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Review

Building Information Modeling (BIM), Blockchain, and LiDAR Applications in Construction Lifecycle: Bibliometric, and Network Analysis

Amir Faraji [1,2], Shima Homayoon Arya [1,*], Elnaz Ghasemi [1], Payam Rahnamayiezekavat [2] and Srinath Perera [2]

[1] Construction Project Management Department, Faculty of Architecture, Khatam University, Tehran 1991813741, Iran; a.faraji@khatam.ac.ir or a.faraji@westernsydney.edu.au (A.F.); el.ghasemi@khatam.ac.ir (E.G.)
[2] School of Engineering, Design and Built Environment, Western Sydney University, Penrith, NSW 2751, Australia; p.zekavat@westernsydney.edu.au (P.R.); srinath.perera@westernsydney.edu.au (S.P.)
* Correspondence: sh.homayoon@khatam.ac.ir

Abstract: Investigating Industry 4.0 technologies and studying their impacts on various aspects of the construction industry, including stakeholders and the lifecycle, is vital to enhance novel applications of such technologies in an industry that is known as Construction 4.0. The main objective of the current state-of-the-art review is to provide a comprehensive literature review on three widely used Industry 4.0 technologies, Building Information Modeling (BIM), Blockchain, and LiDAR, which have strong potential to promote and optimize different activities of the project, and also, the integration of them can greatly impact the construction industry in the whole project lifecycle. A bibliometric analysis of keyword co-occurrence and citations revealed a significant number of publications from 2014 to 2023 investigating the selected technologies. Recent trends indicate that the majority of papers have considered the selected technologies in the integration with each other. However, a specific gap exists in the literature regarding the interactions and potential synergies among these technologies. This gap limits the understanding of how these integrations can address challenges unique to the construction industry and hinders the development of comprehensive solutions. The review has been analyzed and discussed in reference to the type of article, single or multi technologies, the lifecycle, and their applications. The study showed that the integration of BIM, Blockchain, and LiDAR, as a recent trend and as a beneficial solution to automate the whole construction process, has considerable capacities to improve the productivity of the construction industry. Finally, some application areas for the integration of these three technologies are concluded and are suggested, and therefore, an advantageous reference has been provided for scholars to plan their future research in this sector.

Keywords: building information modeling (BIM); blockchain technology (BCT); light detection and ranging (LiDAR); construction industry; project lifecycle

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1. Introduction

Today, innovative tools and methods employed in construction are seen as vital elements within the industry's frameworks. The construction sector, influential in economies globally due to its output and infrastructure, plays a significant role. Factors, such as rapid population growth, heightened demand, the urgency to expedite project completion, and the need to hasten investors' returns have necessitated a shift from traditional construction methods. The surge of Industry 4.0 and advancements in information technology platforms have propelled the focus on intelligent systems across various industries [1], holding promise for enhancing the efficiency of construction. Embracing new concepts and technologies could potentially steer construction towards becoming a tech-driven industry.

During the era of Industry 4.0, production systems structured as cyber-physical systems have the capacity to make informed decisions by engaging in real-time communication and collaboration between the "production of things" [2]. The pivotal attributes of Industry 4.0—connection, automation, digitalization, and decentralization—redefine traditional production setups into self-enhancing and self-adjusting systems, transitioning them into more adaptable and optimized forms [3,4]. Considerable attention has been drawn to the industry's accomplishments amid the fourth industrial revolution, prompting a global restructuring in production, resource utilization, human endeavors, and international interactions [5]. A smart construction site amalgamates diverse technologies, like BIM, drones, the Internet of Things (IoT), blockchain, and autonomous machinery, capable of functioning autonomously and responding to their surroundings [6]. The rise of digitization and the accessibility of industrial process data have led to a surge in job roles centered on digital transformation. These positions significantly influence the industry's future digitalization at the strategic "decision-making level" [7]. The industry's future lies in leveraging new technologies and methods by replicating processes, benefiting the entire construction lifecycle from site preparation and design to investment, construction, and ongoing building maintenance [8]. Embracing Industry 4.0 presents a significant opportunity to harmonize developmental objectives with the ongoing digital revolution in industrial progress [9]. This evolution is expected to enhance economic, environmental, and societal aspects by integrating modern technologies and processes [10].

Primarily, the utilization of IoT, digitalization, sensors, and big data [11] can ensure precise execution across various project dimensions [12]. Focusing on the importance of technology in the building design and construction phases, this section delves into the assessment and exploration of three specific Industry 4.0 technologies and their applications in construction. A digital platform is crucial, allowing all stakeholders to visualize designs, project planning, costs, and more, virtually spanning from feasibility studies to project completion before actual implementation. Seamless information integration, particularly within a platform capable of simulating, designing, predicting, and optimizing processes and systems in a digital environment, stands as a key approach to address construction challenges [13]. The construction sector amalgamates a diverse array of products and processes, stemming from various sources and distinct systems, all culminating in the common objective of erecting structures. Digitizing the constructed entity offers a unified platform enabling stakeholders to design, simulate, and optimize processes and solutions for optimal outcomes [14]. The capability to extract and input information within the model equips the design team with data to trace all of their decisions. Certain technologies possess the precision required to generate a digital replica encompassing the physical appearance, functionalities, features, processes, and systems [15]. BIM, Blockchain, and LiDAR are among these technologies. In the following, selected articles are provided for the text analysis of each of the mentioned technologies, and they are described respectively.

1.1. Building Information Modeling (BIM)

BIM is presented as a pivotal platform within the architecture, engineering, and construction (AEC) industry, enhancing collaboration and real-time interaction through added data layers during the design phase [16]. This innovation significantly improves material prediction, management, and monitoring, revolutionizing the industry [17]. BIM serves as the primary driver for bolstering collaboration, data exchange, and production in the ongoing digital transformation of the construction sector. It empowers operators to access comprehensive project data, including design, location, plans, and costs, by linking BIM models with real-time project progress [18]. Essentially functioning as a comprehensive "database with drawings", BIM serves as an information repository for the complete lifecycle of assets, from planning through maintenance and deconstruction [19]. Moreover, BIM has become a mechanism enabling all stakeholders to generate, share, exchange, and manage information across the project lifecycle [20,21], reshaping the construction landscape from design to maintenance [22]. By optimizing existing technical infrastructure, BIM empowers construction and design teams [23]. This methodology streamlines data generation and management throughout the entire AEC project lifecycle by consolidating interdisciplinary documents into a single repository [24].

Oyuga et al. define BIM application as the analysis and comparison of daily on-site work activities with generated plans, validating predicted performance before or during projects [25]. Additionally, Durdyev et al. emphasize the significance of BIM in small construction projects, enabling rapid and precise decision-making for construction managers based on crucial inputs, thereby impacting project success [26]. BIM's integration with various technologies, from imaging and geospatial tools to virtual and augmented reality, underscores its adaptability [27,28]. Four-dimensional BIM models, as highlighted by Hyarat et al., are imperative for monitoring and evaluating building processes [29]. Furthermore, BIM serves as the foundational step toward digital construction, integrating with a range of construction operations, like facility elevations, prefabricated projects, and project management activities [30]. The effective progress management of construction activities, previously challenging, becomes a fundamental responsibility of BIM [31]. Notably, Berges-Alvarez et al. emphasize the link, established by BIM, between sustainability-related choices and their impact on the environment and economy [32]. Despite challenges, such as uncertainty, failure, and misuse in BIM-based projects, Olanrewaju et al. propose employing a robust proof-of-concept to drive BIM into the conceptual design phase, facilitating informed decisions at the earliest stages of building design, albeit with the process being partially automated [33].

1.2. Blockchain Technology

Construction endeavors generate a vast array of data and information that necessitates preservation, continual updates, and consolidation. Enhanced management and analysis of construction data lead to expedited decision-making, thereby bolstering project quality and augmenting project profitability. Blockchain technology, heralded as a forthcoming database innovation, operates on an open, digital, and peer-to-peer premise, ensuring each node's responsibility for maintaining the ledger's integrity and authenticity. This quality makes Blockchain technology exceptional for auditing and accounting activities [34]. Moreover, Blockchain technology has demonstrated substantial potential in various sectors, such as the Internet of Things, transportation, and supply chain management [35]. As part of distributed ledger technologies (DLTs), Blockchain technology is introduced to tackle challenges associated with data transparency, immutability, trust, security, and privacy [36]. It obviates the need for trusted intermediaries in the conventional banking industry and oversees a shared, distributed ledger [37] facilitating peer-to-peer cryptographic currency transactions. The integration of Blockchain in construction projects significantly contributes to the sector's decentralization and digitalization. Utilizing a distributed public ledger with a shared and synchronized database, Blockchain records transactions while ensuring robust data provenance for BIM-supported projects [38].

As a disruptive innovation, blockchain technology has surpassed the transmission control protocol/Internet protocol and the Internet. Also known as DLT due to its utilization of distributed digital ledgers [39]. Blockchain technology originated in 2008 when an unidentified individual or group, Satoshi Nakamoto, launched Bitcoin, the world's first decentralized digital currency [40]. Since the start of 2022, approximately 16,911,700 blockchains have been mined, processing an average of 154,167 transactions per day, with an estimated market capitalization of US$326.525 billion [41]. Blockchain provides the possibility of exchanging data directly between different parties participating in a network without the need for intermediaries or third parties. It allows all network participants to jointly store and verify transaction information [42]. The Building-Lifecycle-Management-focused BIMCHAIN application combines the BIM idea with blockchain enablers, like decentralization and open collaboration, to boost BIM capabilities [43]. Through the usage of authorized parties listed in a ledger, blockchain contributes to the creation of trust inside an organization [44,45].

For the more efficient oversight and maintenance of contract agreements, a distributed ledger system is utilized, wherein each data block is intricately linked and replicated across multiple computers [46]. Users have the ability to select data to reside within a block within Blockchain, ensuring identical copies of these data are dispersed throughout the ledger [47]. Blockchain incorporates robust mechanisms for managing verified users, ensuring both accountability and scalability, fostering efficiency. While still in its nascent phase of implementation, Blockchain exhibits potential in handling design-related data across various disciplines, ensuring seamless data integration and connectivity among project stakeholders [48]. With the rising importance of construction, driven by advancements, like mobile applications and sensors, Blockchain technologies offer avenues for enhancing stakeholders', suppliers', and the value chain's interactions through novel authorization and accessibility methods [19]. The advent of smart contracts [49] has expanded the application of blockchain technologies beyond financial realms, finding utility in supply chain management, data storage across edge devices, and industrial control systems, among other diverse use cases [50].

1.3. Light Detection and Ranging (LiDAR)

LiDAR is a technology used for remote sensing, employing laser pulses to measure distances [51]. By recording the time it takes for the laser pulse to travel to and from a target, LiDAR calculates distance [52]. This information is utilized to generate a point cloud, a dataset featuring points in x, y, and z coordinates, along with supplementary details, like the phase and intensity [53]. Various types of LiDAR sensors exist, including portable triangulation laser scanners, Terrestrial Laser Scanners (TLSs), which are stationary and scan from a fixed position [54], Mobile Mapping Systems (MMSs) for scanning on the move (often mounted on vehicles or drones), Backpack-mounted Laser Scanners (BMLSs), Aerial Laser Scanners (ALSs), and UAV-based laser scanners. LiDAR finds applications in creating digital elevation models, surface modeling, facade analysis, and 4-D analysis for monitoring changes over time [55]. Additionally, it aids in offset analysis in design, reality capture, and as-built record-keeping. Combining LiDAR data with other datasets, such as subsurface data from geophysical methods, allows for comprehensive models for analysis across various industries and fields. Overall, LiDAR delivers high-quality, high-density data that seamlessly integrate into software for further analysis and visualization, proving invaluable across numerous applications [56]. The fusion of BIM and LiDAR opens new avenues for real-time construction fault identification and quality control beyond conventional data acquisition and analysis windows. LiDAR technology proves promising for surveying construction sites and has diverse applications, like as-built 3D building modeling and urban planning [22]. Oh et al. developed a technique for 3D as-built development using LiDAR. The authors' conceptual framework employed LiDAR for project interiors and an Unmanned Aerial Vehicle (UAV) for project exteriors [57]. Wang et al. provided a methodology for QC in construction tasks using BIM and LiDAR. A LiDAR-equipped quadrotor will fly on a specified path on the working site to collect the actual building or building components depending on their structure. A BIM-based system will follow the same flight path. A systematic QC approach for 3D created objects may be provided by comparing the geography attribute of the LiDAR-based and BIM-based components [58]. In general, LiDAR brings up a new field for augmented reality (AR) in terms of object tracking. Image Processing (IP) was formerly the primary tracking method for AR and spatial processing because it was the only viable option. However, IP is prone to calculation errors, is computationally costly, and adds an unnecessary degree of abstraction to the creation of geographical data. LiDAR is becoming increasingly essential in AR since to its rising price and inclusion on handheld devices [59].

This research evaluates previous studies on Industry 4.0 technologies—BIM, Blockchain, and LiDAR—aiming to comprehensively review their applications across various phases of the construction lifecycle. The study identifies gaps in integrating these technologies, emphasizing the potential for automating the entire construction process. It provides a comprehensive literature review to assist researchers in understanding this field and addresses key questions:

What is the current status of selected technologies research in the AECO industry?

What role does the integration of BIM, Blockchain, and LiDAR play in realizing the goals of industry 4.0, such as smart construction?

What are the future research directions of the mentioned technologies in the construction industry?

The paper's structure includes sections on article reviews, screening strategies, and categorization based on publication specifics. It discusses the applications of singular and combined technologies across the lifecycle, examines research subjects based on publication relevance, outlines future study areas, and concludes with a summary of findings.

2. Materials and Methods

The current study employs bibliometric and network analysis to explore the uses of BIM, Blockchain, and LiDAR throughout the construction lifecycle. Utilizing a scientific framework and data-driven approach, the collected articles were examined, focusing on the phrases "BIM", "Blockchain", and "LiDAR" within paper titles, abstracts, and keywords. This analysis was conducted on April 9, using scientific databases, including Web of Science, Science Direct, and Scopus, and the time range was set from 2014 to 2023. Table 1 shows the number of articles based on their paper type (Research, Review, Conference) and the three different databases. Considering that 2023 has not yet ended, the scope of the considered articles is up to May 2023. Certainly, the number of published articles until the end of 2023 is more than the collected values.

Table 1. Number of general literature search articles classified based on the paper type.

	Web of Science	ScienceDirect	Scopus
Research	5721	3873	4015
Review	2956	1611	834
Conference	472	548	206
Total	9149	6032	5055

The research delves into Industry 4.0 and advanced technologies within construction, aiming to facilitate integrated design and construction processes for enhanced monitoring, reduced design errors and environmental impacts, and minimized rework. Therefore, three technologies (BIM, LiDAR, and blockchain) were selected in order to achieve these goals. Consequently, there is a need for research to ensure that the proposed technologies, in addition to being new and up to date in the world, are currently used and exploited in most countries and are available for implementation in the construction stages of the project.

The articles have been refined in four stages. In the first stage, more than 1134 studies have been identified. Web of Science, Science Direct, and Scopus were chosen as primary sources due to their comprehensive coverage of scientific publications and swift indexing capabilities. These databases are the most common for conducting literature searches. After identifying the valid articles, several criteria were developed to improve the quality of the article review. First, articles in the English language were selected. Then, by removing duplicates and limiting studies only to prestigious academic journals and conference articles, this list was reduced to 734 articles. In the second stage, the articles were screened based on their title and abstract and the research questions. Only the articles that focused on technology in the construction industry were included in the final list. After this process, 561 articles remained. In the third step, articles with unrelated texts along with papers that do not have any access to the entire article were removed. Ultimately, 324 articles underwent data analysis due to their commitment to transparency, comprehensiveness, and an exploratory approach, allowing for the more objective scrutiny of search outcomes and the eradication of bias and errors. Figure 1 illustrates the steps of the methodology of this paper.

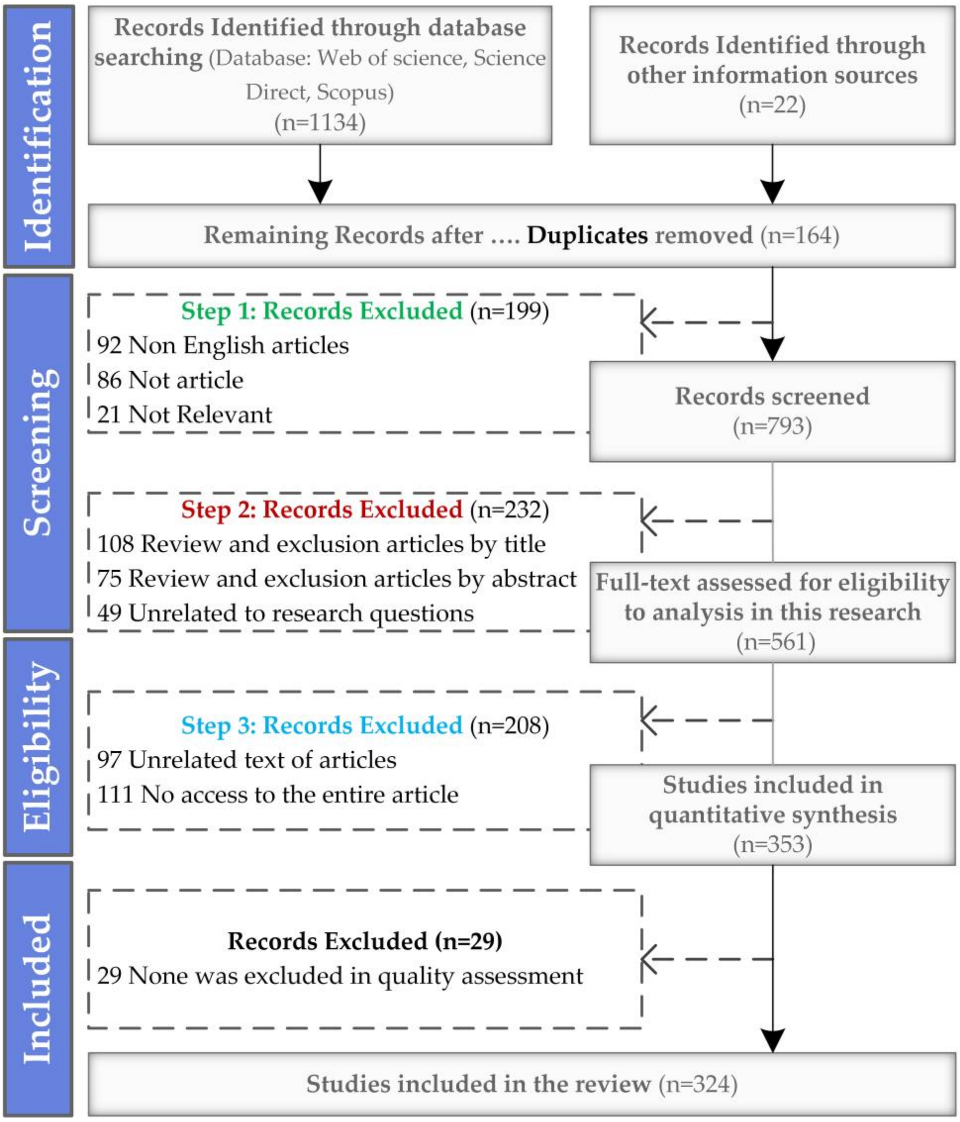

Figure 1. Research methodology.

This study employed a systematic review process alongside manual filtering, mitigating bias in the literature review results, enabling the transparent and replicable identification, evaluation, and synthesis of all pertinent studies. This method is also conducive to gaining a deeper understanding of quantitative and qualitative aspects. The selected articles underwent descriptive statistical analysis encompassing annual publication trends, citations, and journal and country distribution. Finally, content analysis summarized the primary research topics and stimulated in-depth discussions.

According to Figure 2, in Step 1, the papers with keywords including, "BIM" or "Blockchain" or "LiDAR" and" Construction Projects" were selected to be analyzed in the next step. In step 2, papers that analyzed the mentioned technologies in a project lifecycle were selected, and the targeted keywords were "Project Phase" or "Project Stage" or" Project lifecycle" or "Project Life Span" or any other expressions related to project lifecycle analysis. Finally, in the last step, papers incorporating combinations of keywords including, "BIM + LiDAR" or "Blockchain + BIM" or "LiDAR + Blockchain" or "BIM + LiDAR + Blockchain" were selected.

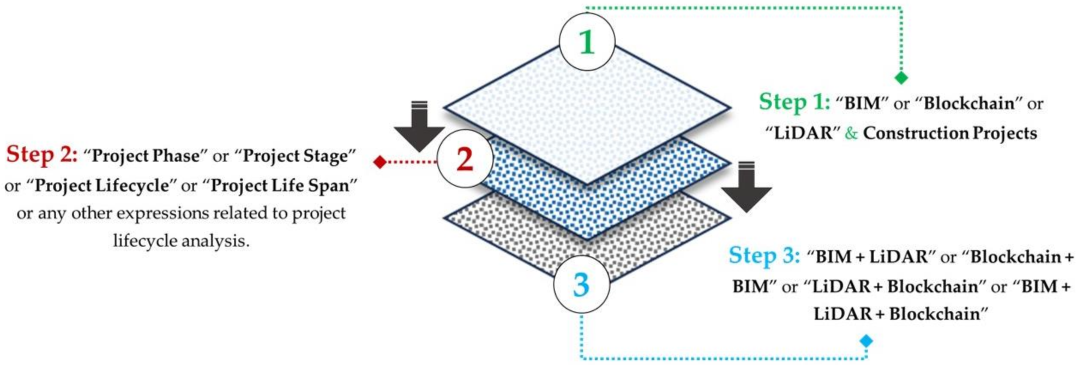

Figure 2. Selection criteria for the included studies and the databases searched.

For an in-depth and scientific assessment of the roles of these technologies in various stages of the AECO industry, it was imperative to meticulously evaluate and segregate article specifications. These selected articles were evaluated based on diverse criteria, such as the title, article type, year, keywords, objectives, lifecycle, journal, citation, country, findings, and authors. This data helped categorize articles based on technology utilization in recent years across different global regions and project lifecycles. Table 2 offers an illustrative sample of how data from prior research were categorized.

Table 2. An illustration of a reference employed within this analysis to classify data from earlier studies.

Title	Type	Year	Keywords	Objectives	Lifecycle	Journal	Citation	Country	Findings	Author(s)
Automatic BIM detailing using deep features of 3D views [60]	Case Study	2023	Building information modeling BIM detailing Deep features Motion-bearing components NBS BIM library	Introduces a method for automated BIM detailing using deep features (DFs) derived from BIM 3D views	Design	Automation in Construction	4	China	Presents a new and efficient method for automated BIM detailing, accompanied by measurable experimental proof of the efficacy of DFs in BIM applications.	Sou-Han Chen, Fan Xue

Categorizing the applications of each technology based on the project lifecycle in order to recommend smart construction.

The aim of this review is to evaluate technological tools related to digital twins, including BIM, BCT, and LiDAR, as an in-progress achievements of Industry 4.0. Thus, 324 published articles from 2014 to 2023 were selected, which are classified into three groups of research, review, and conference papers. Results from Table 3 showed that research papers have the highest percentage, and the conference papers have the lowest percentage from the latest published articles.

Figure 3 illustrates the publication trajectory of articles within the AECO industry's technological domain. Spanning from 2014 to 2023, publications are categorized by types—research, review, and conference. The publication count has steadily risen since 2014, hitting its highest point by 2022. Anticipations suggest that the number of articles by the end of 2023 might surpass recent years. Initially, the interest in this field was not substantial, but there has been a consistent uptick in publications related to construction industry technology since 2014, culminating in a peak in 2022. The number of articles produced this year is probably going to be higher than in past years because of the dynamic development in interest in this subject, which highlights its significance and current relevance. The graph created using historical statistical data reveals that the AECO industry's specialists and researchers are now aware of the latest technologies, including BIM, Blockchain, and LiDAR.

Table 3. Classification of the published articles.

Type of Article	Number	Percentage
Research	189	58.33%
Review	93	28.70%
Conference	42	12.96%
Total	324	100%

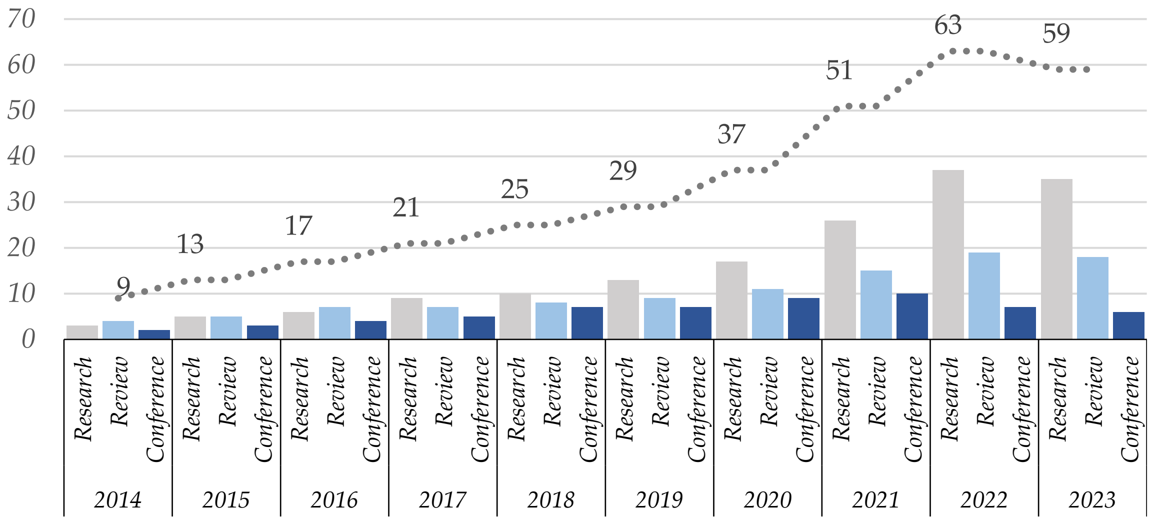

Figure 3. Distribution of articles categorized by their publication years.

The methodology employed VOSviewer 1.6.20 software in line with a systematic literature review and focused on the aforementioned technologies. VOSviewer, a software facilitating bibliometric network creation and visualization, was utilized by the researchers [61]. Subsequently, 324 published articles served as inputs for VOSviewer, utilizing its text-mining functionality to construct and display co-occurrence networks based on significant terms from the scientific literature [62].

Keywords are pivotal in encapsulating core concepts within research fields. Employing author keywords in VOSviewer entailed setting a minimum occurrence threshold of two for mapping co-occurrence networks. Following this, keywords sharing similar meanings were amalgamated. Figure 4 showcases the final visualization, delineating main keywords by the node size, interconnections by arcs, and link strength by the line thickness.

The analysis via VOSviewer underscores the significance of BIM, Blockchain, and LiDAR in integration with Industry 4.0 technologies, showcasing a focal point within AEC industries. These technologies interrelate closely with other advancements, like deep learning and the Internet of Things (IoT). Additionally, the color variations in the nodes within the VOS map indicate the timeline of technology integration into Industry 4.0, with lighter colors signifying newer concepts within Construction 4.0.

Moreover, the literature review considered various factors, such as the keywords, year, and notably, the number of citations. Table 4 outlines the top five most cited articles individually addressing BIM, Blockchain, and LiDAR. For example, Volk et al. [63] discussed BIM challenges in construction projects focusing on maintenance and deconstruction lifecycle stages. Li et al. [64] explored distributed ledger technologies' potential in the construction sector. Chen et al. [65] surveyed Digital Terrain Model generation methods, emphasizing multi-source fusion for enhanced performance.

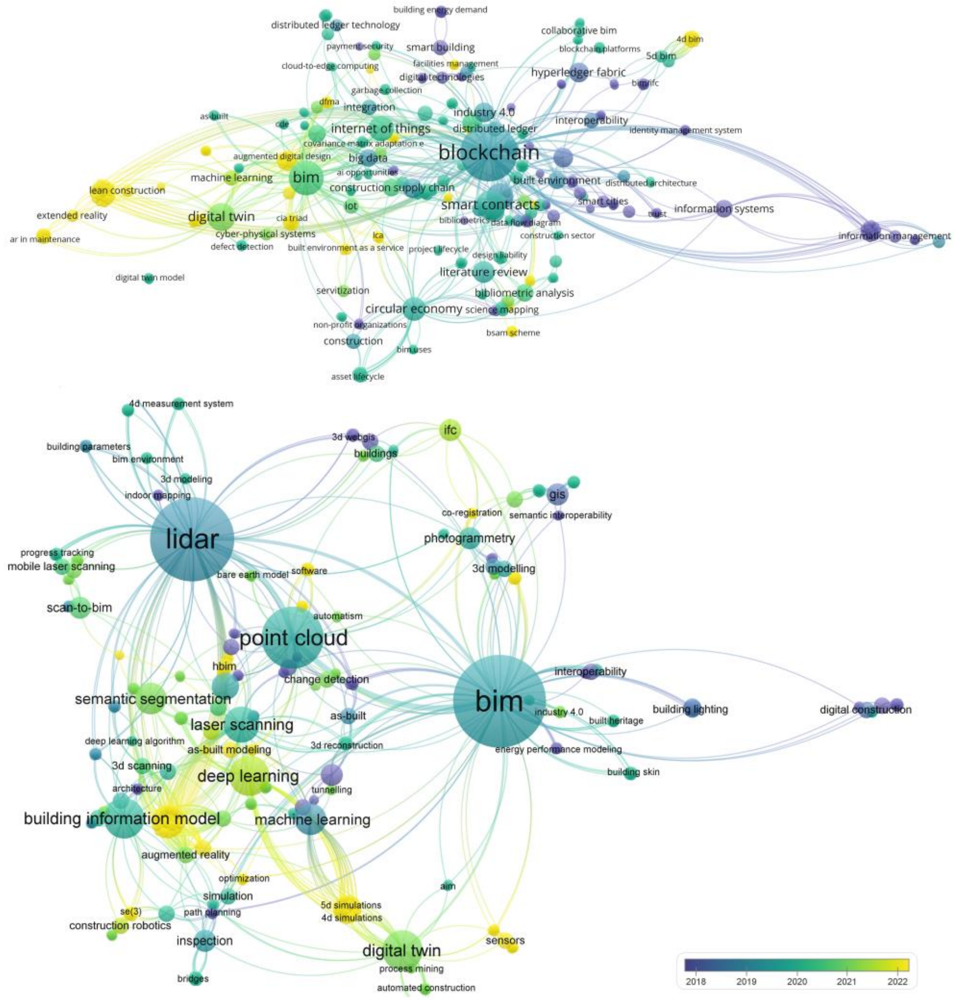

Figure 4. Keyword co-occurrence network.

Another classification reviewed papers utilizing two or three of the selected technologies. Wang et al. [22] proposed an integrated BIM and LiDAR system for real-time onsite quality information. Xue and Lu [66] introduced an approach to minimize information redundancy in BIM and blockchain integration. Nawari and Ravindran [67] surveyed Blockchain applications in AEC industries and their potential incorporation within the BIM process for post-disaster rebuilding. Table 4 provides the classification of the top-ten most-cited articles examining these technologies in conjunction.

Table 4. Top-ten most-cited articles related to integrations of BIM, Blockchain, and LiDAR in the field of construction.

No.	Ref.	Year	No. of Citation	BIM	BCT	LiDAR	Journal
1	[68]	2020	174	✓	✓		Automation in Construction
2	[22]	2015	169	✓		✓	Journal of Intelligent & Robotic Systems
3	[69]	2020	138		✓	✓	Computers and Electrical Engineering
4	[66]	2020	131	✓	✓		Automation in Construction
5	[67]	2019	125	✓	✓		Buildings
6	[70]	2019	88	✓	✓		Electronics
7	[71]	2021	51	✓	✓		Applied sciences
8	[72]	2018	46		✓	✓	Proceedings
9	[73]	2020	30	✓		✓	Remote Sensing
10	[74]	2022	24	✓		✓	Automation in Construction

In the following sections, the selected papers are classified into two categories of singular and multiple. Papers that are in the singular category are the ones that assess only one of the technologies of BIM, Blockchain, and LiDAR in their research. The multiple category includes the papers that examine two or three of the mentioned technologies in integration with each other. Then, the applications of the selected technologies related to the specific lifecycle phase is presented. After that, the journal and country of the chosen papers are discussed. Finally, in conclusion the application of these three technologies in combination with each other based on the desired lifecycle phase in suggested. The concept of current study is shown in Figure 5.

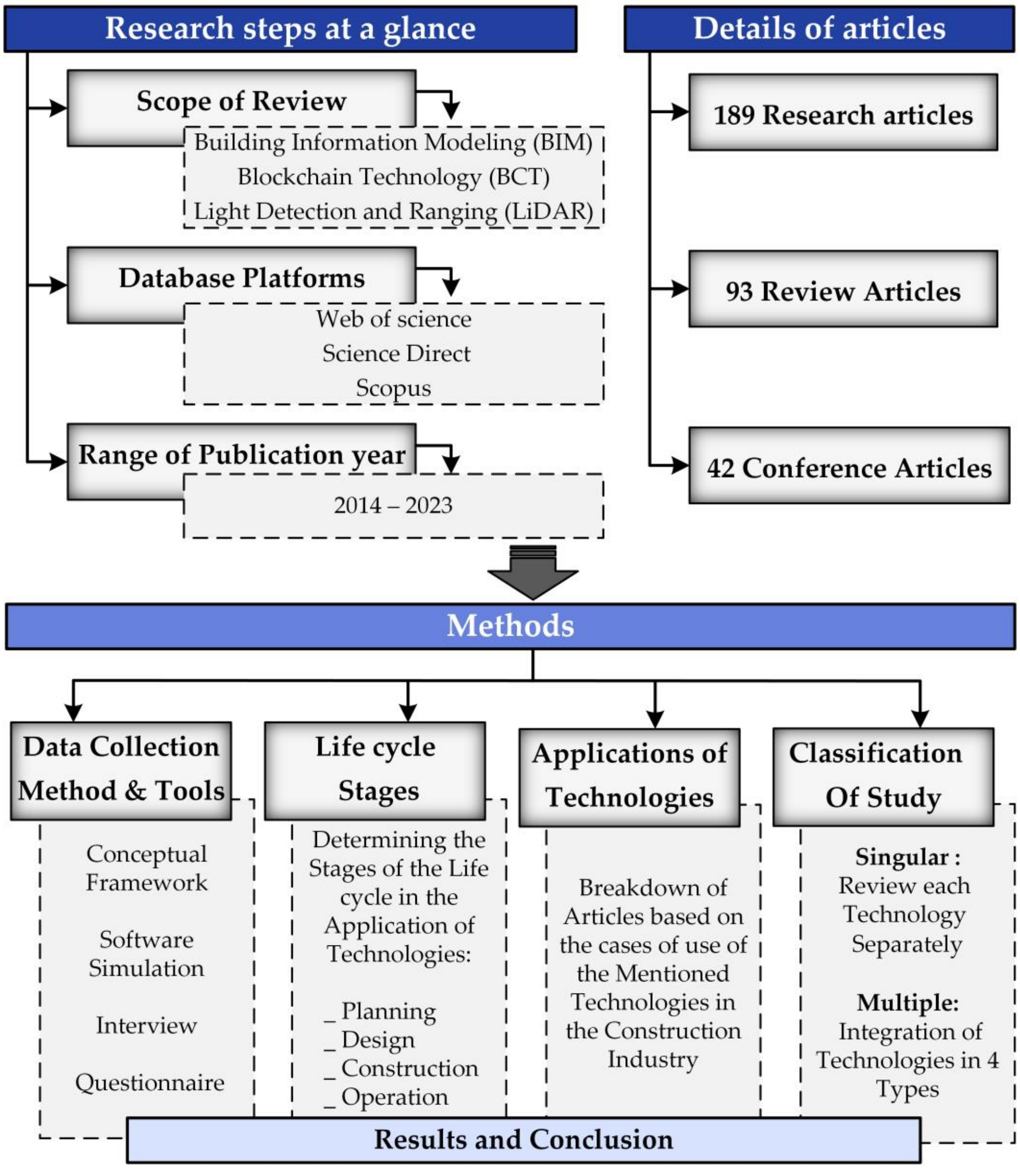

Figure 5. Research concept framework.

3. Results

The necessity for industries to keep pace with advancing technologies has never been more crucial. This study delved deeply into the evolving industry 4.0 technologies using bibliometric and content analyses. Since 2018, there has been a notable surge in published papers, primarily centered on conceptual frameworks. While research on BIM, Blockchain, and LiDAR indicates their significant impact on the design process and precise 3D simulation in construction projects, only recently have studies emerged focusing on proofs of concept and testing in simulated environments. Additionally, they strengthen the real-time monitoring, automated payment and improve the construction process and information management. In the following, the selected papers are divided into two groups of singular technology and multiple technologies due to their implementation of technologies in their research. Figure 6 shows the classification of the articles based on the integration of technologies in the research.

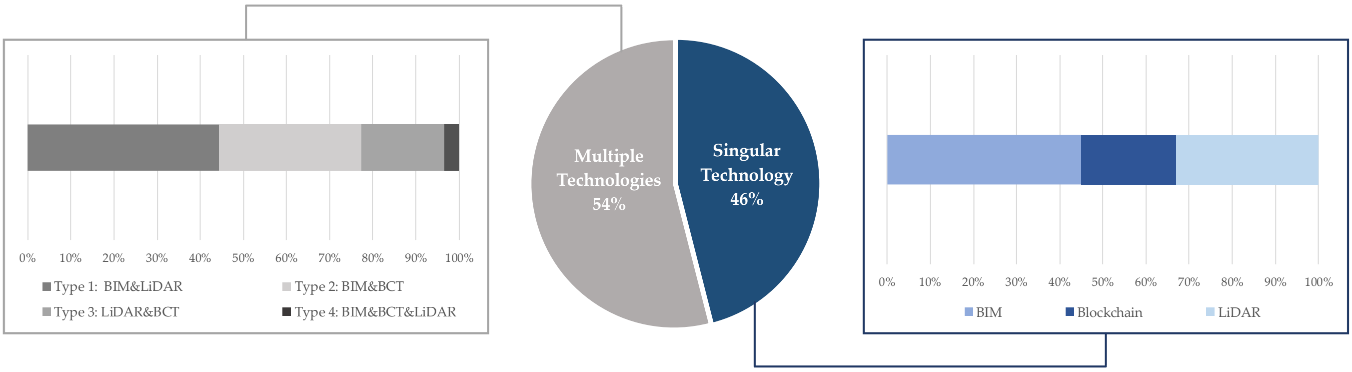

Figure 6. Classification of selected articles into two categories of singular technology and multiple technologies.

For multiple technologies, four types were defined. Type 1 referred to papers that investigated their research on BIM and LiDAR, Type 2 is for articles that analyze BIM and Blockchain Technology (BCT) in combination with each other, Type 3 is related to the studies that implemented LiDAR and BCT as two technologies of industry 4.0 in the construction sector, and Type 4 represents the papers that applied BIM, BCT, and LiDAR in integration.

As it is shown in Figure 7. The publication of multiple papers has increased from 2014, from which, it can be assumed that the construction industry is moving forward to smart and automated processes and attempting to integrate the construction activities and phases.

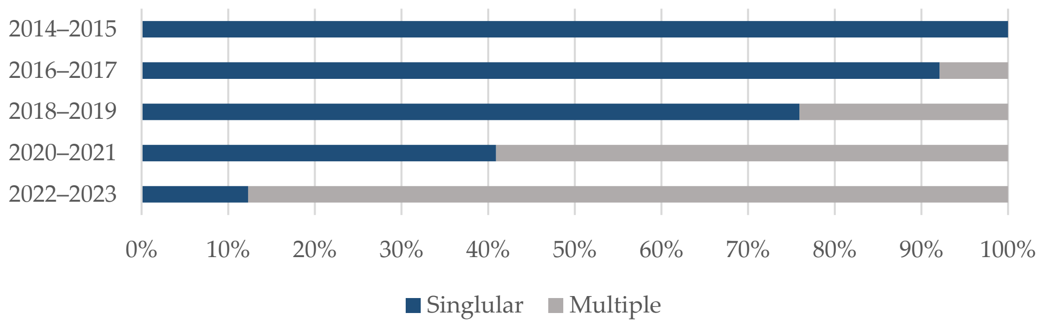

Figure 7. Comparison between the year of publication of singular and multiple papers.

3.1. *Singlular Technology-Based Articles*

Papers that investigated singular technology from BIM, BCT, and LiDAR are reviewed in this part. First, their classification based on the technology, which is implemented in the article, is presented. Then, the application of the specific technology based on the construction lifecycle is explored.

3.1.1. Classification Based on Technologies

Articles with singular technology from BIM, BCT, and LiDAR are shown in Figure 8, based on their year of publication. This chart shows each of the technologies separately in the years of 2014–2023. According to the obtained results, BIM and LiDAR have been used in the construction industry since 2014. For instance, Chen and Luo [75] explored the benefits of 4D BIM in quality application based on construction codes by creating a model. Sepasgozar et al. [76] developed an efficient framework for as-built modeling in terms of time, cost, and performance by collecting LiDAR point clouds and constructed solid 3-dimensional models of a building. While blockchain was implemented in the construction industry since 2017, before that, it was used in other industries, such as digital currency or Bitcoin. And with the passage of time, the use of blockchain in automated payment platforms [77], electronic document management, and supply chain management [78] has been increased.

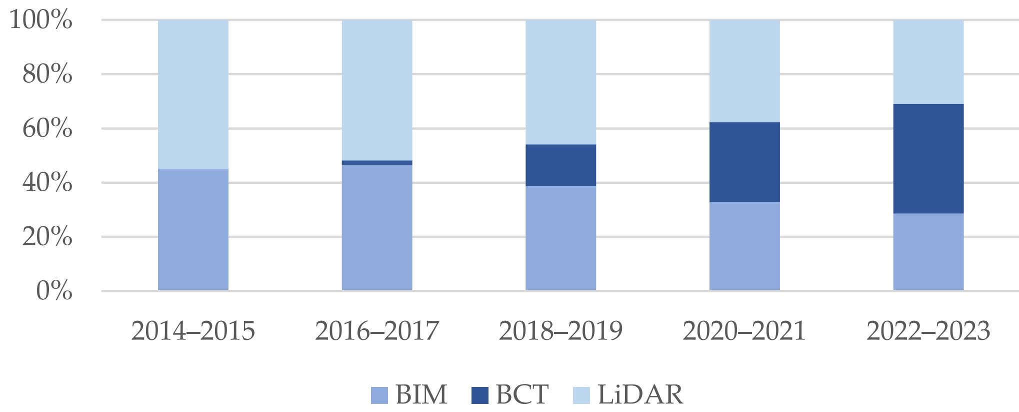

Figure 8. Singular-type papers classification from 2014–2023.

In this part, 149 papers that investigated just one of the mentioned technologies were reviewed, and the most significant applications for each technology were identified. Figures 9–11 represents the top five applications for each technology based on the construction lifecycle of a project.

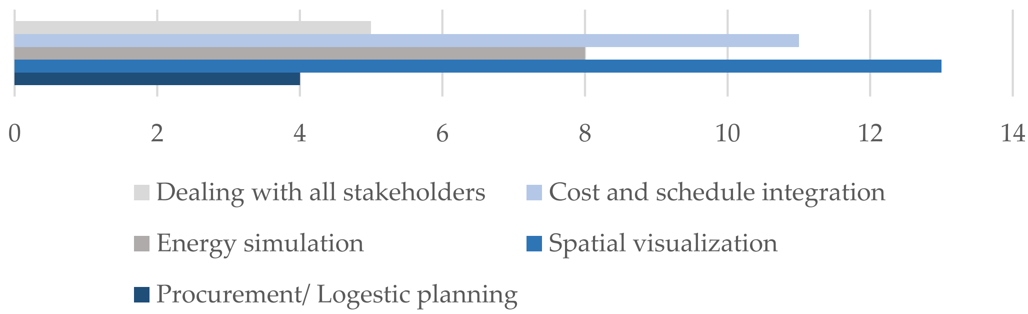

Figure 9. Key applications of BIM.

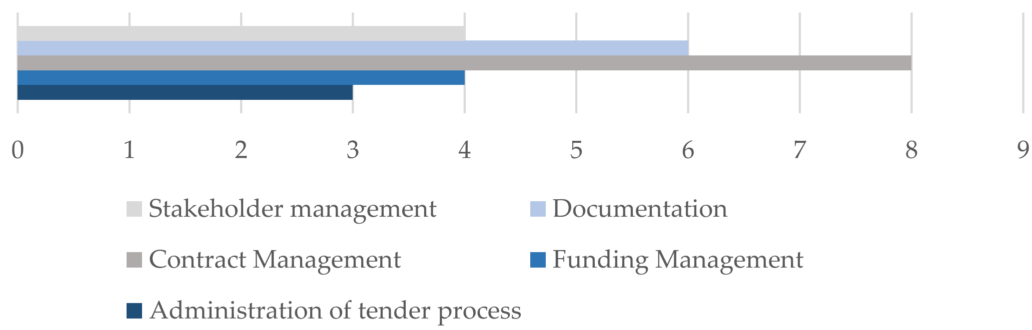

Figure 10. Key applications of Blockchain technology.

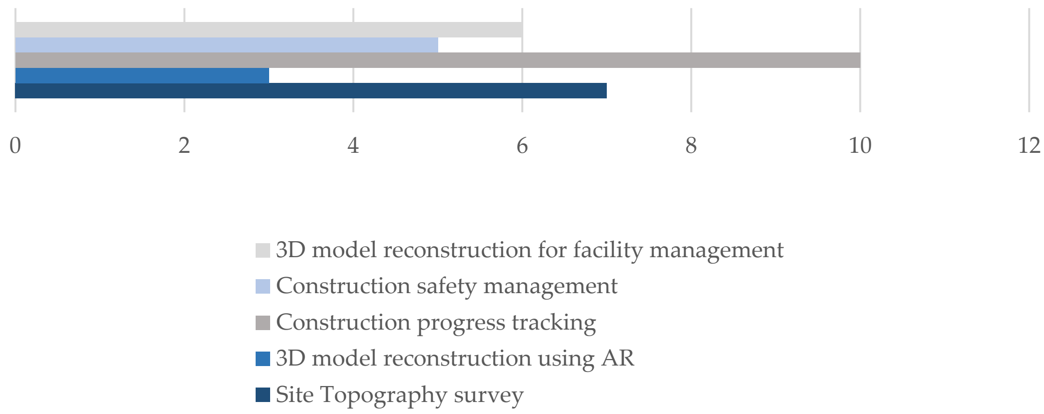

Figure 11. Key applications of LiDAR.

BIM has the greatest number of articles with the application of spatial visualization and cost and schedule integration in the design phase. For example, Raza et al. [79] demonstrated how BIM enhances project information accessibility, fostering collaboration and communication among stakeholders.

In the initial phase of project planning, the use of Blockchain in managing contracts stands out prominently within the construction sector. San et al. [78] emphasized that employing a well-coordinated Smart Contract system could enable a greater number of construction projects to progress based on labor, breaking down construction tasks into smaller, more specific work segments. This application of blockchain integrates automated legal processes into construction agreements through the implementation of algorithms and rules within a smart contract platform.

According to Wang and Kim [80], the monitoring of construction advancement could potentially achieve more effective and automated tracking through the utilization of point cloud data. This involves employing such data to monitor the progress of construction tasks. Typically gathered across different periods, point cloud data from construction activities are cross-referenced with a 4D BIM representation that encompasses the scheduled timeline of the construction activity. By juxtaposing the point cloud data with the 4D BIM model, any deviations between the actual and planned schedules can be identified, pinpointing tasks that are lagging behind.

3.1.2. Classification Based on Lifecycle

In this section, an extensive examination of the literature has led to the identification and subsequent listing of applications related to BIM, BCT, and LiDAR throughout various stages of the construction lifecycle. According to the results of the previous sources, the lifecycle was divided into four parts in this article, including the Planning phase (when the client, consultants, and, if applicable, the contractor have early conversations about what will be built, whether it will be approved by local authorities, and considerations, such as the scope and quality assumptions.), Design phase, which commences upon approval of the project budget, encompassing design-related documents, professional hours for the project manager, designer, potential contractors, and design contingency, the Construction phase (the actual process of constructing, as well as other associated operations, such as landscaping, renovating, site clearance, and demolition), and the Operation phase (the period of time that a building is used for its intended function. It begins once the construction is finished and occupied and continues until it is no longer in use or is adapted for a different use.). Based on the classification of the articles, each of these technologies (BIM, Blockchain, LiDAR) was used in one of these phases.

As per the cited sources, BIM involves site analysis, an evaluation of design alternatives, three-dimensional visualization, and design coordination during the design phase [81–83]. Blockchain includes payments and transactions [77], the development of automated payment systems [84], construction information sharing [85], and document management [86]. And LiDAR has applications of construction progress tracking, construction safety management [80], data acquisition [87], and real-time locating systems [88] in the construction phase. Based on these, Tables 5–7 were collected, according to which the reviewed articles are separated by the phase and the applications of each technology in that phase.

Table 5. BIM applications in the construction industry based on the lifecycle.

Lifecycle	BIM Applications	Ref.
Planning	Accessing and sharing real-time data	[89,90]
	Coordinating partners and working groups engaged	[81,89]
	Sustainability evaluation	[91,92]
	Utility and infrastructure administration	[89,91]
	Cost and schedule integration	[79,93]
Design	Analyzing design options	[81,82,94]
	Design coordination	[81,82,94,95]
	Energy simulation	[81,82,96–98]
	Detecting potential clashes	[89,99]
	Increased levels of detail	[89,100]
Construction	Recording and managing project progress	[75,89]
	Constructability	[101–103]
	Project supply chain	[104–106]
	Safety communication	[79,107–109]
	Lower waste and omissions	[75,79,98,110,111]
Operation	O&M prospective planning	[100,106]
	Automatic creation of detailed as-built BIM models	[90,112]
	Enhancement of indoor environmental quality (IEQ) and energy efficiency	[90,113]
	Measures for building fire prevention and disaster relief	[90,114]
	Control of electric appliances wirelessly	[90,115]

Table 6. Utilization of Blockchain technology in the construction sector throughout its lifecycle.

Lifecycle	Blockchain Applications	Ref.
Planning	Administration of tender process	[116]
	Contract Management	[78,117–121]
	Funding Management	[78]
	Stakeholder management	[64,117,122,123]
	Collaborative planning process	[84]
Design	Supply chain management and circular economy	[78,124–127]
	Documentation	[84]
	Information management	[117,128–130]
	Creating and coding smart contract	[131,132]
	Optimization of the design process	[133]
Construction	Payments and transactions	[77]
	Development of automated payment systems	[84,124]
	Monitoring and managing BIM-Blockchain updates and tasks	[77]
	Construction information sharing	[85,133,134]
	Financial management	[133,135]
Operation	Coordination of facility management services	[136,137]
	Authenticating and transforming digital assets through reality capture	[138,139]
	Smart Asset Management (SAM) integrated into BIM	[138,140]
	Asset data protection	[84,133,136]
	Tracking operation and maintenance costs	[133,138]

Table 7. LiDAR applications in the construction industry based on the lifecycle.

Lifecycle	LiDAR Applications	Ref.
Planning	Site topography survey	[141]
	Environmental change Assessment	[141]
	Images and accurate geometry information	[74]
Design	3D model reconstruction using AR	[80]
	Decision-making	[80]
Construction	Monitoring the progress of construction work	[142]
	Managing safety protocols during construction	[80]
	Data gathering	[87,88]
	Utilization of real-time locating systems in the construction industry	[87,88]
	Geometry quality inspection	[87]
Operation	Building performance analysis	[80]
	Indoor localization systems	[87,143]
	Asset location tracking framework	[87]
	Applications of digital twins for construction safety	[87,144]
	Robot navigation	[80]

3.2. Multiple Technology-Based Articles

As discussed in the singular section, various articles analyzed only one of the selected technologies, while a series of articles has examined technologies in integration with each other. This article defines four types of integrations for multiple technology-based articles.

- Type 1: BIM- LiDAR,
- Type 2: BIM- Blockchain,
- Type 3: Blockchain-LiDAR,
- Type 4: BIM-Blockchain-LiDAR.

In today's world, the digital construction can be a collection of data, sensors, and documentation, for which in this paper, BIM is assigned to collect the data, LiDAR is defined as a sensor for monitoring, and Blockchain is used for an automated payment system and a trusted database for documentation. Figure 12 illustrates the above concept of digital construction and the integration of the selected technologies in four different types.

The integration of these technologies has led to the creation of benefits in different phases and is used in different construction areas, such as MEP, energy consumption, and quality control. For example, in 2021, Wang et al. [74] formulated an algorithm for extracting components with instance awareness from LiDAR point clouds, considering the rough distribution of objects in three-dimensional space. Following this extraction process, the BIM model was reconstructed using the obtained component extraction results. Various numbers of useful multiple articles based on their citations that were published in the years 2014 to 2023 have been reviewed.

According to the studies in the table above and other articles, the integration of technologies with each other improves a series of benefits [145–148] and creates features that singular technology does not have. Table 8 presents part of the multiple technologies-based papers that were reviewed in this study. The mentioned papers are analyzed based on the year of publication, area, and lifecycle (P: Planning, D: Design, C: Construction, O: Operation).

Table 8. List of multiple technologies-based articles.

Type	Ref.	Year	Methodology	Area	Lifecycle			
					P	D	C	O
Type 1 (BIM and LiDAR)	[74]	2022	Semantic rich 3D map	MEP system			✓	
	[145]	2019	3D Modeling	Hallway with a continuous glass wall				✓
	[149]	2021	Case Study	Ancient building				✓
	[150]	2019	Semi-automated BEPS input	Energy consumption		✓		
	[151]	2020	Simulation	Full scan of the environment			✓	
	[152]	2018	Classical surveying techniques	Historical building				✓
	[73]	2020	Automated geometric quality inspection	Two prefabricated bathroom units (PBUs)	✓			
	[22]	2015	Simulation	Quality control			✓	
	[153]	2017	2-level optimization module	Implementing a PV system				✓
	[154]	2023	Auto-scan-to-BIM	As-built plan			✓	
	[155]	2022	Modeling	Construction progress monitoring			✓	
	[156]	2023	5D progress tracking	Control			✓	
Type 2 (BIM and BCT)	[157]	2019	Integrative Framework	Post-Disaster Recovery			✓	
	[70]	2019	SustaRIinable Building Design Information Management Framework	Sustainable Building		✓		
	[158]	2017	Review	Procurement	✓			
	[146]	2021	DCDE framework for BIM-based design	Managing design changes	✓	✓		
	[159]	2019	Blockchain collaboration mechanism	Built environment		✓		
	[71]	2021	Digital contract management workflow	Automated payment	✓			
	[160]	2020	Analyzing the potential applications of ERP	Recyclable construction materials				✓
	[161]	2018	Literature review	Information management		✓		
	[162]	2022	Survey	Payment			✓	
	[163]	2023	Design Science Research (DSR) activities	Supply chain		✓		
Type 3 (LiDAR and BCT)	[147]	2020	Literature review	Smart city's real-time monitoring			✓	
	[164]	2021	Deep Neural Network (DNN)-based prediction algorithm	Vehicle Positioning			✓	
	[165]	2021	Hazard and Operability (HAZOP) and Threat and Operability (THROP) techniques	Risk management				✓
	[166]	2021	AI algorithms at the edge servers	Smart cities			✓	
	[167]	2023	Actual edge computer	Smart monitoring				✓
	[168]	2023	Multiple-sensor fusion	Smart Warehousing			✓	
Type 4 (BIM and BCT and LiDAR)	[148]	2023	BIM-model	Prefabrication			✓	
	[169]	2023	Comparing smart technologies in MiC development	Sustainability			✓	
	[60]	2023	Case Study	Component detailing		✓		
	[170]	2022	Concept-centric trends synthesis	Spatial planning and land management	✓			

As demonstrated by the findings mentioned earlier, 54% of the reviewed papers examined a combination of two or three technologies among BIM, BCT, and LiDAR, falling under the category of studies focusing on multiple technology applications.

One of the examples illustrating the successful integration of BIM, BCT, and LiDAR is in prior research by Loo and Wong (2023); they outlined a four-stage approach for integrating BIM, Blockchain, and LiDAR in construction. The first stage involves applying BIM, RFID, and Blockchain to support Modular Integrated Construction (MiC) production. In the second stage, the digital platform expands to serve third parties, like the government, focusing on monitoring, authentication, visualization, and real-time updates for MiC projects. The third stage prioritizes the safety and well-being of workers and drivers with IoT devices, sensors, robotics, CCTV, dashboards, and cloud-based monitoring. Finally, the fourth stage centers on the entire construction lifecycle, establishing a centralized smart command center with diverse data sources, including LiDAR, robotics data, and open data, aiming to involve all stakeholders, like architects for smart construction. Additionally, it integrates with other relevant open data sources [170].

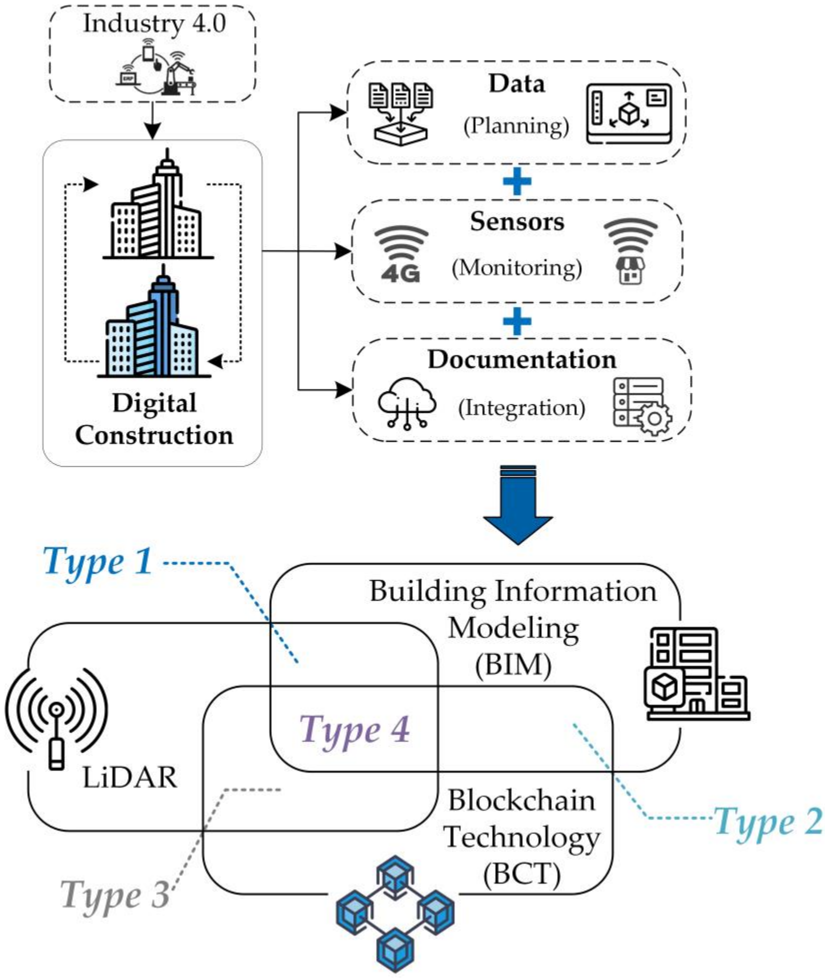

Figure 12. Classification of different types of multiple technology-based articles as **Type 1** ([22,73,74,145,149–156]), **Type 2** ([84,85,112,113,115,128,135]), **Type 3** ([86–88,116,117]) and **Type 4** ([60,118,119]).

Considering this paper's aim to explore the applications of these technologies throughout the construction lifecycle, this section delves into investigating the integration of these selected technologies, visually represented in Figure 13.

The multiple type of articles includes four types of BIM and LiDAR, BIM and BCT, BCT and LiDAR, and BIM and BCT and LiDAR. According to the previous section, each of the technologies had a series of applications in each phase, so based on the references, integrating these technologies together with their characteristics can lead to the improvement of the previous features and how the integration of technologies can support in what exact direction.

In this chart, singular articles that include BIM, Blockchain, and LiDAR and multiple articles that include BIM and LiDAR, BIM and BCT, BCT and LiDAR, and BIM and BCT and LiDAR are shown according to their year of publication. Based on these statistics, the number of single articles that examine each technology separately decreases in the recent years from 2014, and the number of articles that analyzed multiple technologies increases so far in 2023. BIM and LiDAR as type 1, have the highest number of publications and after that, it is type 2 of BIM and Blockchain. As a result, today, with the emergence of technologies, such as digital twin, it is possible to integrate technologies, and the current articles and research in the academic and industrial dimension are more towards the integration of technologies for better efficiency. Figure 14 compares the number of singular and multiple technologies papers in details in the years of 2014–2023.

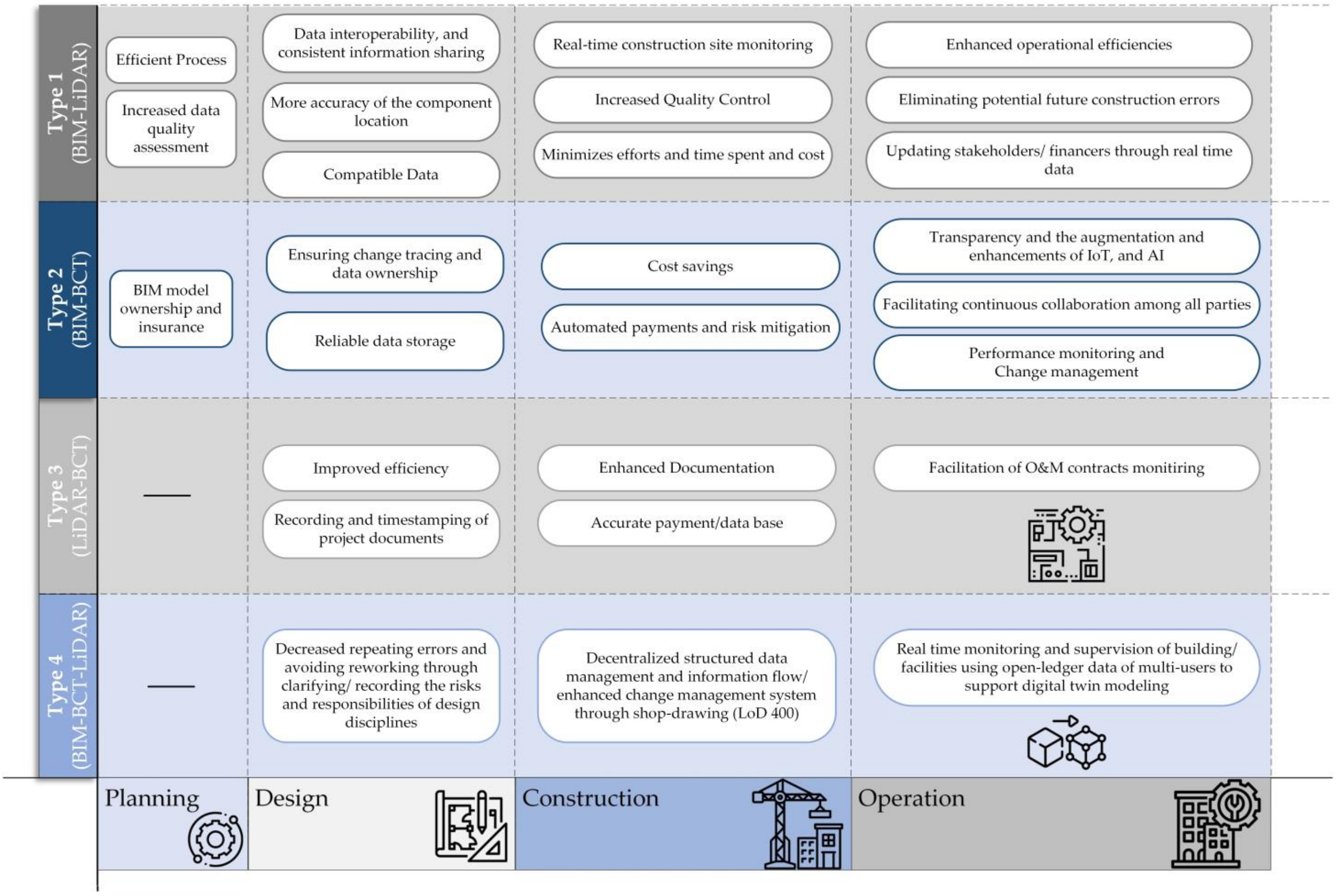

Figure 13. Applications of the four types of technologies from the integration of BIM, BCT, and LiDAR based on life cycle phases including Planning ([73,151,158]), Design ([22,60,70,147,149,164]), Construction ([67,74,152,155,162,166,168,169]) and Operation ([146,150,153,160,167,170]).

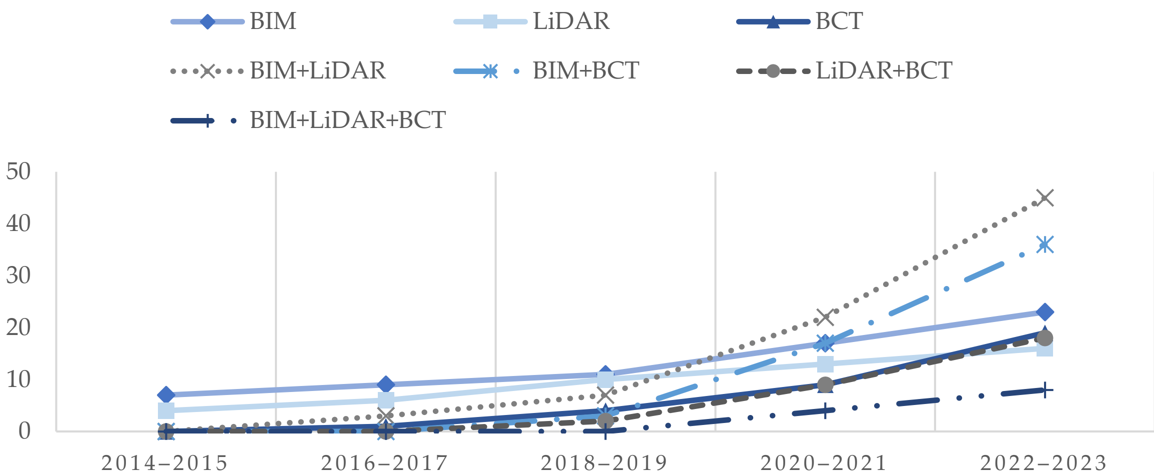

Figure 14. Number of singular and multiple technologies-based papers during 2014–2023.

3.3. Journals

Readers can access the most relevant information and identify suitable journals for future reference by conducting a statistical assessment of various publications. Among the 324 selected papers, 282 were sourced from journals, while the remaining papers originated from conferences. Illustrated in Figure 15, 197 papers were sourced from 12 journals, each of which published a minimum of two articles. Additionally, 85 papers, not depicted in Figure 15, were individually published across various journals. Notably, Automation in Construction emerged as the leading journal in this domain, contributing a total of 36 papers, highlighting its prominence in the field.

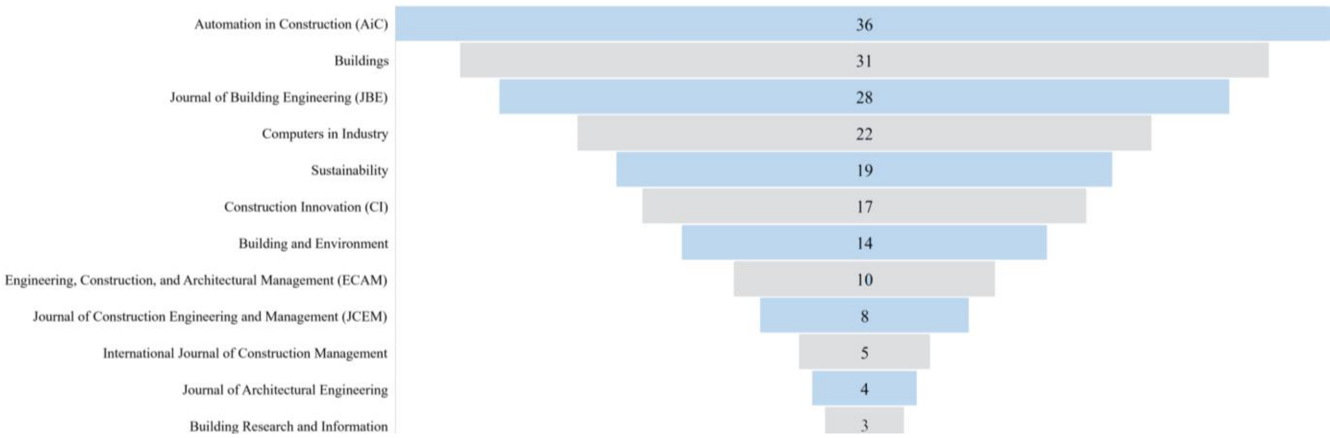

Figure 15. Analysis of published papers in journals and their quantity.

3.4. Countries

In this section, countries that have published articles in this field are discussed. In Figure 16 and according to the geographical distribution of the author's institutions, 34 participating countries were identified, which are displayed in blue color according to the image. The intensity of the color in each region corresponds to the quantity of articles published by a country. The figure below ranks countries based on their publication volume in this particular field, showcasing the top 10 nations with the highest number of publications.

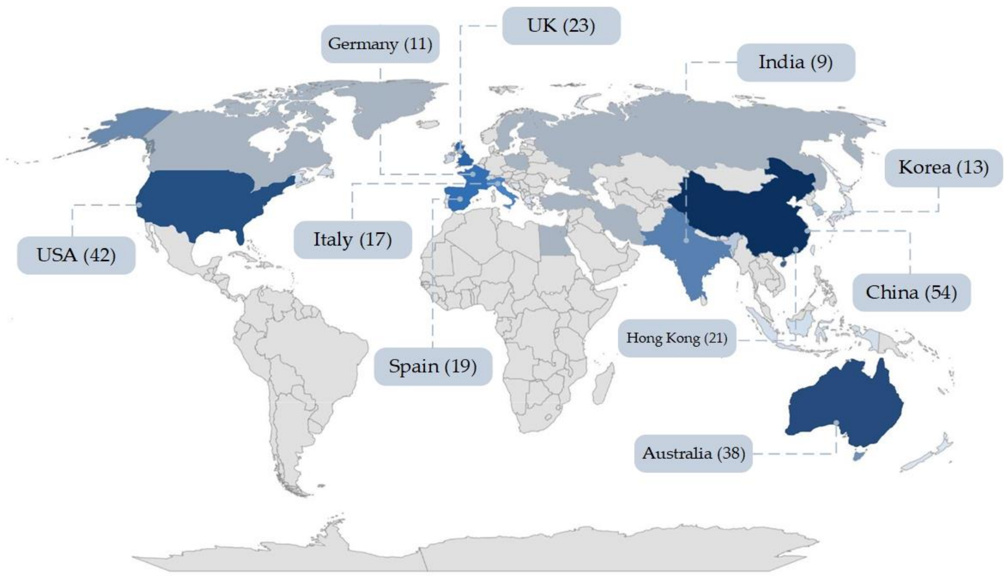

Figure 16. Distribution map of articles in different countries of the world.

In Figure 16, the countries are shown based on the name and number of articles published in that location. According to the research conducted in each country, China [75,171], America [46,140], and Australia [84] had the most articles, respectively. Despite the novelty of the topics in the field of technology, countries, such as Iran, India, Morocco, etc., have published studies in this field. It is worth mentioning that although there is more research on this matter in leading countries, countries like Slovenia, although it has published only two articles, the number of citations is high. The distribution of studies across continents and nations highlights the global significance of the discussed subject, indicating its relevance even in developing and less affluent countries, which are also inclined towards adopting novel design and construction systems. The primary objectives driving the development of new technologies include cost reduction in construction, mitigation of the environmental impact, energy conservation, and timely project completion. Consequently, this approach is likely to be embraced by project stakeholders in financially unstable countries. To effectively reduce project costs, it is vital to offer suitable solutions that diminish the construction duration, drawing upon project planning and control expertise. A holistic understanding of the building production process, considering additional requirements, is pivotal in attaining desired outcomes. According to the statistics of multiple and singular, in a series of countries, such as China, over time, the number of singular articles has decreased, while the number of multiple articles has increased. This process continues in America and Australia. However, in countries, such as Italy and Germany, the potential of each of these technologies is still being investigated separately. According to the results shown in Figure 16, China has the highest number of published articles with the total of 54 articles, followed by America, Australia, and United Kingdom.

4. Discussion

The study confines its examination of BIM, Blockchain, and LiDAR literature solely to academic papers sourced from the Web of Science, Science Direct, and Scopus databases. The integration of these technologies into the construction process brings about various challenges and limitations, including the following:

- Resistance to change: The construction industry traditionally holds a conservative stance toward change, posing substantial resistance to adopting new methods, necessitating significant alterations in construction practices.
- Lack of standards: Establishing universally accepted standards within the construction sector is pivotal for the transformation induced by these technologies. Despite notable progress, substantial efforts are still required to implement standardized data and processing protocols.
- Unclear value proposition: Embracing innovation demands a clear value proposition for all involved stakeholders. The intricate nature of this sector's value chain and its transactional dynamics make it challenging to document benefits and financial gains, leading construction firms to hesitate when investing in these technologies.
- Demand for advanced skills: The industry currently grapples with a shortage of skilled labor. Without substantial improvements in education and training, there is a deficit in a proficient workforce capable of handling various aspects, potentially requiring new roles, functions, and team structures. This scarcity poses a significant challenge to successful implementation.
- To address these limitations this paper suggests some solutions. For instance, Overcoming the inherent resistance to change within the construction industry requires a multi-faceted approach. Firstly, targeted education and training programs can be implemented to familiarize stakeholders with the benefits and functionalities of these technologies. Offering courses and workshops focused on BIM, Blockchain, and LiDAR can equip professionals with the necessary skills to embrace innovation.
- The establishment of universally accepted standards is essential for the seamless integration of these technologies. Collaboration with regulatory bodies and industry organizations can facilitate the development and implementation of standardized data

and processing protocols. Additionally, initiatives aimed at promoting interoperability and data exchange between different platforms can help bridge existing gaps.

- Providing a clear value proposition is crucial to incentivize construction firms to invest in these technologies. Start-ups specializing in construction technology can play a vital role in demonstrating the tangible benefits and financial gains associated with their implementation. By showcasing successful case studies and quantifiable outcomes, these start-ups can alleviate concerns and build confidence among stakeholders.
- Addressing the shortage of skilled labor requires concerted efforts in education and training. Integrating IT-related courses and programming languages into construction curricula can empower the workforce to adapt to evolving technological requirements. Additionally, regulatory bodies can collaborate with educational institutions to develop certification programs that validate proficiency in BIM, Blockchain, and LiDAR technologies.
- While the integration of BIM, Blockchain, and LiDAR technologies presents promising opportunities for the construction industry, addressing the aforementioned limitations is paramount for successful implementation. By investing in education, fostering collaboration with regulatory bodies, and leveraging the expertise of start-ups, construction firms can navigate challenges and unlock the full potential of these transformative technologies.

The potential opportunities and advantages arising from the integration of BIM, Blockchain, and LiDAR within the construction industry encompass several key aspects:

- Improved sustainability: This integration facilitates the industry's adoption of a comprehensive lifecycle approach, promoting resource efficiency with notable reductions in energy consumption and emissions.
- Elevating industry perception: The convergence of digital and physical technologies has the potential to transform the perception of the industry by reshaping work, the workforce, and workspaces, making it more appealing to attract and retain skilled professionals.
- Cost efficiency: Leveraging digital technologies in industrial construction can curb inefficiencies and waste. Real-time access to abundant data at the physical level enhances decision-making and stimulates financial collaboration and innovation among project teams.
- Time optimization: Modern construction methodologies, like prefabrication, additive manufacturing, and on-site assembly, contribute to expediting construction processes. Simultaneous access to field data helps to preempt possible delays, resulting in time savings.
- Enhanced collaboration and communication: Utilizing cloud-based project management tools, Blockchain, centralized information repositories, and real-time data access engenders increased trust among project team members, fostering improved communication and coordination.

5. Conclusions

Industry 4.0 has expedited the construction sector's shift towards digitalization, encompassing all facets of the industry. This transformation yields various advantages in design and construction, such as time efficiency, enhanced safety measures, improved quality, sustainability, better collaboration, communication, and heightened predictability regarding time and cost. Given that the construction industry contributes 9% to the global gross product, its substantial impact on a country's economic advancement is evident. Leveraging automation and integration presents opportunities to bolster productivity and quality in design and construction. This study undertakes a comprehensive literature review focusing on BIM, Blockchain, and LiDAR within the construction lifecycle. It represents the first systematic approach to scrutinize the integration of BIM, Blockchain, and LiDAR, examining their applications across lifecycle phases through the analysis of 324 academic papers. The literature review reveals prevalent keywords, countries, prominent journals, and ongoing research areas within the BIM, Blockchain, and LiDAR domain. The findings indicate a decline in standalone examinations of individual technologies since 2014, replaced by an upward trend in articles exploring multiple technologies up to 2023. By categorizing and studying the applications of these integrated technologies, this research aims to furnish scholars with a more comprehensive understanding and well-organized knowledge framework concerning BIM, Blockchain, and LiDAR.

Considering the advancements in structural systems within Industry 4.0 and the growing prevalence of methods like prefabrication aimed at cost-reduction and quicker execution in construction, it is recommended to incorporate these technologies into innovative structural systems. Furthermore, as Industry 4.0 emphasizes sustainability across its three key pillars—environmental, social responsibility, and economic aspects—leveraging technologies, like BIM, Blockchain, and LiDAR, throughout the construction lifecycle can significantly enhance sustainability, particularly addressing environmental concerns. Industry 4.0 encompasses cyber-physical technologies, including the aforementioned ones, and also involves discussions about the circular economy. Future studies could explore the impact of these technologies within the context of the circular economy. Additionally, these three selected technologies could be further examined in conjunction with other technologies, like IoT and digital innovations.

In considering the short-term and long-term perspectives, future research endeavors could delve into the potential cost savings, efficiency gains, and environmental benefits stemming from the adoption of these technologies. Additionally, examining the social implications, such as changes in job roles, workforce dynamics, and community engagement, would provide a more holistic understanding of the transformative effects on industry practices. By incorporating a thorough analysis of the economic, environmental, and social impacts, this paper can offer valuable insights for industry stakeholders, policymakers, and researchers seeking to navigate the complexities of technology integration in the construction sector. This holistic approach ensures that considerations extend beyond technical feasibility to encompass broader societal implications, fostering informed decision-making and sustainable development within the industry.

In line with the principles of Industry 4.0, which encompass the convergence of digital technologies to revolutionize industrial processes, this paper acknowledges the need for the continuous monitoring of emerging technologies. This includes the integration of not only BIM, Blockchain, and LiDAR but also other Industry 4.0 technologies, such as the Internet of Things (IoT), robotics, artificial intelligence (AI), and augmented reality/virtual reality (AR/VR). By embracing the concept of Construction 4.0, which leverages these cutting-edge technologies to drive efficiency, productivity, and sustainability in construction practices, stakeholders can stay abreast of advancements and proactively adapt their strategies. Highlighting emerging technologies within the context of Construction 4.0 not only enriches the discourse surrounding technology integration but also provides valuable insights for future research directions and industry adoption strategies.

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References

1. You, Z.; Feng, L. Integration of industry 4.0 related technologies in construction industry: A framework of cyber-physical system. *IEEE Access* **2020**, *8*, 122908–122922. [CrossRef]
2. Lu, Y.; Xu, X.; Wang, L. Smart manufacturing process and system automation—A critical review of the standards and envisioned scenarios. *J. Manuf. Syst.* **2020**, *56*, 312–325. [CrossRef]

3. Liu, X.; Cao, J.; Yang, Y.; Jiang, S. CPS-based smart warehouse for industry 4.0: A Survey of the underlying technologies. *Computers* **2018**, *7*, 13. [CrossRef]
4. Xu, X.; Lu, Y.; Vogel-Heuser, B.; Wang, L. Industry 4.0 and Industry 5.0—Inception, conception and perception. *J. Manuf. Syst.* **2021**, *61*, 530–535. [CrossRef]
5. Woodhead, R.; Stephenson, P.; Morrey, D. Digital construction: From point solutions to IoT ecosystem. *Autom. Constr.* **2018**, *93*, 35–46. [CrossRef]
6. Oztemel, E.; Gursev, S. Literature review of Industry 4.0 and related technologies. *J. Intell. Manuf.* **2020**, *31*, 127–182. [CrossRef]
7. Faraji, A.; Rashidi, M.; Tezangi, M.R.; Perera, S. Multihybrid dispute resolution framework for projects of downstream sector of petroleum industry. *J. Leg. Aff. Disput. Resolut. Eng. Constr.* **2021**, *13*, 04521026. [CrossRef]
8. Maskuriy, R.; Selamat, A.; Maresova, P.; Krejcar, O.; David, O.O. Industry 4.0 for the construction industry: Review of management perspective. *Economies* **2019**, *7*, 68. [CrossRef]
9. Maresova, P.; Soukal, I.; Svobodova, L.; Hedvicakova, M.; Javanmardi, E.; Selamat, A.; Krejcar, O. Consequences of industry 4.0 in business and economics. *Economies* **2018**, *6*, 46. [CrossRef]
10. Beier, G.; Ullrich, A.; Niehoff, S.; Reißig, M.; Habich, M. Industry 4.0: How it is defined from a sociotechnical perspective and how much sustainability it includes—A literature review. *J. Clean. Prod.* **2020**, *259*, 120856. [CrossRef]
11. Faraji, A.; Arya, S.H.; Ghasemi, E.; Soleimani, H. *IoT Core Applications in AEC: Investigation of the Most Compatible Technologies of Industry 4.0*; ResearchGate: Berlin, Germany, 2024.
12. Ordieres-Meré, J.; Remon, T.P.; Rubio, J. Digitalization: An opportunity for contributing to sustainability from knowledge creation. *Sustainability* **2020**, *12*, 1460. [CrossRef]
13. De Gaetani, C.I.; Mert, M.; Migliaccio, F. Interoperability analyses of BIM platforms for construction management. *Appl. Sci.* **2020**, *10*, 4437. [CrossRef]
14. Santiago, P. Achieving Sustainability in Construction Through Digitally Informed Decisions. In *Industry 4.0 for the Built Environment: Methodologies, Technologies and Skills*; Springer: Berlin/Heidelberg, Germany, 2022; pp. 247–269.
15. Ghosh, A.K.; Ullah, A.S.; Kubo, A. Hidden Markov model-based digital twin construction for futuristic manufacturing systems. *AI EDAM* **2019**, *33*, 317–331. [CrossRef]
16. Murphy, M. Implementing innovation: A stakeholder competency-based approach for BIM. *Constr. Innov.* **2014**, *14*, 433–452. [CrossRef]
17. Alaloul, W.S.; Liew, M.S.; Zawawi, N.A.W.A.; Kennedy, I.B. Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain Shams Eng. J.* **2020**, *11*, 225–230. [CrossRef]
18. Soltaninejad, M.; Noorzai, E.; Faraji, A. Enhancing the level of confidence in the safe fire evacuation operation employing a combination of BIM and fuzzy TOPSIS method. In *Smart and Sustainable Built Environment*; Emerald Insight: Leeds, UK, 2023.
19. Celik, Y.; Petri, I.; Barati, M. Blockchain supported BIM data provenance for construction projects. *Comput. Ind.* **2023**, *144*, 103768. [CrossRef]
20. Becerik-Gerber, B.; Jazizadeh, F.; Li, N.; Calis, G. Application areas and data requirements for BIM-enabled facilities management. *J. Constr. Eng. Manag.* **2012**, *138*, 431–442. [CrossRef]
21. Motawa, I.; Almarshad, A. A knowledge-based BIM system for building maintenance. *Autom. Constr.* **2013**, *29*, 173–182. [CrossRef]
22. Wang, J.; Sun, W.; Shou, W.; Wang, X.; Wu, C.; Chong, H.-Y.; Liu, Y.; Sun, C. Integrating BIM and LiDAR for real-time construction quality control. *J. Intell. Robot. Syst.* **2015**, *79*, 417–432. [CrossRef]
23. Waqar, A.; Qureshi, A.H.; Alaloul, W.S. Barriers to Building Information Modeling (BIM) deployment in small construction projects: Malaysian construction industry. *Sustainability* **2023**, *15*, 2477. [CrossRef]
24. Alaloul, W.S.; Qureshi, A.H.; Musarat, M.A.; Saad, S. Evolution of close-range detection and data acquisition technologies towards automation in construction progress monitoring. *J. Build. Eng.* **2021**, *43*, 102877. [CrossRef]
25. Oyuga, J.O.; Gwaya, A.; Njuguna, M.B. Investigation of the current usage of BIM capabilities by large-sized building contractors in Kenya based on theory of innovation diffusion. *Constr. Innov.* **2023**, *23*, 155–177. [CrossRef]
26. Durdyev, S.; Ashour, M.; Connelly, S.; Mahdiyar, A. Barriers to the implementation of Building Information Modelling (BIM) for facility management. *J. Build. Eng.* **2022**, *46*, 103736. [CrossRef]
27. Qureshi, A.H.; Alaloul, W.S.; Wing, W.K.; Saad, S.; Ammad, S.; Altaf, M. Characteristics-based frame-work of effective automated monitoring parameters in construction projects. *Arab. J. Sci. Eng.* **2023**, *48*, 4731–4749. [CrossRef] [PubMed]
28. Qureshi, A.H.; Alaloul, W.S.; Wing, W.K.; Saad, S.; Ammad, S.; Musarat, M.A. Factors impacting the implementation process of automated construction progress monitoring. *Ain Shams Eng. J.* **2022**, *13*, 101808. [CrossRef]
29. Hyarat, E.; Hyarat, T.; Al Kuisi, M. Barriers to the implementation of building information modeling among Jordanian AEC companies. *Buildings* **2022**, *12*, 150. [CrossRef]
30. Qureshi, A.H.; Alaloul, W.S.; Wing, W.K.; Saad, S.; Alzubi, K.M.; Musarat, M.A. Factors affecting the implementation of automated progress monitoring of rebar using vision-based technologies. In *Construction Innovation*; Emerald Insight: Leeds, UK, 2022.
31. Olanrewaju, O.I.; Kineber, A.F.; Chileshe, N.; Edwards, D.J. Modelling the relationship between Building Information Modelling (BIM) implementation barriers, usage and awareness on building project lifecycle. *Build. Environ.* **2022**, *207*, 108556. [CrossRef]
32. Berges-Alvarez, I.; Sanguinetti, C.M.; Giraldi, S.; Marín-Restrepo, L. Environmental and economic criteria in early phases of building design through Building Information Modeling: A workflow exploration in developing countries. *Build. Environ.* **2022**, *226*, 109718. [CrossRef]

33. Olanrewaju, O.I.; Enegbuma, W.I.; Donn, M.; Chileshe, N. Building information modelling and green building certification systems: A systematic literature review and gap spotting. *Sustain. Cities Soc.* **2022**, *81*, 103865. [CrossRef]
34. Abdelmegid, M.; González, V.; Poshdar, M.; O'Sullivan, M.; Walker, C.; Ying, F. Barriers to adopting simulation modelling in construction industry. *Autom. Constr.* **2020**, *111*, 103046. [CrossRef]
35. Vadgama, N.; Tasca, P. An analysis of blockchain adoption in supply chains between 2010 and 2020. *Front. Blockchain* **2021**, *4*, 610476. [CrossRef]
36. Nakamoto, S. Bitcoin: A peer-to-peer electronic cash system. In *Decentralized Business Review*; Satoshi Nakamoto Institute: Austin, TX, USA, 2008. Available online: https://pdhonline.com/courses/c731/01_BIM_Project_Execution_Planning_Guide_V2.1_(two-sided).pdf (accessed on 4 January 2024).
37. Faraji, A.; Arya, S.H.; Ghasemi, E.; Rashidi, M.; Perera, S.; Tam, V.; Rahnamayiezekavat, P. A conceptual framework of decentralized blockchain integrated system based on building information modeling to steering digital administration of disputes in the IPD contracts. *Constr. Innov.* **2024**, *24*, 384–406. [CrossRef]
38. Puthal, D.; Mohanty, S.P.; Kougianos, E.; Das, G. When do we need the blockchain? *IEEE Consum. Electron. Mag.* **2020**, *10*, 53–56. [CrossRef]
39. Su, D.; Zhang, L.; Peng, H.; Saeidi, P.; Tirkolaee, E.B. Technical challenges of blockchain technology for sustainable manufacturing paradigm in Industry 4.0 era using a fuzzy decision support system. *Technol. Forecast. Soc. Chang.* **2023**, *188*, 122275. [CrossRef]
40. Kochupillai, M.; Gallersdörfer, U.; Köninger, J.; Beck, R. Incentivizing research & innovation with agrobiodiversity conserved in situ: Possibilities and limitations of a blockchain-based solution. *J. Clean. Prod.* **2021**, *309*, 127155.
41. Singh, A.K.; Kumar, V.P.; Dehdasht, G.; Mohandes, S.R.; Manu, P.; Pour Rahimian, F. Investigating the barriers to the adoption of blockchain technology in sustainable construction projects. *J. Clean. Prod.* **2023**, *403*, 136840. [CrossRef]
42. Lee, D.; Lee, S.H.; Masoud, N.; Krishnan, M.S.; Li, V.C. Integrated digital twin and blockchain framework to support accountable information sharing in construction projects. *Autom. Constr.* **2021**, *127*, 103688. [CrossRef]
43. Soltaninejad, M.; Faraji, A.; Noorzai, E. Recognizing the effective factors in managing fire incidents to reduce the collateral damages and casualties. *Facilities* **2021**, *39*, 805–827. [CrossRef]
44. Brito, J.; Castillo, A. *Bitcoin: A Primer for Policymakers*; Mercatus Center at George Mason University: Arlington, VA, USA, 2013.
45. Lutecium, S. *MVP. V1 Technical Architecture Document*; BIMCHAIN: Paris, France, 2019.
46. Nawari, N.O.; Ravindran, S. Blockchain and the built environment: Potentials and limitations. *J. Build. Eng.* **2019**, *25*, 100832. [CrossRef]
47. Nayak, A.; Dutta, K. Blockchain: The perfect data protection tool. In Proceedings of the 2017 International Conference on Intelligent Computing and Control (I2C2), Coimbatore, India, 23–24 June 2017; IEEE: New York, NY, USA, 2017; pp. 1–3.
48. Al-Jaroodi, J.; Mohamed, N. Blockchain in Industries: A Survey. *IEEE Access* **2019**, *7*, 36500–36515. [CrossRef]
49. Khan, S.N.; Loukil, F.; Ghedira-Guegan, C.; Benkhelifa, E.; Bani-Hani, A. Blockchain smart contracts: Applications, challenges, and future trends. *Peer Peer Netw. Appl.* **2021**, *14*, 2901–2925. [CrossRef] [PubMed]
50. Koe, A.S.V.; Ai, S.; Chen, Q.; Tang, J.; Chen, K.; Zhang, S.; Li, X. Hieraledger: Towards malicious gateways in appendable-block blockchain constructions for IoT. *Inf. Sci.* **2023**, *632*, 87–104.
51. Díaz-Medina, M.; Fuertes, J.M.; Segura-Sánchez, R.J.; Lucena, M.; Ogayar-Anguita, C.J. LiDAR attribute based point cloud labeling using CNNs with 3D convolution layers. *Comput. Geosci.* **2023**, *180*, 105453. [CrossRef]
52. Song, C.; Chen, Z.; Wang, K.; Luo, H.; Cheng, J.C.P. BIM-supported scan and flight planning for fully autonomous LiDAR-carrying UAVs. *Autom. Constr.* **2022**, *142*, 104533. [CrossRef]
53. López, A.; Ogayar, C.J.; Jurado, J.M.; Feito, F.R. Metaheuristics for the optimization of Terrestrial LiDAR set-up. *Autom. Constr.* **2023**, *146*, 104675. [CrossRef]
54. Hendricks, R. Introduction to LiDAR and Its Uses in the Building Enclosure and Beyond. In *IIBEC Interface*; International Institute of Building Enclosure Consultants: Raleigh, NC, USA, 2023.
55. Huang, Y.; Zhou, J.; Li, X.; Dong, Z.; Xiao, J.; Wang, S.; Zhang, H. MENet: Map-enhanced 3D object detection in bird's-eye view for LiDAR point clouds. *Int. J. Appl. Earth Obs. Geoinf.* **2023**, *120*, 103337. [CrossRef]
56. Rashdi, R.; Martínez-Sánchez, J.; Arias, P.; Qiu, Z. Scanning technologies to building information modelling: A review. *Infrastructures* **2022**, *7*, 49. [CrossRef]
57. Oh, B.; Kim, M.; Lee, C.; Cho, H.; Kang, K.I. 3D modeling approach of building construction based on point cloud data using LiDAR. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*; IAARC Publications: New York, NY, USA, 2019; pp. 906–912.
58. Wang, L.-C. Enhancing construction quality inspection and management using RFID technology. *Autom. Constr.* **2008**, *17*, 467–479. [CrossRef]
59. Karji, A.; Rokooei, S.; Mainzer, E. Integration of lidar and augmented reality for construction quality control, a conceptual framework. In Proceedings of the CSCE 2021 Annual Conference, Las Vegas, NV, USA, 26–29 May 2021; pp. 26–29.
60. Chen, S.-H.; Xue, F. Automatic BIM detailing using deep features of 3D views. *Autom. Constr.* **2023**, *148*, 104780. [CrossRef]
61. Oladinrin, O.T.; Arif, M.; Rana, M.Q.; Gyoh, L. Interrelations between construction ethics and innovation: A bibliometric analysis using VOSviewer. *Constr. Innov.* **2023**, *23*, 505–523. [CrossRef]
62. Cao, H.; Ou, H.; Ju, W.; Pan, M.; Xue, H.; Zhu, F. Visual Analysis of International Environmental Security Management Research (1997–2021) Based on VOSviewer and CiteSpace. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2601. [CrossRef] [PubMed]

63. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
64. Li, J.; Greenwood, D.; Kassem, M. Blockchain in the built environment and construction industry: A systematic review, conceptual models and practical use cases. *Autom. Constr.* **2019**, *102*, 288–307. [CrossRef]
65. Chen, Z.; Gao, B.; Devereux, B. State-of-the-art: DTM generation using airborne LIDAR data. *Sensors* **2017**, *17*, 150. [CrossRef] [PubMed]
66. Xue, F.; Lu, W. A semantic differential transaction approach to minimizing information redundancy for BIM and blockchain integration. *Autom. Constr.* **2020**, *118*, 103270. [CrossRef]
67. Nawari, N.O.; Ravindran, S. Blockchain and building information modeling (BIM): Review and applications in post-disaster recovery. *Buildings* **2019**, *9*, 149. [CrossRef]
68. Elghaish, F.; Abrishami, S.; Hosseini, M.R. Integrated project delivery with blockchain: An automated financial system. *Autom. Constr.* **2020**, *114*, 103182. [CrossRef]
69. Gupta, R.; Tanwar, S.; Kumar, N.; Tyagi, S. Blockchain-based security attack resilience schemes for autonomous vehicles in industry 4.0: A systematic review. *Comput. Electr. Eng.* **2020**, *86*, 106717. [CrossRef]
70. Liu, Z.; Jiang, L.; Osmani, M.; Demian, P. Building information management (BIM) and blockchain (BC) for sustainable building design information management framework. *Electronics* **2019**, *8*, 724. [CrossRef]
71. Sigalov, K.; Ye, X.; König, M.; Hagedorn, P.; Blum, F.; Severin, B.; Hettmer, M.; Hückinghaus, P.; Wölkerling, J.; Groß, D. Automated payment and contract management in the construction industry by integrating building infor-mation modeling and blockchain-based smart contracts. *Appl. Sci.* **2021**, *11*, 7653. [CrossRef]
72. Fernández-Caramés, T.M.; Blanco-Novoa, O.; Suárez-Albela, M.; Fraga-Lamas, P. A UAV and block-chain-based system for industry 4.0 inventory and traceability applications. *Multidiscip. Digit. Publ. Inst. Proc.* **2018**, *4*, 26.
73. Tan, Y.; Li, S.; Wang, Q. Automated geometric quality inspection of prefabricated housing units using BIM and LiDAR. *Remote Sens.* **2020**, *12*, 2492. [CrossRef]
74. Wang, B.; Wang, Q.; Cheng, J.C.; Song, C.; Yin, C. Vision-assisted BIM reconstruction from 3D LiDAR point clouds for MEP scenes. *Autom. Constr.* **2022**, *133*, 103997. [CrossRef]
75. Chen, L.; Luo, H. A BIM-based construction quality management model and its applications. *Autom. Constr.* **2014**, *46*, 64–73. [CrossRef]
76. Sepasgozar, S.M.E.; Lim, S.; Shirowzhan, S.; Kim, Y.M. Implementation of as-built information modelling using mobile and terrestrial lidar systems. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*; IAARC Publications: New York, NY, USA, 2014; p. 1.
77. Maciel, A. Use of blockchain for enabling Construction 4.0. In *Construction 4.0*; Routledge: London, UK, 2020; pp. 395–418.
78. San, K.M.; Choy, C.F.; Fung, W.P. The potentials and impacts of blockchain technology in construction industry: A literature review. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *495*, 012005. [CrossRef]
79. Raza, M.S.; Tayeh, B.A.; Abu Aisheh, Y.I.; Maglad, A.M. Potential features of building information modeling (BIM) for application of project management knowledge areas in the construction industry. *Heliyon* **2023**, *9*, e19697. [CrossRef] [PubMed]
80. Wang, Q.; Kim, M.-K. Applications of 3D point cloud data in the construction industry: A fifteen-year review from 2004 to 2018. *Adv. Eng. Inform.* **2019**, *39*, 306–319. [CrossRef]
81. CIC, C. *BIM Project Execution Planning Guide–Version 2.1*; Pennsylvania State University: University Park, PA, USA, 2012; Available online: http://bim.psu.edu/resources/owner/bim_planning_guide_for_facility_owners-version_pdf (accessed on 4 January 2024).
82. Cao, D.; Li, H.; Wang, G. Impacts of isomorphic pressures on BIM adoption in construction projects. *J. Constr. Eng. Manag.* **2014**, *140*, 04014056. [CrossRef]
83. Isikdag, U.; Underwood, J.; Aouad, G. An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes. *Adv. Eng. Inform.* **2008**, *22*, 504–519. [CrossRef]
84. Mahmudnia, D.; Arashpour, M.; Yang, R. Blockchain in construction management: Applications, advantages and limitations. *Autom. Constr.* **2022**, *140*, 104379. [CrossRef]
85. Das, M.; Tao, X.; Liu, Y.; Cheng, J.C.P. A blockchain-based integrated document management frame-work for construction applications. *Autom. Constr.* **2022**, *133*, 104001. [CrossRef]
86. Pradeep, A.S.E.; Yiu, T.W.; Amor, R. Leveraging blockchain technology in a BIM workflow: A literature review. In *International Conference on Smart Infrastructure and Construction 2019 (ICSIC) Driving Data-Informed Decision-Making*; ICE Publishing: Miami Lakes, FL, USA, 2019; pp. 371–380.
87. Rao, A.S.; Radanovic, M.; Liu, Y.; Hu, S.; Fang, Y.; Khoshelham, K.; Palaniswami, M.; Ngo, T. Real-time monitoring of construction sites: Sensors, methods, and applications. *Autom. Constr.* **2022**, *136*, 104099. [CrossRef]
88. Li, H.; Chan, G.; Wong, J.K.W.; Skitmore, M. Real-time locating systems applications in construction. *Autom. Constr.* **2016**, *63*, 37–47. [CrossRef]
89. Abanda, F.; Mzyece, D.; Oti, A.; Manjia, M. A Study of the potential of cloud/mobile BIM for the management of construction projects. *Appl. Syst. Innov.* **2018**, *1*, 9. [CrossRef]
90. Yang, A.; Han, M.; Zeng, Q.; Sun, Y. Adopting building information modeling (BIM) for the development of smart buildings: A review of enabling applications and challenges. *Adv. Civ. Eng.* **2021**, *2021*, 8811476. [CrossRef]

91. Herrera, R.F.; Mourgues, C.; Alarcón, L.F.; Pellicer, E. Analyzing the association between lean design management practices and BIM uses in the design of construction projects. *J. Constr. Eng. Manag.* **2021**, *147*, 04021010. [CrossRef]
92. Rojas, M.J.; Herrera, R.F.; Mourgues, C.; Ponz-Tienda, J.L.; Alarcón, L.F.; Pellicer, E. BIM use assessment (BUA) tool for characterizing the application levels of BIM uses for the planning and design of construction projects. *Adv. Civ. Eng.* **2019**, *2019*, 9094254. [CrossRef]
93. Melzner, J.; Feine, I.; Hollermann, S.; Rütz, J.; Bargstädt, H. The influence of building information modelling on the communication management of construction projects. In Proceedings of the 15th International Conference on Construction Applications of Virtual Reality, Banff, AB, Canada, 22–25 June 2015.
94. Gao, J.; Fischer, M. *Cifecenter for Integrated Facility Engineering Framework & Case Studies Comparing Implementations & Impacts of 3D/4D Modeling Across Projects*; Stanford University: Stanford, CA, USA, 2008.
95. Hartmann, T.; Gao, J.; Fischer, M. Areas of application for 3D and 4D models on construction projects. *J. Constr. Eng. Manag.* **2008**, *134*, 776–785. [CrossRef]
96. Azhar, S.; Carlton, W.A.; Olsen, D.; Ahmad, I. Building information modeling for sustainable design and LEED®rating analysis. *Autom. Constr.* **2011**, *20*, 217–224. [CrossRef]
97. Bynum, P.; Issa, R.R.A.; Olbina, S. Building information modeling in support of sustainable design and construction. *J. Constr. Eng. Manag.* **2013**, *139*, 24–34. [CrossRef]
98. Eastman, C.M. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors*; John Wiley & Sons: Hoboken, NJ, USA, 2011.
99. Peterson, F.; Hartmann, T.; Fruchter, R.; Fischer, M. Teaching construction project management with BIM support: Experience and lessons learned. *Autom. Constr.* **2011**, *20*, 115–125. [CrossRef]
100. Musarat, M.A.; Alaloul, W.S.; Cher, L.S.; Qureshi, A.H.; Alawag, A.M.; Baarimah, A.O. Applications of Building Information Modelling in the Operation and Maintenance Phase of Construction Projects: A Framework for the Malaysian Construction Industry. *Sustainability* **2023**, *15*, 5044. [CrossRef]
101. Faraji, A.; Arya, S.H.; Ghasemi, E.; Soleimani, H.; Rahnamayiezekavat, P. A Constructability Assessment Model Based on BIM in Urban Renewal Projects in Limited Lands. *Buildings* **2023**, *13*, 2599. [CrossRef]
102. Seo, J.-H.; Lee, B.-R.; Kim, J.-H.; Kim, J.-J. Collaborative process to facilitate BIM-based clash detection tasks for enhancing constructability. *J. Korea Inst. Build. Constr.* **2012**, *12*, 299–314. [CrossRef]
103. Sulankivi, K.; Tauriainen, M.; Kiviniemi, M. Safety aspect in constructability analysis with BIM. In Proceedings of the CIB W099 International Conference Achieving Sustainable Construction Health and Safety, Lund, Sweden, 2–3 June 2014.
104. Khanzadi, M.; Sheikhkhoshkar, M.; Banihashemi, S. BIM applications toward key performance indicators of construction projects in Iran. *Int. J. Constr. Manag.* **2020**, *20*, 305–320. [CrossRef]
105. Aram, S.; Eastman, C.; Sacks, R. Requirements for BIM platforms in the concrete reinforcement supply chain. *Autom. Constr.* **2013**, *35*, 1–17. [CrossRef]
106. Irizarry, J.; Karan, E.P.; Jalaei, F. Integrating BIM and GIS to improve the visual monitoring of construction supply chain management. *Autom. Constr.* **2013**, *31*, 241–254. [CrossRef]
107. Shaqour, E. The role of implementing BIM applications in enhancing project management knowledge areas in Egypt. *Ain Shams Eng. J.* **2022**, *13*, 101509. [CrossRef]
108. Maliha, M.N. Building Information Modelling (BIM) in Order to Enhance the Capabilities of Project Managers in Applying Knowledge Areas in the Architecture. Engineering and Construction (AEC) Industry in Palestine. Ph.D. Dissertation, The Islamic University of Gaza, Gaza, Palestine, 2019.
109. Maliha, M.N.; Tayeh, B.A.; Aisheh, Y.I.A. Building information modeling (BIM) in enhancing the applying of knowledge areas in the architecture, engineering and construction (AEC) industry. *Open. Civ. Eng. J.* **2020**, *14*, 5. [CrossRef]
110. Mactavish, A.; Iqbal, N.; Marsh, D. Resources Efficiency through BIM: A Guide for BIM Managers. In *Guidance on Resource Efficient Construction*; National Federation of Builders: Gatwick, UK, 2013.
111. Zuppa, D.; Issa, R.R.A.; Suermann, P.C. BIM's impact on the success measures of construction projects. In *Computing in Civil Engineering*; ASCE: Washington, DC, USA, 2009; pp. 503–512.
112. Xue, F.; Lu, W.; Chen, K.; Zetkulic, A. From semantic segmentation to semantic registration: Derivative-free optimization–based approach for automatic generation of semantically rich as-built building information models from 3D point clouds. *J. Comput. Civ. Eng.* **2019**, *33*, 04019024. [CrossRef]
113. Habibi, S. Smart innovation systems for indoor environmental quality (IEQ). *J. Build. Eng.* **2016**, *8*, 1–13. [CrossRef]
114. Cheng, M.-Y.; Chiu, K.-C.; Hsieh, Y.-M.; Yang, I.-T.; Chou, J.-S.; Wu, Y.-W. BIM integrated smart monitoring technique for building fire prevention and disaster relief. *Autom. Constr.* **2017**, *84*, 14–30. [CrossRef]
115. Rashid, K.M.; Louis, J.; Fiawoyife, K.K. Wireless electric appliance control for smart buildings using indoor location tracking and BIM-based virtual environments. *Autom. Constr.* **2019**, *101*, 48–58. [CrossRef]
116. Adamska, B.A.; Blahak, D.; Abanda, F.H. Blockchain in construction practice. In *Collaboration and Integration in Construction, Engineering, Management and Technology: Proceedings of the 11th International Conference on Construction in the 21st Century, London 2019*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 339–343.
117. Xu, Y.; Chong, H.-Y.; Chi, M. Blockchain in the AECO industry: Current status, key topics, and future research agenda. *Autom. Constr.* **2022**, *134*, 104101. [CrossRef]

118. Fulford, R.; Standing, C. Construction industry productivity and the potential for collaborative practice. *Int. J. Proj. Manag.* **2014**, *32*, 315–326. [CrossRef]
119. Saghiri, A.M. *Blockchain architecture. Advanced Applications of Blockchain Technology*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 161–176.
120. Sheng, D.; Ding, L.; Zhong, B.; Love, P.E.D.; Luo, H.; Chen, J. Construction quality information management with blockchains. *Autom. Constr.* **2020**, *120*, 103373. [CrossRef]
121. Li, J.; Greenwood, D.J.; Kassem, M. *Blockchain in the Built Environment: Analysing Current Applications and Developing an Emergent Framework*; Diamond Congress Ltd., Budapest University of Technology and Economics: Budapest, Hungary, 2018.
122. Das, M.; Luo, H.; Cheng, J.C.P. Securing interim payments in construction projects through a block-chain-based framework. *Autom Constr.* **2020**, *118*, 103284. [CrossRef]
123. Li, J.; Kassem, M.; Watson, R. A blockchain and smart contract-based framework to increase traceability of built assets. In Proceedings of the 37th CIB W78 Information Technology for Construction Conference (CIB W78), São Paulo, Brazil, 2–4 June 2020; pp. 347–362.
124. Wang, J.; Wu, P.; Wang, X.; Shou, W. The outlook of blockchain technology for construction engineering management. *Front. Eng. Manag.* **2017**, *4*, 67–75. [CrossRef]
125. Su, H.-N.; Lee, P.-C. Mapping knowledge structure by keyword cooccurrence: A first look at journal papers in Technology Foresight. *Scientometrics* **2010**, *85*, 65–79. [CrossRef]
126. Jo, B.W.; Khan, R.M.A.; Lee, Y.-S. Hybrid Blockchain and internet-of-things network for underground structure health monitoring. *Sensors* **2018**, *18*, 4268. [CrossRef] [PubMed]
127. Ahmadisheykhsarmast, S.; Sonmez, R. Smart contracts in construction industry. In Proceedings of the 5th International Project and Construction Management Conference (IPCMC2018), Girne, North Cyprus, 16–18 November 2018; pp. 767–774.
128. Perera, S.; Nanayakkara, S.; Rodrigo, M.; Senaratne, S.; Weinand, R. Blockchain technology: Is it hype or real in the construction industry? *J. Ind. Inf. Integr.* **2020**, *17*, 100125. [CrossRef]
129. Kim, K.; Lee, G.; Kim, S. A study on the application of blockchain technology in the construction industry. *KSCE J. Civ. Eng.* **2020**, *24*, 2561–2571. [CrossRef]
130. Turk, Ž.; Klinc, R. Potentials of blockchain technology for construction management. *Procedia Eng.* **2017**, *196*, 638–645. [CrossRef]
131. Celik, Y.; Petri, I.; Rezgui, Y. Integrating BIM and Blockchain across construction lifecycle and supply chains. *Comput. Ind.* **2023**, *148*, 103886. [CrossRef]
132. Faraji, A. Smart contract based conceptual model for optimizing risk distribution in construction industry. In Proceedings of the 3rd International Conference on Applied Researches in Structural Engineering and Construction Management, Chicago, IL, USA, 26–27 June 2019; pp. 26–27.
133. Adu-Amankwa, N.A.N.; Rahimian, F.P.; Dawood, N.; Park, C. Digital Twins and Blockchain technologies for building lifecycle management. *Autom. Constr.* **2023**, *155*, 105064. [CrossRef]
134. Sun, C.; Wang, M. Research on Trust Influence of Building Supply Chain Members Based on Blockchain Technology. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *525*, 012019. [CrossRef]
135. Yang, R.; Wakefield, R.; Lyu, S.; Jayasuriya, S.; Han, F.; Yi, X.; Yang, X.; Amarasinghe, G.; Chen, S. Public and private blockchain in construction business process and information integration. *Autom. Constr.* **2020**, *118*, 103276. [CrossRef]
136. Shojaei, A. Exploring applications of blockchain technology in the construction industry. In Proceedings of the International Structural Engineering and Construction, Chicago, IL, USA, 20–25 May 2019; p. 6.
137. Hargaden, V.; Papakostas, N.; Newell, A.; Khavia, A.; Scanlon, A. The role of blockchain technologies in construction engineering project management. In Proceedings of the 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC), Valbonne, France, 17–19 June 2019; IEEE: New York, NY, USA, 2019; pp. 1–6.
138. Xu, Y.; Tao, X.; Das, M.; Kwok, H.H.; Liu, H.; Wang, G.; Cheng, J.C. Suitability analysis of consensus protocols for blockchain-based applications in the construction industry. *Autom. Constr.* **2023**, *145*, 104638. [CrossRef]
139. Siountri, K.; Skondras, E.; Vergados, D.D. Towards a smart museum using BIM, IoT, blockchain and advanced digital technologies. In Proceedings of the 3rd International Conference on Vision, Image and Signal Processing, Vancouver, BC, Canada, 26–28 August 2019; pp. 1–6.
140. Chen, G.; Liu, M.; Zhang, Y.; Wang, Z.; Hsiang, S.M.; He, C. Using Images to Detect, Plan, Analyze, and Coordinate a Smart Contract in Construction. *J. Manag. Eng.* **2023**, *39*, 04023002. [CrossRef]
141. Pittman, S.J.; Costa, B.; Wedding, L.M. LiDAR applications. In *Coral Reef Remote Sensing: A Guide for Mapping, Monitoring and Management*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 145–174.
142. Yuan, X.; Smith, A.; Sarlo, R.; Lippitt, C.D.; Moreu, F. Automatic evaluation of rebar spacing using LiDAR data. *Autom. Constr.* **2021**, *131*, 103890. [CrossRef]
143. Deak, G.; Curran, K.; Condell, J. A survey of active and passive indoor localisation systems. *Comput. Commun.* **2012**, *35*, 1939–1954. [CrossRef]
144. Faraji, A.; Arya, S.H.; Ghasemi, E.; Soleimani, H. Considering the Digital Twin as the Evolved Level of BIM in the Context of Construction 4.0. In Proceedings of the 1st National & International Conference on Architecture, Advanced Technologies and Construction Management (IAAC), Tehran, Iran, 15 November 2023.

145. Cicconi, P.; Raffaeli, R.; Borghi, A. A Design Approach to Support BIM for Existing Structures. In Proceedings of the Advances on Mechanics, Design Engineering and Manufacturing II: Proceedings of the International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2018), Catania, Italy, 14–16 September 2016; Springer: Berlin/Heidelberg, Germany, 2019; pp. 292–300.
146. Tao, X.; Das, M.; Liu, Y.; Cheng, J.C. Distributed common data environment using blockchain and Interplanetary File System for secure BIM-based collaborative design. *Autom. Constr.* **2021**, *130*, 103851. [CrossRef]
147. Masuda, D.; Shinkuma, R.; Inagaki, Y.; Oki, E. Blockchain framework for real-time streaming data generated in image sensor networks for smart monitoring. In Proceedings of the 2020 2nd Conference on Blockchain Research & Applications for Innovative Networks and Services (BRAINS), Paris, France, 28–30 September 2020; IEEE: New York, NY, USA, 2020; pp. 217–221.
148. Liu, X.; Zhao, J.; Sun, G.; Zhou, G.; Han, X. Supply Chain Management For modular construction using building information modeling. *PCI J.* **2023**, *68*, 57–71. [CrossRef]
149. Liu, Y.-J.; Li, W.; Li, Y.-H.; Li, S.-J. Application Research of BIM Technology in Ancient Architecture Restoration. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *787*, 012163. [CrossRef]
150. O'donnell, J.; Truong-Hong, L.; Boyle, N.; Corry, E.; Cao, J.; Laefer, D.F. LiDAR point-cloud mapping of building façades for building energy performance simulation. *Autom. Constr.* **2019**, *107*, 102905. [CrossRef]
151. Song, C.; Wang, K.; Cheng, J.C.P. BIM-aided scanning path planning for autonomous surveillance UAVs with LiDAR. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*; IAARC Publications: New York, NY, USA, 2020; pp. 1195–1202.
152. Yaagoubi, R.; Miky, Y. Developing a combined light detecting and ranging (LiDAR) and building information modeling (BIM) approach for documentation and deformation assessment of historical buildings. In *MATEC Web of Conferences*; EDP Sciences: Les Ulis, France, 2018; p. 02011.
153. Salimzadeh, N.; Hammad, A. High-Level Framework for GIS-Based Optimization of Building Photovoltaic Potential at Urban Scale Using BIM and LiDAR. In Proceedings of the International Conference on Sustainable Infrastructure, New York, NY, USA, 26–28 October 2017; pp. 123–134.
154. Zeng, R.; Shi, J.J.S.; Wang, C.; Lu, T. Integrating as-built BIM model from point cloud data in construction projects. In *Engineering, Construction and Architectural Management*; Emerald Insight: Leeds, England, 2023.
155. Meyer, T.; Brunn, A.; Stilla, U. Change detection for indoor construction progress monitoring based on BIM, point clouds and uncertainties. *Autom. Constr.* **2022**, *141*, 104442. [CrossRef]
156. ElQasaby, A.R.; Alqahtani, F.K.; Alheyf, M. Automated Schedule and Cost Control Using 3D Sensing Technologies. *Appl. Sci.* **2023**, *13*, 783. [CrossRef]
157. Mathews, M.; Robles, D.; Bowe, B. BIM+Blockchain: A Solution to the Trust Problem in Collaboration? CITA BIM Gathering 2017, 23–24 November 2017. Available online: https://arrow.tudublin.ie/cgi/viewcontent.cgi?article=1032&context=bescharcon (accessed on 4 January 2024).
158. Dounas, T.; Lombardi, D.; Jabi, W. *Towards Blockchains for Architectural Design Consensus Mechanisms for Collaboration in BIM*; ORCA: Victoria, BC, Canada, 2019.
159. Akbarieh, A.; Carbone, W.; Schäfer, M.; Waldmann, D.; Teferle, F.N. *Extended Producer Responsibility in the Construction Sector through Blockchain, BIM and Smart Contract Technologies*; ORBilu: Luxembourg, 2020.
160. Ye, Z.; Yin, M.; Tang, L.; Jiang, H. Cup-of-Water theory: A review on the interaction of BIM, IoT and blockchain during the whole building lifecycle. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction*; IAARC Publications: New York, NY, USA, 2018; pp. 1–9.
161. Sonmez, R.; Ahmadisheykhsarmast, S.; Güngör, A.A. BIM integrated smart contract for construction project progress payment administration. *Autom. Constr.* **2022**, *139*, 104294. [CrossRef]
162. Elghaish, F.; Hosseini, M.R.; Kocaturk, T.; Arashpour, M.; Ledari, M.B. Digitalised circular construction supply chain: An integrated BIM-Blockchain solution. *Autom. Constr.* **2023**, *148*, 104746. [CrossRef]
163. Li, C.; Fu, Y.; Yu, F.R.; Luan, T.H.; Zhang, Y. Vehicle position correction: A vehicular blockchain networks-based GPS error sharing framework. *IEEE Trans. Intell. Transp. Syst.* **2020**, *22*, 898–912. [CrossRef]
164. Muram, F.U.; Javed, M.A. Drone-based risk management of autonomous systems using contracts and blockchain. In Proceedings of the 2021 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER), Honolulu, HI, USA, 9–12 March 2021; IEEE: New York, NY, USA, 2021; pp. 679–688.
165. Reebadiya, D.; Rathod, T.; Gupta, R.; Tanwar, S.; Kumar, N. Blockchain-based secure and intelligent sensing scheme for autonomous vehicles activity tracking beyond 5g networks. *Peer-to-Peer Netw. Appl.* **2021**, *14*, 2757–2774. [CrossRef]
166. Hirai, K.; Akiyama, K.; Shinkuma, R.; Mine, A. Real-Time Hash Aggregation for Blockchain System With 3D Sensor Network. In Proceedings of the 2023 IEEE 20th Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, USA, 8–11 January 2023; IEEE: New York, NY, USA, 2023; pp. 354–359.
167. Balakrishnan, S.; Azman, A.D.; Nisar, J.; Ejodame, O.E.; Cheng, P.S.; Kin, T.W.; Yi, Y.J.; Das, S.R. IoT-Enabled Smart Warehousing with AMR Robots and Blockchain: A Comprehensive Approach to Efficiency and Safety. In Proceedings of the International Conference on Mathematical Modeling and Computational Science, Belgrade, Serbia, 28–31 August 2023; Springer: Berlin/Heidelberg, Germany, 2023; pp. 261–270.
168. Min, H. Smart Warehousing as a Wave of the Future. *Logistics* **2023**, *7*, 30. [CrossRef]

169. de Vries, W.T. Trends in the adoption of new geospatial technologies for spatial planning and land management in 2021. *Geoplanning J. Geomat. Plan.* **2021**, *8*, 85–98. [CrossRef]
170. Loo, B.P.Y.; Wong, R.W.M. Towards a Conceptual Framework of Using Technology to Support Smart Construction: The Case of Modular Integrated Construction (MiC). *Buildings* **2023**, *13*, 372. [CrossRef]
171. He, X.; Pan, S.; Gao, W.; Lu, X. LiDAR-Inertial-GNSS fusion positioning system in urban environment: Local accurate registration and global drift-free. *Remote Sens.* **2022**, *14*, 2104. [CrossRef]