as an input to analytical and operational decision support.

Decision-support capabilities are also being extended to logistics and material management. A Digital Twin-based shipping system is proposed using silos for transportation and temporary storage, with potential to reduce carbon emissions, although its implementation depends on project-specific conditions, road infrastructure, and reliable cost estimates [91]. The integration of Discrete Event Simulation with Digital Twins for construction logistics showed how this combination can support real-time scheduling, responsiveness, and adaptive planning when conditions change [92]. In addition, research on BIM-enabled materials management identified relationships between supplier collaboration, supply chain optimization, and BIM adoption [93]. These studies suggest that digital decision support can contribute to sustainable supply chains not only through design-stage assessment, but also through operational logistics and coordination. However, the sustainability effects depend on how analytical outputs are integrated into actual material-management and supply chain processes.

The cluster also highlights the importance of extending decision support beyond immediate construction operations and conventional building materials. Historic-BIM (HBIM) has been used to monitor structural deterioration and material degradation to support decisions about maintenance and intervention, although reliance on static databases can constrain its adaptability [94]. Research on earth-based construction materials identifies their potential to support a transition from linear to circular construction, while noting technical barriers related to testing protocols, thermal and mechanical performance, and durability under freeze–thaw conditions [95]. Complementary work on circularity indicators demonstrates the need to evaluate material and building characteristics systematically when comparing alternative design configurations [84]. Together, these studies indicate that informed sustainability decisions require not only geometric and material information, but also reliable data on condition, performance, durability, and circularity.

Despite these developments, the scope and reliability of decision-support approaches remain uneven. Some methods are restricted to particular building components, material categories, or geographical contexts [79,82]. Others are constrained by incomplete databases, limited coverage of life cycle impacts, or poor interoperability between BIM and LCA tools, which can necessitate manual calculations and reduce practical efficiency [81–83]. Moreover, improved analytical capability does not guarantee that decisions will be implemented effectively. Supplier constraints, transportation conditions, organizational collaboration, and the availability of reliable information can influence whether model-based recommendations are feasible in practice [87,93]. The evidence therefore suggests that decision quality depends on the integration of analytical methods with the operational and organizational context of construction supply chains.

For SSCM, the key contribution of this cluster is the potential to connect material and project information with decisions that have environmental, economic, and logistical consequences. BIM-based assessments can help compare alternatives, while Digital Twins

and dynamic data sources may extend these capabilities by reflecting changing asset and operational conditions. However, the reviewed literature does not yet establish that such integration consistently improves whole supply chain sustainability. Future research should examine how LCA, cost analysis, circularity indicators, procurement optimization, and real-time operational information can be combined within decision-support processes. Such work should also assess how recommendations are used by different supply chain actors and whether the resulting decisions lead to measurable improvements in resource efficiency and circularity.

Cluster 8: Communication/Data Exchange

Communication and data exchange form a cross-cutting requirement for coordinating information and decisions among construction supply chain participants. The reviewed studies associate BIM adoption with improved collaboration, communication, and supply chain optimization, while also indicating that the resulting sustainability benefits depend on organizational and supply chain conditions [96]. Digital Twins have been proposed to provide timely information and improve responsiveness [97,98], while digital supply chain twin models and related data-driven approaches aim to facilitate information exchange and disruption management [25,99]. Blockchain-based approaches have also been considered as a means of supporting secure and transparent information sharing across organizational boundaries [100,101]. Together, these studies suggest that effective communication is not simply a technical function: it is part of the coordination infrastructure needed to connect material information, operational activities, and decisions.

A recurring limitation is that improved information exchange does not necessarily produce coordinated circular material flows. Digital Twins may enhance visibility and operational monitoring, yet their specific role in enabling reuse, recovery, and reverse logistics remains insufficiently developed [97,98]. Research also identifies persistent problems involving data integration, information security, stakeholder responsibilities, and the practical exchange of information across organizational systems [100,101]. In addition, the uptake of recovered materials depends on market conditions, stakeholder confidence, and incentives; communication frameworks alone cannot eliminate these barriers [102]. These findings point to a distinction between making information available and establishing the collaborative arrangements through which that information is used.

From an SSCM perspective, communication and data exchange should connect information about material identity, condition, availability, location, and recovery potential with the decisions of designers, suppliers, contractors, logistics providers, and recovery organizations. BIM can provide structured information, while Digital Twins can support the updating and operational use of relevant data. However, these capabilities require agreed data requirements, clear responsibilities, reliable access arrangements, and appropriate governance. Future research should therefore investigate how secure and interoperable information exchange can be linked directly to procurement, reuse, and RL, and how organizational incentives influence the willingness of supply chain participants to share and act on information.

Cluster 9: Implementation

The implementation literature examines the organizational, financial, technical, and institutional conditions that influence the adoption of BIM, Digital Twins, and circular economy practices in construction supply chains. Research on global BIM adoption has highlighted the continuing challenges associated with translating BIM's technical capabilities into widespread practical implementation [103]. These challenges are particularly relevant for Small & Medium-Sized Enterprises (SMEs), which may face limited financial resources and technical expertise. Digital Twin implementation additionally requires appropriate model development, data quality control, information security, stakeholder

education, and interoperability [104,105]. Research on public sector procurement indicates that unclear responsibilities, limited early stakeholder involvement, and the absence of BIM-oriented procurement processes can restrict adoption [106]. Related work emphasizes the importance of incorporating BIM requirements into tendering, procurement documentation, and contractual arrangements [107]. Collectively, these findings indicate that implementation depends not only on the capabilities of digital technologies but also on the institutional mechanisms through which information requirements, responsibilities, and implementation expectations are established.

The same challenge extends to circular economy implementation. Research has identified a tendency to focus on recycling and recycled materials rather than addressing a wider range of life cycle strategies, including prevention, reuse, and recovery [108]. Other studies emphasize the need for CE strategies that address different stages of the built environment life cycle [109]. At the same time, supply chain resilience research highlights the importance of considering the viability and adaptive capacity of broader networks rather than assessing individual organizations in isolation [110]. Taken together, these findings show that the availability of technical solutions is not sufficient to ensure adoption. Implementation is also shaped by procurement incentives, contractual obligations, staff capabilities, regulatory conditions, organizational readiness, and the ability of supply chain actors to collaborate.

This cluster provides an implementation-oriented perspective on the preceding themes. Material Passports, AI-supported decision tools, interoperable digital systems, and RL processes can contribute to circular supply chains only when organizations have the capacity and incentives to use them. For SSCM, implementation should therefore be understood as a coordinated process involving technology, procurement, governance, skills development, and life cycle responsibilities. Future research should examine how these conditions interact across different project types and organizational contexts, with particular attention to SMEs and the practical allocation of implementation costs and benefits. Pilot projects and comparative case studies could help establish which combinations of technical and institutional arrangements are most feasible and how digital circularity strategies can be sustained beyond isolated demonstrations. Table 8 summarizes each cluster's key findings, including identified related challenges.

Table 8. Summary of Research Clusters and Key Findings.

Cluster	Key Themes	Findings	Challenges/Gaps
Material Passport	BIM-based material passports; LCA; disassembly and reuse information; integration with AI, RFID, and blockchain	Material Passports can structure material information and connect design-stage records with material management, recovery, and reuse decisions. Their value depends on whether information supports decisions across the material life cycle.	Incomplete design-stage data; fragmented databases; limited interoperability; insufficient economic indicators; weak connection between material information and practical procurement and recovery decisions.

Table 8. *Cont.*

Cluster	Key Themes	Findings	Challenges/Gaps
Reverse Logistics (RL)	BIM-supported material recovery; reclaimed-material assessment; AR, RFID, and GIS; reclaimed timber; integration of forward and reverse logistics	Digital tools can support material identification, condition assessment, recovery planning, and the incorporation of reclaimed components into subsequent construction and manufacturing activities.	Uncertainty regarding recovered material condition and availability; inspection and processing costs; limited market coordination; insufficient validation and scalability of integrated systems; weak integration with forward logistics and procurement.
Off-site Construction	BIM and Digital Twins in prefabrication; production and logistics coordination; carbon assessment; assembly planning; component standardization	OSC provides a structured setting for coordinating production, transportation, and assembly. BIM and Digital Twins can improve information flow, supply chain visibility, resource efficiency, and planning.	Narrow assessment of sustainability outcomes; limited consideration of cost, quality, recovery, and reuse; geographically or component-specific evidence; insufficient integration of design for disassembly and EOL planning.
Artificial Intelligence	AI-enabled Digital Twins; disruption prediction; sustainable material selection; predictive analytics; adaptive decision-making	AI can convert data from construction and supply chain activities into predictions and decision support for procurement, material allocation, logistics, and disruption response.	Data-quality and interoperability issues; overfitting; algorithm aversion and trust; limited evidence of scalability and commercial implementation; insufficient empirical validation of sustainability and resilience outcomes.
Technology Integration	BIM–Digital Twin integration; Blockchain and smart contracts, IoT, GIS, RFID, and data analytics; traceability and monitoring	Integrating digital technologies can connect information across systems and stakeholders and support transparency, traceability, logistics, procurement, and risk management.	Technical interoperability and cybersecurity challenges; legacy systems; regulatory uncertainty and cost; limited stakeholder acceptance; conceptual rather than operational validation; weak evidence linking integration to measurable sustainability outcomes.
Construction & Demolition Waste (CDW)	BIM-based waste quantification; BIM-LCA; AI-based waste prediction; circularity assessment; deconstruction and material recovery	Digital technologies can improve waste visibility, environmental assessment, material selection, waste prediction, and identification of reuse and recycling opportunities.	Incomplete environmental and economic indicators; inconsistent standards; limited reliable material data; insufficient validation across contexts; regulatory, training, and infrastructure barriers; weak connection between waste prediction and actual material recovery.

Table 8. *Cont.*

Cluster	Key Themes	Findings	Challenges/Gaps
Decision Making	BIM-based quantity surveying and 4D planning; LCA and multi-criteria assessment; procurement optimization; Digital Twin-based logistics; circularity indicators	BIM and analytical methods can support decisions about materials, design alternatives, procurement, transportation, and life cycle performance. Digital Twins may extend these capabilities through updated operational information and adaptive planning.	Incomplete databases and life cycle coverage; limited interoperability between BIM and LCA tools; context-specific methods; supplier and logistics constraints; insufficient evidence that improved analytical capabilities consistently lead to implemented decisions and measurable supply chain sustainability.
Communication/Data Exchange	BIM-enabled collaboration; Digital Twin-based information exchange; digital supply chain twins; blockchain-enabled transparency; secure inter-organizational communication	Information exchange provides a coordination mechanism linking material information, operational activities, and decisions among supply chain participants. BIM and Digital Twins can support structured and updated information, while blockchain-based approaches may enhance transparency and security.	Data integration and security concerns; unclear responsibilities; fragmented organizational systems; insufficient connection between information sharing and circular material flows; market and incentive barriers; limited evidence of direct effects on reuse and reverse logistics.
Implementation	BIM and Digital Twin adoption; procurement and contractual requirements; organizational readiness; SME capabilities; CE implementation and supply chain resilience	Adoption depends on the combined influence of technical capabilities, procurement arrangements, governance, skills, organizational readiness, and institutional conditions. Digital circularity requires coordinated implementation rather than isolated technological solutions.	Limited financial and technical capacity, particularly among SMEs; inadequate training; unclear responsibilities; weak procurement incentives and contractual provisions; regulatory and organizational barriers; limited comparative evidence on feasible implementation arrangements and the allocation of costs and benefits.

Considering the content analysis provided above, the research gap could be explored in five main groups interconnected to several clusters as follows:

The nine clusters collectively reveal that the literature has progressed considerably in developing digital technologies for construction, but their integration with circular supply chain processes remains fragmented. Across the Material Passport, RL, Technology Integration, Communication/Data Exchange, and Implementation clusters, BIM, Digital Twins, AI, Blockchain, IoT, RFID, and GIS are increasingly proposed to improve information availability, traceability, decision-making, and supply chain visibility. However, the connections between these digital capabilities and actual circular flows of materials, particularly reuse, recovery, and RL, remain comparatively underdeveloped.

A second cross-cluster gap concerns interoperability and data governance. Fragmented databases, heterogeneous information environments, limited data quality, weak interop-

erability, and insufficient information-sharing mechanisms recur across several clusters. These findings indicate that increasing the volume of digital information alone does not guarantee circular supply chain performance; rather, effective circularity requires interoperable, trusted, and continuously updated information flows across project actors and life cycle stages.

Third, the literature remains predominantly technology-centric, while organizational and institutional conditions for implementation receive comparatively less attention. Barriers including stakeholder resistance, limited technical knowledge, financial constraints, regulatory uncertainty, algorithm aversion, and institutional inertia appear across the clusters, suggesting that the transition toward digital circular supply chains is basically socio-technical rather than purely technological.

Although numerous conceptual frameworks and technology-enabled solutions have been proposed, their empirical validation, scalability, and economic feasibility remain limited. Many studies rely on individual case studies, theoretical models, or technology-specific demonstrations, with insufficient evidence regarding their performance across different project contexts, supply chain configurations, and organizational environments.

Finally, the cluster structure suggests that CE applications in construction remain strongly associated with waste reduction and recycling, while higher-value circular strategies such as reuse, material recovery, RL, and design for deconstruction remain less integrated with digital technologies. This fragmentation highlights the need for an integrated framework that connects lifecycle information, digital technologies, circular material flows, and supply chain decision-making rather than treating these elements as independent research domains.

4. Proposal of a New Digital–Circular Supply Chain Framework for Construction

Focusing on the review performed, this study proposes a Digital–Circular Supply Chain Framework as presented in Figure 7, to demonstrate the flow of information within a circular system, and the function of different tools in implementing circular supply chain. The framework employs BIM as the static information backbone, Digital Twins to enable the dynamic system feedback, and emerging technologies, such as AI, IoT, Blockchain, etc., as the enablers of circular value loops.

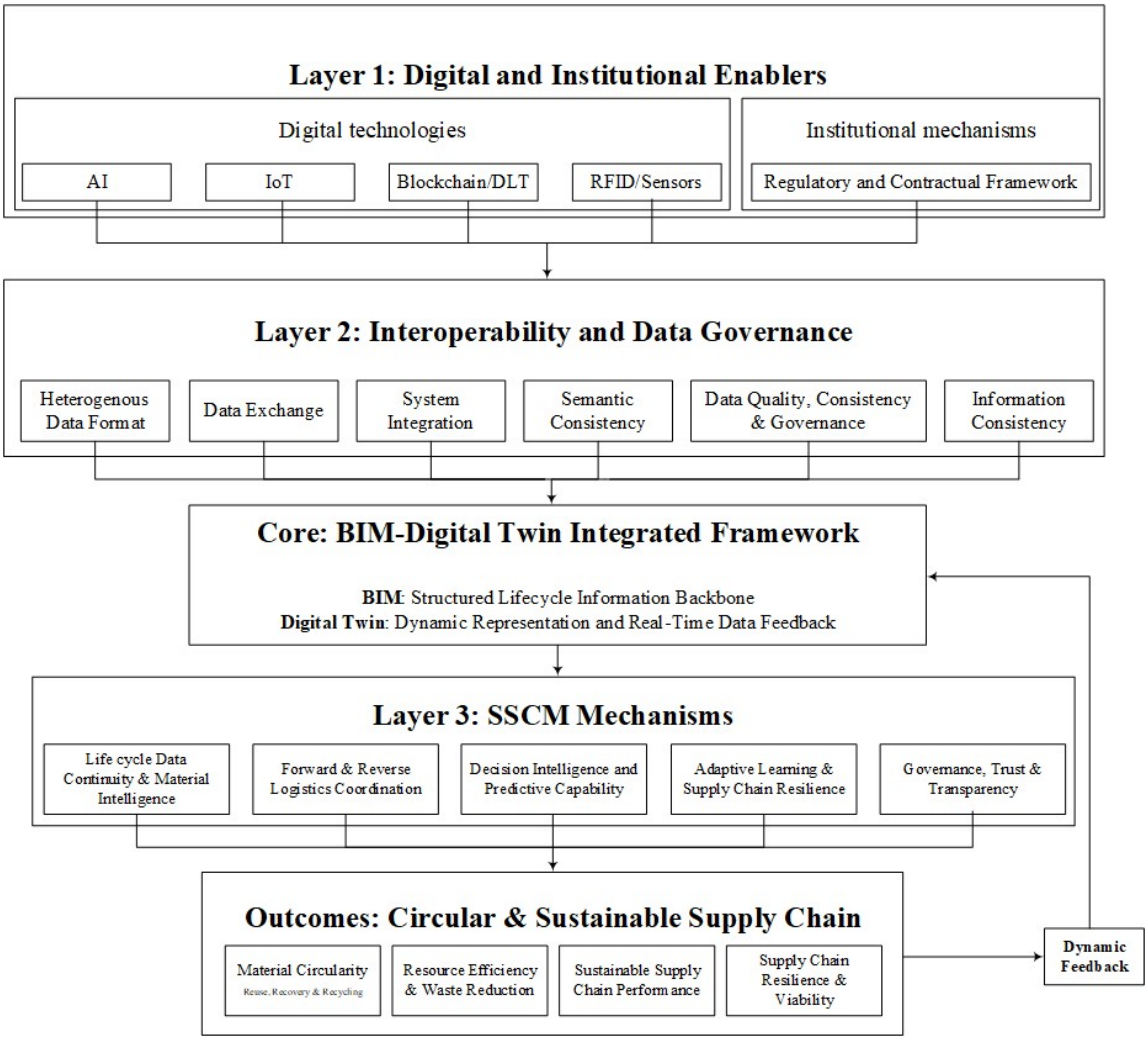

Figure 7. Digital–Circular Supply Chain Framework.

4.1. Proposed Digital–Circular Supply Chain Framework

Considering the explored gaps within the recent studies identified through the state-of-the-art review, this research proposes a Digital–Circular Supply Chain framework that conceptualizes BIM and Digital Twins as the fundamental digital infrastructures, and emerging digital technologies (including AI, IoT, Blockchain, Sensors, etc.) and regulatory and contractual frameworks as the complementary basis, to jointly enable the transition from a linear and fragmented construction supply chain to a data-driven, integrated, circular, and adaptive supply network.

The proposed framework was developed through a two-stage synthesis of the reviewed evidence. First, the findings and challenges identified within each of the nine thematic clusters were examined to identify recurring digital capabilities, supply chain functions, and implementation barriers. Second, findings that addressed similar supply chain functions across different clusters were consolidated through cross-cluster analysis. This process resulted in five higher-level mechanisms that represent the principal functions required to connect digital capabilities with sustainable and circular supply chain processes. Thus, the framework does not map one-to-one onto the nine clusters; rather, the clusters constitute the empirical knowledge base from which the higher-level mechanisms were derived. The traceability matrix is presented in Table 9.

Table 9. Traceability of the Framework to the Identified Research Clusters.

Research Cluster	Explored Gap	Framework Component
Material Passport	Material traceability, reuse information, data continuity	Life cycle Data Continuity & Material Intelligence
RL	Material recovery and weak integration with forward logistics	Forward & Reverse Logistics Coordination
OSC	Supply-chain visibility, logistics, sensors, continuous information	Data Continuity + Logistics Coordination
AI	Prediction, optimization, disruption management, algorithmic trust	Decision Intelligence + Adaptive Learning
Technology Integration	BIM–IoT–Blockchain–RFID–DT integration, interoperability, cybersecurity	Interoperability & Data Governance + Decision Intelligence
CDW	Waste quantification, LCA, material recovery, circularity	Material Intelligence + Reverse Logistics
Decision Making	LCA/LCC, planning, optimization, sustainability assessment	Decision Intelligence & Predictive Capability
Communication/Data Exchange	Information sharing, transparency, collaboration	Data Continuity + Governance, Trust & Transparency
Implementation	SMEs, skills, data quality, interoperability, regulation	Institutional Enablers + Interoperability + Governance

The framework is underpinned by digital and institutional foundations. First, BIM serves as the static and structured information backbone, integrating material, geometric, financial, and environmental data throughout the design and construction phases. The second phase pinpoints the interoperability and data-governance that increases the data and information to be utilized by BIM and Digital Twin. Third, Digital Twins extend the utility of BIM into the operational and EOL stages by facilitating dynamic feedback loops, real-time monitoring, and predictive analytics through continuous synchronization with physical assets. Fourth, emerging digital technologies, including AI, IoT, Blockchain, and RFID, act as critical enablers that enhance data acquisition, interoperability, and decentralized trust among supply chain actors. Finally, a robust regulatory and contractual pillar establishes the necessary governance, providing the mandates, incentives, and legal structures required to institutionalize circular supply chain practices within the industry. Together, these pillars support five interrelated mechanisms designed to optimize circular performance.

The proposed Digital–Circular Supply Chain Framework was derived through a structured synthesis of the nine thematic clusters identified in the scientometric and thematic analysis. Rather than directly translating individual clusters into framework components, conceptually related findings were consolidated into higher-level mechanisms representing the functions required for digital circular supply chain integration.

The upper layer of the framework represents the digital and institutional enablers identified across the clusters. AI, IoT, Blockchain/DLT, RFID/sensors, and regulatory and contractual mechanisms were retained as enabling capabilities rather than treated as independent outcomes because the reviewed literature consistently positioned them as technologies or institutional conditions that facilitate information capture, exchange, prediction, traceability, and coordination.

In the core layer of the framework, BIM and Digital Twins represent complementary but distinct digital capabilities. BIM serves as the static information backbone of the construction lifecycle, functioning as a structured repository for project, asset, material, and

lifecycle information and facilitating information accessibility and exchange [27]. In contrast, a Digital Twin extends this information foundation by providing a dynamic representation of the physical asset or process through continuous data acquisition and real-time feedback [27]. While BIM primarily supports the creation, management, and exchange of structured lifecycle information, the Digital Twin enables dynamic monitoring, condition assessment, prediction, and adaptive decision-making based on continuously updated data [27]. Therefore, the proposed framework does not treat BIM and Digital Twins as interchangeable technologies; rather, BIM provides the information foundation upon which the Digital Twin can operate, while the Digital Twin adds dynamic and real-time capabilities to the BIM-based information environment.

A cross-cutting issue identified across the thematic clusters is interoperability and data governance. The reviewed studies repeatedly identified fragmented databases, heterogeneous data structures, limited information exchange between BIM and other digital platforms, and insufficient interoperability among Digital Twins as barriers to implementation. Therefore, interoperability is not treated as an isolated technological component in the proposed framework; rather, it is considered a cross-cutting condition that enables continuous information exchange among BIM, Digital Twins, IoT, RFID/sensors, Blockchain/DLT, and downstream decision-making and supply chain processes. This condition is particularly important in circular supply chains, where material information must remain accessible and usable across different organisations and lifecycle stages, from design and procurement to construction, deconstruction, recovery, and reuse. Without interoperable and governed data, Material Passports may remain isolated repositories, Digital Twins may operate as disconnected models, and RL decisions may lack reliable information.

Five core mechanisms explored directly from this synthesis:

- Life cycle data continuity and material intelligence, primarily informed by the Material Passport, CDW Management, and OSC clusters;
- Forward and reverse logistics coordination, derived particularly from the RL and OSC clusters;
- Decision intelligence and predictive capability, supported by the AI and Decision-Making clusters;
- Adaptive learning and supply chain resilience, informed by the AI, Communication/Data Exchange, and Implementation clusters;
- Governance, trust, and transparency, reflecting recurring findings from Technology Integration, Communication/Data Exchange, and Implementation.

4.2. Core SSCM Mechanisms of the Framework

4.2.1. Life Cycle Data Continuity and Material Intelligence

The first mechanism points to the continuity and accumulation of material-related data during the entire building life cycle, spanning from design to deconstruction. BIM-based material libraries, when extended through Digital Twins, create persistent digital identities, encompassing material, component, and equipment, that would be promptly accessible to stakeholder during the maintenance phase for real-time monitoring [16] and offline information [111].

This mechanism underpins circular strategies such as material passports by providing stakeholders with a comprehensive information of material composition and analysis of sustainability indicators, design for disassembly (DfD) and reuse planning allowing efficient decision making upon the reusable based on design principals and recoverable materials, components, and equipment through a reliable and up-to-date quality control (QC) report remains accessible beyond the construction phase. Unlike traditional documentation practices, which often result in information loss at handover, the integration of

BIM and Digital Twins supports long-term material intelligence, persistent, accessible, and a prerequisite for effective CE implementation.

However, the literature reveals that this mechanism is constrained by data fragmentation [74], inconsistent standards [8], and limited interoperability between digital platforms [82], highlighting the need for integrated data governance structures within circular supply chains.

4.2.2. Digital Coordination of Forward and Reverse Supply Chain Flows

The second mechanism relates to the coordination of forward and reverse logistics. Where forward logistics encompass procurement, construction, and related logistics supply chain flow and reverse logistic pinpoints deconstruction, reuse, recycling supply chain flows.

Considering that most construction supply chains are designed and optimized for forward logistics [40], circular supply chains require the systematic integration of RL pathways and infrastructures.

BIM enables material recovery planning from early stage of design phase by embedding circularity considerations into construction design decisions and anticipation of demolition engineering requirement [112], while Digital Twins support real-time monitoring and adaptive coordination [113], expectedly during deconstruction and material redistribution. This dual capability allows supply chain actors to transition from reactive waste management to proactive circular logistics planning.

The review indicates that existing studies often treat RL as an isolated process. In the proposed framework, RL is positioned as an integral and digitally coordinated component of the supply chain, thereby addressing a key structural weakness in current CE-oriented construction practices, which allows design team to consider rehabilitation and strengthening of used material and elements prior to reuse, if required.

4.2.3. Decision Intelligence and Predictive Capability

The third mechanism emphasizes intelligent decision-making, enabled through the integration of BIM and Digital Twins with AI and advanced analytics. Digital Twins facilitate simulating various scenarios, allowing stakeholders to compare alternative design [114], procurement [60], and BIM enables comparing EOL strategies under different conditions (e.g., economic, environmental, and operational) [35]. This mechanism is expected to support sustainability assessment during the early-stage design phase, life cycle cost (LCC) and carbon emission optimization, predictive maintenance and material degradation forecasting, and risk-aware supply chain decision-making.

It is noted that the previous studies largely overlooked behavioural and organizational dimensions of decision intelligence, such as trust in algorithmic outputs, human-AI collaboration, and institutional readiness. Without addressing these factors, decision-support systems may experience partial adoption due to technical sophistication.

4.2.4. Adaptive Learning and Supply Chain Resilience

The fourth mechanism interprets BIM and Digital Twins as tools for adaptive learning and resilience-building within construction supply chains. Employing continuous data gathering and analysing, as well as performance monitoring, Digital Twins allow supply chains to learn from past projects, respond to issues and disruptions, and adjust circular strategies over time.

This mechanism is exactly points to the context of supply chain disruptions, material scarcity and price volatility, and rules and regulations updates related to sustainability indicators and waste management.

Embedding learning and adaptability into digital supply chain infrastructures, the proposed framework will extend circularity beyond static efficiency improvements toward long-term system viability and resilience.

4.2.5. Governance, Trust, and Transparency Across the Supply Chain

The fifth mechanism concentrates on governance and trust, critical enablers of circular supply chains which are under the control and management of multi-actor collaboration within longtime horizons. Integration of Blockchain and distributed ledger technologies with BIM and Digital Twins can enhance transparency, traceability, and accountability in material transactions and data exchange [15,115].

This mechanism strengthens verification of material origin and quality, sharing of sensitive data across organization within a secure communication, and amplifying circular procurement, RL, and contractual obligations.

In the proposed framework, the digital trust mechanisms not only literally emphasize technical features but also consider institutional enablers that affect stakeholder requirements to participate in circular supply chains. The absence of rule and regulation infrastructure and standardized contractual models is still a pivotal barrier to realizing these benefits in practice.

5. Future Research Directions

Based on the discussed clusters, the following future research directions are proposed.

5.1. Empirical Validation and Scalability of the Proposed Framework

Future research should empirically validate the proposed framework through case studies, pilot implementations, and longitudinal investigations across different construction projects and supply-chain contexts. Such studies are needed to examine whether the relationships identified in the literature can be translated into measurable improvements in information continuity, resource efficiency, waste reduction, and supply-chain resilience. Comparative studies across project types and organizational contexts could also clarify the scalability and boundary conditions of the framework.

5.2. Interoperability and Data Governance Across the Digital Supply Chain

A second direction concerns interoperability and data governance. The reviewed literature indicates that fragmented data environments, heterogeneous formats, and inconsistent information exchange remain important barriers to integrating BIM, Digital Twins, and complementary technologies. Future studies should therefore investigate common data structures, semantic interoperability, data ownership, access rights, and governance mechanisms that enable reliable information continuity across organizations and lifecycle stages.

5.3. AI-Enabled Decision Intelligence and Dynamic Digital Twins

Future research should further examine how AI can be integrated with BIM and Digital Twins to support predictive and adaptive decision-making. Particular attention is needed for the quality and reliability of real-time data, the explainability of AI-supported decisions, and the interaction between human decision-makers and algorithmic recommendations. This direction could strengthen the transition from digital representation and monitoring toward decision intelligence within construction supply chains.

5.4. Integration of Forward and Reverse Logistics

Another important direction is the integration of forward and reverse logistics. The reviewed studies indicate that procurement and material flows are often examined sepa-

rately from recovery, reuse, and recycling processes. Future research should investigate how BIM and Digital Twins can provide continuous information about material location, condition, availability, and recovery potential across both forward and reverse flows, thereby supporting more coordinated circular supply-chain operations.

5.5. Circular Material Management and Resource Recovery

Further research is also needed to connect digital information with practical circular resource management. Material Passports, BIM, Digital Twins, and waste-management technologies should be investigated not only as information repositories but as mechanisms for enabling material reuse, recovery, recycling, and design for disassembly. Empirical research should examine how such information can be incorporated into procurement, project planning, demolition, and post-use recovery decisions.

5.6. Organizational, Contractual, and Institutional Implementation

Finally, future studies should examine the organizational and institutional conditions required for implementation. Technical capabilities alone may not ensure successful adoption of BIM–Digital Twin-based supply-chain systems. Research is therefore needed on contractual arrangements, procurement requirements, data responsibilities, investment and cost considerations, organizational capabilities, and regulatory mechanisms that influence implementation across different supply-chain actors, particularly smaller organizations.

Overall, the future research agenda should move from technology-centred investigation toward empirically validated, interoperable, and supply-chain-oriented applications of BIM and Digital Twins. Greater integration of digital technologies with logistics, circular resource management, decision-making, and institutional mechanisms is therefore an important area for further investigation.

6. Research Limitations

Although this study aims to provide a comprehensive review of research on the application of BIM and Digital Twins in sustainable supply chain management, several limitations should be acknowledged:

- Database selection: Scopus was used as the sole bibliographic database, which may have resulted in the omission of relevant publications indexed exclusively in other databases. Although snowballing was employed to identify additional studies, future reviews could combine Scopus with Web of Science and other relevant databases to improve coverage and reduce potential database-selection bias.
- Search terminology: The use of predefined BIM-related terminology may have excluded some relevant studies that employed alternative expressions, such as "building information model," without explicitly mentioning BIM in the searched fields. Future research could broaden the search strategy to incorporate additional terminology and variations in how BIM and Digital Twins are described in the literature.
- Absence of formal quality appraisal: Given the integrated review approach adopted in this study, a formal study-level quality appraisal was not conducted. Consequently, the included studies were synthesized primarily based on their relevance to the research objectives rather than through a systematic assessment of their methodological quality. Future reviews could incorporate formal quality-assessment criteria to strengthen the evaluation of the evidence base.
- Citation-based selection bias: The use of a minimum threshold of 50 citations for the primary literature set may have favored older and more established publications, which have had more time to accumulate citations, while potentially underrepresenting recent and emerging research. This limitation is particularly relevant to rapidly evolving

topics such as Material Passports, RL, and AI-enabled Digital Twins. To mitigate this limitation, the citation-based selection was complemented by forward snowballing, which identified 13 additional conceptually relevant studies. Furthermore, supplementary publications from 2024 with at least one citation and all relevant publications from 2025, regardless of their citation counts, were incorporated into the review. Although these measures helped broaden the literature coverage, they may not have eliminated citation-related selection bias entirely.

7. Conclusions

This paper explored the application of BIM and Digital Twins in SSCM and CE within the construction industry. Through a comprehensive Scientometric and thematic review of 83 papers including 50 highly cited papers from Scopus (January 2019–20 July 2025), 13 papers selected using the snowball system, 14 papers in 2024 with 1 or more citations, and all related papers published in 2025 equal to 6, the study identified key research trends, categorized the literature into BIM and Digital Twins, and analysed their roles in advancing sustainable construction practices.

The findings demonstrate that BIM and Digital Twins can significantly optimise material usage, reduce waste, and enhance collaboration across construction supply chains. These technologies facilitate data-driven decision-making, improve LCA, and support the integration of CE principles, promoting the reuse and recycling of materials. However, challenges such as limited industry awareness, resistance to change, and inadequate technical expertise persist, hindering their widespread adoption. Addressing the challenges and offering incentives, including an extra technical bonus in the tender phase for Circular Supply Chain implementation in previous projects, as well as financial support, will enhance CE implementation in construction projects. In the meantime, promoting the reuse of materials in construction projects through clarification campaigns, publishing test results comparing the performance of reusable materials with the original materials, and reducing the price of reusable materials by providing a free-of-charge warehouse with easy access are workable solutions. These solutions will motivate the industry leaders to utilise secondary materials. Answering the second question, innovative achievements still need to be developed. Although various studies contribute to the development of frameworks and approaches to promote circular supply chains in the construction industry, the transition to practical outcomes is lacking.

The study proposes several future research directions, including the development of more accessible BIM tools for SMEs, the exploration of BIM integration with emerging technologies such as AI and IoT, and the establishment of standardised frameworks for data interoperability. Additionally, there is a need for further research on applying BIM and Digital Twins in real-world projects, particularly in regions with limited digital infrastructure.

By addressing these gaps, the construction industry can fully harness the potential of BIM and Digital Twins, contributing to more sustainable, cost-effective, and efficient supply chain management practices. The insights from this research can guide policymakers, practitioners, and researchers in promoting and implementing sustainable construction methods to mitigate the industry's environmental impact.

The study tries to encompass a comprehensive range of research focused on the application of BIM and Digital Twins in sustainable supply chain management; however, limitations are recognized. One limitation concerns the use of Scopus as the sole bibliographic database. Although snowballing was used to identify additional relevant studies, publications indexed exclusively in other databases may have been missed. Future reviews could combine Scopus with Web of Science and other relevant databases to reduce potential database-selection bias. The use of a defined BIM terminology may have excluded a limited

number of studies that used alternative expressions, such as "building information model", without referring explicitly to BIM in the searched fields. Also, considering the integrated review approach utilized for the research, a formal study-level quality appraisal is not performed. Moreover, the use of a citation threshold of 50 citations for the primary literature set may introduce citation-related selection bias. Highly cited publications are more likely to be older and to have had greater opportunities to accumulate citations, whereas recent and emerging research may be underrepresented. This limitation is particularly relevant to rapidly developing areas such as Material Passports, RL, and AI-enabled Digital Twins. To reduce this issue, the citation-based selection was complemented by forward snowballing, through which 13 additional conceptually relevant studies were identified. In addition, a supplementary set of papers was added, which included those published during 2024 with one or more citations and all related 2025 papers regardless of the number of citations.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/infrastructures11110397/s1.

Author Contributions: Conceptualization, F.Z. and R.M.; methodology, F.Z.; software, F.Z.; formal analysis, F.Z.; resources, R.M.; data curation, R.M.; writing—original draft preparation, F.Z.; writing—review and editing, R.M.; visualization, F.Z. and R.M.; supervision, R.M.; project administration, R.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The bibliographic records and search results used in this study were retrieved from Scopus. The datasets generated or analysed during the study are available from the corresponding author upon reasonable request, subject to the terms and conditions governing access to the underlying bibliographic database.

Acknowledgments: The authors acknowledge the use of ChatGPT-4o for refining the language used in the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
BIM	Building Information Modelling
CE	Circular Economy
CDW	Construction and Demolition Waste
DfD	Design for Disassembly
EOL	End-of-Life
GIS	Geographic Information System
HBIM	Historic-BIM
LCA	Life Cycle Assessment
LCC	life cycle costs
ML	Machine Learning
SMEs	Small & Medium-Sized Enterprises
OSC	Off-Site Construction
QC	Quality control
RFID	Radio Frequency Identification
RL	Reverse Logistics
SSCM	Sustainable Supply Chain Management

References

1. Jalaei, F.; Zoghi, M.; Khoshand, A. Life Cycle Environmental Impact Assessment to Manage and Optimize Construction Waste Using Building Information Modeling (BIM). *Int. J. Constr. Manag.* **2021**, *21*, 784–801. [CrossRef]

2. Tafesse, S.; Girma, Y.E.; Dessalegn, E. Analysis of the Socio-Economic and Environmental Impacts of Construction Waste and Management Practices. *Heliyon* **2022**, *8*, e09169. [CrossRef] [PubMed]
3. Guerra, B.C.; Shahi, S.; Mollaei, A.; Skaf, N.; Weber, O.; Leite, F.; Haas, C. Circular Economy Applications in the Construction Industry: A Global Scan of Trends and Opportunities. *J. Clean. Prod.* **2021**, *324*, 129125. [CrossRef]
4. Kneese, A.V. The Economics of Natural Resources. *Suppl. Popul. Resour. West. Intellect. Tradit.* **2025**, *1*, 281–309. [CrossRef]
5. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the Circular Economy: An Analysis of 114 Definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
6. Chen, X.; Qiu, D.; Chen, Y. Reverse Logistics in the Construction Industry: Status Quo, Challenges and Opportunities. *Buildings* **2024**, *14*, 1850. [CrossRef]
7. Trubina, N.; Leindecker, G.; Askar, R.; Karanafti, A.; Gómez-Gil, M.; Blázquez, T.; Güngör, B.; Bragança, L. Digital Technologies and Material Passports for Circularity in Buildings: An In-Depth Analysis of Current Practices and Emerging Trends. In *Presented at the 4th International Conference "Coordinating Engineering for Sustainability and Resilience"*; Springer: Cham, Germany, 2024. [CrossRef]
8. Gómez-Gil, M.; Askar, R.; Karanafti, A.; Trubina, N.; Blázquez, T.; Güngör, B.; Bragança, L.; Leindecker, G. Unlocking the Potential of Material and Building Passports. In *International Conference "Coordinating Engineering for Sustainability and Resilience"*; Springer: Cham, Germany, 2024. [CrossRef]
9. Karanafti, A.; Trubina, N.; Giarma, C.; Tsikaloudaki, K.; Theodosiou, T. Integrating BIMs in Construction and Demolition Waste Management for Circularity Enhancement-A Review. In *Presented at the International Conference "Coordinating Engineering for Sustainability and Resilience"*; Springer: Cham, Germany, 2024. [CrossRef]
10. Zahedi, F.; Dang, H.; Majrouhi Sardroud, J. Development of a BIM Implementation Roadmap: The Case of Iran. *J. Build. Des. Environ.* **2023**, *2*, 16336. [CrossRef]
11. Charef, R. The Use of Building Information Modelling in the Circular Economy Context: Several Models and a New Dimension of BIM (8D). *Clean. Eng. Technol.* **2022**, *7*, 100414. [CrossRef]
12. Akanbi, L.A.; Oyedele, L.O.; Akinade, O.O.; Ajayi, A.O.; Davila Delgado, M.; Bilal, M.; Bello, S.A. Salvaging Building Materials in a Circular Economy: A BIM-Based Whole-Life Performance Estimator. *Resour. Conserv. Recycl.* **2018**, *129*, 175–186. [CrossRef]
13. Behún, M.; Behúnová, A. Advanced Innovation Technology of BIM in a Circular Economy. *Appl. Sci.* **2023**, *13*, 7989. [CrossRef]
14. Jemal, K.M.; Kabzhassarova, M.; Shaimkhanov, R.; Dikhanbayeva, D.; Turkyilmaz, A.; Durdyev, S.; Karaca, F. Facilitating Circular Economy Strategies Using Digital Construction Tools: Framework Development. *Sustainability* **2023**, *15*, 877. [CrossRef]
15. AlJaber, A.; Alasmari, E.; Martinez-Vazquez, P.; Baniotopoulos, C. Life Cycle Cost in Circular Economy of Buildings by Applying Building Information Modeling (BIM): A State of the Art. *Buildings* **2023**, *13*, 1858. [CrossRef]
16. Zahedi, F.; Alavi, H.; Majrouhi Sardroud, J.; Dang, H. Digital Twins in the Sustainable Construction Industry. *Buildings* **2024**, *14*, 3613. [CrossRef]
17. Kaewunruen, S.; Baniotopoulos, C.; Guo, Y.; Sengsri, P.; Teuffel, P.; Bajare, D. 6D-BIM Applications to Enrich Circular Value Chains and Stakeholder Engagement Within Built Environments. In *Presented at the International Conference "Coordinating Engineering for Sustainability and Resilience"*; Springer: Cham, Germany, 2024. [CrossRef]
18. Charef, R.; Morel, J.-C.; Rakhshan, K. Barriers to Implementing the Circular Economy in the Construction Industry: A Critical Review. *Sustainability* **2021**, *13*, 12989. [CrossRef]
19. Badenko, V.; Bolshakov, N.; Celani, A.; Puglisi, V. Principles for Sustainable Integration of BIM and Digital Twin Technologies in Industrial Infrastructure. *Sustainability* **2024**, *16*, 9885. [CrossRef]
20. Theeraworawit, M.; Suriyankietkaew, S.; Hallinger, P. Sustainable Supply Chain Management in a Circular Economy: A Bibliometric Review. *Sustainability* **2022**, *14*, 9304. [CrossRef]
21. Nguyen, T.D.; Adhikari, S. The Role of BIM in Integrating Digital Twin in Building Construction: A Literature Review. *Sustainability* **2023**, *15*, 10462. [CrossRef]
22. Benachio, G.L.F.; Freitas, M.D.C.D.; Tavares, S.F. Circular Economy in the Construction Industry: A Systematic Literature Review. *J. Clean. Prod.* **2020**, *260*, 121046. [CrossRef]
23. Elshater, A.; Abusaada, H. Developing Process for Selecting Research Techniques in Urban Planning and Urban Design with a PRISMA-Compliant Review. *Soc. Sci.* **2022**, *11*, 471. [CrossRef]
24. Chen, C.; Hu, Z.; Liu, S.; Tseng, H. Emerging Trends in Regenerative Medicine: A Scientometric Analysis in CiteSpace. *Expert Opin. Biol. Ther.* **2012**, *12*, 593–608. [CrossRef] [PubMed]
25. Ivanov, D.; Dolgui, A. A Digital Supply Chain Twin for Managing the Disruption Risks and Resilience in the Era of Industry 4.0. *Prod. Plan. Control* **2021**, *32*, 775–788. [CrossRef]
26. Baduge, S.K.; Thilakarathna, S.; Perera, J.S.; Arashpour, M.; Sharafi, P.; Teodosio, B.; Shringi, A.; Mendis, P. Artificial Intelligence and Smart Vision for Building and Construction 4.0: Machine and Deep Learning Methods and Applications. *Autom. Constr.* **2022**, *141*, 104440. [CrossRef]

27. Sacks, R.; Brilakis, I.; Pikas, E.; Xie, H.S.; Girolami, M. Construction with Digital Twin Information Systems. *Data-Centric Eng.* **2020**, *1*, e14. [CrossRef]
28. Li, J.; Kassem, M. Applications of Distributed Ledger Technology (DLT) and Blockchain-Enabled Smart Contracts in Construction. *Autom. Constr.* **2021**, *132*, 103955. [CrossRef]
29. Bortolini, R.; Formoso, C.T.; Viana, D.D. Site Logistics Planning and Control for Engineer-to-Order Prefabricated Building Systems Using BIM 4D Modeling. *Autom. Constr.* **2019**, *98*, 248–264. [CrossRef]
30. Etikan, I. Comparision of Snowball Sampling and Sequential Sampling Technique. *Biom. Biostat. Int. J.* **2015**, *3*, 6–7. [CrossRef]
31. Sanchez, B.; Honic, M.; Leite, F.; Herthogs, P.; Stouffs, R. Augmenting Materials Passports to Support Disassembly Planning Based on Building Information Modelling Standards. *J. Build. Eng.* **2024**, *90*, 109083. [CrossRef]
32. Honic, M.; Kovacic, I.; Sibenik, G.; Rechberger, H. Data- and Stakeholder Management Framework for the Implementation of BIM-Based Material Passports. *J. Build. Eng.* **2019**, *23*, 341–350. [CrossRef]
33. Atta, I.; Bakhoum, E.S.; Marzouk, M.M. Digitizing Material Passport for Sustainable Construction Projects Using BIM. *J. Build. Eng.* **2021**, *43*, 103233. [CrossRef]
34. de Neyra, P.L.A.; Celoza, A. Deconstruction Information Model-Based Material Passports for Promoting Circular Economy in the AEC Industry through the Use of Building Information Modeling: A Literature Review. In *Construction Research Congress 2024*; ASCE Library: Reston, VA, USA, 2024. [CrossRef]
35. Charef, R.; Emmitt, S. Uses of Building Information Modelling for Overcoming Barriers to a Circular Economy. *J. Clean. Prod.* **2021**, *285*, 124854. [CrossRef]
36. Olumo, A.; Haas, C. Building Material Reuse: An Optimization Framework for Sourcing New and Reclaimed Building Materials. *J. Clean. Prod.* **2024**, *479*, 143892. [CrossRef]
37. Chileshe, N.; Jayasinghe, R.S.; Rameezdeen, R. Information Flow-Centric Approach for Reverse Logistics Supply Chains. *Autom. Constr.* **2019**, *106*, 102858. [CrossRef]
38. Yen, Y.-W.; Svilans, T. A Digital Framework for Robotic Processing of Reclaimed Timber. Presented at the World Conference on Timber Engineering 2025, Brisbane, Australia, 22–26 June 2025. [CrossRef]
39. Zboinska, M.A.; Göbel, F. Digital Tool Integrations for Architectural Reuse of Salvaged Building Materials. *Autom. Constr.* **2025**, *170*, 105947. [CrossRef]
40. Ding, L.; Wang, T.; Chan, P.W. Forward and Reverse Logistics for Circular Economy in Construction: A Systematic Literature Review. *J. Clean. Prod.* **2023**, *388*, 135981. [CrossRef]
41. Wang, Y.; Li, H.; Shen, K.; Yang, S. From Profit to Preservation: A Review of Digital Technology Enabling Sustainable Prefabricated Building Supply Chain Management. *Buildings* **2025**, *15*, 2004. [CrossRef]
42. Ding, Z.; Liu, S.; Luo, L.; Liao, L. A Building Information Modeling-Based Carbon Emission Measurement System for Prefabricated Residential Buildings during the Materialization Phase. *J. Clean. Prod.* **2020**, *264*, 121728. [CrossRef]
43. Gbadamosi, A.-Q.; Mahamadu, A.-M.; Oyedele, L.O.; Akinade, O.O.; Manu, P.; Mahdjoubi, L.; Aigbavboa, C. Offsite Construction: Developing a BIM-Based Optimizer for Assembly. *J. Clean. Prod.* **2019**, *215*, 1180–1190. [CrossRef]
44. Lee, D.; Lee, S. Digital Twin for Supply Chain Coordination in Modular Construction. *Appl. Sci.* **2021**, *11*, 5909. [CrossRef]
45. Ivanov, D. Intelligent Digital Twin (iDT) for Supply Chain Stress-Testing, Resilience, and Viability. *Int. J. Prod. Econ.* **2023**, *263*, 108938. [CrossRef]
46. Dietvorst, B.J.; Simmons, J.P.; Massey, C. Overcoming Algorithm Aversion: People Will Use Imperfect Algorithms If They Can (Even Slightly) Modify Them. *Manag. Sci.* **2018**, *64*, 1155–1170. [CrossRef]
47. Kremer, M.; Moritz, B.; Siemsen, E. Demand Forecasting Behavior: System Neglect and Change Detection. *Manag. Sci.* **2011**, *57*, 1827–1843. [CrossRef]
48. Banihashemi, S.; Meskin, S.; Sheikhkhoshkar, M.; Mohandes, S.R.; Hajirasouli, A.; LeNguyen, K. Circular Economy in Construction: The Digital Transformation Perspective. *Clean. Eng. Technol.* **2024**, *18*, 100715. [CrossRef]
49. Kiu, M.S.; Chia, F.C.; Wong, P.F. Exploring the Potentials of Blockchain Application in Construction Industry: A Systematic Review a Systematic Review. *Int. J. Constr. Manag.* **2020**, *22*, 2931–2940. [CrossRef]
50. Shojaei, A. Exploring Applications of Blockchain Technology in the Construction Industry. *Proc. Int. Struct. Eng. Constr.* **2019**, *6*, CON-31-1–CON-31-6. [CrossRef]
51. Elghaish, F.; Hosseini, M.R.; Kocaturk, T.; Arashpour, M.; Bararzadeh Ledari, M. Digitalised Circular Construction Supply Chain: An Integrated BIM-Blockchain Solution. *Autom. Constr.* **2023**, *148*, 104746. [CrossRef]
52. Heydari, M.H.; Naderi, H.; Shojaei, A. BIM and Blockchain Integration in Construction Procurement Planning. Presented at the Construction Research Congress 2024, Des Moines, IA, USA, 20–23 March 2024. [CrossRef]
53. Li, X.; Lu, W.; Xue, F.; Wu, L.; Zhao, R.; Lou, J.; Xu, J. Blockchain-Enabled IoT-BIM Platform for Supply Chain Management in Modular Construction. *J. Constr. Eng. Manag.* **2022**, *148*, 04021195. [CrossRef]

54. Hijazi, A.A.; Perera, S.; Calheiros, R.N.; Alashwal, A. Rationale for the Integration of BIM and Blockchain for the Construction Supply Chain Data Delivery: A Systematic Literature Review and Validation through Focus Group. *J. Constr. Eng. Manag.* **2021**, *147*, 03121005. [CrossRef]
55. Liu, H.; Han, S.; Zhu, Z. Blockchain Technology toward Smart Construction: Review and Future Directions. *J. Constr. Eng. Manag.* **2023**, *149*, 102694. [CrossRef]
56. Zhang, Z.; Wei, Z.; Court, S.; Yang, L.; Wang, S.; Thirunavukarasu, A.; Zhao, Y. A Review of Digital Twin Technologies for Enhanced Sustainability in the Construction Industry. *Buildings* **2024**, *14*, 1113. [CrossRef]
57. Tsilimantou, E.; Delegou, E.T.; Nikitakos, I.A.; Ioannidis, C.; Moropoulou, A. GIS and BIM as Integrated Digital Environments for Modeling and Monitoring of Historic Buildings. *Appl. Sci.* **2020**, *10*, 1078. [CrossRef]
58. Deng, Y.; Gan, V.J.L.; Das, M.; Cheng, J.C.P.; Anumba, C. Integrating 4D BIM and GIS for Construction Supply Chain Management. *J. Constr. Eng. Manag.* **2019**, *145*, 04019016. [CrossRef]
59. Chen, P.-H.; Nguyen, T.C. A BIM-WMS Integrated Decision Support Tool for Supply Chain Management in Construction. *Autom. Constr.* **2019**, *98*, 289–301. [CrossRef]
60. Chen, Q.; Adey, B.T.; Haas, C.; Hall, D.M. Using Look-Ahead Plans to Improve Material Flow Processes on Construction Projects When Using BIM and RFID Technologies. *Constr. Innov.* **2020**, *20*, 471–508. [CrossRef]
61. Wang, Z.; Hu, H.; Gong, J.; Ma, X.; Xiong, W. Precast Supply Chain Management in Off-Site Construction: A Critical Literature Review. *J. Clean. Prod.* **2019**, *232*, 1204–1217. [CrossRef]
62. Copeland, S.; Bilec, M. Buildings as Material Banks Using RFID and Building Information Modeling in a Circular Economy. *Procedia CIRP* **2020**, *90*, 143–147. [CrossRef]
63. Nguyen, T.; Duong, Q.H.; Nguyen, T.V.; Zhu, Y.; Zhou, L. Knowledge Mapping of Digital Twin and Physical Internet in Supply Chain Management: A Systematic Literature Review. *Int. J. Prod. Econ.* **2022**, *244*, 108381. [CrossRef]
64. Barykin, S.Y.; Bochkarev, A.A.; Kalinina, O.V.; Yadykin, V.K. Concept for a Supply Chain Digital Twin. *Int. J. Math. Eng. Manag. Sci.* **2020**, *5*, 1498–1515. [CrossRef]
65. Demestichas, K.; Daskalakis, E. Information and Communication Technology Solutions for the Circular Economy. *Sustainability* **2020**, *12*, 7272. [CrossRef]
66. Çetin, S.; De Wolf, C.; Bocken, N. Circular Digital Built Environment: An Emerging Framework. *Sustainability* **2021**, *13*, 6348. [CrossRef]
67. Olawumi, T.O.; Chan, D.W.M. An Empirical Survey of the Perceived Benefits of Executing BIM and Sustainability Practices in the Built Environment. *Constr. Innov.* **2019**, *19*, 321–342. [CrossRef]
68. Figueiredo, K.; Pierott, R.; Hammad, A.W.A.; Haddad, A. Sustainable Material Choice for Construction Projects: A Life Cycle Sustainability Assessment Framework Based on BIM and Fuzzy-AHP. *Build. Environ.* **2021**, *196*, 107805. [CrossRef]
69. Soust-Verdaguer, B.; Llatas, C.; Moya, L. Comparative BIM-Based Life Cycle Assessment of Uruguayan Timber and Concrete-Masonry Single-Family Houses in Design Stage. *J. Clean. Prod.* **2020**, *277*, 121958. [CrossRef]
70. Spišáková, M.; Mandičák, T.; Mésároš, P.; Špak, M. Waste Management in a Sustainable Circular Economy as a Part of Design of Construction. *Appl. Sci.* **2022**, *12*, 4553. [CrossRef]
71. Munaro, M.R.; Tavares, S.F. A Review on Barriers, Drivers, and Stakeholders towards the Circular Economy: The Construction Sector Perspective. *Clean. Responsible Consum.* **2023**, *8*, 100107. [CrossRef]
72. Akinade, O.O.; Oyedele, L.O. Integrating Construction Supply Chains within a Circular Economy: An ANFIS-Based Waste Analytics System (A-WAS). *J. Clean. Prod.* **2019**, *229*, 863–873. [CrossRef]
73. O'Grady, T.M.; Brajkovich, N.; Minunno, R.; Chong, H.-Y.; Morrison, G.M. Circular Economy and Virtual Reality in Advanced BIM-Based Prefabricated Construction. *Energies* **2021**, *14*, 4065. [CrossRef]
74. Chen, Q.; Feng, H.; Garcia De Soto, B. Revamping Construction Supply Chain Processes with Circular Economy Strategies: A Systematic Literature Review. *J. Clean. Prod.* **2022**, *335*, 130240. [CrossRef]
75. Schützenhofer, S.; Kovacic, I.; Rechberger, H.; Mack, S. Improvement of Environmental Sustainability and Circular Economy through Construction Waste Management for Material Reuse. *Sustainability* **2022**, *14*, 11087. [CrossRef]
76. Hossain, M.U.; Ng, S.T.; Antwi-Afari, P.; Amor, B. Circular Economy and the Construction Industry: Existing Trends, Challenges and Prospective Framework for Sustainable Construction. *Renew. Sustain. Energy Rev.* **2020**, *130*, 109948. [CrossRef]
77. Shi, Y.; Xu, J. BIM-Based Information System for Econo-Enviro-Friendly End-of-Life Disposal of Construction and Demolition Waste. *Autom. Constr.* **2021**, *125*, 103611. [CrossRef]
78. Liu, J.; Wu, P.; Jiang, Y.; Wang, X. Explore Potential Barriers of Applying Circular Economy in Construction and Demolition Waste Recycling. *J. Clean. Prod.* **2021**, *326*, 129400. [CrossRef]
79. Khadim, N.; Agliata, R.; Marino, A.; Thaheem, M.J.; Mollo, L. Critical Review of Nano and Micro-Level Building Circularity Indicators and Frameworks. *J. Clean. Prod.* **2022**, *357*, 131859. [CrossRef]
80. Khosakitchalert, C.; Yabuki, N.; Fukuda, T. Improving the Accuracy of BIM-Based Quantity Takeoff for Compound Elements. *Autom. Constr.* **2019**, *106*, 102891. [CrossRef]

81. 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. *Can. J. Civ. Eng.* **2020**, *47*, 186–201. [CrossRef]
82. Su, S.; Wang, Q.; Han, L.; Hong, J.; Liu, Z. BIM-DLCA: An Integrated Dynamic Environmental Impact Assessment Model for Buildings. *Build. Environ.* **2020**, *183*, 107218. [CrossRef]
83. Zhang, Y.; Jiang, X.; Cui, C.; Skitmore, M. BIM-Based Approach for the Integrated Assessment of Life Cycle Carbon Emission Intensity and Life Cycle Costs. *Build. Environ.* **2022**, *226*, 109691. [CrossRef]
84. Morel, J.-C.; Charef, R.; Hamard, E.; Fabbri, A.; Beckett, C.; Bui, Q.-B. Earth as Construction Material in Thecircular Economy Context: Practitioner Perspectives on Barriers to Overcome. *Philos. Trans. R. Soc. B* **2021**, *376*, 20200182. [CrossRef] [PubMed]
85. Chang, Y.-T.; Hsieh, S.-H. Development and Application of an Enhanced Building Circularity Indicator: A Pilot Study in Taiwan. *J. Clean. Prod.* **2025**, *502*, 145363. [CrossRef]
86. Yardimci, Y.; Kurucay, E. LCA-TOPSIS Integration for Minimizing Material Waste in the Construction Sector: A BIM-Based Decision-Making. *Buildings* **2024**, *14*, 3919. [CrossRef]
87. Najjar, M.K.; Figueiredo, K.; Evangelista, A.C.J.; Hammad, A.W.A.; Tam, V.W.Y.; Haddad, A. Life Cycle Assessment Methodology Integrated with BIM as a Decision-Making Tool at Early-Stages of Building Design. *Int. J. Constr. Manag.* **2022**, *22*, 541–555. [CrossRef]
88. Kalantari, M.; Taghaddos, H.; Heydari, M. BIM Framework for Efficient Material Procurement Planning. *Autom. Constr.* **2024**, *168*, 105803. [CrossRef]
89. Meng, X. Lean Management in the Context of Construction Supply Chains. *Int. J. Prod. Res.* **2019**, *57*, 3784–3798. [CrossRef]
90. Li, S.; Fang, Y.; Wu, X. A Systematic Review of Lean Construction in Mainland China. *J. Clean. Prod.* **2020**, *257*, 120581. [CrossRef]
91. Al-Qazzaz, I.; Osorio-Sandoval, C.A.; Tokbolat, S.; Thermou, G. Integration of Building Information Modeling into Building Circularity Assessment: A Systematic Review. *Built Environ. Proj. Asset Manag.* **2025**, *15*, 574–593. [CrossRef]
92. Greif, T.; Stein, N.; Flath, C.M. Peeking into the Void: Digital Twins for Construction Site Logistics. *Comput. Ind.* **2020**, *121*, 103264. [CrossRef]
93. Agalianos, K.; Ponis, S.T.; Aretoulaki, E.; Plakas, G.; Efthymiou, O. Discrete Event Simulation and Digital Twins: Review and Challenges for Logistics. *Procedia Manuf.* **2020**, *51*, 1636–1641. [CrossRef]
94. Junussova, T.; Nadeem, A.; Kim, J.R.; Azhar, S. Key Drivers for BIM-Enabled Materials Management: Insights for a Sustainable Environment. *Buildings* **2024**, *14*, 84. [CrossRef]
95. Mol, A.; Cabaleiro, M.; Sousa, H.S.; Branco, J.M. HBIM for Storing Life-Cycle Data Regarding Decay and Damage in Existing Timber Structures. *Autom. Constr.* **2020**, *117*, 103262. [CrossRef]
96. Soust-Verdaguer, B.; Gutiérrez Moreno, J.A.; Cagigas, D.; Hoxha, E.; Llatas, C. Supporting Sustainability Assessment of Building Element Materials Using a BIM-Plug-in for Multi-Criteria Decision-Making. *J. Build. Eng.* **2024**, *97*, 110818. [CrossRef]
97. Alsehaimi, A.; Waqar, A.; Alrasheed, K.A.; Bageis, A.S.; Almujibah, H.; Benjeddou, O.; Khan, A.M. Building a Sustainable Future: BIM's Role in Construction, Logistics, and Supply Chain Management. *Ain Shams Eng. J.* **2024**, *15*, 103103. [CrossRef]
98. Preut, A.; Kopka, J.-P.; Clausen, U. Digital Twins for the Circular Economy. *Sustainability* **2021**, *13*, 10467. [CrossRef]
99. Bakhshi, S.; Ghaffarianhoseini, A.; Ghaffarianhoseini, A.; Najafi, M.; Rahimian, F.; Park, C.; Lee, D. Digital Twin Applications for Overcoming Construction Supply Chain Challenges. *Autom. Constr.* **2024**, *167*, 105679. [CrossRef]
100. Badakhshan, E.; Ball, P. Applying Digital Twins for Inventory and Cash Management in Supply Chains under Physical and Financial Disruptions. *Int. J. Prod. Res.* **2023**, *61*, 5094–5116. [CrossRef]
101. Çimen, Ö. Construction and Built Environment in Circular Economy: A Comprehensive Literature Review. *J. Clean. Prod.* **2021**, *305*, 127180. [CrossRef]
102. Chen, Z.; Huang, L. Digital Twins for Information-Sharing in Remanufacturing Supply Chain: A Review. *Energy* **2021**, *220*, 119712. [CrossRef]
103. Ogunmakinde, O.E.; Sher, W.; Egbelakin, T. Circular Economy Pillars: A Semi-Systematic Review. *Clean Technol. Environ. Policy* **2021**, *23*, 899–914. [CrossRef]
104. Hijazi, A.A.; Perera, S.; Calheiros, R.N.; Alashwal, A. Stakeholder's Development Stack for Integrating BIM and Blockchain in Construction Supply Chain. In *Presented at the 2024 International Conference on Electrical, Computer and Energy Technologies (ICECET)*; IEEE: New York, NY, USA, 2024. [CrossRef]
105. Vidalakis, C.; Abanda, F.H.; Oti, A.H. BIM Adoption and Implementation: Focusing on SMEs. *Constr. Innov.* **2020**, *20*, 128–147. [CrossRef]
106. Moshood, T.; Nawanir, G.; Sorooshian, S.; Okfalisa, O. Digital Twins Driven Supply Chain Visibility within Logistics: A New Paradigm for Future Logistics. *Appl. Syst. Innov.* **2021**, *4*, 29. [CrossRef]
107. Alhusban, M.; Nasereddin, M.; Alghossoon, A.; Hatamleh, M.T. A Hybrid Conceptual Procurement Framework for BIM Uptake to Enhance Buildings' Sustainability Performance in the Jordanian Public Sector. *Int. J. Build. Pathol. Adapt.* **2025**, *43*, 93–116. [CrossRef]

108. Ivanov, D.; Dolgui, A. Stress Testing Supply Chains and Creating Viable Ecosystems. *Oper. Manag. Res.* **2022**, *15*, 475–486. [CrossRef]
109. Rahla, K.M.; Mateus, R.; Bragança, L. Selection Criteria for Building Materials and Components in Line with the Circular Economy Principles in the Built Environment—A Review of Current Trends. *Infrastructures* **2021**, *6*, 49. [CrossRef]
110. Matos, B.C.; Cruz, C.O.; Branc, F.B. Digitalization and Procurement in Construction Projects: An Integrated BIM-Based Approach. *J. Inf. Technol. Constr.* **2024**, *29*, 400–423. [CrossRef]
111. Zahedi, F.; Majrouhi Sardroud, J.; Kazemi, S. Global BIM Adoption Movements and Challenges: An Extensive Literature Review. Presented at the Creative Construction e-Conference 2022, Online, 9–11 July 2022. [CrossRef]
112. Gupta, S.; Jha, K.N.; Vyas, G. Proposing Building Information Modeling-Based Theoretical Framework for Construction and Demolition Waste Management: Strategies and Tools. *Int. J. Constr. Manag.* **2022**, *22*, 2345–2355. [CrossRef]
113. Turner, C.J.; Oyekan, J.; Stergioulas, L.; Griffin, D. Utilizing Industry 4.0 on the Construction Site: Challenges and Opportunities. *IEEE Trans. Ind. Inform.* **2020**, *17*, 746–756. [CrossRef]
114. Shahzad, M.; Shafiq, M.T.; Douglas, D.; Kassem, M. Digital Twins in Built Environments: An Investigation of the Characteristics, Applications, and Challenges. *Buildings* **2022**, *12*, 120. [CrossRef]
115. Cornelis, A.J. Dimension 6 BIM Implementation (Sustainability & Efficiency) in the Procurement Cycle Goods & Services. *Indones. J. Multidiscip. Sci.* **2022**, *1*, 1288–1298. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.