Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 10, No. 05, May, 2024

Integration of Blockchain-Enabled Smart Contracts in Construction: SWOT Framework and Social Network Analysis

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Received 09 February 2024; Revised 13 April 2024; Accepted 18 April 2024; Published 01 May 2024

Abstract

The construction sector, one of the most ancient industries globally, holds a crucial role in the progress and development of societies. However, it faces persistent productivity and efficiency challenges, rendering it a relative setback when compared to other sectors. In the ever-evolving landscape of the construction industry, characterized by complex projects, numerous stakeholders, and intricate contractual agreements, the integration of emerging technologies presents an unprecedented opportunity for transformation. Smart contracts (SCs), underpinned by blockchain (BC) technology, hold the potential to streamline and revolutionize traditional construction processes. Current literature shows a lack of comprehensive quantitative understanding of how Blockchain-enabled Smart Contracts (BSC) can affect the construction sector. To address this gap, the authors have (1) conducted a systematic keyword analysis of literature on SC in construction from Scopus and Web of Science (WoS) databases; (2) conducted a strengths–weaknesses–opportunities–threats (SWOT) analysis of BSC's adoption in the construction industry from 174 peer-reviewed papers; (3) identified a holistic list of 72 factors steering BSC adoption in construction, categorized into the 4 aspects of the SWOT framework; (4) performed social network analysis (SNA) to quantitively assess the literature in terms of the identified factors; and (5) conducted clustering analysis to categorize combination of factors frequently highlighted in research publications into common groups. This research offers a comprehensive and methodical evaluation of the potential advantages, applications, and challenges associated with integrating BSC in the construction industry. The findings of SNA and clustering reveal a notable lack of investigation into certain combinations of factors in existing academic research. This disparity and the ensuing knowledge gaps may affect SC's adoption in the construction sector. To this end, this study equips stakeholders with the insights necessary to make informed decisions in this rapidly evolving sector and contributes to a roadmap for future BSC construction-related research.

Keywords: Smart Contracts; Blockchain; Construction; SWOT Analysis; Social Network Analysis; Clustering.

1. Introduction

The construction sector is marked by inherent adversarial relationships and legal conflicts that adversely impact a project's cost and duration—two critical elements of the triad of construction performance constraints [1, 2]. Trust is a central concern, affecting inter-organizational relationships and stakeholder dynamics, leading to cautious behavior and contractual breaches [3–5]. Technological integration is essential to foster trust and enhance performance [3, 4]. Challenges also extend to transparency, traceability, and data completeness, with the management of extensive contractual data during project execution being vital for timely decision-making [6–8]. However, outdated document

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http://dx.doi.org/10.28991/CEJ-2024-010-05-020

and information management processes heighten the risk of information fraud and undermine accountability [9, 10]. Furthermore, the sector struggles with issues in monitoring and controlling procedures, exacerbated by incomplete or ambiguous information, unpredictable stakeholder behavior, a lack of standardized procedures, and non-compliance, all of which increase the risk of delays, cost escalations, and disputes [11–13]. This paper aims to bridge these gaps by proposing solutions to improve trust, transparency, and data management, thereby enhancing overall project efficiency and reducing disputes in the construction industry. With these considerations in mind, the adoption of blockchain-enabled smart contracts (BSC) holds promise for enhancing the construction industry. Smart contracts (SCs), which are self-executing agreements built on blockchain (BC) with predefined rules and conditions, can enhance trust and transparency, streamline data management, and facilitate efficient monitoring of construction projects. By automating and enforcing contractual obligations, SCs minimize the likelihood of disputes and provide a secure and transparent platform for all project stakeholders to interact. Nevertheless, it is important to acknowledge the significant challenges that could impede the extensive utilization of SCs. Effectively managing these challenges will be crucial for their seamless integration into the broader commercial landscape.

As the construction industry navigates the complexities of integrating BSC into the construction sector, scholarly efforts have examined this innovation through various lenses. The body of literature encompasses a broad spectrum of methodological approaches and thematic terrains, each contributing to a piecemeal understanding of BSC's facets, as discussed shortly. This preliminary examination lays the groundwork for a deeper exploration into the nuanced dynamics of BSC adoption, setting the stage for a comprehensive investigation that seeks to unify these disparate strands of research into a cohesive narrative.

The literature demonstrates a range of methodological approaches used to explore the adoption of BSC in the construction industry. These include, for instance, literature reviews [8, 14–18], case studies [19–22], descriptive analyses [23–26], and bibliometric and content analyses [27–30]. Moreover, it is noteworthy to highlight that while some studies focus exclusively on qualitative research [31–33], others adopt quantitative methods, using statistical analyses to review the literature without qualitative techniques like interviews or thematic content, as highlighted in Shishehgarkhaneh et al. [34] and Ameyaw et al. [35]. Meanwhile, a third group integrates both approaches, notably [36–40], highlighting the methodological diversity in the field. This diversity, while enriching, leads to a lack of consistency and cohesion, which impedes the effective comparison and integration of findings. Moreover, the existing dichotomy between in-depth qualitative reviews and narrowly focused quantitative methods underscores a significant gap in the literature. There is a critical need for a more integrated approach that combines qualitative and quantitative research to provide a comprehensive understanding of the factors affecting the adoption of SCs in construction. Additionally, the thematic focus of existing studies tends to be narrow, often confined to specific contexts or areas within the BSC domain. Many studies have solely concentrated on the technological and functional analysis of SCs [41, 42], while others have delved into legal and regulatory considerations [23, 29], economic and financial impacts [43, 44], administrative and organizational performance [36, 45], or case studies and practical implementations [46, 47]. The scope limitations of these studies often restrict their findings to specific geographical regions, such as Sweden [48], Nigeria [49], the UK [50], and Malaysia [31, 51].

Furthermore, a segment of the literature focuses on specific applications of BSC, neglecting other potential applications. For instance, payment applications, as explored by [4, 52–54], supply chain, as outlined in the works of [5, 55–57], as well as integration with other technologies [28, 53, 58–63]. Such focused research underscores the literature's gap, showing a lack of comprehensive, cross-contextual analysis that could provide a holistic understanding of BSCs across different thematic areas. Besides, some studies have narrowly concentrated on specific dimensions of BSC, such as exclusively examining the challenges [40, 64, 65] or potentials [66–68]. Although a few have attempted to combine two or more dimensions, notably [17, 30, 69, 70]; however, a comprehensive and holistic study that integrates these aspects remains absent, particularly in terms of quantitative analysis. Additionally, some focus on specific dimensions in certain applications of SC, like the potential benefits of integration of BC with BIM [59], the potential of SCs in construction payments [52, 71], and legal issues in BC for construction supply chains [64]. Yet these studies often fail to provide a broader perspective, highlighting the need for more integrated and expansive research in the field.

Thus, this paper aims to bridge these gaps by providing a comprehensive and methodical assessment of the potential advantages, applications, and challenges associated with integrating BSC in the construction industry, leveraging a systematic keyword analysis, employing a comprehensive strengths–weaknesses–opportunities–threats (SWOT) analysis, and social network analysis (SNA), followed by clustering analysis to offer a nuanced understanding of the multifaceted influences impacting the adoption of BSC.

The structure of this paper is organized as follows: Following the introduction, Section 2 discusses the research contributions, highlighting the study's unique approach to understanding BSC adoption in construction. Section 3 provides a comprehensive background on BC technology and SCs, establishing the foundation for their application in construction. Section 4 delves into the methodology, outlining the systematic keyword analysis, SWOT analysis, and SNA, culminating in clustering analysis to assess the multifaceted influences on BSC adoption in the construction sector.

Section 5 provides an in-depth analysis of these results within the SWOT framework of BSC's adoption in the construction context, positioning it as the analytical cornerstone of this study for a systematic and comprehensive investigation of 72 factors affecting the adoption of BSC in construction. This section is further enriched through SNA and K-means clustering, categorizing BSC's factors in terms of scholarly attention and reflecting their importance in shaping the technology's implementation landscape. Section 6 concludes the paper with a summary of the study's key insights and contributions to the field. Finally, Section 7 discusses the study’s limitations and suggests directions for future research.

2. Research Contributions

The research landscape in SCs for the construction industry is evolving; while insightful, it lacks a holistic and quantifiable analysis of the multifaceted influences impacting their adoption. Scholarly examinations indicate that the research domain of SCs is often fragmented, with a predominant focus on specific perspectives when exploring the factors of BSCs, resulting in a lack of a cohesive and thorough framework. This study fills this gap and pioneers an extensive framework in the domain by employing comprehensive SWOT analysis, which establishes the groundwork for the entire analytical process of this study by providing a systematic and holistic perspective, which is crucial for investigating the different factors associated with BSC adoption in the construction industry. Moreover, unlike prior studies that might depend solely on qualitative analyses or limited quantitative methodologies, this research merges both approaches to provide a comprehensive analysis of the factors influencing BSC's adoption.

The SWOT framework is enhanced by the innovative application of SNA and K-Mean Clustering (K-mean) studies of BSC within the construction industry. The authors used SNA due to its effectiveness in revealing complex interconnections and assessing the significance of each identified factor. The SNA networks show how the factors are connected and the strength of these connections. The study employed Degree Centrality (DC) within SNA, which reflects a factor's prominence based on the number of papers connecting it with other factors. Additionally, the application of K-mean provides a novel perspective on categorizing these factors by grouping them based on their prominence in scholarly literature, thereby unveiling patterns and themes that traditional SWOT analyses might overlook. This clustering highlights the most critical areas for future research and development and offers a clear understanding of where the academic and industrial focus has been, thus guiding more targeted and impactful future inquiries. Together, these methodologies enrich the research by providing both a macro and micro perspective, allowing for a more comprehensive and strategic approach to integrating BSC in the construction industry. This mixed approach also allows stakeholders to identify not only the individual strengths, weaknesses, opportunities, and threats but also how these elements interact and influence each other within the broader ecosystem of BSC adoption.

Considering the foregoing, the authors analyzed the literature, aiming to explore the potential of SCs in revolutionizing the construction industry and improving its overall performance. The authors employed a methodological framework grounded on the SWOT analysis of SC’s adoption in the construction industry, which was subsequently complemented by SNA, and K-mean of the SWOT results, with the objective of (1) providing a holistic examination of factors that can affect the adoption of BSC within the construction industry in terms of their salient features, applications and drawbacks underpinned by SWOT framework; (2) delving into the common themes and patterns emerging from the identified factors and quantitatively analyzing the weight of interrelations between these factors in terms of their co-occurrence in literature; (3) analyzing where the current research stands by classifying BSC factors into groups based on research popularity within this domain; and hence (4) offering a foundational cornerstone for future research endeavors and guiding scholars and practitioners towards a more comprehensive understanding of the subject matter.

3. Background

3.1. Blockchain

BC is a form of distributed ledger technology (DLT) first introduced in 2008 under the enigmatic pseudonym Satoshi Nakamoto [72]. It is a decentralized and immutable ledger system that is distributed and synchronized among diverse locations, institutions, or regions, enabling access for multiple individuals [73]. It consists of a chain of blocks, each containing a set of transactions, which include details such as parties’ information, date, time, documentation, price, and updates. The chain is built from prior transactions stored in distinct blocks linked in a sequential and chronological sequence [74].

The distinctive feature of BC is its decentralized nature, which effectively eliminates the need for a central authority or intermediary. Instead, transactions are validated by a network of participants, often referred to as nodes or miners, who achieve consensus through a cryptographic process [49]. Consensus in BC technology is the foundational mechanism that allows multiple participants in a decentralized network to unanimously validate and agree on the ledger state, ensuring data integrity and security [75].

Once a block of transactions is verified, it is cryptographically linked to the previous block, forming a chain that is exceedingly difficult to alter [76]. This immutability and transparency make BC an ideal solution for recording and tracking transactions, assets, and data in a secure and trustless environment. The "trustless" concept in BC means that trust is not required between parties for transactions to be securely executed; BC itself provides the necessary security and verification mechanisms, ensuring the integrity and reliability of transactions. [34].

The potential applications of BC in construction management are vast. By eliminating the need for intermediaries and enhancing transparency, BC can streamline processes, reduce costs, and mitigate risks in engineering projects. After exploring BC technology, it's essential to highlight its evolution into the second generation, where the focus shifts to SCs.

3.2. Smart Contracts

The inception of SCs precedes the introduction of BC, with their origins dating back to the 1990s and first being conceived by Szabo [77] as a means to automate contracts based on predefined conditions [78]. Challenges related to trust and data integrity constituted obstacles to the widespread adoption of SCs for an extended period, spanning over 15 years. Nevertheless, the emergence of BC in 2008 facilitated the practical implementation of SCs in real-world applications, primarily owing to the technology's inherent features and practical advantages [79].

SCs represent a recent development within the domain of BC that has the potential to bring about a transformative shift in the execution and enforcement of contractual agreements. SCs are described as "computer programs" capable of automatically executing the terms of a contract [80]. Szabo [77], for instance, described SCs as "a set of promises, including protocols within which the parties perform other promises. The protocols are usually implemented with programs on a computer network or in other forms of digital electronics; thus, these contracts are "smarter" than the paper-based ancestors. No use of artificial intelligence is implied." By means of SCs, the contractual clauses established by the contracting parties can be encoded into a programming language, and these clauses can then undergo examination and enforcement by means of a decentralized validation mechanism, all while circumventing the need for direct human involvement [81, 82].

Therefore, during the execution of the contract, the predetermined transaction, exchange, or contractual obligation will occur automatically and reliably when a predetermined event occurs or a specified time period expires, in full compliance with the initial contractual agreement established by the contracting parties at the contract's commencement [83]. To sum up, according to Lim et al. [84] and Hsiao [85], the advantages of SCs are essentially twofold: (1) the conversion of trust into a digital form by ensuring execution certainty; and (2) the enhancement of operational efficiency by eliminating intermediaries and the cost associated with them in the transaction process.

4. Research Methodology

The authors employed an integrated research approach, illustrated in Figure 1. The following subsections contain detailed information on each of the methodology's steps.

4.1. Scientometric Analysis

The databases chosen for sourcing information were Scopus and Web of Science (WoS), selected for their extensive range of scientific literature and rapid indexing capabilities, which facilitate the gathering of relevant publications. Data collection was initiated in May 2023, and the data were updated and revised through September 2023. The keywords employed for searching in the two databases included: "smart contract" or "intelligent contract" and "construction" or "civil engineering" or "building" or "built environment".

Given the nascent nature of 'smart contract' research in the construction industry, the authors did not set a time limit. The initial retrieval process yielded 315 papers, after which various inclusions and exclusions criteria were established to enhance this review's quality. First, the language was selected as "English" and the document type was restricted to be "journal articles" or "conference articles" or "Books chapter". From both databases, 113 duplicate papers were identified and removed. Subsequently, the titles and abstracts of the preliminarily selected articles were sorted. Following this elimination process, 177 articles remained; however, three full texts were unavailable. Finally, a total of 174 articles remained and were deemed appropriate for in-depth analysis, where the authors proceeded to download and read the full texts of these papers. The precise strategies for literature search and screening are illustrated in Figure 2. The selected articles and their details are presented in Table 1.

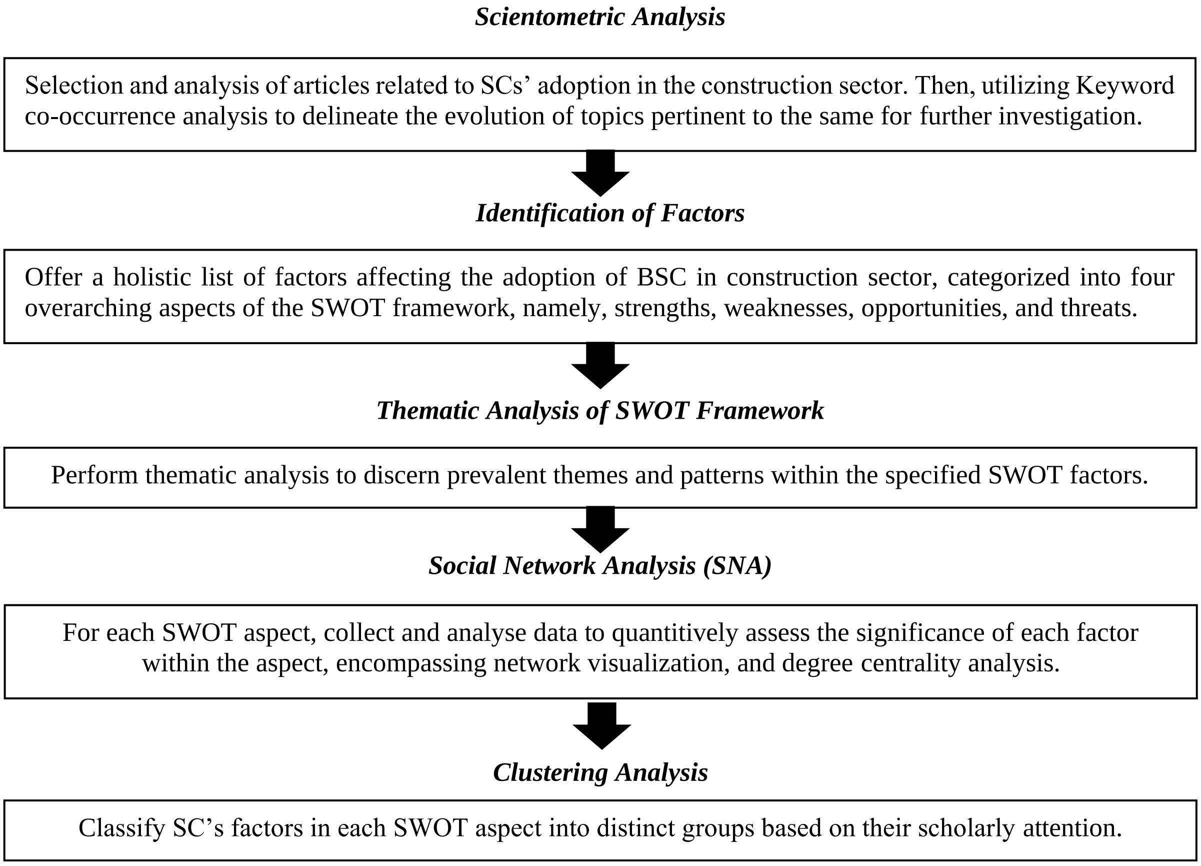


Figure 1. Adopted Research Methodology

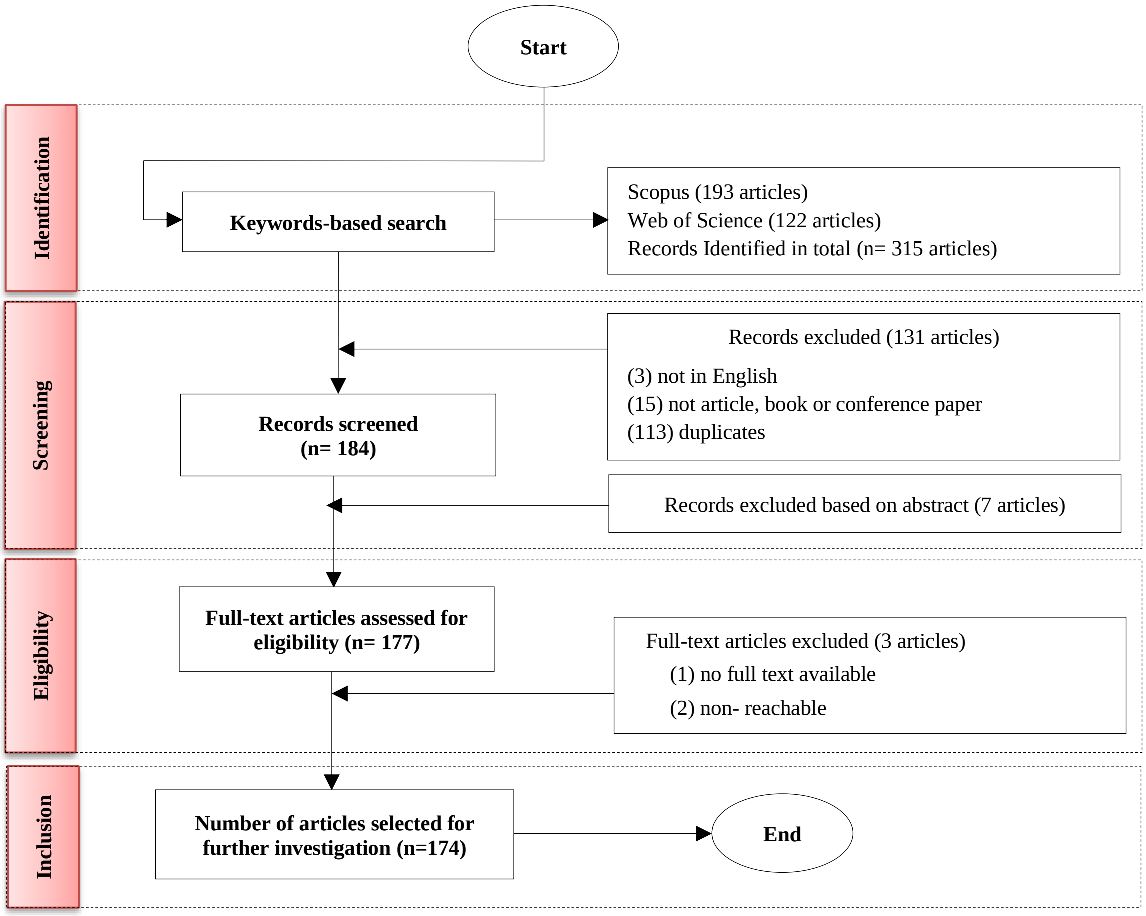


Figure 2. Literature Search and Screening Strategy

Table 1. List of Analyzed Articles

Year	Investigated articles	Count references
2017	[86]	1
2018	[51, 87]	2
2019	[24, 26, 48, 55, 59, 60, 88–98]	17
2020	[4, 10, 11, 19–21, 25, 30, 52, 54, 58, 64, 99–112]	26
2021	[9, 14–16, 27, 28, 37, 38, 50, 53, 65, 113–135]	34
2022	[1, 5, 17, 18, 22, 31, 32, 39, 40, 42, 45, 61, 63, 69–71, 136–177]	58
2023	[23, 29, 33–36, 41, 43, 44, 46, 47, 49, 56, 57, 62, 68, 73, 178–196]	36

Figure 3 illustrates the distribution of the publications over the years, totaling 174 publications by September 2023. The data presented shows an upward trend in the number of publications pertaining to the adoption of SCs within the construction sector, with a consistent annual increase, indicating an increase in research interest. Additionally, keyword co-occurrence analysis is utilized to trace the evolution of topics relevant to SCs within the construction industry. This analysis is a highly efficient method for demonstrating the dynamic progression of scientific trends and subjects over time. The analysis was performed using VOSviewer software [197] as an open-source program for building and displaying bibliometric networks utilizing the visualization of similarities technique.

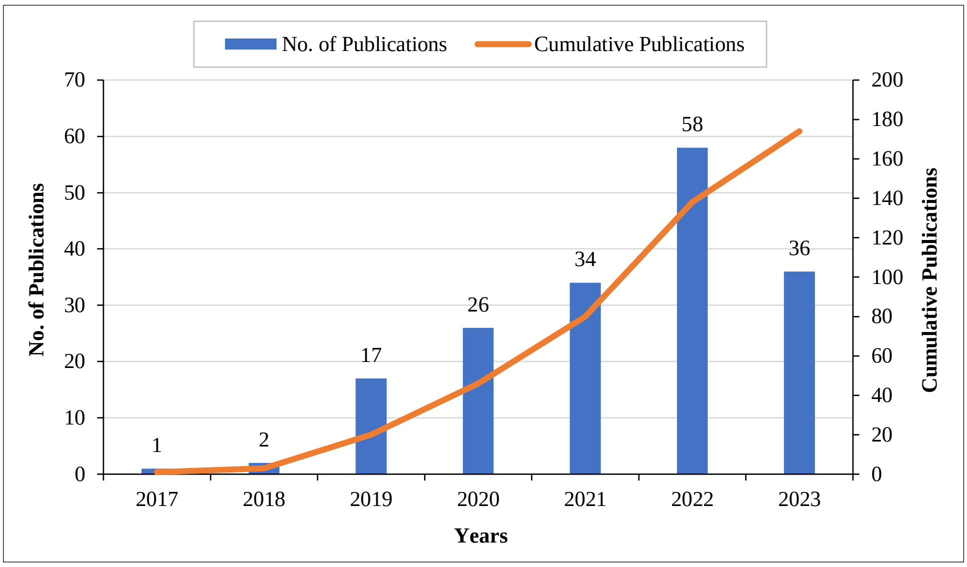


Figure 3. Articles Distribution Over the Years

4.2. SWOT Analysis Framework

The keyword analysis provides a foundational basis for conducting a SWOT analysis on the adoption of SCs in the construction industry. SWOT analysis is widely used in the realm of business management and serves to evaluate the strengths, weaknesses, opportunities, and threats associated with new technologies or strategic orientations within the purview of an organization or industry [198]. This analysis aids in identifying ways to strengthen strengths, leverage opportunities, mitigate weaknesses, and safeguard against threats [108]. The SWOT analysis framework establishes the groundwork for the entire analytical process of this study, providing a systematic and holistic perspective, essential for dissecting the multifaceted aspects of BSC adoption in the construction sector. Thus, it offers a robust foundation for understanding and addressing the complexities inherent in this technological innovation. A breakdown of this SWOT is presented in Table 2.

Table 2. Description of SWOT Framework of BSC Adoption in Construction

Category	Description
Strengths	The internal technical attributes within BSC that can be leveraged in construction. These are positive factors or advantages that can be harnessed to achieve the adoption objectives.
Weaknesses	The internal factors and limitations that may hinder the successful adoption of BSC in construction projects. These are areas of vulnerability or constraints that need to be addressed or overcome.
Opportunities	They are pertaining to external conditions, trends, or applications in the broader business environment of the construction industry that can be enhanced or facilitated by the adoption of BSC. These are external applications of the sector that can be facilitated by BSC.
Threats	They are external factors and risks in the construction industry's broader environment that could potentially hinder or pose challenges to the successful adoption of BSC. These are negative external conditions that need to be monitored and mitigated to ensure successful adoption.

4.3. Social Network Analysis

The third step involves undertaking SNA based on the BSC factors identified in the SWOT analysis and the selected papers. SNA stands as a mathematical method founded in graph theory, offering insights into network behavior and component connections [199]. It is informed by diverse academic fields, including sociology, psychology, statistics, and graph theory. Jacob Moreno pioneered sociometry, which laid the foundation for the systematic study of social relationships [200]. SNA established a significant presence within the realm of social sciences, exerting a substantial influence on various academic disciplines [201]. This evolutionary path subsequently paved the way for the inception of network science, a multidisciplinary field that investigates an array of intricate networks with the primary goal of enhancing our comprehension of complex systems [202]. Notable instances include the exploration of dynamic modeling within the context of construction projects [203] and the examination of modular construction methodologies [204, 205]. Applying SNA in this study is vital, providing a deeper and more nuanced understanding of the interconnected factors influencing BSC deployment in the construction sector. By meticulously mapping and quantitatively analyzing the strength of these interrelations, SNA offers insights into the most investigated and underrepresented aspects within this domain. Consequently, it serves as a key tool for identifying and prioritizing areas for future research and development.

4.4. Clustering Analysis

The fourth step involves conducting clustering analysis based on the constructed SNA model. The primary aim of such analysis is to categorize BSC factors in each SWOT aspect into distinct groups based on their varying levels of scholarly attention. Clustering, an unsupervised machine learning method, aims to assemble entities into similar groups. Its applicability spans numerous domains, such as data mining and pattern recognition [206]. Clustering typically employs K-means, which groups data points into clusters focusing on minimizing the squared distances to the nearest cluster center, or spectral algorithms, which identify clusters in a graph based on how elements are connected [138]. However, in this case, clustering is meant to pinpoint combinations of factors that frequently appear together in scholarly literature.

As highlighted by Ostrovsky et al. [207], K-means clustering stands as a widely embraced and validated technique in clustering methodology. This method operates on a centroid-centered principle, seeking to group entities into a predetermined number of clusters by optimizing the centroid locations, aiming to minimize the squared distances between entities and their respective centroids. Determining the appropriate number of clusters (K) involves the use of various methodologies, including the Hubert statistic, Davies-Bouldin index, Dunn index, score function, elbow plot, and silhouette plot techniques [208]. For this study, the elbow plot method, acknowledged by [209] as reliable, is used to determine the cluster number.

This study applied K-means clustering using SNA data, which was organized in an adjacency matrix and normalized before being processed with the K-means model. The K-means clustering was implemented using Python, a programming language highly regarded and extensively used in scientific computing, engineering, data science, and machine learning for its widespread use and robust functionality. It follows a three-step process: (1) initialization of initial centroids for the clusters; (2) assignment of each point to its nearest centroid; and (3) designation of new centroids for updated points, followed by computing the variance between these newly established and the previous centroids. The algorithm continues to repeat the second and third steps until the change in the centroids' positions becomes very small and falls below a set threshold.

Hence, the objective of the k-means is to reduce cluster inertia, expressed as the within-cluster sum-of-squares (WCSS) criterion in Equation 1, wherein X_i denotes the samples, U_j is the mean of samples within each cluster, and n is the total number of samples that are being analyzed and clustered. The determination of the appropriate number of clusters aligns with the elbow plot technique, which depicts distortion scores for varying cluster counts based on Equation 1. The "elbow" point marks the clusters' count, where adding more clusters does not significantly lower the WCSS.

$$WCSS = \sum_{i=0}^{n} min_{U_j \in C}\left(\|X_i - U_j\|^2\right) \tag{1}$$

5. Thematic Analysis of SWOT Framework for BSC Adoption in Construction Sector

5.1. Keyword Analysis

The analysis encompassed all keywords present within the publications under scrutiny, with a predetermined threshold set at a minimum of 20 occurrences. The outcome revealed that a total of 57 keywords, out of 879, surpassed this threshold. Figure 4 reveals that the 57 keywords constructed four main clusters (i.e., red, blue, yellow, and green). The size of the nodes denotes the frequency at which each keyword appears; the arcs symbolize the co-occurrence connections among keywords; and the thickness of the lines reflects the intensity of these relationships. The yellow cluster corresponds to 'blockchain'; the red cluster represents' smart contracts'; green signifies 'construction industry'; and the blue cluster denotes 'technology and management'. The main keywords are linked to the main dominant co-occurred keywords, which are the largest nodes in the network (i.e., Smart Contract and Blockchain). Figures 4 and 5 reveal 57 items, 4 clusters, 840 links, and a total link strength of 2412.

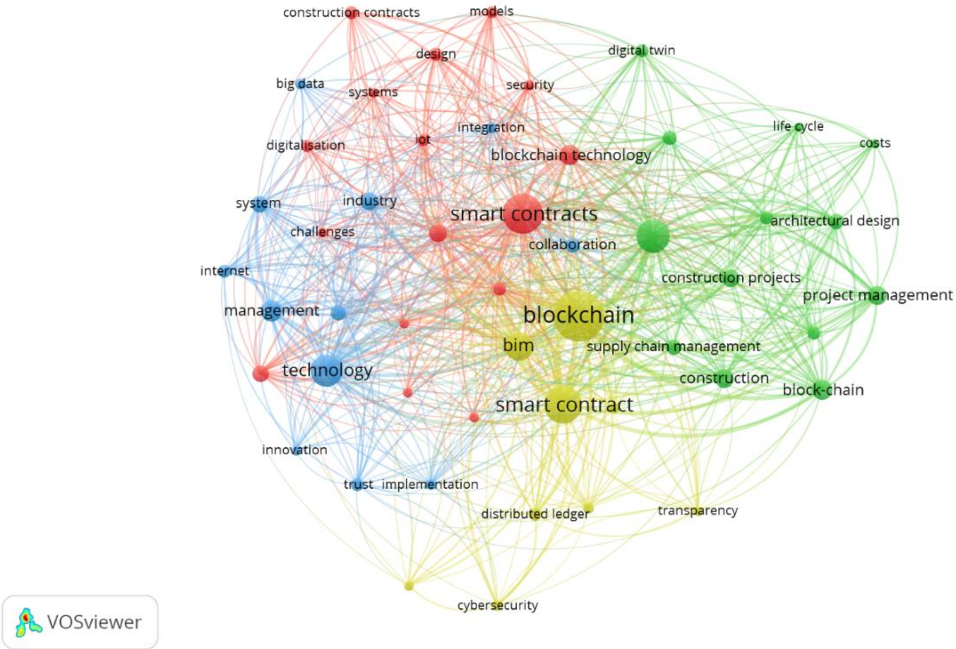


Figure 4. Co-occurrence of the Top Keywords

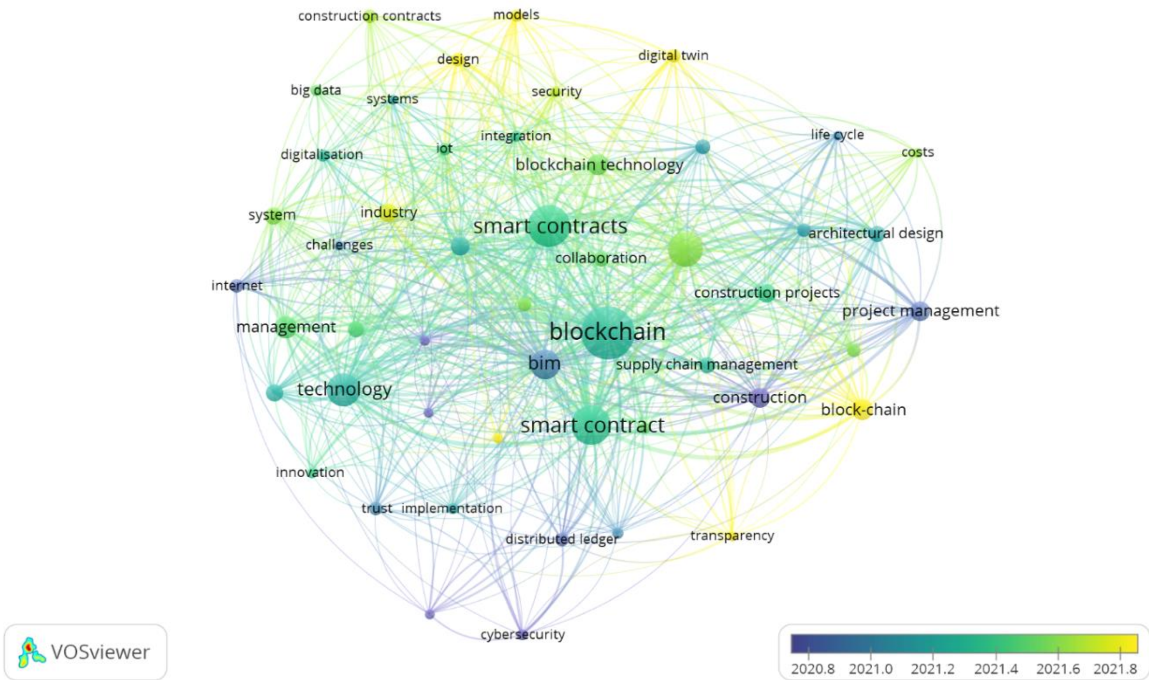


Figure 5. Evolution of Keywords Co-occurrence

The findings from the keyword analysis reveal a dynamic expansion and diversification of research within SCs in the construction industry. This analysis uncovers a significant shift towards integrating BC technology, indicating a strong interest in leveraging these tools for enhancing project management, efficiency, and transparency. The patterns identified suggest an evolving research landscape, where the focus increasingly gravitates towards innovative applications of SCs to solve traditional industry problems. Interestingly, the analysis disclosed that the predominant keywords underscoring the salient features of BSCs encompass transparency, trust, security, digitalization, and distribution. Simultaneously, certain keywords highlight the prospective applications of SCs within the construction sector, including supply chain, project management, and design. Additionally, this encompasses the integration of SCs with other technologies such as Building Information Modelling (BIM) and the Internet of Things (IoT). Although these keywords underscore a significant interest in employing SCs in the construction industry, the research also explores the challenges hindering their adoption within this sector.

To conclude, the keyword analysis reveals potential advantages, applications, and challenges associated with integrating SCs in the construction industry. Hence, it provides a foundational basis for conducting a SWOT analysis on the adoption of SCs in the construction industry.

Figure 5 maps the growth and prevalence of terminologies over specific time intervals pertaining to key trends in the adoption of SC in construction. Core concepts such as "blockchain" and "smart contracts" are prominently featured, affirming their central relevance. The gradient color spectrum, which transitions from a deeper blue to a vibrant yellow, acts as a chronological marker, indicating the temporal progression and relevance of the depicted concepts. Such a representation potentially offers insights into the evolving nature of academic and industrial focus, emphasizing shifts in research emphasis and technological advancements within the stipulated time frame.

5.2. BSC Factors of the SWOT Analysis

An extensive review of 174 papers was made, where each publication was carefully examined to extract and comprehend the factors within the SWOT aspects related to the adoption of BSC in construction. The authors thoroughly examined and categorized these factors based on their characteristics and identifiable attributes as related to the SWOT framework. The categorization method relied on detailed scrutiny of the factors' unique attributes and implications as documented in the sources utilized, ensuring an objective and representative classification that is reflective of the insights directly derived from the scholarly literature. Following this extraction process, the authors undertook a detailed procedure to refine the initially gathered list of factors, eliminating duplicate mentions and merging factors that held similar meanings or perspectives under unified terms. It's important to note that the extraction of factors was based on their actual recurrence in the literature rather than mere citation frequency. This approach emphasizes the rigorous methodology utilized in this study, extending to a comprehensive understanding of the content and context of each publication.

The authors identified a total of 72 distinct factors that exert influence on BSC adoption within the construction sector. These factors were subsequently categorized into four overarching aspects of the SWOT framework, namely, strengths (25 factors), weaknesses (11 factors), opportunities (20 factors), and threats (16 factors), as shown in Table 3. All selected factors are listed in Supplementary B, along with their relevant identified sources.

Table 3. BSC Factors of the SWOT Analysis

Strengths (25)	Opportunities (20)
• **S1:** Traceability	• **O1:** Document management/ information management
• **S2:** Immutability	• **O2:** Supply chain management
• **S3:** Data irreversibility/ Tamper proof/ Persistency	• **O3:** procurement management
• **S4:** Transparency	• **O4:** Automated payments
• **S5:** Information sharing	• **O5:** Funding/ cashflow management
• **S6:** Decentralization	• **O6:** Facility/ asset management
• **S7:** Trust/ reliability	• **O7:** Contract management/ administration
• **S8:** Increased data security	• **O8:** Quality management/ compliance checking
• **S9:** Increased data privacy	• **O9:** Site management
• **S10:** Automation	• **O10:** Stakeholder management
• **S11:** Improved risk contingency	• **O11:** Dispute resolution
• **S12:** Reducing bureaucracy	• **O12:** Safety Management
• **S13:** Auditability	• **O13:** Design management
• **S14:** Chronological data recording	• **O14:** Change/ dynamic management
• **S15:** Time-stamping/ real-time information	• **O15:** Risk management
• **S16:** Accountability/ clarity in authority	• **O16:** Subcontract management
• **S17:** Time-saving	• **O17:** Integrated technology - BIM
• **S18:** Saving efforts/ increasing productivity	• **O18:** Integrated technology - Digital twin
• **S19:** Efficient international trade	• **O19:** Integrated technology - IOT
• **S20:** Lower transaction and administrative cost	• **O20:** Integrated technology - Artificial intelligence
• **S21:** Disintermediation	
• **S22:** Improving collaboration and communication	
• **S23:** Veracity/ authenticity	
• **S24:** Decision-making	
• **S25:** Efficiency/ improve work progress	

Weaknesses (11)	Threats (16)
• **W1:** High energy consumption/ computational power • **W2:** Malicious attacks/ cybersecurity • **W3:** Lack of interoperability • **W4:** Low connectivity and bandwidth • **W5:** Privacy • **W6:** Limited storage capacity • **W7:** Transaction processing limitation/ scalability issues • **W8:** Data latency • **W9:** High cost of adoption/ financial constraints • **W10:** Jurisdiction challenges/ choice of law • **W11:** Complexity of BSC	• **T1:** Lack of technological capabilities in the industry • **T2:** Lack of required skills/ untrained personnel • **T3:** Low level of awareness/ understanding/ knowledge • **T4:** Resistance to change • **T5:** Lack of legal regulation • **T6:** Error-coding of SCs • **T7:** Lack of trust/ hesitation • **T8:** Complexity of construction projects • **T9:** Lack of collaborative culture • **T10:** Absence of industry-specific standards for BSC • **T11:** Not all obligations are code-expressed • **T12:** Difficulty in defining unforeseen conditions • **T13:** Irrevocable nature • **T14:** Oracles Paradox • **T15:** Insufficient evidence on industry business cases/ unclear usage advantages • **T16:** Lack of dispute resolution mechanism

5.2.1. Strengths

This section explores the varied strengths of applying BSC in the construction industry. A comprehensive Table 4 at the end of the section summarizes these strengths alongside their corresponding references, offering a detailed overview:

- *Traceability:* Traceability in construction projects refers to the ability to trace the history of various aspects of the project, from contract creation and management to the execution of tasks and payments [11, 94, 146, 167].
- *Immutability:* It ensures that once a SC is deployed, its code and logic cannot be changed or modified. This feature preserves project specifications, information, and payment terms throughout the project's lifecycle, ensuring no unilateral changes [19, 30, 145, 167].
- *Data Irreversibility/Persistency/Tamper-proofing:* Once construction data is recorded on BC, it becomes extremely difficult to alter or delete. BC ensures data irreversibility, making information on the ledger tamper-proof and resistant to unauthorized alterations [151].
- *Transparency:* BSC promotes transparency in construction projects by recording all transactional data in an immutable and accessible ledger. This provides all stakeholders with real-time insights into project progress, financial transactions, and contractual obligations, fostering trust and accountability while reducing the likelihood of disputes [146, 148, 167].
- *Information sharing/Exchanging information:* BSC facilitates information sharing and data exchange by automating and streamlining the exchange of project-related information, so stakeholders can access and update critical data efficiently and securely [5]. This improved data exchange facilitates decision-making processes, reduces miscommunication risks, and boosts collaboration among project teams, ultimately enhancing efficiency and outcomes [11].
- *Decentralization:* It eliminates the need for intermediaries, granting participants direct access to verify transaction records and project data, minimizing reliance on central authorities, and enhancing trust within the construction ecosystem. In other words, no sole entity, company, or party has exclusive control over the data or information [19, 145, 146].
- *Ensuring trust:* BC enhances trust by requiring consensus from the majority of participants before data is added to the definitive BC, reducing the need for intermediaries. In the construction industry, where trust among stakeholders is crucial, BSC fosters trust by ensuring transparency and reliance on automated systems, allowing participants to enter binding agreements with confidence [59, 138].
- *Increased data security:* BC is known for its security features. This enhances data security and financial transactions, and prevents unauthorized access and tampering, which is vital in construction where sensitive information is prevalent [19, 148, 157].
- *Increased data privacy:* BSC enhances privacy, ensuring that sensitive data, such as proprietary designs or financial details, is only accessible by authorized parties [131]. By selectively disclosing information and automating access through cryptography, BSC enables stakeholders to protect their confidential data, fostering trust and cooperation and safeguarding information from unauthorized disclosure or tampering [19, 59].
- *Automation:* SC enables the automation of various processes in construction projects, such as resource allocation, quality inspections, and milestone tracking. This automation reduces manual intervention, eliminates bureaucratic verification procedures, and lowers the potential for errors [30, 59, 89, 167].

- *Improved risk contingency:* Construction projects inherently carry risks such as delays, budget overruns, and quality issues. SCs can evaluate project risks and trigger predefined actions to mitigate these risks. For example, they can automatically adjust resource allocations or release contingency funds when certain risk thresholds are reached [146].
- *Reducing Bureaucracy:* SCs in the construction industry streamline administrative processes, reducing extended administrative time, bureaucratic hurdles, and paperwork. Automation of tasks like payments, compliance checks, and change orders reduces the need for manual intervention, leading to more efficient project management and resource allocation [148].
- *Auditability:* BSC enhances auditability in construction projects by creating an immutable record of all project transactions and contract terms. This transparent and tamper-proof ledger simplifies the auditing process, allowing for effective and accurate verification of financial and operational aspects, reducing the risk of errors and fraud [19, 145, 151].
- *Chronological data recording (record keeping):* SCs ensure chronological data recording on a BC ledger, establishing a transparent and immutable record of all actions and transactions. This feature enhances record-keeping accuracy and security, enabling audits, compliance checks, and dispute resolution in construction projects. Project-related data are significantly more reliable compared to traditional delivery systems, with any alterations to the project model being diligently recorded and communicated to relevant stakeholders within the BC network [146].
- *Real-time information/ Time-stamping:* Information or transaction records are timestamped, substantiating the existence of digitalized assets at specific temporal instances. Stakeholders can access real-time project data, enabling informed decision-making [11]. This is particularly beneficial for project managers, who can monitor progress, identify bottlenecks, and make necessary adjustments [24, 30].
- *Clarity in Responsibility (Authority and Accountability):* SCs establish clear lines of responsibility, defining who is accountable for what tasks at what time. This clarity ensures that project roles and obligations are clearly documented, reducing disputes and fostering a collaborative environment [21, 87].
- *Time-saving:* BSC saves time spent on tasks by automating various project' processes, such as transaction verification, payment execution, and record-keeping [68]. These automations streamline the need for manual oversight and the processing of paperwork, ultimately speeding up the execution of contractual obligations and project milestones [179].
- *Saving Efforts/Increasing productivity:* SCs reduce the need for extensive manual effort required for tasks like document verification, data entry, and reconciliation; automating complex admin work that can be effort-intensive and prone to human errors [44]. This enhances time and effort, streamlines processes, improves record-keeping, boosts accuracy, and enables focusing on core tasks, leading to increased productivity [33].
- *Efficient International Trade:* BC's global and trust-based infrastructure can mitigate geographical barriers in international construction by fostering collaboration among client, consultant, and contractor firms from diverse countries. This enables parties to engage in SCs, thus expanding international construction and supply chain operations [92].
- *Reducing transaction costs:* BSC can significantly reduce transaction costs by automating the payment process, reducing the need for intermediaries like lawyers and banks, and streamlining supply chain management, resulting in more efficient and cost-effective operations [103]. Accordingly, it enhances the industry's competitiveness and profitability [101, 155].
- *Disintermediation:* BSC eliminates the need for traditional intermediaries, such as banks, escrow services, and legal entities, in the contractual and payment processes. This reduces transaction costs and boosts efficiency and trust among stakeholders, as payments and contract execution are automated, secured, and directly peer-to-peer [145].
- *Improving collaboration and communication:* BSC enhances communication and collaboration in the construction industry by providing a secure and transparent platform for all stakeholders to access and update project-related information in real-time. This enhances coordination among different stakeholders, leading to better outcomes and reduced delays [5].
- *Veracity/Integrity:* BC enhances record integrity by immutably replicating historical ledger data across a distributed network of nodes. The consensus-driven record verification process elevates data accuracy by promptly detecting and removing fraudulent entries that fail to gain consensus. This ensures the accuracy and authenticity of contractual agreements and updates [131].
- *Decision-making:* BSCs in the construction industry empower stakeholders with real-time access to project data, enabling more informed and timely decision-making [195]. Project managers, contractors, and clients can assess progress, identify issues, and make adjustments based on accurate, up-to-date information [105].
- *Increased efficiency/Improving work:* BSC automates contract execution, provides transparency, and reduces

administrative overhead and disputes. Thus, it enhances work efficiency and timely decision-making while also recording and verifying project milestones for increased accountability and client satisfaction [23, 94, 157].

Table 4. List of Strengths of BSC, and its Relevant Identified Sources

#	Strength	References	Mention Count
1	Traceability	[1, 4, 5, 9–11, 14, 16, 17, 21, 25, 27, 29, 30, 34, 36, 37, 39, 40, 42, 43, 48, 56–58, 60–62, 71, 73, 92, 94, 96, 101–104, 106, 108, 109, 114, 121–124, 128, 131, 132, 134–136, 138, 140, 143, 145, 147, 150, 151, 153, 154, 156–158, 162, 163, 165–167, 169, 170, 172–174, 176–180, 183, 185, 189, 195, 210]	83
2	Immutability	[4, 9, 10, 14, 16, 17, 19, 22, 25, 30, 32, 34, 35, 37–40, 42, 43, 46–48, 50, 52–54, 56, 60, 63, 64, 71, 73, 89, 93, 97, 98, 103, 104, 106, 108, 112–115, 118, 119, 121–124, 127, 131, 132, 134–136, 138–140, 142, 144–146, 150–157, 160, 162–167, 169, 170, 172, 174, 178, 179, 181, 184–186, 189–193, 195]	95
3	Data Irreversibility/ persistency/ Tamper-proofing	[5, 10, 11, 17, 20, 22, 23, 33, 34, 38, 40, 48–51, 53, 58, 59, 61–65, 70, 86, 87, 90, 91, 94, 96, 97, 104, 106, 108, 109, 113, 116, 121, 123, 124, 127, 128, 130, 135, 136, 142, 144–147, 150-154, 159, 163, 166, 167, 172, 174, 176, 177, 179, 180, 182, 185, 191, 192, 195]	69
4	Transparency	[1, 4, 9–11, 14–17, 19–25, 27–29, 33–35, 37–41, 43, 45–48, 50, 53, 54, 56, 57, 61–65, 68, 73, 89, 92, 94, 97, 99, 101–104, 106, 108, 109, 112–115, 117–119, 121–124, 126, 128, 130–132, 134, 135, 137, 138, 140, 142–144, 146–149, 151–153, 155–157, 160–165, 167, 169, 170, 174, 176, 178–180, 182–184, 188, 190, 191, 193, 195, 196]	113
5	Information sharing/ exchanging information	[5, 10, 11, 14–17, 20–22, 33, 34, 37, 48, 52, 53, 56–58, 60, 65, 68–70, 73, 86, 87, 91–93, 96, 101, 105, 113–116, 120–123], 125–128, 131, 134, 136, 137, 139, 140, 142–145, 151, 153, 154, 157, 158, 163–165, 171, 172, 178, 179, 181, 185, 188, 189, 192, 193, 195]	74
6	Decentralization	[1, 18, 19, 26, 30, 31, 33, 34, 37–39, 41, 46–48, 50, 51, 54, 56, 58, 65, 68, 71, 87, 89, 96, 106, 108, 112, 113, 115–117, 119, 120, 124, 127, 128, 132, 133, 136–138, 140, 141, 143–146, 148, 151–154, 157, 159, 162, 163, 166, 174, 176, 178, 179, 182, 184, 185, 190–192, 195]	70
7	Ensuring trust	[5, 9–11, 14, 16, 17, 19, 20, 22, 24, 25, 29, 33, 35–39, 41, 44, 45, 47, 48, 50, 52, 54–60, 62, 64, 68, 69, 71, 73, 86–89, 91, 93–95, 97, 100–102, 104, 106, 107, 110, 112, 114–122, 124, 126, 128, 130–132, 134, 136–140, 142, 143, 146, 147, 149–154, 156–158, 163, 165, 168–170, 172–174, 177, 178, 180–182, 184, 186, 190, 191, 193, 195, 196]	111
8	Increased data security	[1, 4, 11, 14, 17, 19, 22, 23, 28, 29, 32, 35, 37, 38, 46, 47, 50, 51, 53, 54, 56, 57, 61, 62, 70, 71, 73, 89, 91, 92, 99, 103–106, 108, 110, 113, 115, 119–122, 124–128, 134–139, 141, 143–149, 151, 152, 155, 157, 162–165, 168, 171, 172, 174, 176, 177, 182, 188, 193, 195]	80
9	Increased anonymity/ privacy	[1, 4, 11, 16, 19, 29, 30, 34, 37, 39, 43, 47, 58, 59, 65, 69, 70, 73, 86, 89, 92, 108, 115, 119, 120, 124, 125, 133, 144–146, 150, 151, 156, 163, 172, 184, 186, 189, 191, 193, 195, 196]	43
10	Automation	[1, 4, 9–11, 14–17, 21, 22, 24, 28, 29, 31, 33–35, 37, 38, 40, 42, 43, 45, 50, 52–54, 56, 58, 59, 62, 65, 68, 86, 88–90, 92, 98, 100, 101, 104, 107–109, 111–114, 117, 120–122, 124, 126, 128, 129, 131, 134, 136–140, 142–146, 149, 151, 152, 154, 157–159, 162–167, 170, 174, 175, 177, 178, 180, 181, 183, 185, 186, 189–191, 193–196]	102
11	Improve risk contingency	[37, 56, 114, 146, 178]	5
12	Reducing bureaucracy	[30, 33, 104, 148, 151, 182]	6
13	Auditability	[19, 37, 60, 65, 119, 144, 145, 147, 151, 154, 156]	11
14	Chronological data-recording (record keeping)	[4, 22, 24, 26, 33, 34, 42, 43, 49, 54, 58, 62, 63, 68, 69, 92, 96, 98, 101, 104 – 106, 108, 113, 120, 121, 123 – 126, 132, 134, 135, 137 – 139, 143, 145, 146, 151, 154, 156, 159, 160, 166, 167, 170, 172, 174, 178, 191, 192, 195]	53
15	Time-stamping/ real-time information	[1, 4, 10, 11, 16, 22, 24, 30, 37, 41, 44, 50, 51, 60, 62, 64, 65, 69, 70, 73, 86, 88, 89, 102, 104, 108, 111, 113, 118, 121, 128, 135, 138, 139, 142, 143, 151, 153, 154, 156–158, 165, 170, 175, 176, 179, 180, 191]	49
16	Clarity in Responsibility (Authority and Accountability)	[10, 14, 16, 18, 21, 25, 26, 31, 33, 35, 37, 41, 43, 62, 69, 87, 95, 100, 102, 103, 118, 119, 121, 122, 124, 138, 142, 146, 148, 150, 152, 154, 158, 163, 167, 170, 174, 182, 195]	39
17	Time-saving	[1, 14, 17, 32, 33, 35, 52, 58, 65, 68, 95, 99, 101, 103, 107, 117, 120, 124, 130, 137, 151, 153–155, 179, 185, 191, 196]	28
18	Saving Efforts/ increasing productivity	[33, 38, 44, 121, 126, 151, 155, 195]	8
19	Efficient international trade	[53, 92, 94, 134, 138, 164]	6
20	Reducing transaction costs	[1, 9, 15, 17, 18, 22, 23, 25, 30, 32–37, 39, 44, 49, 50, 53, 55, 56, 60, 64, 65, 68, 69, 89, 101–104, 106–108, 113, 114, 117, 120, 121, 124, 130, 132, 137, 138, 146, 147, 151, 153–155, 160, 164, 165, 170, 172, 178, 179, 181, 185, 191, 193, 196]	63
21	Disintermediation	[4, 5, 10, 14, 16, 17, 19, 21–23, 31–35, 37–39, 44, 47, 48, 50–52, 65, 68, 69, 71, 73, 87, 89, 92, 94, 96, 97, 99, 102, 104, 108, 113–117, 121, 122, 125, 128, 131, 132, 134–138, 144–146, 149–151, 153, 154, 156–158, 160, 164–166, 173, 176, 179, 181, 184–186, 189, 191, 193, 195, 196]	82
22	Improving collaboration/ communication	[5, 9, 10, 14, 17, 18, 21, 25–27, 33–38, 40, 47, 48, 52, 53, 56–58, 60, 62, 64, 68, 69, 73, 89, 93, 97, 100–106, 108, 109, 114–118, 120, 123, 126, 130–132, 135–138, 140, 142–144, 149–153, 158–160, 162, 165, 169, 176–178, 180, 185, 186, 190, 193–196]	83
23	Veracity/ integrity	[1, 10, 11, 14, 19, 22, 33, 37, 45–47, 50, 63, 104, 107, 112, 113, 115, 119, 121, 122, 124, 125, 130, 131, 133, 135, 142, 144, 145, 156, 160, 162, 166, 167, 170, 172, 174, 177, 178, 182, 195]	43
24	Decision-making	[34, 60, 62, 68, 73, 105, 125, 128, 145, 149, 151, 190, 193, 195]	14
25	Efficiency/ improving work	[9, 10, 21–23, 32–35, 37, 47, 48, 53–55, 57, 60, 65, 68, 89, 91, 99, 101, 104–106, 112, 113, 119, 121, 127–130, 132, 133, 137, 142, 144, 147, 149, 151, 153, 154, 156–159, 163, 166, 167, 170, 173, 177, 178, 184–186, 188, 190, 193, 195]	62

5.2.2. Weaknesses

This section delves into the multifaceted weaknesses of leveraging BSC in the construction sector. For a detailed synthesis, Table 5 concludes this segment by methodically cataloging these weaknesses and their corresponding scholarly citations, providing a holistic overview.

- *Energy consumption/Computational power:* The BC is criticised for its energy use as it relies on computer power to function. As the construction increasingly adopts BC, the associated energy-intensive computations could amplify the sector's overall carbon footprint, necessitating a balance between technological advancements and environmental responsibility [194].
- *Malicious attacks/Cybersecurity:* The integration of digital technologies in the construction industry may lead to substantial economic consequences due to its susceptibility to cybercriminal attacks [38]. Ensuring robust security measures is imperative to prevent unauthorized access and protect against breaches, thereby mitigating the peril of compromised contract integrity and associated losses [23, 37, 194].
- *Lack of interoperability:* This refers to the inability of different BC networks, applications, or platforms to seamlessly communicate and interact with each other [38]. In essence, BCs often operate in isolation with no standardized protocols or methods for sharing data, assets, or executing transactions across different BC ecosystems. Such incompatibility can hinder seamless communication and data sharing among stakeholders, leading to inefficiencies and communication breakdowns [190, 194].
- *Connectivity and bandwidth:* BC often requires continuous internet connectivity to operate efficiently, which can be problematic in remote or construction site environments with limited access to high-speed internet. Thus, it may impact the real-time execution and management of SCs, potentially leading to delays and operational challenges [38].
- *Lack of privacy:* SCs in the construction industry grapple with privacy concerns, particularly on public BC networks like Ethereum, where data transparency exposes transaction details to all participants. Ensuring privacy while maintaining transparency remains a challenge, impacting applications that necessitate higher levels of anonymity [190, 194].
- *Limited storage capacity:* Another challenge associated with BCs is their unsuitability for storing big data. Where extensive project-related data is generated, the limitations in data storage and bandwidth can hinder transactions' recording and handling substantial amounts of project data [59, 162, 194].
- *Transaction processing limitation/Scalability issues/Throughput issues:* The scalability issue in BC pertains to the challenge of accommodating a growing number of users and transactions while maintaining network performance and consensus mechanisms. BC systems often face limitations in handling increased loads, potentially causing congestion and slower transaction processing [37, 194].
- *Latency:* The latency issue in BC arises from the time it takes to confirm and add transactions to the system, which can be slower compared to traditional centralized systems. This delay can impact real-time applications and user experiences, particularly in high-transaction volume scenarios [162, 194].
- *High cost of adopting BC/Operation costs/Financial constraints:* The construction industry faces significant challenges related to the high cost of adopting BC technology [28]. This includes initial setup costs, expensive contract coding, and ongoing transactional costs associated with energy consumption, which can deter small companies from embracing this technology [9, 108, 194].
- *Jurisdiction challenge/Choice of law:* Contracting parties have the right to designate the governing law, yet in the absence of explicit agreement, the prevailing practice defers to the local law of the state with the closest nexus to the transaction and involved parties. In international SC transactions, clarity in specifying applicable law and competent jurisdiction is imperative to mitigate potential conflicts [64]. However, the unresolved question of SC situs due to BC's global distribution poses challenges in establishing a definitive jurisdiction and identifying the involved parties or applicable legal framework [23, 92].
- *Complexity of BSC:* In construction industry, the complexity of BSC not only demands specialized expertise but also leads to incurring additional costs. Employing or training professionals with the necessary skills to design, deploy, and oversee BC-based systems can be resource-intensive. Moreover, the intricacy of these systems can introduce operational challenges, potentially slowing down project workflows and decision-making processes [194].

Table 5. List of Weaknesses of BSC, and its Relevant Identified Sources

#	Weakness	References	Mention Count
1	Energy consumption= computational power	[4, 15, 36, 53, 95, 98, 124, 130, 168, 170, 185]	11
2	Malicious attacks/ cybersecurity	[4, 9, 16, 24, 30, 31, 35–38, 42, 45, 46, 48, 49, 58, 60, 63, 68, 71, 73, 108, 114, 127, 130, 134, 138, 144, 148, 153, 156, 168, 188, 194, 196]	35
3	Lack of interoperability	[9, 25, 36, 37, 45, 46, 48, 49, 58, 64, 68, 73, 98, 128, 130, 138, 146, 169, 170, 176, 193, 194, 196]	23
4	Connectivity and bandwidth	[30, 49, 58, 130, 134]	5
5	Lack of privacy	[4, 9, 16, 18, 24, 25, 30, 36, 45, 53, 56, 58, 60, 64, 73, 86, 94, 115, 128, 131, 134, 144, 146, 148, 149, 166, 169, 170, 188, 193, 194, 196]	33
6	Limited storage capacity	[4, 16, 18, 36, 45, 49, 58, 64, 86, 112, 128, 156, 169, 170, 193]	15
7	Transaction processing limitation/ scalability issues/ throughput issues	[4, 9, 18, 20, 24, 25, 30, 36, 37, 45, 46, 49, 58, 60, 64, 104, 108, 110, 115, 121, 123, 131, 132, 134, 146, 148, 153, 156, 161, 163, 168–170, 176, 182, 186, 193, 196]	36
8	Latency	[25, 30, 49, 134, 161, 182, 186]	7
9	High cost of adopting BSC/ operation costs/ financial constraints	[15, 16, 20, 24, 25, 30, 35, 36, 45, 46, 49, 58, 60, 63, 64, 98, 107, 108, 112, 115, 122, 131, 132, 134, 137, 138, 142, 148, 150, 152, 156, 163, 170, 179, 186, 188, 193, 196]	38
10	Jurisdiction challenge/ choice of law	[23, 68, 73, 92, 100, 110, 147, 168]	8
11	Complexity of BSC	[32, 36, 37, 68, 93, 104, 108, 128, 169, 170, 188, 193]	12

5.2.3. Opportunities

The section explores the transformative potential of BSC in the construction industry, addressing various operational improvements and strategic advantages. Refer to Table 6 for a detailed enumeration of these opportunities, along with their associated references.

- *Project Management:* SCs empowered by BC foster a cohesive management ecosystem that intersects diverse areas such as information, supply chain, procurement, financial, facility, contract, quality, site, stakeholder, safety, design, change, and risk management, as underlined below.
    - Document and Information Management: SCs' automated processes and real-time data exchange standardize and streamline workflows, eliminating duplications in data handling and managerial functions. The single source of truth offered by BC-based platforms mitigates risks associated with information asymmetry and enhances communication clarity [10, 15, 89, 122, 150].
    - Supply chain and Procurement Management: SCs automate order placement and tracking, facilitating material traceability and optimized logistics [30, 60, 95, 134], while ensuring compliance and efficient resource allocation, informed by immutable transaction records [15, 22, 50, 151].
    - Financial Management: SCs transform cash flow and funding management by triggering instant alerts when budget overruns or unexpected expenses occur, allowing for quick and informed decision-making. Moreover, they allow for the creation of dynamic payment schedules that adjust based on real-time project progress [19, 71, 143].
    - Facility and Site Management: They benefit from SCs through automated maintenance schedules, inventory management, and asset tracking [19, 22, 165], ensuring operational continuity and effective resource utilization [9, 37, 132, 180].
    - Contract and Stakeholder Management: Administrative tasks are streamlined and stakeholder engagement is enriched with timely, accurate information sharing, enhancing cooperation standards and decision-making efficiency [33, 95, 165, 169].
    - Quality and Safety Management: SCs enforce adherence to standards, facilitate rapid response to deviations or hazards, and ensure proper certification and training, thus fostering a culture of compliance and proactive safety practices [23, 46, 104, 150, 184].
    - Design and Change Management: SCs promote real-time collaborative revision handling, seamless approval processes, and integration with BIM systems for compliance validation [40, 61, 125], thereby minimizing delays and supporting dynamic project adaptations with a comprehensive record of transactions and changes [29, 54, 150].
    - Risk Management: SCs automate risk assessments, ensuring proactive risk mitigation, streamlining insurance and warranty processes, and facilitating risk management strategies based on real-time project data [33, 37, 150].
    - Subcontractor Management: SCs link subcontractor activities to verifiable project milestones, enhancing oversight of various subcontractors [95, 175].

- *Late payment:* SCs can revolutionize automated payments in the construction industry through various mechanisms. Firstly, they enable milestone-based payments, which automatically release funds to contractors and suppliers upon the completion of predefined project stages or deliverables. This reduces delays and enhances cash flow management [35, 122]. Secondly, SCs can integrate with IoT sensors and data sources to verify the progress of work, ensuring that payments are triggered only when specific and verifiable criteria are met. Thirdly, they support automated payment adjustments for change orders, eliminating the need for manual calculations and reducing administrative overhead [29]. Fourthly, by recording all payment transactions on an immutable BC ledger, they create an accurate and auditable payment history, which reduces disputes and builds trust among project stakeholders [109]. Lastly, SCs can facilitate multi-party payments by automatically distributing funds to subcontractors and suppliers, making complex payment structures [117].

- *Less room for disputes:* SCs hold immense potential for improving dispute resolution in construction projects. Notably, human factors such as inaccurate estimations, a lack of communication, deficient documentation, and opportunistic behaviours are major contributors to construction disputes. SCs can mitigate these issues by automating processes, offering an immutable record for all project-related transactions, boosting the transparency of contractual clauses, improving the flow of information in real-time, and reducing human misinterpretation [15, 23, 64]. In the event of a dispute, these contracts offer a reliable and verifiable source of truth, significantly reducing the need for costly and time-consuming litigation. Disagreements can be resolved more efficiently as SCs can incorporate predefined dispute resolution mechanisms, such as arbitration or mediation clauses, and automatically execute the agreed-upon resolutions [14, 50].

- *Integrated Technology:* The integration of SCs with various cutting-edge technologies, including Building Information Modeling (BIM), digital twin technology, the Internet of Things (IoT), and Artificial Intelligence (AI), represents a transformative paradigm in construction project management. Table 7 outlines the significance of such technologies, where “Functions” details the key functions or capabilities of the technology; "Integration benefits with BSCs" refers to the specific advantages or gains derived from integrating a technology itself with BSC. However, "Process enhancements" explain how the integration of a technology with BSCs leads to improvements in the actual workflows, procedures, or methodologies within construction management.

Table 6. List of Opportunities of BSC, and its Relevant Identified Sources

#	Opportunity	References	Mention Count
1	Document/ information management	[1, 9, 11, 15, 19–21, 25, 26, 29, 30, 38, 40, 43–47, 51–53, 57, 61, 91, 94, 96, 97, 101, 102, 105, 106, 111–113, 115, 116, 118, 121–123, 125, 131–133, 136, 138, 139, 142, 143, 145, 148, 150, 156, 158, 164, 166, 170–174, 176, 179, 194]	66
2	Supply chain management	[1, 4, 5, 9–11, 14–21, 23, 24, 27, 29, 30, 32–34, 37, 38, 40–42, 44, 48–50, 52, 53, 55–58, 60, 61, 64, 69–71, 73, 90, 92, 94, 95, 102, 104, 106–108, 110–112, 115–119, 122–124, 128–135, 137–139, 142–145, 147, 151, 153–157, 160, 162, 165, 169, 170, 172, 174, 179, 180, 183, 186, 189, 190, 192]	101
3	Procurement management	[14–16, 18, 22, 29, 31, 37, 38, 43, 69, 102, 107, 112, 123, 129–131, 135, 137–139, 145, 151, 163, 164, 169]	27
4	Automated payments	[1, 4, 9, 10, 14, 15, 18, 19, 21–23, 25, 29–38, 40, 42, 43, 45, 49–54, 56–58, 61, 62, 69–71, 73, 95, 97–99, 102, 106–109, 111, 112, 115–117, 119, 122, 124, 128–131, 134, 136, 138, 142, 145, 149–151, 154, 155, 161–165, 167, 169, 171, 172, 174, 175, 179–182, 186, 187, 190, 191, 193]	93
5	Funding/ cashflow management	[15–19, 29, 35, 38, 42–44, 49, 71, 95, 99, 106, 110, 119, 128, 143, 148, 151]	22
6	Facility management	[16, 17, 19, 22, 24, 30, 37, 40, 44, 70, 73, 88, 105, 107, 129, 132, 155, 165]	18
7	Contract management. administration	[1, 4, 10, 14, 15, 17, 18, 21, 23, 25, 29–31, 33, 35, 44, 49, 50, 69, 70, 86, 95, 99, 109, 112, 122, 128, 129, 133, 143, 149, 150, 154, 163, 169, 172, 186, 192, 196]	39
8	Quality management (Compliance checking)	[1, 9, 10, 17, 20, 23, 29, 30, 40, 44, 48, 61, 65, 73, 89, 97, 104, 112, 118, 120, 124, 132, 134, 138, 145, 147, 150, 163–166, 174, 180, 181, 190]	35
9	Site management	[9, 15, 17, 30, 37, 57, 62, 69, 97, 132, 138, 150, 162, 163, 172, 174, 180]	17
10	Stakeholder management	[18, 51, 132, 136, 150, 165, 169, 171, 176, 178]	10
11	Dispute Resolution	[14, 15, 17, 18, 22, 23, 31–33, 35, 43, 50, 58, 64, 69, 102, 108, 116, 120, 136, 145, 150, 151, 154, 155, 181, 187, 191]	28
12	Safety management	[17, 29, 30, 40, 46, 61, 73, 104, 112, 145, 163, 167, 168, 170, 172, 184]	16
13	Design management	[15–17, 25, 30, 40, 43, 53, 61, 69, 73, 86, 125, 139, 147, 158, 159, 169]	18
14	Change management	[1, 4, 43, 54, 115, 120, 133, 136, 147, 150, 166, 170]	12
15	Risk management	[33, 37, 73, 95, 106, 121, 134, 150, 181]	9
16	Subcontract management	[10, 31, 35, 39, 42, 48, 57, 58, 60, 68, 95, 98, 99, 102, 110, 111, 114–117, 136, 143, 150, 153, 161, 163, 175, 179, 186, 191]	30
17	Integrated technology- BIM	[1, 4, 5, 9, 10, 14–17, 21, 24–26, 28–31, 34, 35, 37, 40, 42–45, 47, 49–54, 56–65, 69, 70, 73, 86, 88–90, 93–98, 100, 102, 104–109, 111–113, 115–118, 120–124, 128–131, 136, 138, 142, 143, 154, 155, 158, 161, 162, 165, 167, 169–172, 175, 176, 178–181, 186, 188, 190, 192, 194, 195]	106
18	Integrated technology- DIGITAL TWIN	[29, 37, 42, 48, 56, 61–63, 73, 88, 102, 108, 112, 115, 120, 121, 141, 142, 161, 163, 174, 178, 179, 193]	24
19	Integrated technology- IOT	[1, 4, 9, 10, 14–16, 21, 28–31, 34, 37, 38, 40, 44, 47, 48, 56, 59, 60, 62, 63, 65, 69, 73, 86, 95, 97, 102, 106, 108, 113, 118, 121, 130, 131, 134, 142, 145, 155, 163–165, 167, 168, 170, 172, 174, 176, 179, 180, 186, 189, 193, 194]	58
20	Integrated technology- Artificial intelligence	[4, 14, 40, 56, 88, 96, 100, 102, 113, 121, 134, 152, 155, 176, 186]	15

Table 7. Integration of BSC with Construction Management Technologies

Technology	Functions	Integration benefits with BSCs	Process enhancement	References
BIM	Ensures information relevance, consistency, and completeness; facilitates 3D/4D visualization, task coordination, process simulation.	Information security, consensus, traceability, identity authentication; aligns well with digital construction management.	Forms the cornerstone of a proactive and data-driven approach to construction project management.	[29, 30, 34, 58, 61, 120, 178]
Digital Twin	Offers real-time project insights, proactive decision-making, real-time progress, automatic payment triggers, and change order management.	Enables agile, data-driven project management adaptable to changing conditions.	Enhances scenario simulations, and bridges the physical and virtual realms, fostering dynamic project management.	[62, 120, 121, 193]
IoT	Collects data on equipment usage, material deliveries, environmental conditions and automates processes such as verification, installation, payments, and safety protocols.	Provides a comprehensive digital footprint of the project for resource optimization, predictive maintenance, and issue resolution.	Enables real-time data for efficient, safe, and cost-effective construction.	[21, 28, 34]
Artificial Intelligence (AI)	Enhances transparency, trust, and traceability; dynamic optimization, machine learning-based forecasting, adaptive governance; improves automation and decision-making capabilities.	Enables processing and analysis of complex data, pattern recognition, and prediction for more efficient construction, cost-effective, and responsive to real-time challenges.	Provides advanced features like forecasting, real-time monitoring, risk assessment, and optimized resource allocation.	[152]

5.2.4. Threats

This section examines the multifaceted threats posed by the application of BSC in the construction industry, highlighting challenges ranging from technological limitations to legal and operational hurdles. Table 8 provides a comprehensive summary of these threats alongside pertinent references, offering a detailed overview for further exploration.

- *Lack of technological capabilities in the industry:* The adoption of BSCs in construction is hampered by reliance on incompatible legacy infrastructure, a shortage of blockchain-savvy professionals, and the industry's reluctance to embrace advanced technology due to concerns about integration and costs [38]. Furthermore, the unique and intricate nature of BC technology can present a steep learning curve, which may further contribute to this capability gap [37, 190].
- *Lack of required skills/Untrained personnel:* There is a significant deficiency in the proficiency required for executing and managing BSCs, stemming from a lack of qualified human resources with in-depth knowledge of the construction sector, BSC technology, and how these fields interact with law, engineering, and construction management [31]. The absence of a skilled workforce capable of managing SC processes efficiently can lead to project delays, mismanagement of digital assets, and increased costs [108, 148].
- *Low level of awareness/understanding/ knowledge:* A significant challenge for stakeholders may be understanding how to utilize BSC technology to create a more efficient and transparent business model [37]. The rapidly evolving nature of BC technology can create a knowledge gap that poses challenges in keeping up with the latest developments and best practices in the field [21, 31].
- *Resistance to change:* The hesitancy of construction players to embrace BSC often arises from the industry's historical reliance on traditional methods, concerns about the technology's complexity, potential disruptions to established workflows, uncertainties regarding implementation costs, and a lack of understanding about how these contracts can effectively be integrated into their existing processes [9, 10, 111].
- *Lack of legal regulation:* The legal validity of BSCs remains a significant obstacle, as there is currently no defined contractual governance that explicitly addresses SCs [53, 181]. A major legal barrier to their adoption is related to enforceability, which is a subject of concern as SCs lack universal recognition across jurisdictions [15, 23]. Their legal status varies, ranging from being treated as electronic contracts governed by electronic commerce laws to completely contract forms that lack recognition under existing legal frameworks, further complicating enforcement. This latter challenge is particularly acute in the construction industry, where a lengthy history of disputes among diverse parties has established a notorious precedent, especially in dispute resolution scenarios. Additionally, the lack of legal clarity within BC technology further complicates the issue of SC enforceability [92].
- *Error-coding of SCs:* The construction industry's adoption of SCs is threatened by the risk of coding errors, which requires meticulous, error-free code development to avoid unintended obligations. These errors may remain undetected, potentially causing one party to assume unfair obligations without their prior knowledge [194].

- *Lack of trust:* Stakeholders may be hesitant to rely on automated, code-driven contracts as they diverge from traditional contracts that are built on interpersonal trust and human interpretation. This apprehension stems from concerns about the reliability, security, absence of a regulatory framework, and potential vulnerabilities of SCs. The matter which can diminish trust in their effectiveness and fairness, thereby impeding their widespread adoption within the industry [148].
- *Complexity of construction projects:* The construction industry is recognized for its relatively slower pace of technological adaptation compared to other sectors. This phenomenon can be attributed to factors including the industry's inherent high complexity, structural fragmentation, limited project repeatability, deficient collaboration, lack of standardized practices, and inadequate innovation investment [53, 194].
- *Lack of collaborative culture:* The construction industry's prevailing contractual relationships often emphasize adversarial relationship dynamics, underlining the challenge of cultivating a cooperative atmosphere necessary for the successful implementation of SC solutions [37, 190].
- *Absence of industry-specific standards for BSC:* Alongside the dearth of industry-specific standards pertaining to BSC, the perceived high risks and doubt stemming from its technological immaturity compel managers within the construction sector to embrace a "wait-and-see" stance regarding the adoption of the same [108].
- *Not all obligations are code-expressed:* In the construction industry, the limitations of SCs become apparent as not all legally significant aspects of construction agreements can be effectively executed through code. Complex contractual provisions like fairness, good faith, and abstract terms such as "reasonable request" are challenging to translate into computer algorithms, leading to potential ambiguities and interpretational issues. Determining what it takes to meet these norms can involve general practice and the parties' interrelationships. The matter which is rather impossible in SCs.
- *Difficulty in defining unforeseen conditions*: In construction projects with high levels of dynamic complexity, initial contracts are frequently changed to account for unforeseen events [40]. Semantic contracts enable legally binding agreements with measurable performance criteria and adaptable contract parameters. One of the major misconceptions regarding SC is that they won't be able to recover the enormous number of variables encountered on a project by replacing subjective, "loose" wording with computer code. The employment of SCs, on the other hand, is more beneficial because it permanently binds the parties to a provision after they have consented to be bound by it, eliminating any possibility of a breach [86]. However, removing this inherent flexibility when applying SC would result in costs that are significantly higher and more difficult to manage than the issues they intend to tackle, particularly in long-lasting contractual relationships where significant changes are likely [52, 86, 102].
- *Irrevocable nature:* The flexibility of construction contracts is deemed essential [102]. However, the irrevocable nature of BSC in the construction industry poses a significant threat, as it leaves no room for flexibility in adapting to unexpected changes or disputes during project execution. This rigidity can lead to protracted legal battles and hinder the industry's ability to effectively address unforeseen challenges [15, 90, 194].
- *Oracles Paradox:* The trustless nature of BSCs systems requires external input from reputable actors, such as Oracles, which interpret real-world data feeds and send them to the BC for execution. Oracles can include unbiased external data, such as interest rates and customer-specific details, and serve as external third-party gateways for the BC. However, external information can be inaccurate or unavailable, leading to the "Oracle Paradox" or "Oracle Problem" which arises from the need to trust Oracles to bridge the real world and the virtual world. This requires assurance that Oracle is trustworthy and third-party, and that there are no security threats during data acquisition. Any malfunction of external sources could result in a compromised SC or could cause the entire system to fail [142].
- *Insufficient evidence on industry business cases/Unclear usage advantages:* The construction industry faces uncertainty in integrating BSCs due to the lack of concrete use cases, limiting the assessment of their benefits and risks. Industry professionals struggle to gauge the extent to which these digital agreements can address the industry's unique complexities and regulatory requirements [49]. As a result, the construction sector continues to grapple with uncertainty regarding the true potential and practicality of integrating BSCs into its operations, which impedes their integration and broader acceptance [108].
- *Lack of dispute resolution mechanism:* The absence of a legal framework and precedents for SCs in the construction industry can undermine trust. Traditional contracts benefit from a well-established legal system with clear guidelines for enforcement and dispute resolution. SCs, however, operate in relatively uncharted legal territory. Stakeholders may be apprehensive about the legal standing of their claims and the remedies available to them in the event of a dispute, leading to a reluctance to fully trust and embrace SCs [23, 194].

Table 8. List of Threats of BSC, and its Relevant Identified Sources

#	Threat	References	Mention Count
1	Lack of technological capabilities in the industry	[14, 15, 19, 29, 30, 35, 36, 38, 49, 50, 69, 86, 102, 111, 137, 150, 151, 153, 154, 186, 190, 191, 195, 196]	25
2	Lack of required skills/ untrained personnel	[24, 25, 33, 35, 38, 49, 50, 53, 69, 90, 104, 108, 111, 124, 129, 138, 146, 148, 151, 154, 157, 186, 190, 194, 196]	25
3	Low level of awareness/ understanding/ knowledge	[10, 21, 30, 31, 36, 49, 50, 53, 69, 89, 92, 98, 108, 129, 160, 191, 194, 196]	18
4	Resistance to change	[10, 14, 15, 20, 25, 28–30, 33, 35, 36, 38, 40, 45, 49, 50, 52, 57, 58, 64, 69, 102, 103, 107, 108, 117, 130, 134, 137, 138, 149–151, 153–155, 160, 176, 186, 190, 196]	41
5	Lack of legal regulation	[10, 14, 15, 17, 23, 25, 29, 31, 33, 35, 36, 38, 40, 41, 45, 49, 50, 53, 57, 69, 89, 90, 92, 102, 108, 117, 124, 137, 138, 148, 151, 153, 155, 160, 163, 176, 181, 182, 186, 190, 191, 194, 196]	43
6	Error-coding of SCs	[14, 15, 19, 29, 31, 33, 36, 38, 50, 55, 101, 103, 108, 116, 138, 142, 150, 163, 181, 182, 194]	21
7	Lack of trust/ hesitation	[21, 27, 40, 45, 48, 49, 58, 69, 106, 107, 111, 138, 148, 151, 154, 170, 196]	17
8	Complexity of construction projects	[14, 20, 33, 35, 45, 49, 53, 58, 89, 90, 102, 103, 116, 142, 146, 154, 190, 194]	18
9	Lack of collaborative culture	[21, 45, 49, 92, 106, 151, 153, 185, 186]	9
10	Absence of industry-specific standards for BSC	[20, 36, 108, 151, 154]	5
11	Not all obligations are code-expressed	[36, 45, 50, 98, 179]	5
12	Difficulty in defining unforeseen conditions	[14, 17, 25, 36, 45, 52, 58, 86, 102, 111, 194, 196]	12
13	Irrevocable nature	[14, 16, 17, 20, 21, 31, 33, 36, 40, 45, 58, 62, 86, 90, 95, 102, 111, 116, 138, 147, 149, 155, 160, 180, 181, 190, 194, 196]	28
14	Oracles Paradox	[29, 102, 138, 142, 150, 151, 153, 160]	8
15	Insufficient evidence on industry business cases/ unclear usage advantages	[31, 49, 64, 69, 108, 124, 142, 149, 151, 181, 196]	11
16	Lack of dispute resolution mechanism	[17, 23, 29, 36, 45, 150, 194, 196]	8

5.3. Social Network Analysis (SNA)

5.3.1. Developing Reference Matrices

Factors for each SWOT aspect, along with their sources, were organized to create reference matrices. In this study, 174 publications were utilized, grouped at one-year intervals from 2017 to 2023 based on their publication year. Sources were alphabetically labeled from S001 to S174, according to authors' last names, within the 2017-2023 timeframe. All selected sources are listed in Supplementary A with their respective publication years and the number of publications for each year.

The reference matrices for SWOT aspects were constructed to represent the identified factors as rows and the selected sources as columns. For instance, the strength matrix includes 174 sources and 25 BSC-identified strength points, creating a matrix with dimensions of 25 by 174. If a relevant factor exists in a source, its corresponding cell contains a value of 1; otherwise, it contains 0.

5.3.2. Constructing a Social Network Adjacency Matrix

Degree Centrality (DC) is calculated for each matrix to determine the significance of individual factors based on their frequency and co-occurrence with other factors in selected prior publications. The computation of DC for nodes requires the creation of an adjacency matrix, which serves to depict the presence or absence of relationships between factors. In this context, the authors have formulated an adjacency matrix for each matrix, employing Equation 2. This matrix is produced by multiplying the reference matrix by its transpose, following by replacing zeros in the diagonal cells of the resulting matrix.

$$A_{n\times n} = W_{n\times m} \times W^{T}_{n\times m} \quad \text{for} \quad i \neq j \tag{2}$$

where $A_{n\,x\,n}$ is an n-by-n adjacency matrix, with n denoting the total count of recognized factors. $W_{n\,x\,m}$ denotes matrix M, where m corresponds to the number of reviewed articles. $W^{T}_{n\,x\,m}$ signifies the transpose matrix of the corresponding reference matrix, and i and j represent the indices for the rows and columns within the matrix, respectively.

Then, color-coded matrices were generated to illustrate the interconnections between different nodes, as depicted in Figure 6. The matrices exhibit symmetry about their diagonal axes and form a triangular configuration. The content of each cell within the color-coded matrices corresponds to the respective value found in the corresponding cell of the adjacency matrix. Both the rows and columns of the color-coded matrix signify the variables under scrutiny, thus facilitating the understanding of the extent of correlation between any two intersecting factors. The color-coded scheme mirrors the intensity of the connections between pairs of factors, with darker shades indicating more robust connections.

1	0																								
2	57	0																							
3	38	41	0																						
4	64	73	46	0																					
5	42	46	35	47	0																				
6	33	47	35	49	32	0																			
7	58	67	44	79	53	45	0																		
8	39	49	35	62	39	39	51	0																	
9	23	29	17	29	22	24	29	25	0																
10	53	61	40	73	51	43	69	49	29	0															
11	4	5	1	5	4	4	5	3	2	5	0														
12	3	3	4	5	2	5	4	4	2	3	0	0													
13	7	9	6	8	7	8	8	7	8	6	1	1	0												
14	31	35	27	36	27	27	32	27	17	38	2	3	4	0											
15	30	29	24	36	24	20	36	24	16	33	1	3	6	18	0										
16	23	24	16	29	15	18	31	17	10	25	2	3	3	14	14	0									
17	12	14	12	20	15	15	20	12	8	20	0	2	3	10	7	7	0								
18	3	5	5	7	5	4	7	6	2	6	0	2	1	5	3	3	3	0							
19	4	4	2	6	4	1	3	5	1	5	0	0	0	3	1	1	0	0	0						
20	31	42	25	47	30	29	45	29	17	40	5	4	6	25	24	13	24	5	3	0					
21	45	57	36	59	46	41	58	42	28	52	3	3	8	27	30	19	18	6	5	39	0				
22	49	52	33	62	42	35	64	35	17	52	4	3	4	25	22	21	17	5	2	37	45	0			
23	23	33	23	36	19	22	30	27	16	29	2	3	6	19	13	15	6	3	0	15	22	17	0		
24	8	8	5	10	11	7	10	10	7	10	0	1	3	8	5	2	2	2	0	5	10	11	3	0	
25	30	39	28	46	33	31	44	31	15	41	2	3	9	22	18	14	13	4	1	30	36	35	22	10	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

(a) Strengths

1	0										
2	4	0									
3	4	14	0								
4	1	5	3	0							
5	4	17	14	3	0						
6	3	7	9	2	12	0					
7	4	19	15	4	21	11	0				
8	0	3	2	3	3	1	7	0			
9	4	19	12	4	17	10	23	5	0		
10	1	3	2	0	1	0	1	0	0	0	
11	2	5	7	0	7	5	7	0	5	1	0
	1	2	3	4	5	6	7	8	9	10	11

(b) Weaknesses

1	0																			
2	42	0																		
3	13	23	0																	
4	39	65	22	0																
5	9	19	7	16	0															
6	6	15	5	11	4	0														
7	15	29	10	32	11	5	0													
8	19	26	6	24	3	7	10	0												
9	10	13	5	15	2	4	7	10	0											
10	6	4	2	7	1	2	3	3	2	0										
11	8	19	10	25	6	3	12	6	4	3	0									
12	9	11	4	10	2	4	6	10	4	0	2	0								
13	10	13	6	10	4	5	7	6	4	1	4	5	0							
14	8	7	1	8	1	0	4	5	1	2	4	1	2	0						
15	3	6	1	8	2	2	3	4	2	1	3	1	1	1	0					
16	10	17	3	22	6	0	9	4	3	2	8	1	0	3	2	0				
17	47	68	17	69	13	15	30	23	13	7	18	11	14	8	6	20	0			
18	9	14	5	17	2	3	3	8	4	1	3	5	2	2	3	7	19	0		
19	28	40	14	39	7	8	16	19	11	2	8	10	7	3	6	10	47	15	0	
20	7	8	2	8	0	3	3	2	0	1	3	1	1	1	2	2	13	4	11	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

(c) Opportunities

1	0															
2	11	0														
3	7	8	0													
4	20	14	9	0												
5	17	18	14	28	0											
6	8	6	5	11	14	0										
7	6	8	4	10	8	1	0									
8	6	9	4	11	11	6	4	0								
9	4	3	3	5	6	0	5	2	0							
10	3	3	2	5	3	2	2	2	1	0						
11	2	1	3	3	3	2	1	1	1	1	0					
12	6	4	3	8	8	3	4	5	1	1	2	0				
13	7	7	6	14	16	8	7	10	2	2	2	10	0			
14	5	2	1	7	6	4	2	2	2	1	0	1	3	0		
15	4	6	5	7	8	4	4	2	2	2	0	1	4	2	0	
16	4	2	3	5	7	4	2	2	1	1	2	5	5	2	1	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

(d) Threats

Figure 6. A Color-coded Matrix of normalized DC

5.3.3. SNA Measures

Following the construction of the adjacency matrices, DC is determined using Equation (3), where DC_i is the Degree Centrality of the factor i, and $V_{i,j}$ represents the value located at the intersection of row i and column j of the corresponding adjacency matrix. Therefore, the DC of a factor in a given adjacency matrix is computed by summing the total connections associated with the node. Consequently, the normalized DC for a given factor i within the network is determined by dividing the DC of the factor under examination by the highest DC value observed within the network being analyzed, as detailed in Equation 4. As a result, the normalized Degree Centrality for any factor is bounded within the interval from 0 to 1.

$$DC_i = \sum_{j:j \neq i} V_{i,j} \tag{3}$$

$$Normalized\, DC_i = \frac{DC_i}{Maximum\ C_i\ in\ the\ Network} \tag{4}$$

5.3.4. Analysis of Results

BSC factors identified in the SWOT analysis were analyzed using SocnetV, which is an open-source software tool designed for SNA and visualization, serving as a valuable tool for researchers and facilitating the exploration of relationships and interactions within diverse network typologies. Figure 7 displays the results of the applied SNA maps, with the visualization representing the calculated normalized DC for each factor donated as a node in relation to its radial position. The radial position of a node is inversely proportional to its normalized DC, indicating that nodes closer to the central point have higher normalized DC values than those farther from the center.

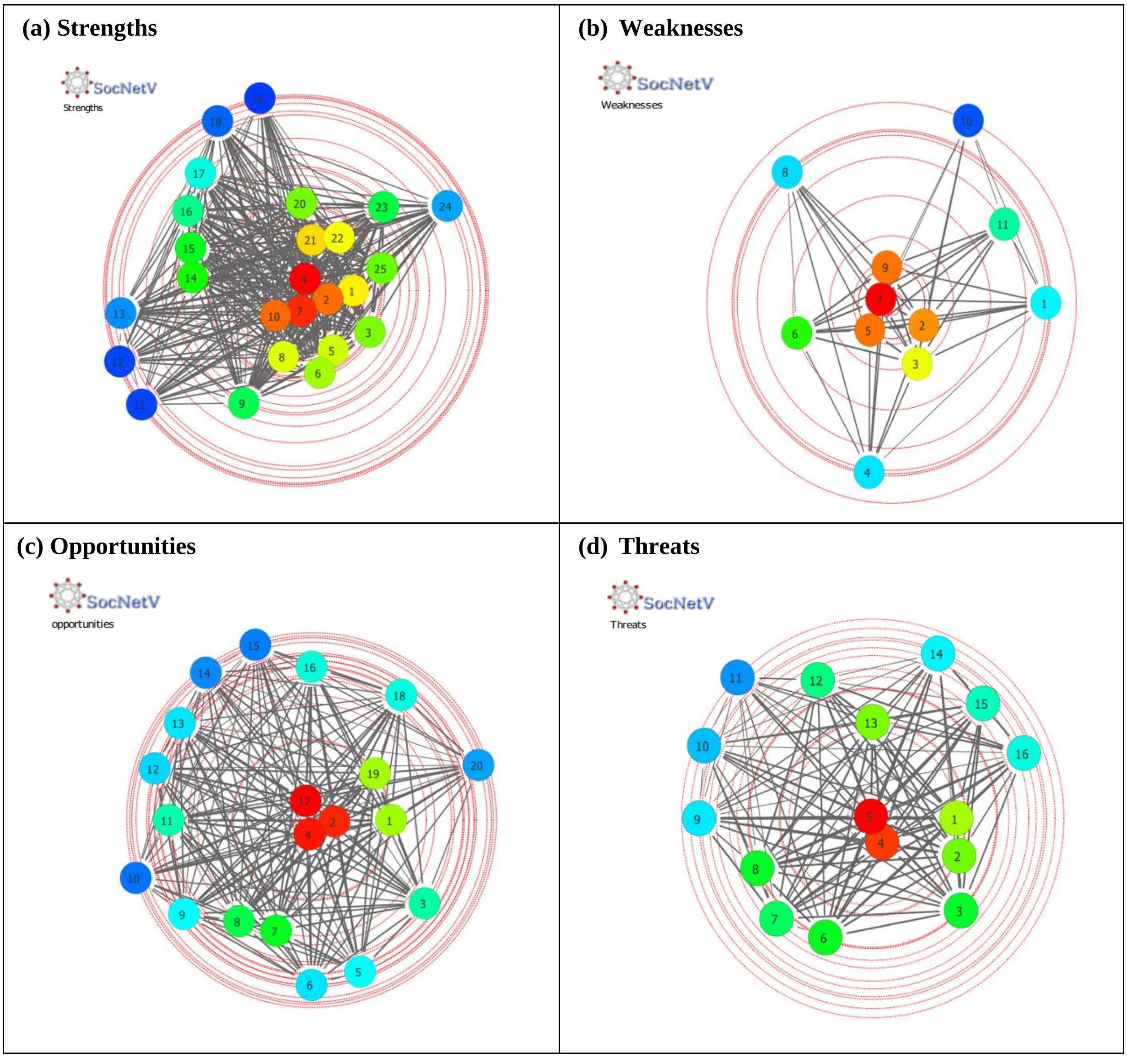


Figure 7. Visualization of the SNA Networks of SWOT Framework

On the other hand, the node colors reflect the DC range, where the nodes turn blue when they move away from the center and red when they get closer. For instance, factors S4 and S7 of the Strengths aspect (i.e., transparency and trust/reliability) with normalized DC equals to 1 and 0.955, respectively); and factor T5 of the Threats aspect (i.e., lack of regal regulation, with normalized DC equals to 1); are situated in closer proximity to the central point, marked in red, indicating their relative importance compared to other factors that are farther away, marked in green and blue, symbolizing their diminished centrality and reduced influence within the network. For example, factor W10 of the Weaknesses aspect (i.e., Jurisdiction challenges, with normalized DC equals to 0.124); factors O10, O15 and O14 of the Opportunities aspect (i.e., stakeholder management, risk management, and change management, with normalized DC of 0.109, 0.124 and 0.135, respectively); represent the factors farthest from the center. According to the studies of [203, 211], the factors are deemed critical when their normalized DC surpasses the threshold of 0.8. Furthermore, [212] employs a comparative approach, designating factors that have a DC higher than the average normalized DC (ANDC) as being of significance. To this end, the authors applied both strategies in order to discern and categorize the identified factors into high, moderate, and low as delineated in Table 9. The ANDC computed as per Equation 5, where threshold for the ANDC of 0.519, 0.549, 0.402 and 0.464 are used for the distinct facets of SWOT analysis, respectively.

$$Average\ Normalized\ DC = \frac{\sum_i^n Normalized\ C_i}{No.\ of\ identified\ factors} \tag{5}$$

Table 9. Matrix of BSC Factors by Research Category

Investigation	SWOT Framework			
	Strengths	**Weaknesses**	**Opportunities**	**Threats**
Most Studied DC ≥ 0.8	• S2: Immutability • S4: Transparency • S7: Trust/ reliability • S10: Automation	• W2: Malicious attacks/ cybersecurity • W5: Privacy • W7: Transaction processing limitation/ scalability issues • W9: High cost of adoption/ financial constraints	• O2: Supply chain management • O4: Automated payments • O17: Integrated technology - BIM	• T4: Resistance to change • T5: Lack of legal regulation
Medium studied 0.8 > DC ≥ average	• S1: Traceability • S3: Data irreversibility/ Tamper proof/ Persistency • S5: Information sharing • S6: Decentralization • S8: Increased data security • S20: Lower transaction and financial/administrative cost • S21: Disintermediation • S22: Improving collaboration and communication • S25: Efficiency/ improve work progress	• W3: Lack of interoperability	• O1: Document management/ information management • O7: Contract management/ administration • O8: Quality management/ compliance checking • O19: Integrated technology – IOT	• T1: Lack of technological capabilities in the industry • T2: Lack of required skills/ untrained personnel • T6: Error-coding of SCs • T8: Complexity of construction projects • T13: Irrevocable nature
Less studied DC < average	• S9: Increased data privacy • S11: Improved risk contingency • S12: Reducing bureaucracy • S13: Auditability • S14: Chronological data recording • S15: Time-stamping/ real-time information • S16: Accountability/ clarity in authority • S17: Time-saving • S18: Saving efforts/ increasing productivity • S19: Efficient international trade • S23: Veracity/ authenticity • S24: Decision-making	• W1: High energy consumption/ computational power • W4: Low connectivity and bandwidth • W6: Limited storage capacity • W8: Data latency • W10: Jurisdiction challenges/ choice of law • W11: Complexity of BSC	• O3: procurement management • O5: Funding/ cashflow management • O6: Facility/ asset management • O9: Site management • O10: Stakeholder management • O11: Dispute resolution • O12: Safety Management • O13: Design management • O14: Change/ dynamic management • O15: Risk management • O16: Subcontract management • O18: Integrated technology - Digital twin • O20: Integrated technology - Artificial intelligence	• T3: Low level of awareness/ understanding/ knowledge • T7: Lack of trust/ hesitation • T9: Lack of collaborative culture • T10: Absence of industry-specific standards for BSC • T11: Not all obligations are code-expressed: • T12: Difficulty in defining unforeseen conditions • T14: Oracles Paradox • T15: Insufficient evidence on industry business cases/ unclear usage advantages • T16: Lack of dispute resolution mechanism

The SNA findings emphasize the scholarly relative investigation of various key factors in the realm of BSC deployment in construction, in contrast to other prominent factors that receive more attention.

The SNA underscores the interconnected nature of factors affecting BSC adoption. High degree centrality values indicate factors that are central to the discourse on BSC in construction, demonstrating their critical role in driving BSC adoption and shaping the operational framework of the technology. This insight helps stakeholders identify which areas require immediate attention and resources and guides decision-makers to strategically invest in areas that significantly influence the technology's implementation landscape of BSC in construction.

Moreover, this analysis also draws attention to the less-interconnected factors, as denoted by lower DC values, underscoring their potential for groundbreaking contributions to BSC in construction. These underexplored areas, while not currently at the forefront of research, are vital for a comprehensive understanding of BSC adoption. Addressing these gaps can lead to innovative solutions, fostering a more robust and inclusive integration strategy that captures the full spectrum of influences on BSC deployment in the construction sector.

5.4. K-Mean Clustering

In this section, the K-Mean Clustering (K-mean) algorithm is utilized, an important tool in data analytics, recognized for its simplicity and efficiency. This method's relevance is especially noteworthy for the study, as it enhances and refines the categories identified through SNA, informed by the threshold of 0.8 and the ANDC, as commonly utilized in existing research. Recognizing the need for a more robust validation method, K-mean is incorporated into this analysis. This technique enhances the reliability of the results by offering a method for categorizing SWOT factors, thereby enriching the analytical depth and reinforcing the integrity of the results.

As previously mentioned, Clustering Analysis is used to identify groups of factors that often appear together. As such, K-mean is applied to the NDC obtained from the adjacency matrix of the SNA. The best number of clusters was found by generating and analyzing an elbow plot, as seen in Figure 8, leading to an optimal number of clusters of three or four. It is opted to choose three clusters, aiming to facilitate a more direct and meaningful comparison of the results obtained from both the SNA and the K-mean. Thereby enhancing the credibility and interpretability of the findings.

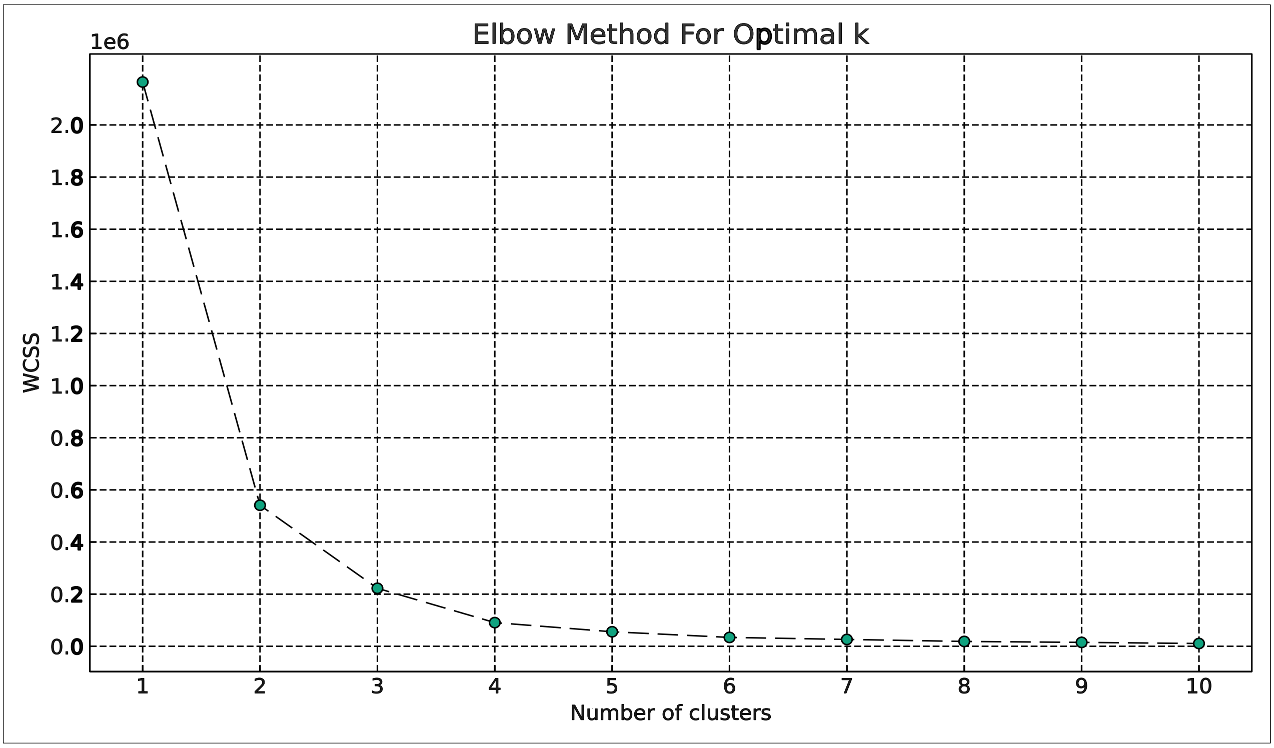
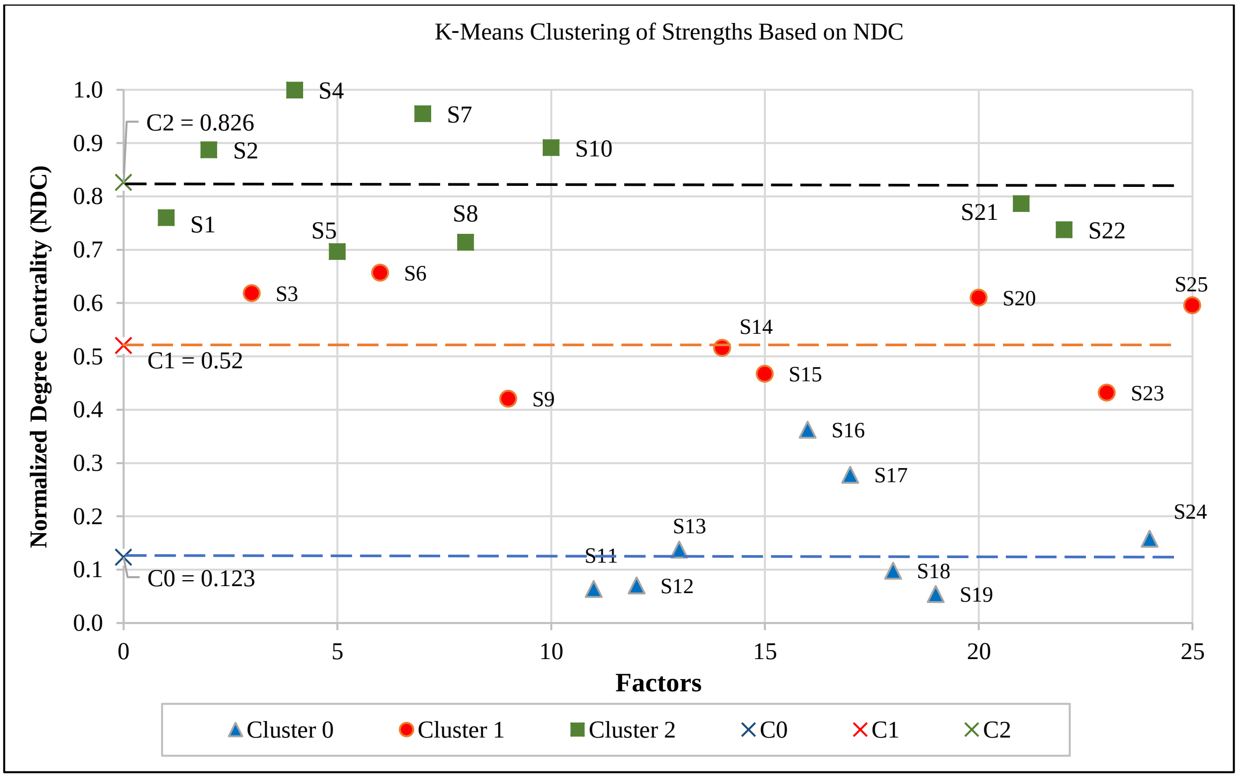


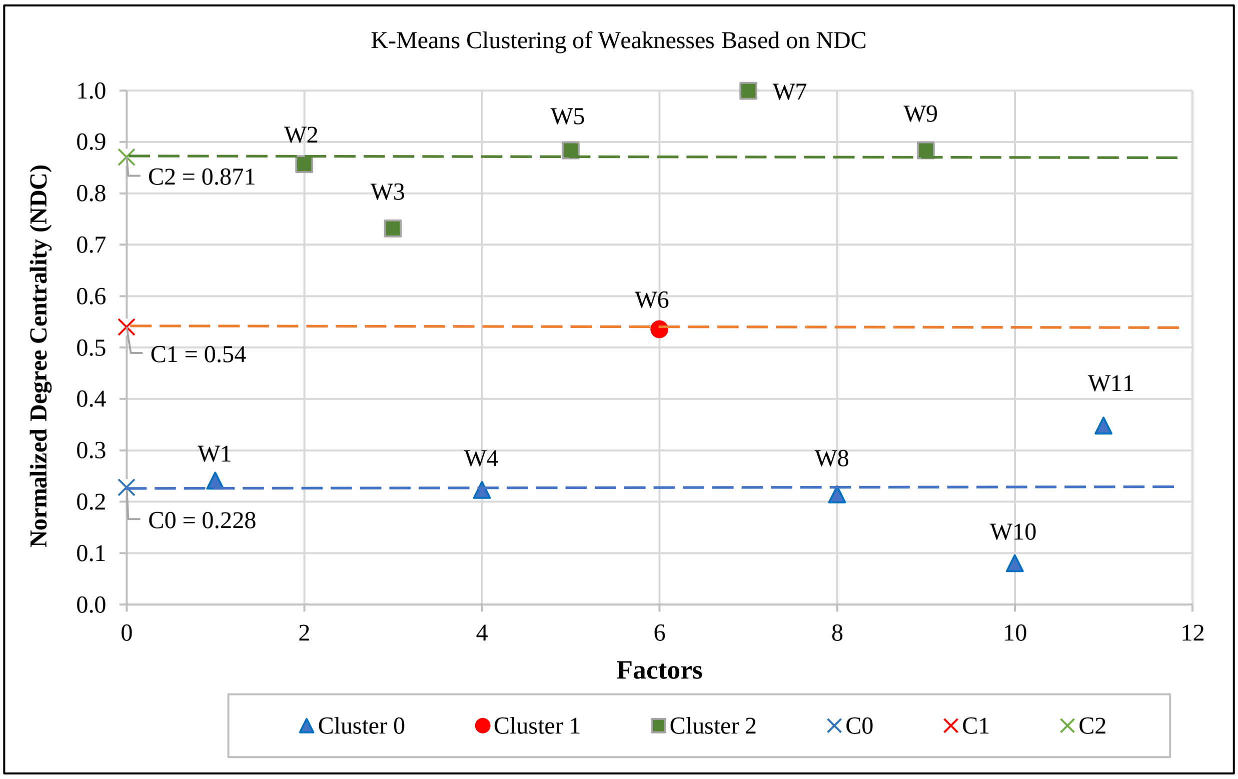
Figure 8. Elbow Plot for the Distortion Score for the Number of Clusters

Figure 9 illustrates the network model, with each cluster colored differently. It's important to consider and interpret these clustering findings in conjunction with the SNA results, where the clusters are ordered from the least to the most studied factors in terms of research focus. Factors in cluster 0, marked by blue triangles, are the factors with low NDC values that have relatively few interconnections with other factors. This suggests that they have received limited attention or interest in the literature. Furthermore, those in cluster 2, represented by green squares, are the most studied. They serve as hubs or central nodes, indicating that they are extensively studied and influential in the field. These factors are at the core of the research network. Factors in cluster 1, shown as red circles that fall in between, are recognized within the research network but may not be the central focus.

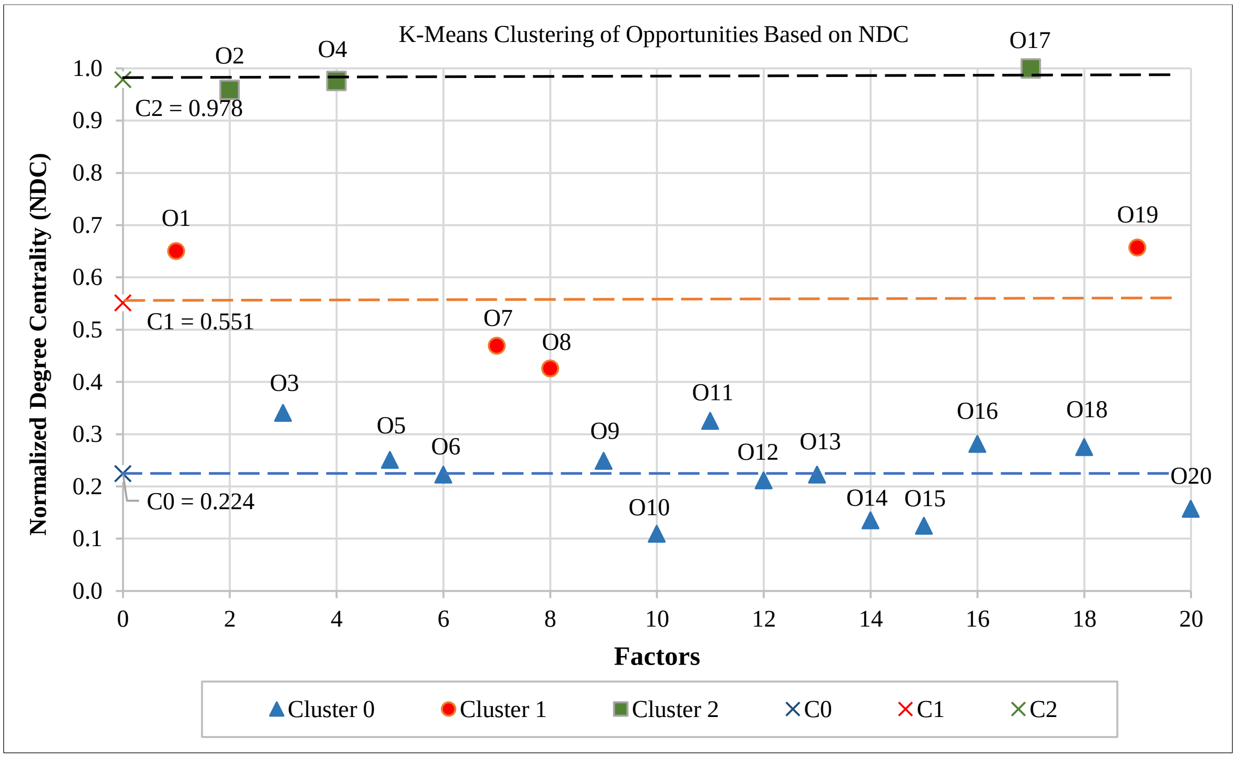
To further deepen the understanding of these clusters, it is vital to assess their practical implications for the construction industry. Factors in cluster 0 (blue triangles), while less studied, may represent emerging trends or overlooked aspects that could lead to significant advancements in BSC adoption. Conversely, the prominence of factors in cluster 2 (green squares) underscores well-established research areas that continue to shape industry standards and practices. Meanwhile, factors in cluster 1 (red circles) offer a balance, indicating areas with potential for further exploration and development. This refined analysis sharpens the research focus and guides stakeholders in prioritizing efforts to enhance BSC integration in construction projects.



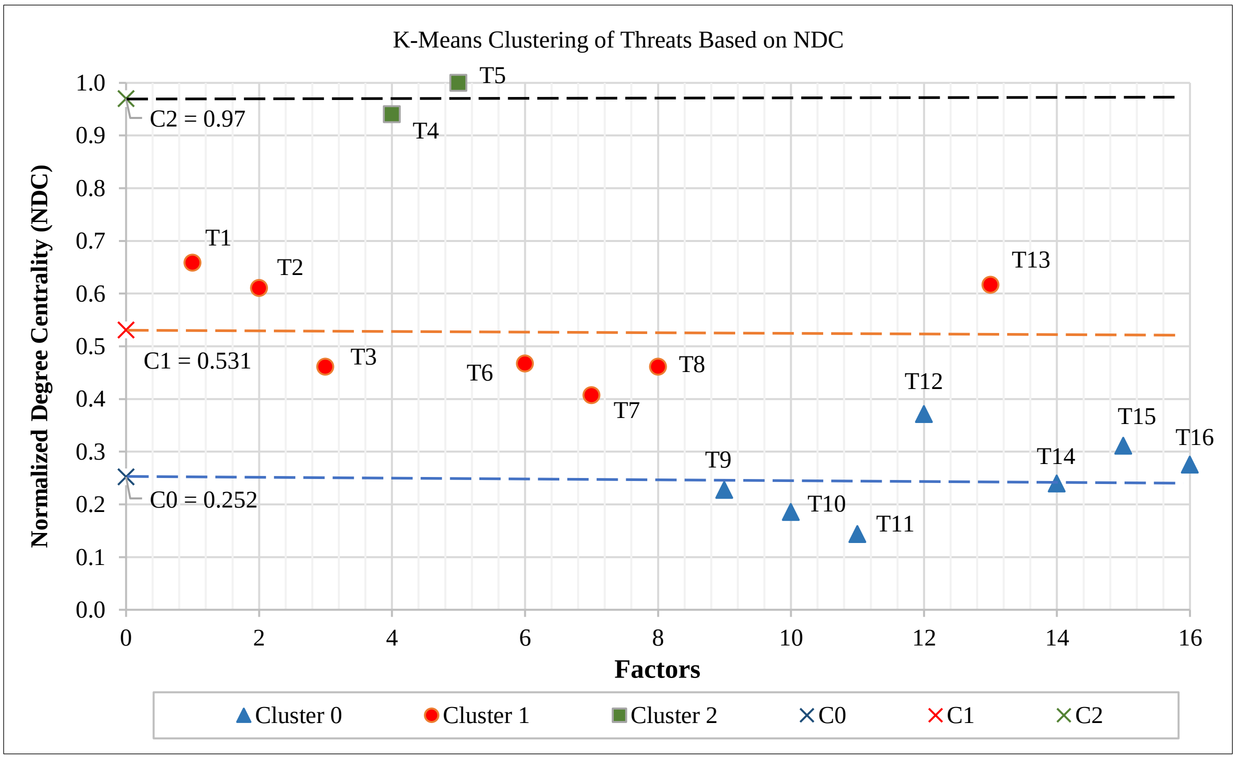
(a) Strengths



(b) Weaknesses



(c) Opportunities



(d) Threats

Figure 9. Network of the Clustering Model

The comparative matrix of the BSC factors (Table 10) presents a holistic and validated classification, supported by both SNA-based significance and K-mean clustering-based groupings. This dual-method approach ensures a comprehensive and reliable analysis of the SWOT factors. Therefore, it does not merely present a systematic classification but also reflects the focus of existing research. This insight is crucial in guiding future investigations to address the overlooked areas, thereby contributing to a more holistic understanding of BSC implementation in construction. In conclusion, the combined results from the clustering and SNA analyses indicate that the factors in Cluster 0 are the least studied, whereas the factors in Cluster 2 are the most researched and interconnected in the literature.

Table 10. Comparative Matrix of BSC Factors by SNA Results and Cluster Analysis

SWOT Aspect	Methodology	Most Studied	Medium Studied	Less Studied
Strengths	SNA	S2 - S4 - S7 - S10	**S1** - S3 - **S5** - S6 - **S8** - S20 - **S21** - **S22**- S25	**S9** - S11 - S12 - S13 - **S14** - **S15** - **S16** - S17 - S18 - **S23** - S24
	K-Mean Clustering	**S1**- S2 - S4 - **S5** - S7 - **S8** - S10 - **S21** - **S22**	S3 - **S9** - **S14** - **S15** - **S16** - S20 - **S23** - S25	S11 - S12 - S13 - S17 - S18 - S19 - S24
Weaknesses	SNA	W2 - W5 - W7 - W9	**W3**	W1 - W4 - **W6** - W8 - W10 - W11
	K-Mean Clustering	W2 - **W3** - W5 - W7 - W9	**W6**	W1 – W4 - W8 - W10 - W11
Opportunities	SNA	O2 - O4 - O17	O1 - O7 - O8 - O19	O3 - O5 - O6 - O9 - O10 - O11 - O12 - O13 - O14 - O15 - O16 - O18 - O20
	K-Mean Clustering	O2 - O4 - O17	O1 - O7 - O8 - O19	O3 - O5 - O6 - O9 - O10 - O11 - O12 - O13 - O14 - O15 - O16 - O18 - O20
Threats	SNA	T4 - T5	T1 - T2 - T6 - T8 - T13	**T3** - **T7** - T9 - T10 - T11 - T12 - T14 - T15 - T16
	K-Mean Clustering	T4 - T5	T1 - T2 - **T3** - T6 - **T7** - T8 - T13	T9 - T10 - T11 - T12 - T14 - T15 - T16

The results reveal a significant overlap in the 'Opportunities' category, where both strategies align closely. Besides, the 'Threats' and 'Weaknesses' aspects exhibit slight variations, with only a couple of factors differing between the two approaches (underlined factors in Table 10). Under 'Weaknesses', factors such as W6 are categorized differently in the two approaches. This occurs because W6's NDC of 0.536 falls just below the ANDC, which is 0.549; thus, it is classified in cluster 0 in the SNA, while its proximity to the centroid of cluster 1 (C1) in K-mean, with a centroid of 0.54, leads to a different categorization. Similarly, factor W3, with a NDC of 0.732, aligns more closely with cluster 2 (C2) in terms of the minimum squared distance of the K-means; however, it falls below the SNA threshold of 0.8, placing it in cluster 1. In the 'Threats' aspect, factors T3 and T7, with NDCs of 0.461 and 0.407, respectively, are positioned below the ANDC of the SNA set to be 0.564, thus categorized in cluster 0. However, K-mean, which focuses on minimizing squared distances to cluster centroids, categorizes them in cluster 1 with a centroid of 0.531.

Notably, the 'Strengths' aspect, which encompasses the most factors, presents a more diverse picture, where nearly half of the identified factors show variations between SNA and K-mean. Such varied factors are underlined in Table 10, where the core of this variation lies in the close proximity of the centroids in K-mean to the thresholds defined in SNA. For instance, the centroid of Cluster 1 in K-mean is 0.52, almost mirroring the SNA threshold of 0.519 for this category. A similar pattern is observed with cluster 2, where its centroid of 0.826 is closely aligned with the SNA threshold of 0.8. As a result, factors that are marginally above or below these pivotal values exhibit different clustering outcomes in the two methodologies. The variance between the two approaches can be attributed to the subtle but significant differences in the clustering criteria of the two methodologies. SNA applies a threshold-based approach, evaluating whether a factor's NDC surpasses a predefined limit. In contrast, K-mean operates on the principle of minimizing the squared distance to the centroids, leading to a more dynamic cluster assignment.

The insights derived from this comparative analysis underscore the need for a multifaceted approach in evaluating the SWOT framework. This analysis highlights that reliance on a single method may offer a limited perspective, potentially overlooking key factors that could be pivotal in further investigation and decision-making. Thus, a combined application of both SNA and K-mean is advantageous, enabling a more comprehensive and accurate representation of BSC factors within the industry.

6. Conclusion

Given the limited adoption of BSC in the realm of construction, this study seeks to delineate a strategic pathway for the effective and efficient integration of BSC within the construction sector. In this endeavor, the SWOT analysis has served as the cornerstone, providing a comprehensive and strategic foundation for the entire analysis made in this study. This endeavor entails a comprehensive examination of existing research to determine where it stands, identify areas lacking sufficient study, and consequently pinpoint future research requirements. The analysis incorporates the examination of 174 peer-reviewed papers extracted from Scopus and WoS databases, the identification of 72 pertinent BSC-related factors, and their categorization into the four aspects of the SWOT framework, encompassing 25 strengths, 11 weaknesses, 20 opportunities, and 16 threats associated with the adoption of BSC in construction.

Additionally, SNA and K-mean were performed to visually and quantitatively evaluate the interrelationships and strengths of these factors. Hence, they highlight: (1) patterns that link BSC factors to one another; (2) the weight of those links, which signifies a relationship or association between the two BSC factors in terms of their co-occurrence in literature; and (3) the extent to which BSC factors are investigated in current scholarly efforts. The analysis points out that specific factors have garnered extensive research attention. Notably, there are "Transparency," "Scalability issues," "BIM integrated technology," and "lack of legal regulation". Moreover, several factors are moderately explored, including "disintermediation," "lack of interoperability," "IOT integrated technology," and the "irrevocable nature of SCs". Meanwhile, certain pivotal factors remain comparatively underexplored, encompassing aspects such as "efficient international trade," "Jurisdictional challenge," "stakeholder management," and "not all obligations are code-expressed," each aligned with the relevant SWOT aspect, respectively.

The existing body of literature shows a significant disparity in focus, leading to crucial research findings that reveal a lack of comprehensive studies covering essential factors and categories that may critically affect the integration of BSC within the construction industry. This finding underscores the urgent need for future research endeavors to address and thoroughly explore these noticeably underexplored factors and categories, which are vital for the successful implementation of BSC. Such research could greatly enhance the application of BSC across various operational systems within the construction sector, thus fostering its overall advancement.

6.1. Limitations

This study, while comprehensive in its approach to integrating BSC in construction, acknowledges some inherent limitations. While the study focuses largely on academic literature, it may not always capture all practical scenarios actively occurring in the construction industry. Moreover, it is important to recognize that the rapidly evolving nature of BSC may lead to new developments not discussed in this study. These limitations are acknowledged as areas for future research and exploration, especially in the context of evolving technologies and their practical applications in the field.

7. Declarations

7.1. Author Contributions

Conceptualization, M.G., E.E., and M.T.; methodology, M.G., E.E., and M.T.; software, M.G.; validation, M.G., E.E., and M.T.; formal analysis, M.G. and M.T.; investigation, M.G. and M.T.; resources, M.G. and M.T.; data curation, M.G. and E.E.; writing—original draft preparation, M.G.; writing—review and editing, E.E. and M.T.; visualization, M.G.; supervision, E.E. and A.E. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Conflicts of Interest

The authors declare no conflict of interest.

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