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Demystifying the Influencing Factors of Construction 4.0 Technology Implementation from a Sustainability Starting Point: Current Trends and Future Research Roadmap

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Abstract: Given the challenges of innovation and adaptation to change, Construction 4.0 (C4.0) is triggering a revolution within construction and industry firms from automation to a greater level of digitalization. Despite the plethora of advantages and growing research interest in certain aspects of C4.0 technology implementation (C4.0TeIm), previous discourses have been largely fragmented and lack a comprehensive investigation of the factors influencing C4.0TeIm. To this end, this study aims to holistically investigate the influencing factors of C4.0TeIm and propose guidelines for future research directions. Informed by the United Nations twin green and digital transition perspectives, this study initiated its exploration in the background by delving into the potential intersections between C4.0 and sustainability. To achieve the aim, this study (i) reviewed 77 relevant articles and discerned a comprehensive list of factors influencing C4.0TeIm; (ii) outlined and quantified the influence and importance of the identified factors using social network analysis and validated results against the simplified analysis; and (iii) revealed gaps in the literature and proposed a research roadmap directing future research needs. The results show that 60 factors could collectively influence construction firms' C4.0TeIm; they can be categorized into the external environment, technology competence, organizational factors, project-based factors, and technology challenges. The findings also reveal that further endeavors should emphasize those understudied factors such as "perceived overall organizational performance improvement", "corporate strategy and management policy", and "availability of resources". Practically, the proposed research guidelines provide valuable references to accelerate C4.0TeIm in both academics and the business world and offer strategies for the top management of firms to maximize potential benefits and gain competitiveness.

Keywords: Industry 4.0; Construction 4.0 (C4.0); construction firms; sustainability; social network analysis (SNA); digitalization transformation; sustainable development goals (SDGs)

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1. Introduction

The global construction market, valued at 10.7 trillion USD in 2020, is projected to reach 15.2 trillion USD by 2030, serving as an engine for economic development and post-COVID-19 recovery [1]. This growth trajectory underscores the construction market's enduring contribution to economic prosperity and its significant role in providing employment opportunities [2]. However, subject to limited innovation and adaptation to change, productivity in construction is inherently slower than in other sectors like manufacturing and electronics [3]. To address these challenges and foster competitiveness, scholars and construction practitioners have turned to technology innovation within the framework of

Industry 4.0 (I4.0) (Wang et al., 2020). According to Newman, et al. [4], I4.0 is reshaping traditional business models, empowering substantial improvements in process flexibility, manufacturing efficiency, and productivity by integrating emerging technologies. The application of I4.0's digital approaches has given rise to Construction 4.0 (C4.0), which encompasses a wide range of emerging technologies, such as robotics, Building Information Modelling (BIM), big data, 3D printing, robotics, and the Internet of Things (IoT) [5,6].

The transition to C4.0 in the context of digital revolution construction entails a subtle restructuring of the social-technical system. In addition to incorporating cutting-edge technology like BIM, IoT and robotics, this shift entails a fundamental reorganization of the dynamics of collaboration among project stakeholders. Recalibrating channels of communication, decision-making procedures, and organizational structures is necessary due to the confluence of human knowledge and technical interfaces. This all-encompassing strategy emphasizes cooperation, flexibility, and skill development throughout the construction ecosystem in recognition of the fact that successful integration of digital tools requires a concurrent evolution in social relations. Acknowledging the broader scope and complexity of digital transformation in the social-technical systems, this study particularly narrowed down the scope to explore the C4.0TeIm, which specifically refers to the practical application and integration of digital technologies within the construction processes.

Traditional production systems in the construction industry have long been associated with ecological imbalances and social hurdles [7]. Environmental degradation, pollution, social inequality, collusive bidding, and corruption are traceable to traditional production systems and technologies [8–10]. Grounded in legitimacy theory, meeting the expectations and requirements of diverse stakeholders—such as carbon emission reductions—is recognized as a catalyst for superior organizational performance [11]. C4.0 has the potential to effectively address ecological and social pressures associated with conventional construction practices, ultimately fostering overall sustainability [12]. These positive outcomes can, in turn, enhance the long-term competitiveness of construction firms.

Despite the plethora of advantages and benefits offered by C4.0, the implementation of current digital technologies in construction is still immature, narrowly focused, and non-strategic compared to other mainstream businesses [5,13,14]. According to McKinsey's report, just a small percentage of companies have started to advance with I4.0 adoption throughout their industrial networks in the last five years. But the great majority are still stuck in pilot purgatory, unable to generate a sufficient return on investment or fully realize the potential of their I4.0 transformative projects [15]. C4.0 technology implementation (C4.0TeIm) by construction firms is influenced by various complex factors that are different from those of traditional production systems and technologies. There is an urgent need to understand and assess the factors influencing construction firms' C4.0TeIm. By embracing C4.0 technologies, the construction industry can navigate these challenges, drive innovation, and foster industry system sustainability.

Despite the need for a deeper comprehension of the influencing factors associated with C4.0TeIm, most recent C4.0 studies primarily lie in (i) discussing challenges and opportunities of C4.0TeIm in the national and international construction markets [16–18]; (ii) exploring the connections between I4.0 and sustainable innovation [13] and construction performance [19]; and (iii) reviewing the current research efforts of C4.0 [13,18,20,21]. Previous discussions regarding factors influencing C4.0TeIm seems to be broad and fragmented. Few studies have brought previous literature together on a cohesive whole and captured a broader picture of the key factors influencing firms' C4.0TeIm in general.

Based on this contextual backdrop, this study aims to holistically unveil the factors affecting C4.0TeIm and provide a guide for future research directions. Informed by the United Nations twin green and digital transition perspectives, this study first initiates its exploration in the background by delving into the potential intersections between C4.0 and sustainability. The specific objectives of this study include (i) conducting a systematic literature review on C4.0TeIm in construction and identifying the influencing factors of C4.0TeIm, (ii) performing social network analysis (SNA) to evaluate the influence and importance of the identified factors and validate the results via the simplified analysis method, and (iii) outline the research gaps and develop a research guideline for the factors that need further investigation. The finding is significant as it provides a valuable reference for scholars, construction firms, and practitioners to understand C4.0TeIm in construction and its associated influencing factors. The results of this study can be used by construction companies' top management to assess internal and external business environments, distribute organizational resources, and implement business plans, all of which will help the company make the transition to digitalization and become more competitive.

2. Research Background

2.1. Construction 4.0 Technology Implementation

In 2011, the German government initiated the concept of "Industry 4.0" as a key component of their economic strategy, marking the onset of the fourth industrial revolution [22]. It outlines a novel approach to intelligent and autonomous manufacturing [12]. Unlike the third industrial revolution, which relied on automation processes that were not fully computer-dependent, I4.0 emphasizes the use of computer systems for automation [5]. This shift towards computer-based automation offers numerous benefits, including improved business models, enhanced efficiency, and better working conditions. As a result, I4.0 has gained considerable traction in the business world and academic circles. The construction industry has also been influenced by this trend, leading to the emergence of the concept of C4.0.

Despite the long-standing interest, the conceptual and definitional vagueness of C4.0 still plagues the field [23]. Berger [24] is often credited with laying the foundations of C4.0 by applying the principles of I4.0 to the construction sector. C4.0 is a method that attempts to integrate and align different technologies to fulfill the requirements and constraints in construction, according to Boton, Rivest, Ghnaya and Chouchen [20]. However, there is a lack of categorization and coherence in the technologies associated with C4.0, which encompass both digital and physical technologies [12]. Generally, the former refers to modern information and communication technologies, e.g., BIM, blockchain, and big data analytics, while the latter primarily refers to Radio-frequency identification (RFID), different types of sensors, and drones. As shown in the supplemental materials, Table S1 summarizes various C4.0 technologies and lists respective sample applications in the construction industry. Although this list is considered as not being all-inclusive, it nonetheless provides insightful information about a variety of C4.0 technologies. Recent studies have shown that current C4.0 technologies tend to be BIM-centric, focusing on integrating data and information (e.g., [4,23,25]). The integration and implementation of various technologies are becoming inevitable in the C4.0 era [26,27].

Despite the prevalence of C4.0TeIm in construction, many construction firms still heavily rely on traditional management approaches and processes. The resistance to embracing C4.0TeIm strategies by top management can be attributed to various factors, ranging from the uncertainty about the cost and time efficiency, lack of practical testing and validation, and data security issues to the difficulty in explaining the output from the new technology to the client [28]. Investigating the factors that influence the wider adoption of construction companies' C4.0TeIm, such as the drives, motivations, and obstacles, is essential to overcoming these obstacles. By gaining a better understanding of these factors, strategies can be developed to address the concerns and encourage the adoption of C4.0 technologies in construction.

2.2. Implementing Construction 4.0 from a Sustainability Starting Point

Sustainability is a broad concept, including economics, environmentalism, and society [29]. Although the definitions of "sustainable construction" or "sustainability in construction" vary, their main objective is to uphold sustainability in economics, environmentalism, and society [30,31]. With the ongoing digital transformation in the construction industry, the principle of sustainability can be integrated into the emerging concept of C4.0

and sustainability. Bai, Dallasega, Orzes and Sarkis [12] argued that the aims and principles of I4.0 technologies could contribute to a more sustainable society rather than mere business and economic performance maximization. Drawing upon the triple-bottom-line theory (TPB), aligning the targets of C4.0 technologies with sustainability targets can yield significant benefits [32].

Regarding the economic dimension, several aspects should be considered for long-term sustainable economic growth, such as supply chain management, innovation, quality management, and customer service. C4.0 technologies such as 3D printing can contribute to economic growth by reducing labor, resource, and time costs, thereby enhancing productivity and production flexibility [33]. These technologies can also improve the efficiency of quality control systems through real-time data sharing and monitoring facilitated by big data and the Internet of Things (IoT) [34].

Regarding the ecological dimension, maintaining environmental equilibrium necessitates attention to construction waste management, noise control, energy conservation, and emission control. For instance, C4.0 technologies can lower resource and energy consumption as well as waste output by utilizing autonomous detection and data analysis throughout the entire supply chain and construction production [35]. They can contribute to reduced waste generation and carbon dioxide emissions [36], as well as enable the disassembly of bulk construction components for reuse, recycling, or reproduction.

In terms of the social dimension of sustainability, digital technologies can support human well-being by automating repetitive and monotonous tasks and improving worker safety and health. For example, AI-based real-time human pose and object detection systems can monitor workers' safety behaviors [37]. Additionally, C4.0 technologies can create new job opportunities for BIM drawers and big data analysts. However, these technologies can also bring challenges to society, including information security issues, reduced employment, and concerns about intellectual property rights [38].

Previous studies have concentrated on various areas of sustainability in mainstream enterprises. Very little research has examined the linkages between C4.0 and sustainability as a foundation to further explore the factors determining C4.0TeIm standing from a sustainability starting point. Some studies have examined the sustainability functions of I4.0 and highlighted the importance of human resource development as a foundation for other sustainability functions [39,40]. Others have discussed data-driven industrial symbiosis and circular economy optimization solutions within I4.0 [41]. However, a comprehensive examination of the connections from a sustainability starting point is still limited.

According to legitimacy theory, firms embrace sustainability practices to address stakeholders' concerns and demands, going beyond mere profit maximization and embracing broader environmental and social responsibilities [8,11]. Consequently, the transformation of industrial construction production through C4.0 to achieve corporate sustainability has become a legitimate goal [42]. As suggested by Bai, Dallasega, Orzes and Sarkis [12], I4.0 technologies can align with the United Nations (UN) 17 Sustainable Development Goals (SDGs). Through the utilization of a comparable toolkit, as suggested by Bai, Dallasega, Orzes and Sarkis [12], this study examined and elaborated on the possible links between SDGs and C4.0 technologies. As indicated in Table 1, each of these 17 objectives support construction companies in attaining sustainable development in all TPB dimensions. These include the economic (SDGs 1, 8, 9, 10), environmental (SDGs 6, 7, 11, 12, 13, 14, 15), and social dimensions (SDGs 2, 3, 4, 5, 16).

Table 1. Possible links between SDGs and Construction 4.0.

No.	Goal	Potential Links with C4.0TeIm	Enabling C4.0 Technology Examples
1	1 NO POVERTY	The impoverished people can be kept out of poverty by using construction technology to increase their access to knowledge and prospective economic possibilities, as well as to more basic infrastructure and better-serving buildings. C4.0 technologies also have the ability to lessen unforeseen financial losses after a crisis and strengthen the resilience of infrastructure.	BIM, IoT, robotics, big data
2	2 ZERO HUNGER	C4.0 technology can help create equitable distribution networks and lower living expenses so that the impoverished can afford to buy more food.	IoT, GIS
3	3 GOOD HEALTH AND WELL-BEING	In addition to facilitating the digitalization of construction activities and offering more affordable and high-quality building assets, C4.0 technologies also encourage healthy lives, effective healthcare services, and safer working conditions for the general public, local communities, and construction workers.	BIM, IoT, GIS
4	4 QUALITY EDUCATION	Certain C4.0 technologies, such as VR/AR, can facilitate education by providing students with a three-dimensional (3D) demonstration so they can learn in a virtual setting.	BIM, VR/AR/MR, GIS
5	5 GENDER EQUALITY	Because C4.0 technologies reduce the need for labor, men and women have equal opportunities to thrive at all levels and in all capacities.	Robotics, CPS
6	6 CLEAN WATER AND SANITATION	C4.0 technologies may contribute to the development of sustainable and reasonably priced equipment for accessing clean water and sanitation in buildings.	IoT, CPS
7	7 AFFORDABLE AND CLEAN ENERGY	C4.0 technology would enable sustainable energy to improve energy quality and reduce user expenses.	BIM, IoT, sensors
8	8 DECENT WORK AND ECONOMIC GROWTH	C4.0 technology would both directly and indirectly support economic growth by generating good, satisfying jobs.	BIM, AI, big data
9	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	C4.0 technologies would increase funding for scientific research and innovation to update conventional infrastructure for sustainable building.	BIM, AI, GIS, Robotics
10	10 REDUCED INEQUALITIES	In order to lessen inequality and the gap in digital development both within and across nations or populations, C4.0 technologies may be able to connect the disconnected.	BIM, AI
11	11 SUSTAINABLE CITIES AND COMMUNITIES	Cities and communities that are smart, green, and sustainable would be developed with the aid of C4.0 technologies.	BIM, big data, GIS, remote sensing, GPS

Table 1. *Cont.*

No.	Goal	Potential Links with C4.0TeIm	Enabling C4.0 Technology Examples
12	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	The implementation of C4.0 technology has the potential to enhance cooperation, augment project consumption trends, and augment transparency within construction supply chains.	Cloud computing, CPS
13	13 CLIMATE ACTION	C4.0 technologies have the potential to lower building energy use, which will lower waste and carbon dioxide emissions.	BIM, Sensors, CPS,
14	14 LIFE BELOW WATER	C4.0 technology can help ensure that materials are used more sustainably, especially when it comes to marine resources.	AI, new materials
15	15 LIFE ON LAND	C4.0 can stop land degradation and biodiversity loss by protecting land resources like timber.	AI, new materials, GIS
16	16 PEACE, JUSTICE AND STRONG INSTITUTIONS	C4.0 has the potential to uphold responsible businesses or construction supply chains, foster social justice and peace in communities, and reduce poverty and hunger.	IoT, blockchain
17	17 PARTNERSHIPS FOR THE GOALS	C4.0 has the potential to bring various stakeholders together to accomplish sustainable development objectives.	Blockchain

2.3. Research Gaps

A review of the previous studies indicates that while valuable insights have been provided across various areas addressing C4.0TeIm, it seems C4.0 is still in the infant stage of development in construction. Many scholars pointed out that the current trend of C4.0 is an integration and implementation of various technologies [3,27]. Consequently, top management of construction firms should consider envisioning an integrated C4.0TeIm management package to enhance supply chain efficiency and information exchange [43]. The current implementation of C4.0TeIm within construction firms, when encapsulated in a sustainable business model, requires objective quantitative metrics to holistically cover and prioritize the factors influencing C4.0TeIm. This allows top management to allocate resources and capabilities and deploy strategies accordingly.

However, previous discussions on the influencing factors of firms' C4.0TeIm have been broad and fragmented, lacking a comprehensive philosophical debate using a holistic and integrated approach. Some scholars argued that construction firms' C4.0TeIm is driven by organizational culture and leadership [44], business strategies, and management policies [45], while others stated that the level of awareness and acceptance in the industry [46], standardization [44], governmental initiatives and incentives [47] could influence construction firms' C4.0TeIm. Therefore, it is crucial to demystify the influencing factors of C4.0TeIm from a holistic perspective. By doing so, new studies can build upon existing findings and contribute valuable insights to the current body of knowledge on C4.0 [28,48].

3. Methods

This study followed a multi-step research procedure, drawing upon hybrid SNA and simple analysis methods, similar to techniques employed in previous studies [28,48,49]. The research procedures are illustrated in Figure 1 and encompass the following steps: (i) conducting a systematic literature review on C4.0TeIm the construction sector; (ii) identifying the influencing factors of C4.0TeIm; (iii) performing SNA to evaluate the importance and influence of the identified factors and validating SNA results through simplified analysis method; and (iv) outlining the research gaps and developing a research guideline for the influencing factors that require further investigation. Similar research approaches, employing hybrid SNA and simple analysis methods, have been utilized in previous studies within construction management. For instance, these methods have been applied to (i) analyze key factors affecting collaborative planning in construction and identify research gaps [48], (ii) examine the risk factors of the cost and schedule performance for modular construction and highlight gaps in the literature [28], and (iii) investigate the construction business failure while identifying research gaps for further exploration [49]. The subsequent sections detail the research methods of this study.

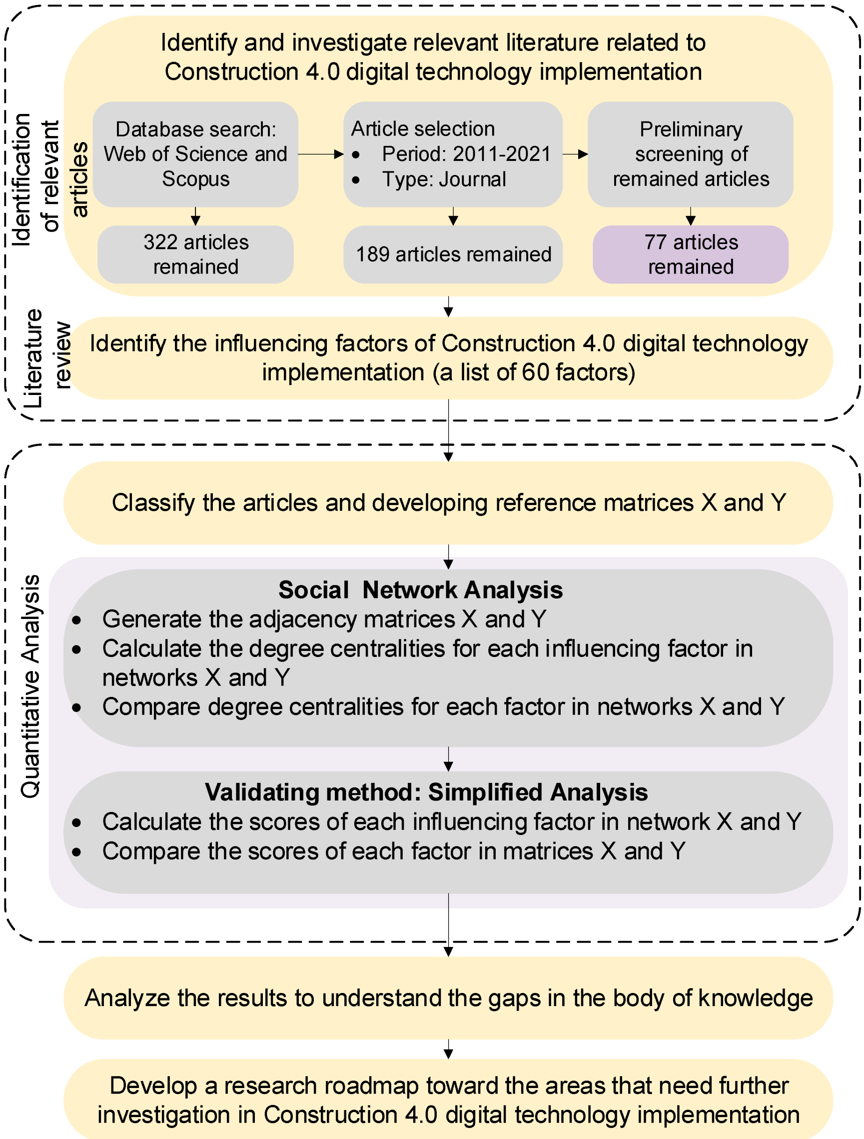


Figure 1. Research procedure of this study. X: theoretical insights of the influencing factors, and Y: developed models, frameworks, and tools incorporating the influencing factors.

3.1. Identification of Relevant Articles and Literature Review

The first step in the research procedure was conducting a literature search. A database search was performed, resulting in 322 articles. These articles were then screened and assessed through a brief review of their titles and abstracts, followed by a full-text assessment. Ultimately, 77 articles were selected for further analysis through a systematic literature review. The exact steps involved in identifying the relevant articles are as follows:

- **Database search (322 articles remained):** Electronic searches were first conducted in two widely accepted search engines—Web of Science and Scopus—to collect the relevant articles in September 2021. These two databases are a good combination of comprehensive and up-to-date publications and can potentially shape research areas [50]. The authors adopted a systematic keyword search approach to retrieve the relevant articles that cover various aspects of C4.0TeIm in the construction industry. The keywords were selected by combining extensive keywords or key terms with appropriate Boolean operators. These keywords include Industry 4.0 (I4.0), Construction 4.0 (C4.0), construction industry, technology, digitalization, Building Information Modeling, 3D printing, augmented reality, virtual reality, mixed reality, artificial intelligence, robotics, big data, blockchain, cloud computing, cyber security, unmanned aerial vehicle, global positioning system, Internet of Things, RFID, unmanned aerial vehicle, LiDAR, 3D Scanner, Modular, prefabrication, Cyber-physical systems, sensors, new materials. These comprehensive keywords were incorporated in the literature search because (i) they are the most frequently used terms in discussions related to C4.0TeIm in previous literature, (ii) they can reflect and encompass the specific technologies applied in C4.0, namely C4.0TeIm, and (iii) the target of the search was to include as much as possible relevant literature on the topic of C4.0TeIm. For instance, synonyms for C4.0 include I4.0, construction industry, technology, and digitalization. The other keywords included in the Boolean operators were selected based on the identified technologies in Table S1 of this study. Similarly, previous studies used systematic keyword search approaches to gather valuable knowledge and guidelines through literature reviews (e.g., [25,35]). Of these, "Title, Abstract, Keywords" were used for search, and "article or early access or review" were filtered as the document types. This initial electronic returned 322 articles;
- **Selection criteria (189 articles remained):** Given that the term "I4.0" was proposed in 2011, the study period was selected between "2011–2021 (by September)". The number of articles was lowered to 248 by this approach. To assure the credibility and reliability of the inquiry, only journal publications were included. Since conference papers and thesis dissertations typically result in peer-reviewed journal publications, they were not included. As a result, 189 articles remained. All retrieved articles were then recorded in the bibliography management software Endnote X9 for further examination;
- **Screening articles (77 articles remained):** The authors performed a preliminary screening in which they quickly skimmed over the titles and abstracts of the retrieved articles and made an initial determination regarding their appropriateness for further analysis. After removing duplications and screening out irrelevant articles, 135 articles remained. A further full-article assessment by reading the entire contents of the remaining results 77 articles for further investigation. The selected articles either qualitatively discussed the C4.0TeIm or focused on establishing applicational models, frameworks, and decision-making tools.

After identifying relevant articles, the authors categorized and analyzed the 77 articles into three types based on similar previous studies [28,48,49]. The categorization of articles is as follows:

- **Type A:** These types of papers primarily offered theoretical insights or discussions into certain influencing factors of C4.0TeIm but did not create practical models, frameworks, or decision-making tools. The term "theoretical discussion" refers to the article's theoretical mention or theoretical explanation of the factors that could influence construction firms' C4.0TeIm. These types of articles were correspondingly included in matrix X. Merschbrock and Munkvold's study [51], for example, is classified as type A since it discussed effective digital collaboration using a case study of the BIM deployment in a hospital building project;

- **Type B:** Compared to other categories of articles, Type B articles mainly concentrated on creating useful frameworks, models, or decision-making tools based on mathematical or computational algebra (referred to as "models" hereinafter). They also offered very little, if any, direct theoretical discussions or insight into the factors influencing construction firms' C4.0TeIm. It is noted that although these types of articles provided very little theoretical discussions on the influencing factors of C4.0TeIm, they practically developed actual models, frameworks, or decision-making tools (e.g., related to technology competence such as design flexibility, cost evaluation, energy efficiency, and mass customization) based on mathematical/computational algorism. In this study, these types of articles were included in matrix Y. For instance, the study of Lee, et al. [52] is classified as type B since it established a behavior-based safety checking model and used BIM to enable visual tracking of important parameters and dynamic analysis of construction safety risks;
- **Type C:** These kinds of articles developed frameworks, models, or instruments for making decisions as well as theoretical discussions. These articles were recorded in both matrices X and Y. For instance, You and Feng's study [53] was classified as type C because it investigated how to integrate C4.0 digital technologies, including big data, cloud computing, IoTs, and BIM, and created a cyber-physical system framework to enhance construction management's overall capabilities.

3.2. Quantitative Analysis of the Influencing Factors

This step involves identifying and quantifying the influence of the various factors of C4.0TeIm. First, the author developed two reference matrices, namely X and Y, and X includes article types A and C, while Y includes article types B and C. The identified factors are indicated by the row in both matrices, and the articles are indicated by the column. An article was assigned a 1 if it discussed the relevant factor; otherwise, it was assigned a 0. Figure S1 of the supplemental materials attached shows an example of a demonstration reference matrix. In this, factors Fi, $Fi + 2$, to Fn are mentioned in Article j. As such, the ith, $i + 2$nd and nth rows of the jth column were given a value of 1, while the other cells were given a value of 0. As mentioned above, reference matrix X represents the theoretical discussions on C4.0TeIm and the associated influencing factors, while matrix Y reflects academic understandings of the state of research on the developed models for C4.0TeIm. These reference matrices reflect the co-occurrence of the factors in matrices X and Y. By comparing two reference matrices that were produced, it is possible to reveal the knowledge gaps in the current body of knowledge. The understudied areas that need to be the focus of future research efforts can also be easily identified. Similar research methods can be found in previous studies (e.g., [35,48]) that provided research guidelines and advanced knowledge in the studied field by reviewing literature and identifying further research directions via calculating the frequency (number) of certain factors in the literature. Afterward, the authors used SNA to quantify the influence of identified factors. To validate the results, a simplified analysis was performed then.

3.2.1. Justifications for Utilizing Social Network Analysis

SNA—associated with the works by Moreno [54]—is a valuable tool for examining social networks and structures using graph theory. It allows scholars to study and characterize the connections and structures formed by nodes (vertices) and edges (links) in a network. These edges represent the interconnectivity between nodes, providing insights into the relationships between them [55]. SNA's ability to visualize complex relationships has made it popular in studying "social issues" [56], as well as "non-social issues" in fields like construction, engineering, and project management [7]. In recent studies, the application of SNA has extended beyond "social factors." For instance, SNA was used by Liu, Ji, AbouRizk and Siu [55] to investigate the movement of equipment between equipment shops and project sites. Hansen, et al. [57] utilized SNA to examine the linkages between property prices and locations. More recently, Zhang, Oo and Lim [7] utilized SNA to analyze the nexus between corporate social responsibility and the organizational performance of construction firms. Overall, SNA provides a powerful approach to understanding complex networks and has been widely employed in various research domains, including those beyond social contexts.

The study used SNA to examine the influencing aspects of C4.0TeIm due to the numerous indispensable advantages it provides. First, factor-based quantitative data analysis is made possible by SNA, which combines the benefits of statistical analysis with mathematics matrix-based approaches [58]. Second, SNA allows for the characterization of network structures formed by nodes (factors) and the edges (links) that connect them, providing insights into the relationships and interactions between factors [55]. Thirdly, SNA facilitates the comparison of the relative influence and importance of different factors, allowing for a better understanding of their significance [59]. Unlike previous approaches in the construction and engineering fields that rely on qualitative measures to identify factors in the literature, SNA provides a quantitative measure to evaluate and compare the different studied factors and their relative importance and impact, which helps identify knowledge gaps [60]. For instance, Abdul Nabi and El-adaway [35] used SNA to identify factors affecting decision-making in modular projects, modeling the identified factors as nodes in the developed networks and examining their importance and impact to propose research gaps and future research directions. In a similar vein, Elsayegh and El-adaway [48] used SNA to measure the importance and influence of the factors affecting collaborative planning in construction. Overall, SNA offers unique advantages in analyzing influencing factors by providing a quantitative perspective, capturing network structures, comparing relative importance, and identifying knowledge gaps, making it a valuable approach in this study.

As suggested by Freeman [61], degree centrality (DC) is one of the measures and major characteristics of SNA. It can be used to determine which nodes (factors) in the network have the greatest number of connections to other nodes. Scholars can determine factors that significantly impact the developed network by analyzing DC. Co-occurrence network description is another important characteristic of SNA. It can be used to analyze relationships between nodes (factors) in a developed network [59]. To this end, many studies examine correlations between research themes and map the knowledge structure and evolution patterns within a network [35,48]. The application of SNA in "non-social" areas, such as construction and engineering, has proven to be valuable in acquiring knowledge content. Co-occurrence analysis and SNA techniques provide insights into the correlations and interconnections between different research themes, facilitating a better understanding of the knowledge landscape. The suitability of SNA for assisting meta-analysis in literature review has been well justified in previous studies [48,62], highlighting its conceptual appropriateness and usefulness in uncovering the underlying relationships and patterns within research networks.

3.2.2. Performing Social Network Analysis

When determining the level of influence that each node in the network has, one of the commonly used metrics in SNA is the degree of centrality (DC) [61]. A node with the highest DC indicates that it has the most significant number of connections with other nodes and has the greatest influence on the network. In this study, we calculated DC for the two developed reference matrices. In particular, the DC determined for matrix X indicates the significance of a factor in terms of its frequency and co-occurrence with factors in theoretical discussions. Similarly, in the developed models concerning C4.0TeIm, the DC of matrix Y indicates the significance of a factor with respect to its frequency and co-occurrence with other factors. We formed two factor–factor matrices (for X and Y) by multiplying a reference matrix by its transpose and substituting zeros for the diagonal cells before computing DC. A sample of the creation of a factor–factor matrix can be found in the supplementary materials in Figure S2. Next, we used Equation (1) to obtain the DC for every factor in two factor–factor matrices.

$$DC_i = \sum_{k=1}^{g} V_{i,k}(i \neq k) \quad (1)$$

where DC_i indicates the degree centrality for factor i. $V_{i.k}$ indicates the value in the ith row and the kth column of the studied factor–factor matrix. The g represents the last value of k, which should be 60 in this study. In particular, DC is calculated by adding up all of the edges in every network that is connected to this node. To ensure consistency of scores between the two networks, a normalized DC for factor i was calculated by using Equation (2), given that they have different numbers of articles. As such, the values of the normalized DC for any factor i should be in the range of 0 to 1.

$$Normalized\ DC_i = \frac{DC_i}{Maximum\ DC_i\ in\ the\ network} \quad (2)$$

3.2.3. Validating the Results: Simplified Analysis

The authors then used a simplified analysis to confirm the SNA results. All the corresponding cells in the row can be added to determine the score for each factor i using Equation (3). For instance, a score of 6 for factor F16 in matrix X suggests that F16 appeared six times in the studied articles in matrix X, and scholars suggest it to be a factor affecting C4.0TeIm. Comparably, an F16 factor score of 1 in matrix Y indicates that it was included in the models that were generated for the particular article and referenced once in the matrix Y articles that were investigated. Like normalized DC, Equation (4) is used to calculate the normalized score as follows:

$$Score_i = \sum_{x=1}^{f} W_{i,j} \quad (3)$$

$$Normalized\ Score_i = \frac{Score_i}{Maximum\ Score_i\ in\ the\ matrix} \quad (4)$$

whereby $W_{i,j}$ indicates the value for factor i (0 or 1) in article j, while $Score_i$ stands for the number of frequencies specified for factor i in the same reference matrix. The last value of j, which in this instance should be 77, is represented by the letter f. Thus, the normalized score ranges from 0 to 1.

Overall, combining SNA and simplified analysis supplies a robust approach to understanding the interplay of factors influencing C4.0TeIm. It enables scholars to gain valuable insights into the relationships and relative importance of these factors, facilitating the development of effective strategies and interventions to promote the successful implementation of C4.0 technologies in the construction industry.

4. Results and Discussion

A brief description analysis was first conducted to have an overview of the retrieved 77 articles. Figure 2 illustrates the annual number of the selected articles. The results show that the relevant research on C4.0TeIm began around 2005 and amounted to only two articles. This may be partly because the discourses of C4.0 are still relatively new compared with the concept of I4.0 in other high-tech industries. The number of articles hovered between 2 and 29 from 2005 to 2021. It is noted that there are only 18 articles in 2021 because the search was executed in September 2021. Over a seven-year period (2015–2021), an average of 11 articles (median of 7 articles) were published annually, and the number of articles has sharply increased since 2019. This increment implies an increasing research interest in C4.0TeIm in recent years. Table S2 in the supplemental materials presents the distribution of included journal articles. The results indicate that the distribution of the analyzed articles was decentralized. Tables S3 and S4 in the supplemental materials summarize the countries or regions included in C4.0TeIm studies, given the likelihood of social, economic, political, and cultural variances in different countries or regions. The studied articles covered 19 countries or regions, with most articles for general use without any specific countries or regions, and 11 articles addressed multi-country issues (e.g., US, UK, and South; UK, China, and the US).

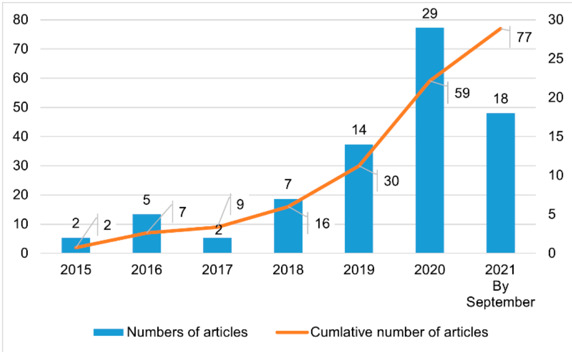


Figure 2. Number of relevant articles published yearly.

4.1. Factors That Influence Construction 4.0 Technology Implementation

The total identified 60 influencing factors of C4.0TeIm are shown in Figure 3. The full list of factors with detailed descriptions is provided in Table S5 of the attached supplemental materials. Acknowledging that some inevitable overlaps may exist between factors, the identified factors were generally grouped into five broad categories based on the attributes of factors under each category; they are external environment, organizational factors, technology challenges, technology competence, and project-based factors. Some of the identified factors constitute multiple areas, e.g., F1, which incorporates all aspects related to the level of awareness, acceptance, market knowledge, and willingness or reluctance to adopt digital technologies. Figure 4 illustrates the identified influencing factors and their references, with the *x*-axis indicating 77 articles and the *y*-axis representing 60 factors.

In Figure 4, a light-red cell indicates that the corresponding publication provided theoretical discussions on the relevant factors. The yellow cell indicates that the corresponding publication heavily focused on developing models, frameworks, or decision-making tools. A red cell represents that the corresponding publication provided both theoretical insights and developed models, frameworks, or decision-making tools related to the factors in question.

4.2. Categorization of Analyzed Articles and Development of Reference Matrices

Once the influencing factors had been identified, two reference matrices, X and Y, were then established. Table S6 in the supplemental materials presents different article types and their corresponding reference matrices. Ultimately, Type A contains 57 (74.03%) articles, Type B contains 10 (13.0%) articles, and Type C includes 10 (13.0%) articles. As such, matrix X consists of 67 articles, encompassing both type A and type C articles. It has dimensions of 60 by 67, representing 60 factors and 67 articles. Equally, matrix Y comprises 20 articles, comprising types B and C articles. It has dimensions of 60 by 20. The distribution of the articles across the three types suggests that there is a greater emphasis on theoretical discussions rather than the development of models for the influencing factors of C4.0TeIm. This finding suggests that in order to support and expedite C4.0TeIm in the construction sector, additional models, frameworks, and tools for decision-making are required.

External environment	
F1	Level of awareness, acceptance, and applications in the industry
F2	Level of standardization
F3	Market demand
F4	Fragmentation of the construction industry
F5	Appropriate legislation
F6	Shared knowledge and training schemes in the industry
F7	Governmental initiatives or incentives
F8	Persuasion and inspiration
F9	Advanced technology development in the industry
F10	Pressure to innovate

Organizational factors	
F18	Availability of capabilities
F19	Availability of resources
F20	Awareness and willingness within organizations
F21	Organizational culture
F22	Corporate strategy and management policy
F23	Organizational business modal adaptation
F24	Unclear benefits, gains, and business value
F25	Consulting

Technology challenges	
F52	Immaturity of the technologies
F53	Data-related issues
F54	Uncertainty about the cost-efficiency
F55	Security of intellectual property and rights
F56	Uncertainty about the time efficiency
F57	Lack of practical validation
F58	Energy consumption
F59	Lack of better-performing devices
F60	Difficulty in explaining the output of the new technology to the client

Project-related factors	
F11	Project size, complexity, site nature, scope, delivery method
F12	Lack of legal framework and contract uncertainties
F13	Effective communication among project stakeholders
F14	Clear contractual provisions
F15	Level of stakeholder collaboration and coordination
F16	Lack of commitment from clients
F17	Health and safety risks in the workplace

Technology competence	
F26	Integration and interoperability
F27	Quality, safety, health, and risk management
F28	Cost-saving
F29	Time-saving
F30	Improved project efficiency and productivity
F31	Simulation and visualization for better decision-making
F32	Design flexibility
F33	Resource and waste optimization
F34	Improved automation and information-sharing level
F35	Energy efficiency
F36	Increased accuracy and reduced errors
F37	Improved facility management and service
F38	Mass customization
F39	Perceived overall organizational performance improvement
F40	Project planning optimization
F41	Improved information retrieval process
F42	Increased competitive advantage
F43	Synchronization of procurement and improved supply chain management
F44	Reduced labor
F45	Shared value or value chain
F46	Improved estimation method
F47	Better project delivery
F48	Easy to use
F49	Reduced claims or litigation (risks)
F50	Optimum performance of manufacturing
F51	Supporting education and training

Figure 3. Factors that influence Construction 4.0 Technology Implementation.

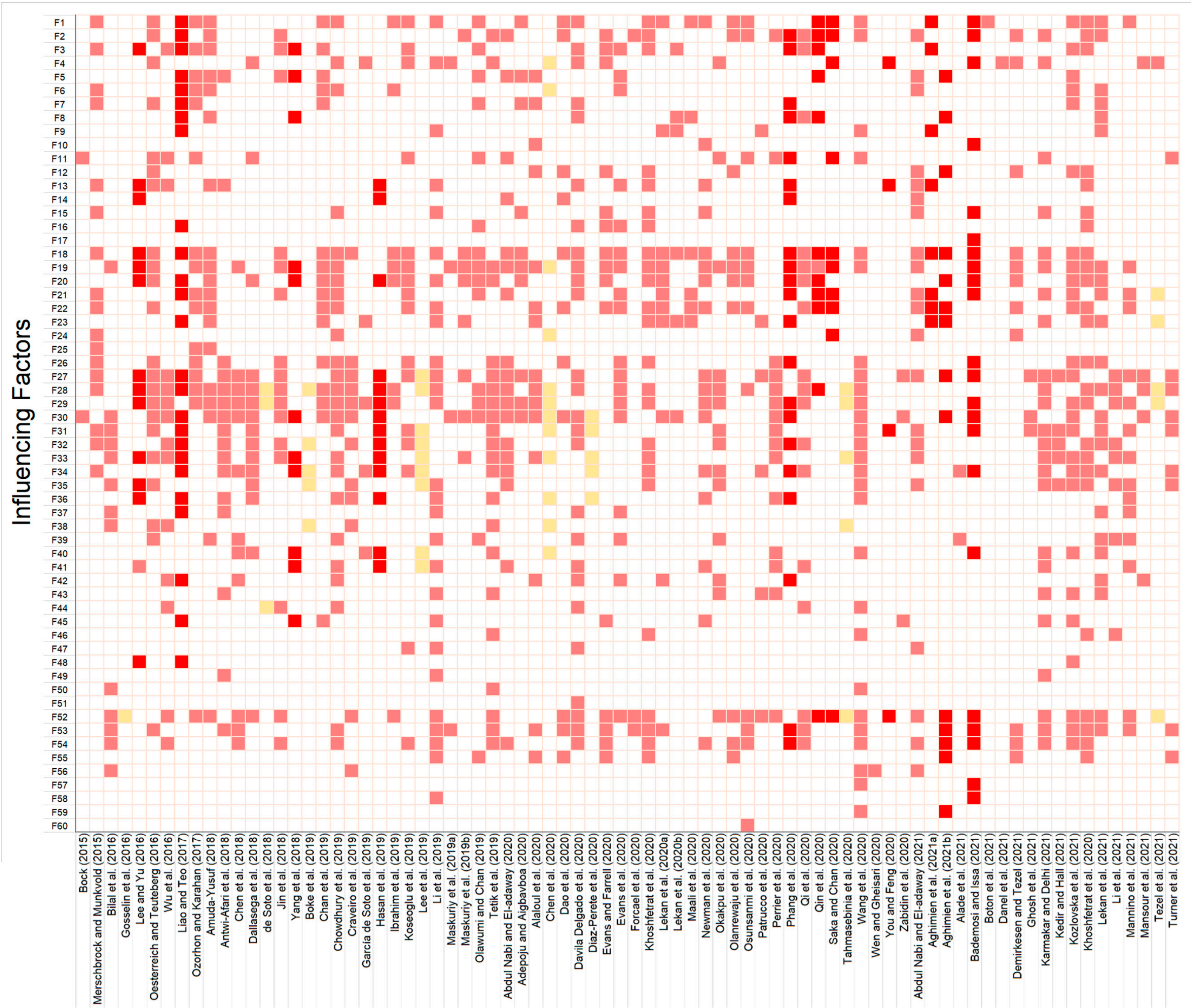


Figure 4. Factor–Reference map [3–5,13,16–21,23,25–28,34–36,38,44–47,51–53,63–108].

4.3. Quantitative Analysis of the Reviewed Articles

4.3.1. Social Network Analysis

The normalized scores for DC for the factors in matrices X and Y are illustrated in Figure 5. Notably, only F7 (Governmental initiatives or incentives), F16 (Lack of commitment from clients), and F4 (Fragmentation of the construction industry) have approximately similar normalized DC values between matrices X and Y. This indicated that factors F7, F16, and F4 were equally emphasized in the theoretical discussions and included in the developed models in the literature. For instance, Bock [63] stressed the significance of government policies and incentives in promoting the adoption of digital technology in the building industry. The need for governing bodies and authorities to offer financial programs to assist small and medium-sized businesses (SMEs) in implementing digital technology was emphasized. Similarly, government support—such as financing for software, training, and consulting—was recognized in the conceptual framework created by Liao and Teo [64] as a crucial success factor for enhancing the adoption of BIM-centralized digital technology in the construction industry.

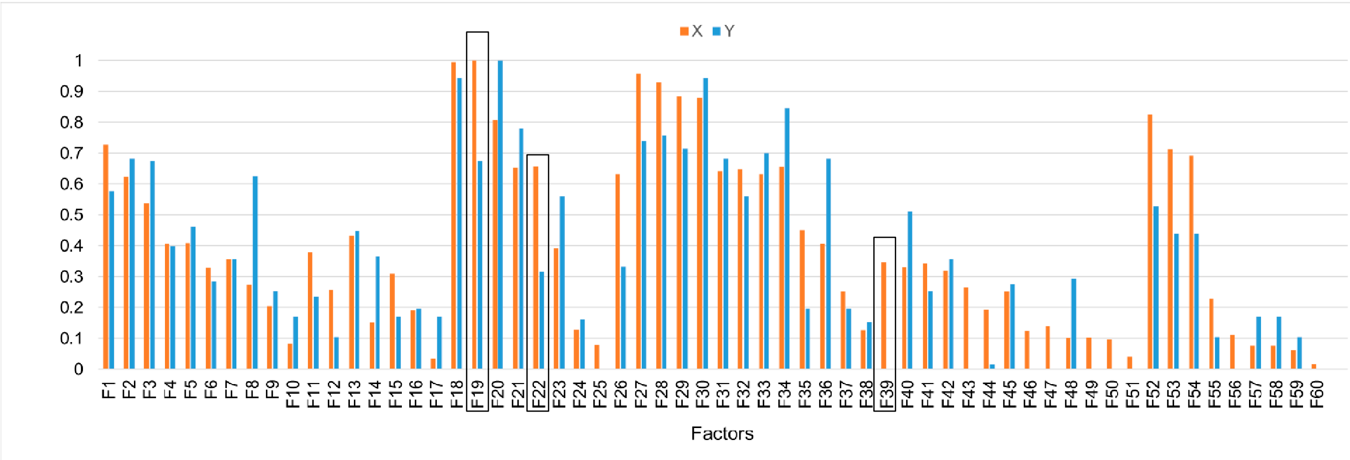


Figure 5. Normalized degree centrality scores for matrices X and Y using SNA.

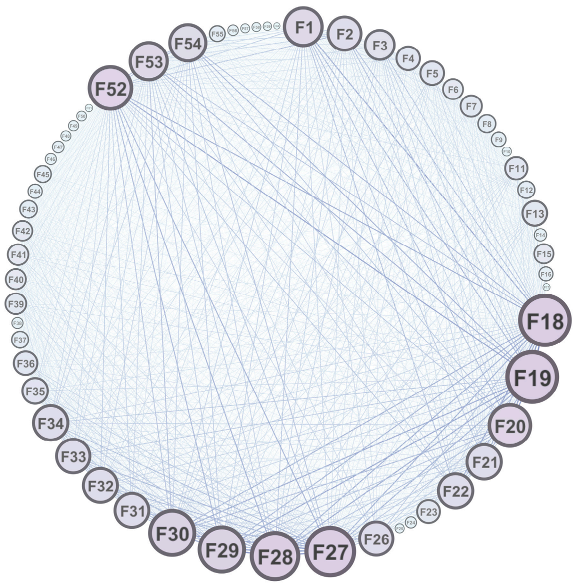
The gaps in the literature between the established models in matrix Y and the theoretical discussions in matrix X are depicted in Figure 5. Rectangles in Figure 5 highlight the top three largest common literature gaps; they are F39 (Perceived overall organizational performance improvement), F22 (Corporate strategy and management policy), and F19 (Availability of resources). The identification of these gaps suggests that these factors have received limited attention in terms of being included in developed models and frameworks despite being discussed theoretically in the literature. This indicates future research directions and the development of models that explore the impact of these factors on achieving C4.0TeIm. For example, factor F39 (Perceived overall organizational performance improvement) refers to the perceived improvement in the overall performance of an organization resulting from implementing C4.0 technologies. Although this factor has been discussed theoretically, a literature gap exists regarding its inclusion in developed models. Further investigation and modeling of the relationship between C4.0TeIm and overall organizational performance improvement can contribute to filling this gap. Similarly, factors F22 (Corporate strategy and management policy) and F19 (Availability of resources) have been identified as understudied factors concerning their theoretical discussions. Future research can focus on developing models and frameworks that explore the role of corporate strategy, management policies, and resource availability in successfully implementing C4.0 technologies in the construction industry. Scholars may enhance their comprehension of the impact and influence of these factors on C4.0TeIm and facilitate the creation of more comprehensive models and frameworks in the field by tackling these gaps in the literature.

Notably, F44 has the lowest normalized scores for matrix Y in SNA, suggesting the lack of development of models incorporating this factor. This suggests a research gap in exploring the impact and implications of reduced labor in the context of C4.0TeIm. Future studies can focus on developing models and frameworks that consider the influence of reduced labor on C4.0TeIm in the construction industry. In contrast, F8 (Persuasion and inspiration), F36 (Increased accuracy and reduced errors), and F14 (Clear contractual provisions) have been incorporated or heavily emphasized in existing models, as indicated by their higher normalized DC scores in matrix Y. This implies that these factors have received considerable attention in the development of models and frameworks related to C4.0TeIm. However, despite their importance—as indicated by their normalized scores in matrix X—a number of factors have not been incorporated into existing models. These factors include F25 (Consulting), F39 (Perceived overall organizational performance improvement), F43 (Synchronization of procurement and improved supply chain management), F46 (Improved estimation method), F47 (Better project delivery), F49 (Reduced claims or litigation (risks)), F50 (Optimum performance of manufacturing), F51 (Supporting education and training), F56 (Uncertainty about the time efficiency), and F60 (Difficulty in explaining the output of the new technology to the client). The absence of these factors in existing models suggests a research gap and highlights the need for further investigation and the development of models that incorporate these factors.

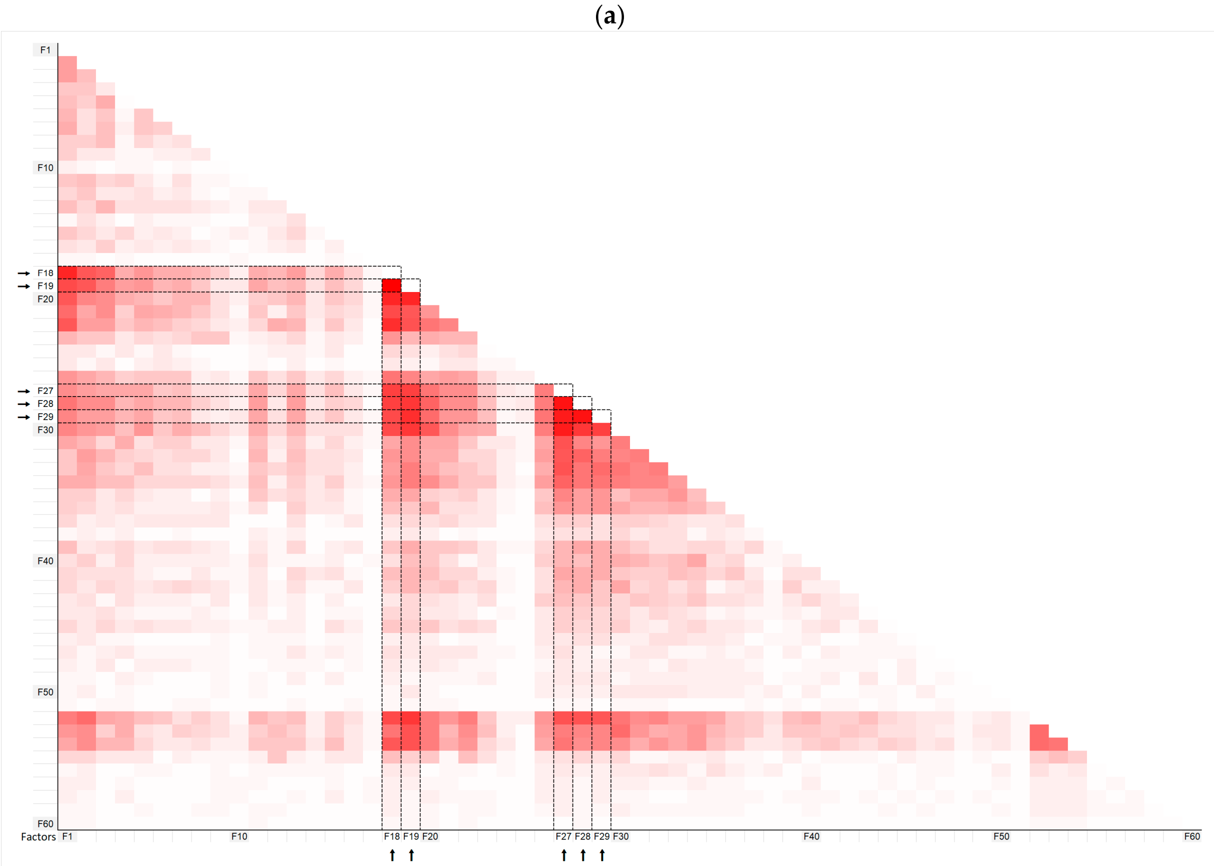
Figures 6 and 7 illustrate normalized DC values of each factor in networks X and Y. The size of each node in the network diagrams, namely Figures 6a and 7a, indicates the magnitude of the respective factor's normalized DC. Notably, the influencing factors of C4.0TeIm are represented by the rows and columns of the triangular color-coded matrices in Figures 6b and 7b. Each cell's red color represents the degree of connection between any two factors; the darker red color shows stronger connections between any two pairs of factors. Figure 6a,b reveals that the top five factors with relatively high normalized DC values in network X are F19 (Availability of resources), F18 (Availability of capabilities), F27 (Quality, safety, health, and risk management), F28 (Cost saving), and F29 (Time saving). These factors have been highlighted as key influencing factors in the theoretical discussions and are supported by a significant number of connections with other factors in the developed network. On the other hand, Figure 7a,b shows the top five factors in network Y, where the factors with higher normalized DC values are F20 (Awareness and willingness within organizations), F18 (Availability of capabilities), F30 (Improved project efficiency and productivity), F34 (Improved automation and information sharing level), and F21 (Organizational culture). In both theoretical discussions and developed models, F18 (Availability of capabilities), similar to network X, stands out as a factor with significant importance and impact. F18 appears frequently in both networks and has high normalized DC values, indicating that it plays a crucial part in the context of C4.0TeIm. The factor has been thoroughly discussed theoretically and included in developed models, demonstrating its importance and applicability in influencing how C4.0 technologies are implemented in the construction sector.

With a high co-occurrence rate, these top-ranked factors in network X indicate that they are mentioned in theoretical discussions and co-mentioned with other factors. Similarly, the top-ranked factors in network Y indicate that extensive effort has been put forward on these factors through developed models and being modeled with other factors with a high co-occurrence rate. In addition, the density of the color-coded matrix X is higher than that of matrix Y, suggesting that theoretical discussions usually provide insights into a diverse range of factors collectively influencing C4.0TeImDeveloped models, on the other hand, typically concentrate on a smaller set of factors to analyze their respective impacts and relationships. Scholars can obtain a more thorough grasp of the factors influencing C4.0TeIm and identify areas where additional study and model development are required to close the gap between theory and practice by considering both theoretical discussions and the developed models.

Figure 8 provides valuable insights into the literature gaps by highlighting the differences in normalized DC values between the two reference matrices, X and Y. Positive values indicate factors for which there is a larger gap in terms of developed models compared to theoretical discussions, while negative values indicate factors for which there is an excess of developed models compared to theoretical discussions. As shown in Figure 8, the top five factors with positive values are F39 (Perceived overall organizational performance improvement), F22 (Corporate strategy and management policy), F19 (Availability of resources), F26 (Integration and interoperability), and F52 (Immaturity of the technologies). This indicates a gap between the theoretical understanding of these factors and the development of models that incorporate them. Scholars can concentrate on creating models and frameworks that address these factors by identifying these gaps in the literature. In the context of C4.0TeIm, this will help bridge the gap between theoretical discussions and practical applications.

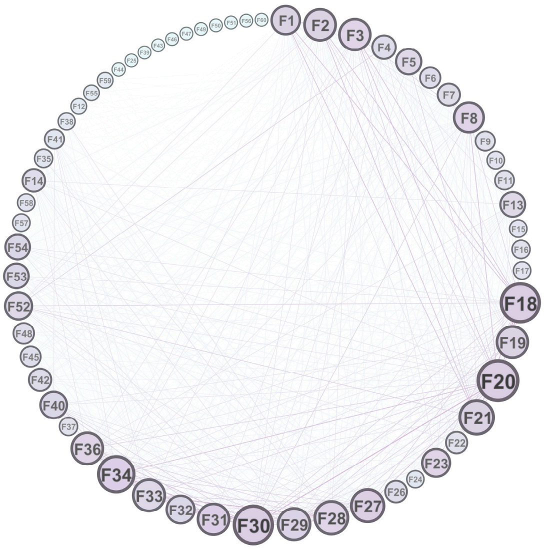


(**a**)

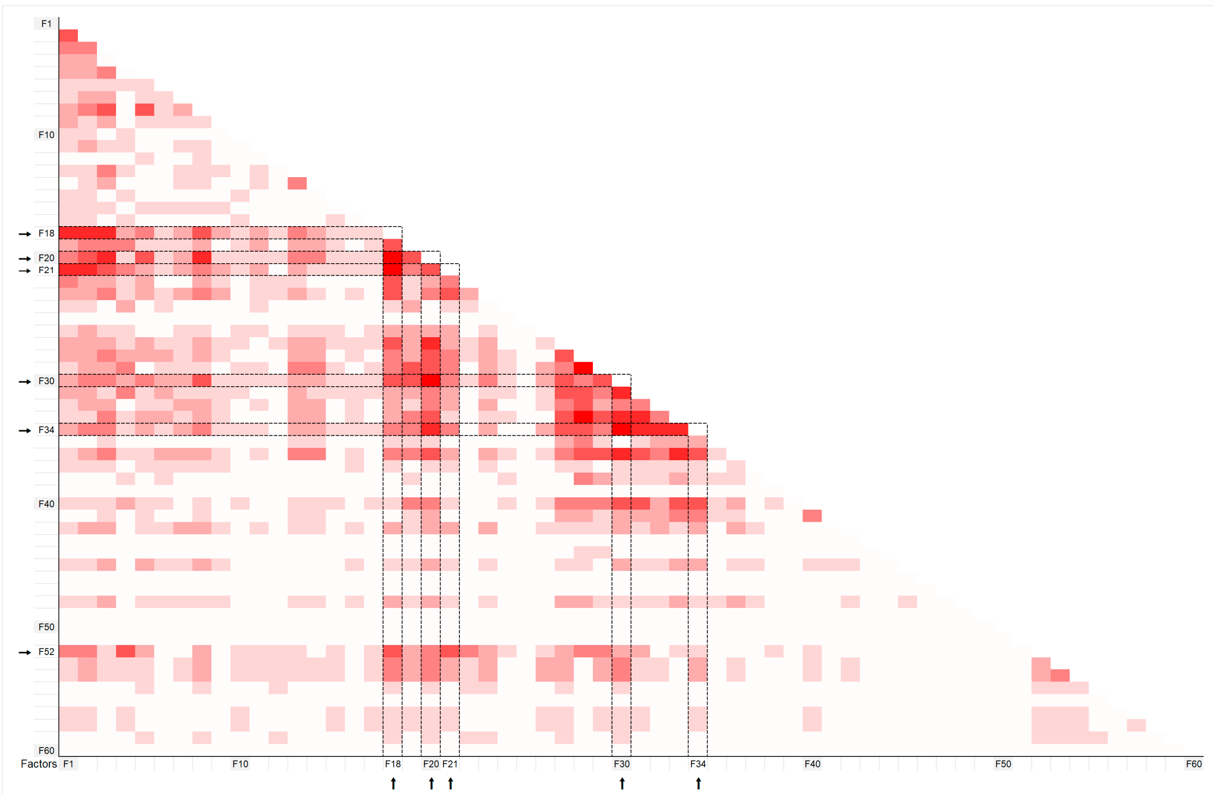


(**b**)

Figure 6. Results of SNA for network X. (**a**) Network diagram (network X). (*Node size denotes the normalized degree centrality*). (**b**) Color-coded matrix X. (*Darkness of color indicates the link strength between each two factors*).



(**a**)



(**b**)

Figure 7. Results of SNA for network Y. (**a**) Network diagram (network Y). (*Node size denotes the normalized degree centrality*). (**b**) Color-coded matrix Y. (*Darkness of color indicates the link strength between each two factors*).

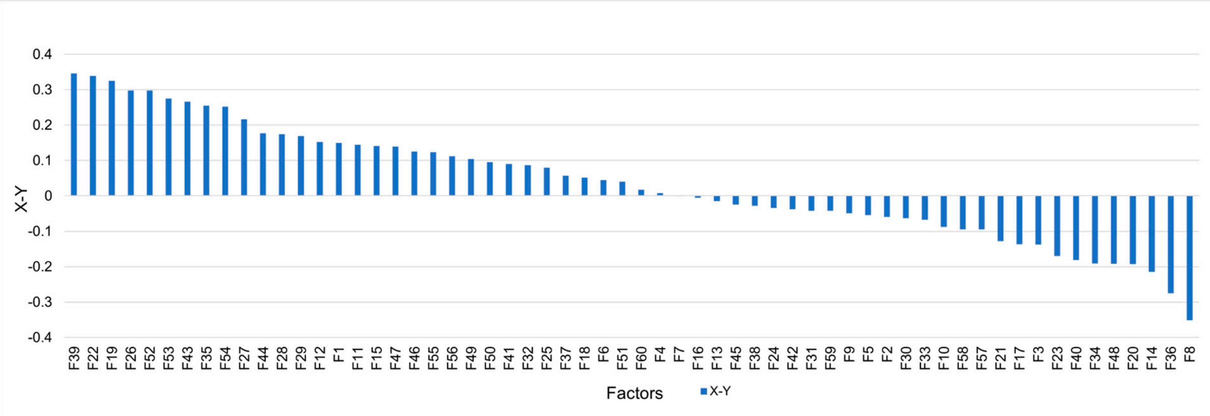


Figure 8. Results of the comparison of the normalized DC values of X and Y matrices.

4.3.2. Validation of Social Network Analysis via Simplified Analysis

As stated in Section 3.2.3, this study employed simple analysis to compare the normalized scores that were derived from two focused matrices with the normalized DC values of the 60 influencing factors that were identified. The discrepancies between the normalized scores in SNA and simplified analysis, or X-Y, are shown in Table S7 in the supplemental materials.

The results indicate that the normalized scores obtained from the simplified analysis are generally close to the results obtained through SNA, with minor differences detected. Indeed, these relatively slight differences can be partially explained by the fact that the advanced measure used in SNA emphasizes the interconnections of diverse factors, while the simplified analysis primarily emphasizes the simple frequency of co-occurrence of factors in factor-factor matrices. Due to these inherent characteristics of the two analyzed methods, these minor differences are deemed within an acceptable range, and the results from SNA can be fairly verified. Building on these results, the authors aim to propose future research guidelines by providing an in-depth interpretation of the interrelated relationships among the identified 60 factors.

5. Research Guidelines and Roadmap

A valuable set of research suggestions and recommendations that highlight potential future study avenues and expand our understanding of C4.0TeIm can be developed based on the findings of this study. The proposed research roadmaps are summarized below. Scholars can use these guidelines as a reference to guide their future investigations, while construction firms and practitioners can use them as a point of reference to gain a better understanding of the industry's development trends.

- Existing models covered, examined, and emphasized certain influencing factors while neglecting some other essential factors, despite the literature analysis highlighting the importance of consisting of a wide spectrum of factors and their interconnections. This phenomenon is illustrated in Figure 5, where the darkness of the matrix's color and the number of links suggest that network X is denser than network Y. This finding supports the importance of the current study by highlighting the fact that previous research focused on a subset of C4.0TeIm factors and ignored others, including F39 (Perceived overall organizational performance improvement), F22 (Corporate strategy and management policy), and F19 (Availability of resources), all of which have been the subject of in-depth theoretical discussion. For instance, Alade, Windapo and Wachira-Towey [34] argued that corporate strategic collaboration plans with industrial experts and academia regarding C4.0TeIm might potentially boost their organizational performance. In supporting this, Davila Delgado, Oyedele, Beach and Demian [65] mentioned that AR and VR technology applications reflect the desire of construction firms to strive for success in the severe market. Applying AR and VR can improve work culture and increase overall organizational performance. This positive perception can further motivate firms to adopt emerging digital technologies actively;

- Given the notable gaps observed between matrix X and Y in Figure 5, it is recommended that scholars expand their future research efforts in exploring the effects of F39, F22, and F19 toward attaining C4.0TeIm. Of these, F39 refers to the perceived overall organizational performance improvement, e.g., the organization's work culture, new and better services, organization efficiency, and productivity when applying C4.0 digital technologies. F22 refers to the strategic decision from top management, top organizational management support, and strategic plan for using C4.0 digital technologies. F19 refers to the availability of technical support from software vendors, equipment specification, time and effort, trainers and training materials, hardware infrastructure, financial resources, information and technology infrastructure, and power supply. Numerous research has addressed the importance and influence of these factors on C4.0TeIm in construction firms (e.g., [66–68]), but many fail to address, evaluate, or validate these factors in developed models or frameworks. Consequently, knowledge gaps still exist regarding the understanding and integration of these critical influencing factors in the context of C4.0TeIm;
- Scholars are also recommended to enhance their future works in the following factors: F25, F46, F47, F49, F50, F51, F56, and F60. As depicted in Figure 5, these factors were relatively less frequently mentioned in theoretical discussions and developed models. Of these, F25 refers to receiving consultancy services from other firms and universities. F46, F47, F49, and F50 refer to the potential benefits of C4.0TeIm, including improved project estimation method, better project delivery, reduced potential claims or litigation (risks), and optimum manufacturing. However, few existing studies that theoretically mentioned these factors shared that these factors might ultimately influence a firm's adoption of C4.0 digital technologies (e.g., [47,67]). Given that these factors in future theoretical discussions or developed models may facilitate C4.0TeIm in the construction industry, further efforts are needed to address these issues. It is worth noting that practical prediction models or tools can be crucial in improving decision-maker awareness and ensuring successful outcomes when implementing relevant technologies. Therefore, additional research is needed to explore and incorporate these factors into studying C4.0TeIm in construction;
- It is recommended that scholars use a holistic approach to incorporate all factors into prediction models in future studies. This careful consideration of factors is crucial for better understanding their practical effects on the implementation of C4.0 technologies in construction firms. To close this gap, future research efforts could concentrate on creating useful models, frameworks, or instruments that concurrently integrate these 60 influencing aspects linked to C4.0TeIm. By integrating these factors into an integrated analysis framework, scholars can improve the overall efficacy of C4.0 implementation and integration. By taking a comprehensive approach to studying these factors' interrelationships and impacts, scholars can potentially provide valuable insights into the complex nature of C4.0TeIm and offer practical solutions for construction firms seeking to adopt and leverage digital technologies effectively.

6. Conclusions and Recommendations

This study reviewed 77 papers related to construction firms' C4.0TeIm from a sustainability starting point and provided future research guidelines in sight of holistically modeling the influencing factors of C4.0TeIm. The authors (i) carried out a meta-analysis of existing studies, (ii) discerned and defined five groups of factors that influence the C4.0TeIm, including external environment, technology competence, organizational factors, project-related factors, and technology challenges, and (iii) performed SNA to quantify the influence and importance of factors. The applicability of applying the SNA approach has been confirmed by the small variation in the normalized score of each factor between the findings of the standard simplified analysis and SNA.

The findings show that 60 factors may collectively influence C4.0TeIm in construction firms, as indicated by the developed factor networks. The results emphasize the strengths and gaps in current knowledge and offer a roadmap to the understudied influencing factors of C4.0TeIm that need to be further examined, such as the perceived overall organizational performance improvement, corporate strategy and management policy, and availability of resources. Although previous investigations offered theoretical insights into these factors, only a few studies have integrated these factors into comprehensive models, frameworks, and tools and have further investigated the collective influence of these factors on construction firms' C4.0TeIm. As such, more attention should be paid to investigating the aforementioned factors influencing construction firms' C4.0TeIm dynamics. Another important finding from this study is the lack of integrated models and frameworks that incorporate all the identified factors influencing C4.0TeIm in construction firms. This emphasizes the need for more study to create robust frameworks, models, or tools for decision-making that effectively support C4.0TeIm and reflect the complexity of the business world. This study lays the groundwork for a more comprehensive framework for advancing C4.0TeIm in the construction sector.

This study offers research guidelines and recommendations to assist the construction industry's holistic management of intricate digitalization transitions. The results of this study make substantial contributions to the current body of knowledge of C4.0TeIm in the construction sector and offer important management implications. First, by evaluating the existing literature and holistically identifying the factors influencing C4.0TeIm, this study's results combine previous studies' findings, using them as a solid foundation for knowledge development on C4.0TeIm in construction. Second, the proposed research guidelines and recommendations based on the review results capture the overall picture of the current research landscape and highlight areas where additional studies are needed. This helps scholars understand the current research focus and guides them toward targeted areas for future studies on C4.0TeIm. Third, this study lays the groundwork for a more comprehensive and holistic framework that enables construction firms to leverage C4.0 digital technologies. Fourth, the study shows how SNA and simplified analysis techniques can be used in practice within the context of C4.0TeIm construction management research. It showcases the utility of SNA for quantifying the influence and importance of different factors and providing managerial insights for less-explored factors influencing C4.0TeIm. Finally, this study used holistic analysis approaches to proactively unveil the influencing factors toward attaining construction firms' C4.0TeIm. The findings can help top management or construction firm decision-makers evaluate the internal and external business environment effectively, allocate organizational resources, deploy business strategies, and provide holistic and sustainable inspirations when applying C4.0 digital technologies.

Although the current study has made various contributions, there are several limitations with the results that could help identify future research areas. First, the exploratory nature of this study means that it provides indicative trends rather than conclusive findings regarding C4.0TeIm. Second, the analysis was built upon a relatively small sample size of 77 articles, considering the complexity of implementing diverse C4.0 digital technologies. Based on this limited sample, fully understanding the interrelationships among all 60 influencing factors may be challenging. Future research can focus on specific important factors for in-depth analysis. Additionally, it is worth noting that the identified key factors are indicative rather than conclusive, as certain factors may have received excessive attention from previous scholars and still require further investigation. Third, since the organizational decision-making process regarding adopting C4.0 digital technologies may be influenced by the collective effects of different factors, this study only implemented SNA analysis to study the links among the different influencing factors regarding their co-occurrences in studied articles. Therefore, future empirical studies in a research setting could be conducted to thoroughly examine the interconnectivity between these influencing factors toward C4.0TeIm by using the results of this study as a basis. Fourth, the results may be limited by the data sets used, as the data were collected before September 2021. Fifth, although this study took a sustainability standpoint in analyzing the influencing factors of C4.0TeIm, the relationships and mechanisms between construction firms' digitalization and sustainability were not thoroughly examined and are out of the scope of the aim and objectives of this study. This highlights the need for further research to investigate the potential tension between firms' digitalization and sustainability transitions. Finally, this study predominantly answers the question of "what" may influence firms' C4.0TeIm in the literature rather than "why" and "how". While understudied areas within the C4.0 domain are identified, further exploration is needed to investigate the sources of these issues and propose strategic solutions.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/buildings14020552/s1. Figure S1: Example of a reference matrix; Figure S2: Example of the development of a factor-factor matrix; Table S1: Descriptions and Sample Applications of Construction 4.0 Technologies; Table S2: Distribution of Included Journals Video; Table S3: Distribution of Countries or Regions; Table S4: Details of Multi-Country Studies; Table S5: Identified Influencing Factors Related to Construction 4.0 Technology Implementation; Table S6: Types of the Reviewed Articles and the Corresponding Reference Matrices; Table S7: Differences Between the Results from Social Network Analysis and Simplified Analysis.

Author Contributions: Conceptualization, Q.Z.; methodology, Q.Z. and C.L.; software, Q.Z., C.L. and W.Z.; formal analysis, Q.Z. and S.M.; writing—original draft preparation, Q.Z.; writing—review and editing, C.L.; visualization, W.Z. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available due to privacy restrictions.

Conflicts of Interest: Author Wenhui Zhu was employed by the company Zhongguancun Smart City Co., Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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