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Review Article

Towards Complexity and Dynamics: A Bibliometric-Qualitative Review of Network Research in Construction

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Social network analysis (SNA) has gained increasing academic attention in the construction domain over the past two decades due to its capability to characterize the complexity and dynamics of interindividual and interorganizational interactions. To date, however, scant attempt has been made to develop an integrated framework to systematically review the diversified network research at different levels in this domain and to quantitatively characterize the evolution of related research interests and research instruments. This study aims to fill this gap by conducting a bibliometric-qualitative review based on 106 papers published from 1997 to 2020. Keyword cooccurrence analysis is employed to reveal the research foci, identify the research trends, and develop a comprehensive categorization framework, which classifies related research based on two interrelated dimensions: the type of network node (individual and organization) and the levelof network analysis (project level, corporate level, and industry level). The framework then facilitates further content analysis in terms of research topics, research designs, and research instruments. The results provide evidence that the research foci in this domain are generally moving towards addressing the complexity and dynamics of project-related relations at more diversified levels, in terms of not only research topics but also research instruments. Future research can be enriched by investigating the multiple types of dynamic interproject relationships, adopting state-of-the-art methodologies for network data collection and triangulation, and employing multiple SNA constructs and inferential statistical methods to reveal how complex networks coevolve and interact with actors' behaviors as well as project and organizational outcomes.

1. Introduction

As a pillar industry in many countries, the construction industry is a typical project-based sector within which production and business activities are generally organized based on temporary and multiorganizational projects [1, 2]. From a short-term perspective, multiple individuals and organizations from diversified disciplines need to closely interact with each other within a project [3–6], thus forming complex intraproject communication and collaboration networks that have the potential to substantially influence project activities and performance [7, 8]. From a long-term perspective, with the initiation and accomplishment of different construction projects, individuals and organizations will further form evolving and complex interproject relationship networks at the corporate and industry levels [3, 9, 10], which also closely relate to how information and knowledge diffuse among different individuals and organizations across projects. As such, relationship networks developed in the construction industry not only demonstrate unique complexity features in terms of multiplex network levels, diversified network actors, and manifold relationship types [3, 11], but also exhibit distinct dynamic characteristics with the initiation and accomplishment of different temporary projects [3, 12].

With the increasing complexity and dynamics of construction projects, multiple approaches have been used to solve complex and dynamics problems in the construction domain, such as system dynamics, agent-based modeling, and social network analysis (SNA) [6, 13–17]. As a theoretical lens that focuses on relational structures rather than self-reliant actors [18], SNA has been increasingly used to characterize interindividual or interorganizational relationship networks in the construction domain since the early work of Loosemore [19] around 1997. In consideration of the increase and significance of network research in the construction domain, previous studies have attempted to summarize the application of SNA in construction research from specific perspectives. By qualitatively tracing the development of SNA research from 1997 to 2011, Chinowsky and Taylor [16] proposed an insightful path forward for future network research in the project organization domain. Zheng et al. [17] conducted a thorough review of the SNA application in the construction project management domain and identified eight main research interests using keyword cooccurrence analysis. Lee et al. [6] qualitatively reviewed 65 papers to discuss the applications of SNA constructs in the complex project management domain. Despite the multiplex levels and manifold relation types of networks in construction, however, scant scholarly attention has been devoted to developing an integrated framework for the network research in the construction domain and providing a systematic view of related research at different levels. Such a framework could not only help to more comprehensively identify research topics, research instruments, and research gaps of extant research as well as potential directions for future research, but also contribute to deepened understandings of the complexity and dynamics inherent in the relationship networks in the construction domain.

This study aims to address this gap by conducting a bibliometric-qualitative review of the network research in the construction domain to systematically map and categorize the research areas, graphically illustrate the evolution of research interests and research instruments, and identify potential directions for future research. Bibliometric analysis is employed to identify the research foci and trends in network research and reorganize the research into a categorization framework to help researchers comprehensively comprehend the research areas in the construction domain. The framework will facilitate further content analysis in terms of research topics, research designs, and research instruments. The next section of this paper contains an introduction to the research methods concerning data retrieval processes, bibliometric analysis, and content analysis. The subsequent section summarizes the findings. The final section draws upon the findings to discuss the main implications and future research directions.

2. Research Methodology

A "mixed-methods systematic review," termed by Harden and Thomas [20], which combines quantitative and qualitative synthesis approaches was used in this study. A traditional systematic review is an effective method to produce a rigorous summary of the literature findings, map out gaps in the research, and guide future research [21]. However, outcome reporting bias may be introduced, and the interpretation of results is prone to be subjective in a manual review [22]. Therefore, a mixed-methods systematic review that combines bibliometric analysis and content analysis is needed to scientifically identify the knowledge base and evolution of a topic [23]. Figure 1 displays the research design of this study. The following subsections will provide details of each stage as shown in Figure 1.

2.1. Data Retrieval Process. To retrieve elaborated SNA-based publications, this study not only adopted the review methods widely employed in the construction domain [17, 24], but also conducted a forward search to ensure the comprehensiveness of the search results. First, a comprehensive database search was conducted in the title/abstract/keyword field of Scopus. Scopus was selected due to its wider coverage of publications in the construction domain as compared to other databases such as Web of Science [25–27], which does not fully cover the Emerging Sources Citation Index (ESCI) journals such as *Journal of Management in Engineering* (JME). Search keywords included "social network," "project network," "network structure," "network theory," "organization network," "network analysis," "SNA," and "stakeholder network." Similar keywords were widely used in previous research [28]. The truncation symbol (∗) was also used to retrieve variations of the search keywords [29]. The search was limited to areas including "computer science," "engineering," "social science," "business, management, and accounting," "environment science," "decision sciences," and "energy." Only publications with "article" as the document type were included. The search code is as follows.

> TITLE-ABS-KEY ("social network ∗ " OR "project network ∗ " OR "network structur ∗ " OR "network theory" OR "organization ∗ network ∗ " OR "network analysis" OR sna OR "stakeholder network ∗ ") AND (LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ENGI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "BUSI") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "DECI") OR LIMIT-TO (SUBJAREA, "ENER") OR LIMIT-TO (SUBJAREA, "ECON")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) Search result: 104,203 (Searched on 29 June 2020)

Noting that a certain proportion of irrelevant papers were present in the results, the target journals were further limited to refine the search. Seven top-ranked journals were selected according to the ranking list of Chau [30]: *Construction Management and Economics* (CME), *Journal of Construction Engineering and Management* (JCEM), *Engineering, Construction and Architectural Management* (ECAM), *Journal of Management in Engineering* (JME), *International Journal of Project Management* (IJPM), *Automation in Construction* (AIC), and *Building Research and Information* (BRI). These journals are impactful in the construction domain and have published the most SNA-related publications as indicated by previous studies [17]. Additionally, two other peer-reviewed journals—*Engineering*

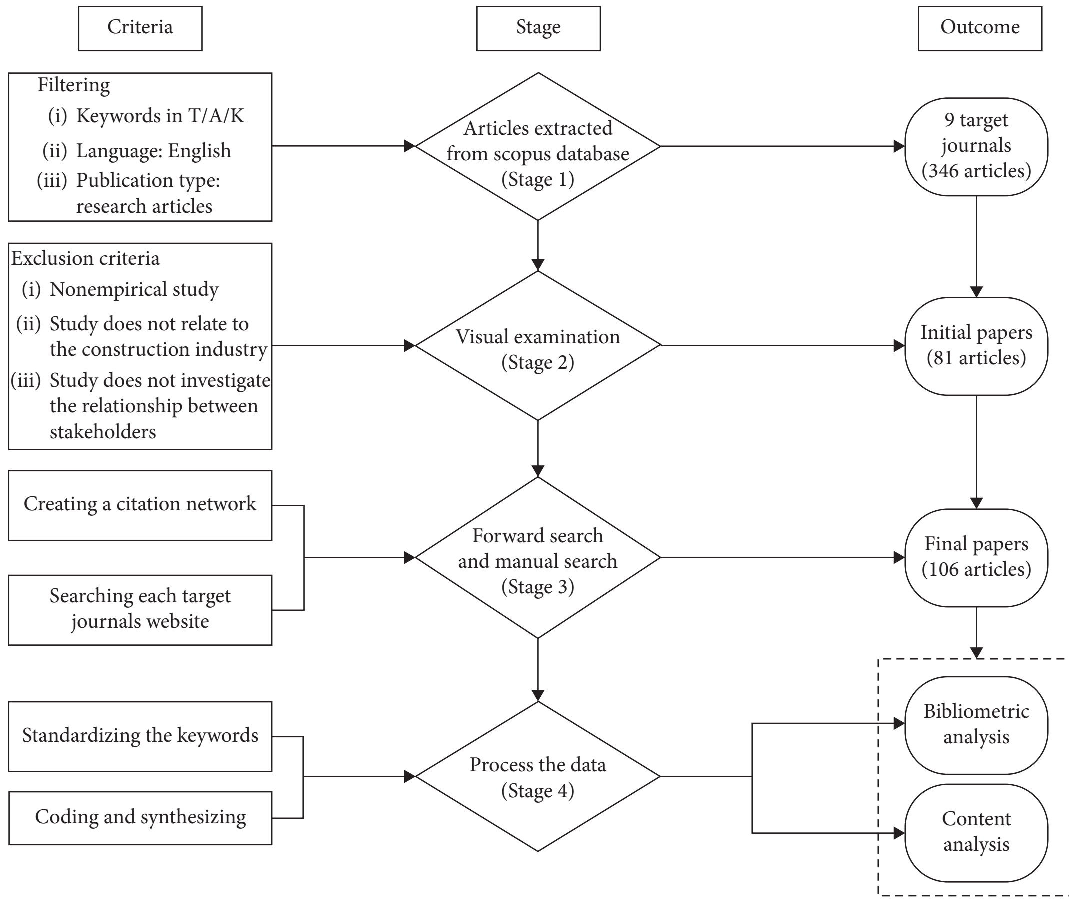

Figure 1: Research design.

Project Organization Journal (EPOJ) and *Project Management Journal* (PMJ)—were also included in the target journal list because they have published frequently cited SNA-based research and are regarded as qualified sources to capture papers in the construction domain [17]. As a result, a total of 346 articles were identified in Stage 1.

In Stage 2, a visual examination of the paper contents was conducted. An article was regarded as relevant if it met the following three criteria: (1) it focuses on empirical research, (2) it is related to the construction domain, and (3) it investigates the relationships between individuals or organizations. The initial selection results (listed in Table 1) revealed that Scopus did not contain the journal EPOJ. Moreover, Scopus did not have full records of some other selected journals [17, 24]. This necessitated the combination of a database search and other supplementary search strategies.

In Stage 3, a forward search and a manual search were conducted to ensure the comprehensive coverage of SNA-based publications. These strategies can help further identify those papers that might be omitted by the former database search [31]. A citation network containing articles that cited the initial 81 papers was created in Scopus. As a result, a total of 370 articles were found from the selected journals. After scanning these papers by reading the titles and abstracts, no additional publication was identified, which verified the comprehensiveness of the database search result. Considering that Scopus did not have full records of the selected journals, a manual search was further carried out. Through searching the websites of all the target journals, 25 additional papers were found, as shown in Table 1. Finally, a total of 106 publications released from 1997 to 2020 were identified. Figure 2 displays the distribution of these studies in 1997–2020. It is evident that the number of publications rapidly increased from 1997 to 2011 and significantly surged in 2017.

2.2. Bibliometric Analysis. Bibliometric analysis refers to visualizing, exploring, and analyzing large-scale historical data from an objective and quantitative perspective [32]. It helps identify the intellectual base of a scientific area and the evolution of research topics [33, 34]. CiteSpace Version 5.5.R2 was used in this study. This software enables researchers to explore both intellectual bases and research fronts within the same time-variant mapping [35].

The SNA-based research (1997–2020) dataset consisted of 81 records extracted from the Scopus database and 25 records added manually. The terms extracted from the title, abstract, and author keywords were used as analytical units as they are regarded as concise and comprehensive descriptions of the research contents [22]. Following data

Table 1: Number of identified publications in the targeted journals.

Journal titles	Number of papers (initial selection)	Number of papers (final selection)
Journal of Construction Engineering and Management	27	31
Construction Management and Economics	16	19
Journal of Management in Engineering	11	15
International Journal of Project Management	8	10
Automation in Construction	7	7
Project Management Journal	6	7
Engineering Construction and Architectural Management	4	5
Building Research and Information	2	3
Engineering Project Organization Journal	0	9
Total	81	106

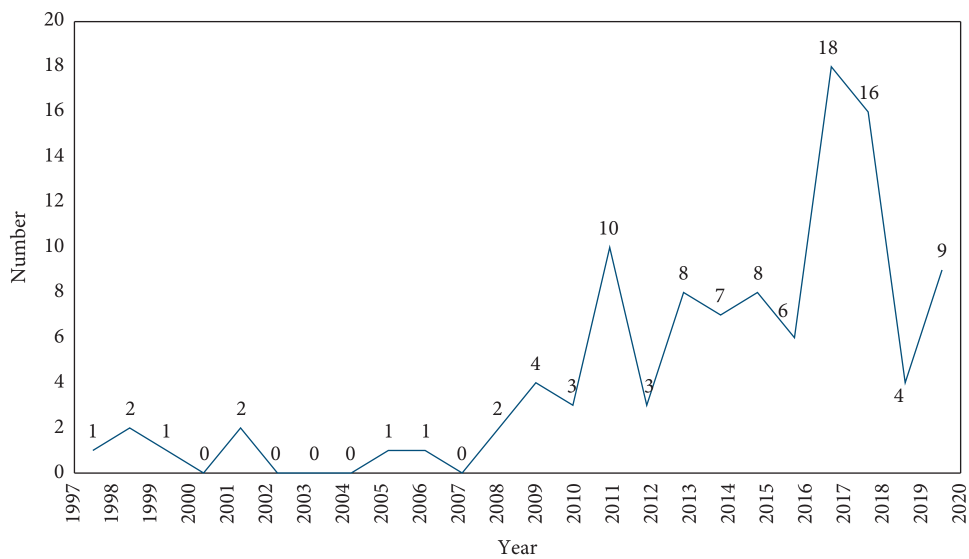

Figure 2: Number of identified publications from 1997 to 2020.

acquisition, data processing is also considered an important part of bibliometric analysis [22]. Noting the differences in several similar terms, keywords such as "building information modeling," "building information modelling," "BIM," and "building information modeling (BIM)" were all standardized as "building information modeling." Keywords that did not add value to this study were excluded, such as "case study," "conceptual framework," "providing insight," "new understanding," "propositional theoretical model," and "anecdotal evidence." After data processing, keyword cooccurrence analysis was employed in both cluster view and time-zone view which will be illustrated in detail in subsequent sections.

2.3. Content Analysis. Content analysis is generally employed to capture the presence of crucial content and elicit meanings of the content [36]. Table 2 shows the codebook employed to code the selected papers. Variables were collected to capture information at three levels: research topics, research designs, and research instruments. Data at the research topics level included the categories of network analysis and types of network relations. Data at the research designs level included boundary specification methods and data collection methods. Data at the research instruments level included SNA constructs (such as degree centrality, betweenness centrality, closeness centrality, and network density) and quantitative analysis methods.

Two coders independently coded the 106 studies. For all variables but two (types of network relations and quantitative analysis methods), Cohen's kappa [44] was employed to measure the interrater reliability (IRR) as it is a commonly used statistic for nominal variables. The IRR of types of network relations and quantitative analysis methods were measured based on the percent agreement as multiple relationships and methods were involved in several studies; the values obtained were 0.972 and 0.926 for types of network relations and quantitative analysis methods, respectively. Using the syntax provided by Hallgren [45], Cohen's kappa was computed in SPSS 23. For each variable, Cohen's kappa ranged from 0.824 to 1, with a mean value of 0.881, indicating perfect agreement between the coders [46]. The IRR of the collected variables is shown in Table 2. The final round of coding was carried out by one coder to resolve the disagreements between the two former coders.

Table 2: Description and interrater reliability of collected variables.

Variables	Descriptions	IRR
	Research topics	
Categories of network analysis	Categorization of network research according to the type of node and the level of analysis	0.894
Types of network relations	Communication network, information and knowledge sharing network, collaboration network, etc.	**0.972**
	Research designs	
Boundary specification methods	Exogenously defined, relationally defined, and methodologically defined	0.864
Data collection methods	Survey and interview, databases, mixed, and others	0.915
	Research instruments	
Degree centrality	The number of direct links with others [37]	0.853
Betweenness centrality	The extent to which a node falls on the geodesic paths between others [38]	0.830
Closeness centrality	The ease of connection from a node to all other nodes [38]	0.933
Eigenvector centrality	The number of links weighted by the centrality of the connectors [39]	0.827
Structure hole	The lack of a direct relation between two nonredundant cliques [40]	0.824
Structural equivalence	The extent to which two nodes share the same pattern of relations [41]	1.000
Network density	The extent of the connectivity of a network [42]	0.887
Network cohesion	The extension of relational cohesion in the network level [42]	0.827
Power-law degree distribution	The so-called "scale-free" property indicates few nodes having many links and many nodes having few links [43]	0.918
Quantitative analysis methods	Descriptive analysis, correlation analysis, regression analysis, simulation analysis, and others	**0.926**

Note: IRR in bold is measured based on percent agreement.

3. Results

3.1. Results of Keyword Cooccurrence Analysis. In this study, the keyword cooccurrence network was derived from the 50 most-cited items in a four-year time interval, ranging from 1997 to 2020. This resulted in a network of 143 nodes with 509 links connecting them, as visualized in Figure 3. The size of a node represents how frequently a term appears in the dataset. The thickness of a link indicates the frequency with which the two terms cooccur. The colors of these links—purple, blue, cyan, green, yellow, and red—correspond to different time slices from 1997 to 2020. The colors of these lines are determined by the first time the two terms were used together.

The network displayed in Figure 3 illustrates the intellectual base and main foci in SNA-based research. Keywords such as "organizational issue," "project-based organization," "project organization," "organizational structural," and "project team" occupied salient positions in the network. This indicates that network studies in the construction domain involve different types of focal actors and that both interindividual and interorganizational relationships were investigated in the literature, which is consistent with the conclusion of Chinowsky and Taylor [16]. Figure 3 also shows that communication, knowledge sharing, and collaboration were the most frequently investigated relationships in the construction literature.

As keyword cooccurrence analysis in the cluster view only displays a static figure [22], the cooccurrence network was further employed in the time-zone view to illustrate the evolution of research interests and identify the research frontiers [35]. As shown in Figure 4, the size of a node represents the degree centrality of a term, the lines

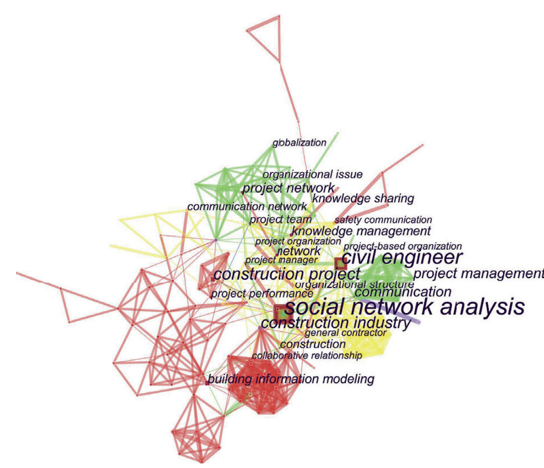

Figure 3: Keywords cooccurrence network (1997–2020).

link the keywords used together, and the colors of these lines represent the time a connection occurred for the first time. Early research tended to focus on communications within project teams, as suggested by the dominance of keywords "communication" and "project team" in the network literature before 2005. Increasing interests have been gathered around "knowledge management" and "cultural boundary issue" since 2009. From 2013 to 2016, "safety," "performance," and "small work crew" became the primary research keywords, which might illustrate an emphasis on addressing more specific problems such as safety management and performance improvement in the network research during this stage. Since 2017, increasing research interests have been emerging on "industry organization," "project-based collaborative network," and "industry-level network". This result tends to suggest that

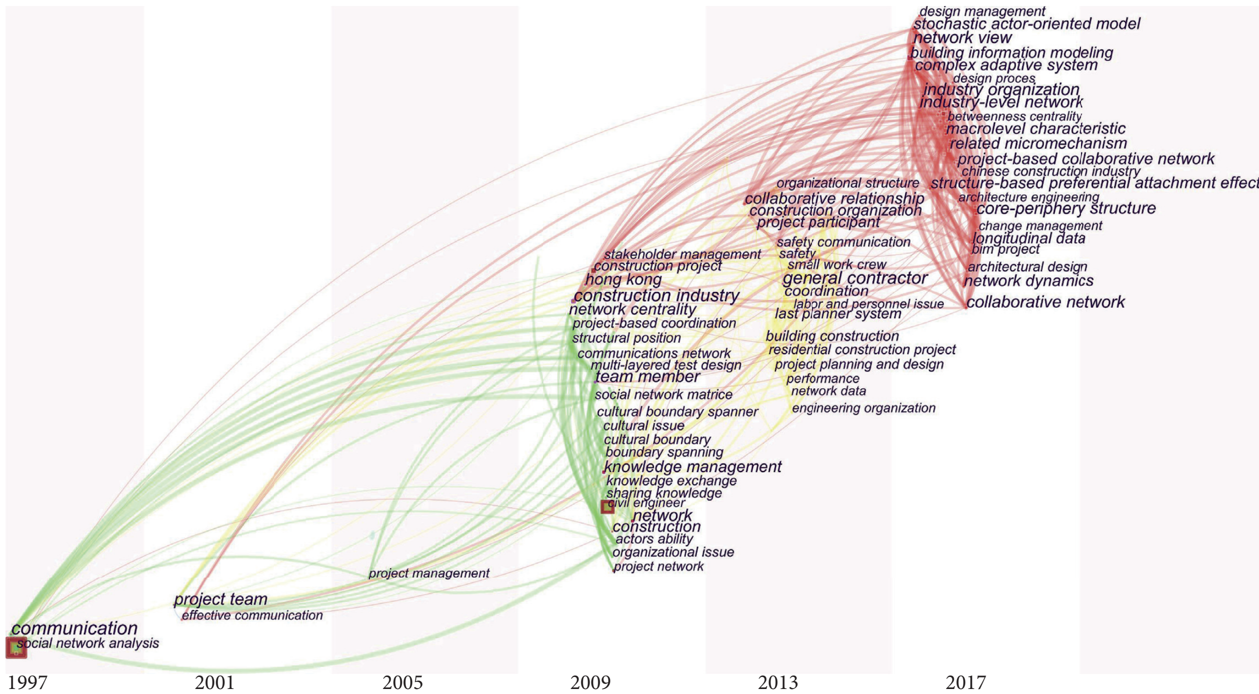

Figure 4: The timeline map of keyword cooccurrence network (1997–2020).

while a large amount of early studies related to networks in construction have focused on examining interindividual or interorganizational relationships within a single construction project [19, 47–50], industry-level relationships across different project contexts began to elicit growing interests in recent years [3, 9, 11, 51–53]. It is also evident from Figure 4 that dynamics-related keywords such as "complex adaptive system," "stochastic actor-oriented model," "longitudinal data," and "network dynamics" distinctly emerged in the keyword cooccurrence network since 2017, suggesting that related research have begun to veer away from a static focus to a dynamic perspective. Taken together, these results provide evidence that research foci of network studies in the construction domain are evolving from simple and statistic networks towards the complexity and dynamics of relationship networks at more diversified levels, which is closely related to the variety of participants and the temporary nature of their collaborative relationships in the construction industry.

The results further indicate that the SNA-based research conducted in the construction domain can be placed into a categorization framework with two dimensions (see Table 3). The first dimension, the *type of network node*, identifies whether the research was focused on relationships among individuals or among organizations. The second dimension, the *level of network analysis*, reflects whether the relationships were analyzed at the project level, corporate level, or industry level. It is worth-noting that the results of keyword cooccurrence analysis can be misinterpreted out of context [22], necessitating the use of content analysis to reduce the ambiguity of the results and enhance the depth of understanding.

3.2. Results of Content Analysis

3.2.1. Research Topics. The sample size for content analysis was 108 because two studies included multicategory analyses [47, 54]. As illustrated in Table 4, network studies in the construction domain predominantly emphasized interindividual and interorganizational relationships within a single project (34.26% and 38.89%, resp.). Interindividual relationships within in a single project (Category I) were the focus of the earliest network studies in the construction domain. Studies addressing interorganizational relationships in a single project (Category III) have been notably increasing since 2005. Corporate-level studies (Category II) and industry-level studies (Category IV) examining relationships across projects began to appear after 2009.

A more substantive analysis of the contents was conducted, focusing on the specific types of network relations addressed in the 108 samples. Figure 5 visualizes the distribution of the publications by types of network relations and categories of network analysis. The colors in Figure 5 show whether the study was conducted in a static or dynamic view. The percentages are based on the sample size. It is important to note that this study did not differentiate between information exchange relation and knowledge exchange relation as these two relations were integrated in some studies. As shown in Figure 5, communication, information, and knowledge exchange, as well as collaboration networks, attracted the most scholarly interest, accounting for 29.63%, 44.44%, and 21.30% of the identified studies, respectively. This result is in line with the conclusions drawn from keyword cooccurrence analysis. Some studies also investigated other types of relationships, such as contractual (11.11%), advice (3.03%), trust (4.04%), influence (2.02%),

Table 3: A categorization framework of network research in construction.

Type of network node	Level of network analysis		
	Intraproject level	Interproject level	
		Corporate level	Industry level
Interindividual relations	Category I: interindividual networks in a single project	Category II: interindividual networks across projects at the corporate level	—
Interorganizational relations	Category III: interorganizational networks in a single project	—	Category IV: interorganizational networks across projects at the industry level

Table 4: Distribution of publications by period and categories of network analysis.

	1997–2000	2001–2004	2005–2008	2009–2012	2013–2016	2017–2020	Total
Category I	4	2	2	6	9	14	37
Category II	0	0	0	4	6	6	16
Category III	0	0	2	8	11	21	42
Category IV	0	0	0	3	3	7	13
Total	4	2	4	21	29	48	108

Note: the sample size for content analysis is 108 as two studies include multicategory analyses [47, 54].

and spatial proximity (3.03%) relations. Contractual relations were investigated as formal relationships [7, 48, 55] and were mostly addressed for improving the efficiency of project governance [49, 50, 56]. Other nonofficial relations such as advice, trust, and influence relations were analyzed to better facilitate technical knowledge synergy [57], interface management [58], performance improvement [59, 60], and stakeholder management [61, 62]. Spatial proximity relations were examined for reducing task variation and improving work plan reliability [63, 64]. Other relations, such as personal confidence, interpersonal friendship, sharing willingness, supply, interface, transaction, and strategic relations, received scant academic attention [56, 58, 60, 65–67]. Ten of the 26 longitudinal studies explored dynamic collaborative networks; several studies discussed the evolution of interpersonal communication relationships (7.41%) as well as information and knowledge exchange relationships (2.78%).

A summary of the literature distribution by categories of network analysis and types of network relations is listed in Table 5, revealing the main foci in each category of network studies. The studies in Category I placed great emphasis on communication as well as information and knowledge exchange relations (17 and 16 of 37 studies in Category I, resp.). The vast majority of the studies in Category II discussed information and knowledge exchange relations (14 of 16 studies in Category II), which indicates that knowledge management attracted the most scholarly interest in corporate-level research. The studies in Category III explored various types of network relations, such as contractual, trust, influence, spatial proximity, interface, and supply networks. The bulk of the studies in Category IV focused on collaboration networks (11 of 13 studies in Category IV). Five of these 11 studies were published after 2015 and were conducted longitudinally, suggesting that the dynamic characteristics of interorganizational collaboration have attracted increasing attention.

3.2.2. Research Designs. The specification of network boundaries and the collection of network data are at central roles in the design of network studies since the exclusion or omission of pertinent relations can result in distorted results [146]. According to Butts [147], network boundaries are most frequently set in three different ways: exogenously defined, relationally defined, and methodologically defined. The exogenously defined represents specifying the network boundary based on the research task or researchers' concern. It is commonly used in small group studies due to the well-defined membership. The relationally defined represents specifying the network boundary through setting a focal unit and finding the relations connected with it. The network boundary can also be defined through the methodology adopted for network data collection, which includes specifying boundaries limited to actors that use the same medium (e.g., e-mail and Twitter) or restricted to special contacts (e.g., all ties connected ego and alter).

Table 6 shows the distribution of publications based on the boundary specification methods and categories of network analysis. The percentages were calculated based on the amount of each category. The exogenously defined method was the most frequently used in Categories I, II, and III, accounting for 67.57%, 62.50%, and 83.33% in these categories, respectively. The relationally defined method was more frequently adopted in Category III (11.90%). Two sampling methods, including snowball sampling [56, 118, 125] and chain-referral sampling [121, 123], were used in these studies. Compared with Category III, the methodologically defined method was more frequently used in Categories I, II, and IV (27.03%, 31.25%, and 92.31%, resp.). For these studies, network data were obtained from social media [143, 144], e-mail dataset [74, 75, 79, 112], design logs [129], ego-centric SNA surveys [93, 107, 127], and online databases [3, 9, 11, 51–53, 67, 139, 141].

The trends of the network data sources employed in the identified studies are shown in Figure 6. The bar graph

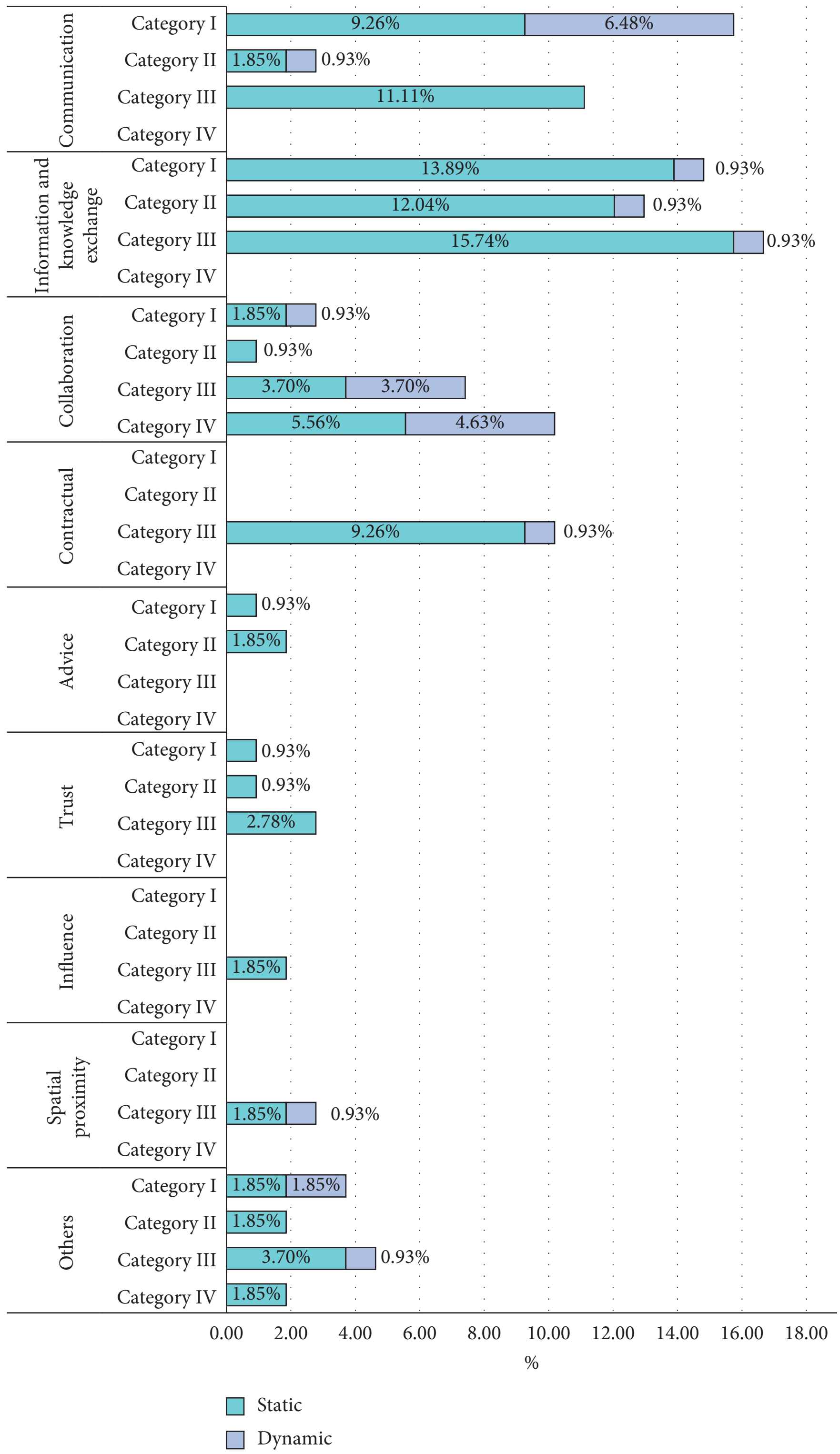

Figure 5: Distribution of publications by types of network relations.

depicts the absolute quantity of each data source, and the line graph represents the relative percentage (based on the total number of publications in each time slice). Surveys and interviews were the predominant data sources with a general downward trend. Mixed sources and online databases sources have gained increasing popularity since 2009. Studies that collected data from other sources, such as site observation and work documents, have decreased since 2013. These results collectively indicate that more emphasis was placed on extracting data from databases and triangulating data from multiple sources because the network data collected from surveys and interviews is retrospective

Table 5: Distribution of publications by types of network relations and categories of network analysis.

Types of network relations	Category I	Category II	Category III	Category IV
Communication	Loosemore [19]; Loosemore [69]; Loosemore [68]; Loosemore [70]; Mead [71]; Thorpe and Mead [72]; Chinowsky et al. [73]; Hossain [74]; Hossain [75]; Hossain and Wu [47]; Di Marco et al. [76]; Ramalingam and Mahalingam [77]; Liao et al. [78]; Franz et al. [79]; Herrera et al. [80]; Lu et al. [81]; and Jafari et al. [54]	Chinowsky et al. [82] Chinowsky et al. [83]; and Hossain and Wu [47]	El-Sheikh and Pryke [48]; Chinowsky et al. [84]; Abbasian-Hosseini et al. [85]; Dogan et al. [86]; Priven and Sacks [87]; Priven and Sacks [88]; Walters [89]; Zedan and Miller [90]; Castillo et al. [60]; Wang et al. [7]; Doloi [91]; and Jafari et al. [54]	—
Information and knowledge exchange	Iorio et al. [92]; Pauget and Wald [93]; Di Marco et al. [94]; Zhang et al. [95]; Alsamadani et al. [96]; Comu et al. [97]; Alsamadani et al. [98]; Lingard et al. [99]; Pirzadeh and Lingard [100]; Allison and Kaminsky [101]; Schröpfer et al. [102]; Al Hattab and Hamzeh [103]; Pryke et al. [12]; Lingard et al. [104]; Pandit et al. [105]; and Herrera et al. [80]	Chinowsky et al. [82]; Pryke et al. [106]; Javernick-Will [107]; Sanaei et al. [108]; Lin and Tan [65]; Wanberg et al. [109]; Wanberg et al. [110]; Poleacovschi and Javernick-Will [111]; Wen and Qiang [112]; Poleacovschi et al. [113]; Wanberg et al. [114]; Castillo et al. [115]; Chinowsky et al. [83]; and Bonanomi et al. [116]	Pryke [49]; Pryke and Pearson [50]; Yang et al. [62]; Chinowsky et al. [84]; Ruan et al. [117]; Heng and Loosemore [118]; Solis et al. [59]; Yang [119]; Zhang et al. [120]; Mok et al. [121]; Papadonikolaki et al. [55]; Park and Lee [122]; Mok et al. [123]; Adami and Verschoore [56]; Castillo et al. [60]; Adami et al. [124]; Verschoore and Adami [125]; and Mollaoglu-Korkmaz et al. [126]	—
Collaboration	Koops et al. [127]; Wen et al. [128]; and Herrera et al. [80]	Zhang and Ashuri [129]	Li et al. [130]; Chowdhury et al. [131]; Opdyke et al. [132]; Wen et al. [133]; Wang et al. [134]; South et al. [135]; Gao et al. [8]; and Wang et al. [136]	Castro et al. [137]; Park et al. [138]; Liu et al. [139]; Sedita and Apa [140]; Lee et al. [9]; Cao et al. [3]; Cao et al. [51]; Tang et al. [11]; Han et al. [52]; Li et al. [53]; and Guevara et al. [141]
Contractual	—	—	Pryke [49]; Pryke and Pearson [50]; El-Sheikh and Pryke [48]; Li et al. [130]; Papadonikolaki et al. [55]; Adami and Verschoore [56]; Wang et al. [134]; Wang, et al. [136]; South et al. [135]; Adami et al. [124]; and Verschoore and Adami [125]	—
Advice	Lin [57]	Pryke et al. [106] and Lin and Tan [65]	—	—
Trust	Herrera et al. [80]	Lin and Tan [65]	Solis et al. [59]; Shen et al. [58]; and Castillo et al. [115]	—
Influence	—	—	Yang et al. [61] and Yang et al. [62];	—
Spatial proximity	—	—	Wambeke et al. [63]; Wambeke et al. [142]; and Abbasian-Hosseini et al. [64]	—
Others	Williams et al. [143]; Lin [57]; Nik-Bakht and El-Diraby [144]; and Herrera et al. [80]	Lin and Tan [65] and Castillo et al. [115]	Pryke [49]; Pryke and Pearson [50]; Shen et al. [58]; Adami and Verschoore [56]; and Xue et al. [145]	Comet [66] and De Biasio and Murray [67]

Table 6: Distribution of publications by boundary specification methods and categories of network analysis.

	Category I	Category II	Category III	Category IV
Exogenously defined	25 (67.57%)	10 (62.50%)	35 (83.33%)	1 (7.69%)
Relationally defined	2 (5.41%)	1 (6.25%)	5 (11.90%)	0 (0.00%)
Methodologically defined	10 (27.03%)	5 (31.25%)	2 (4.76%)	12 (92.31%)

Note: percentages are based on the amount of publications in each category.

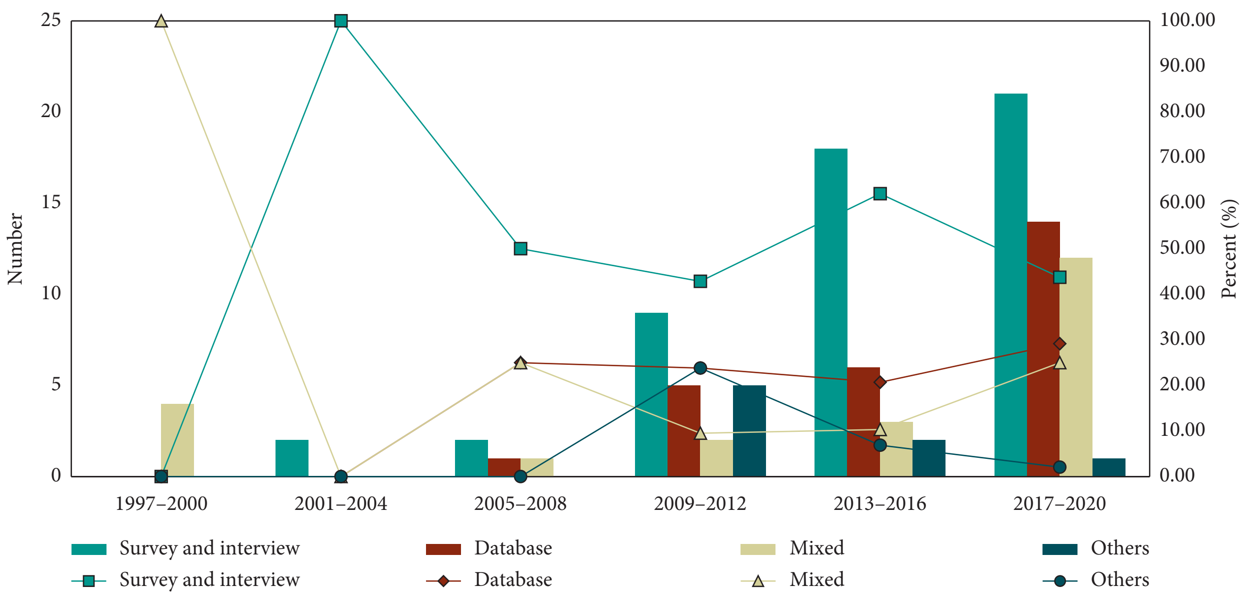

Figure 6: Trends in data sources across years (1997–2020).

and subjective in nature, and a single-source method might lack reliability and generate potential response biases.

To further quantitatively compare different data sources used in each category, the distribution of publications based on data sources and categories of network analysis is reported in Table 7. Surveys and interviews were the most frequently used sources to study project-level and corporate-level relations (accounting for 48.65%, 47.62%, and 81.25% in Categories I, III, and II, resp.). Among these studies, name generators and fixed name rosters were the most commonly used instruments to collect interindividual network data. For most interorganizational research, surveys and interviews were conducted among representative individuals to report on their organizational ties. However, such ties may be prone to involving a person's activities. Future research can be devoted to combining reports by multiple representative persons to determine organizational ties [115]. Interestingly, Table 7 also shows that, compared with interproject level research, intraproject level studies paid more attention to data triangulation (mixed sources accounted for 18.92% and 35.71% in Categories I and III, resp.).

3.2.3. Research Instruments. Multiple network constructs can be used to investigate the structural characteristics of a network. As indicated in previous studies [40, 42], the network constructs can be divided into three different levels (node, dyad, and network level). Considering that the dyad-level constructs are less frequently used, this study only coded most frequently employed constructs in the node and network levels, as shown in Table 8. The node-level constructs enable researchers to depict an actor's position within a network. Among the node-level variables, degree centrality was the most frequently employed construct in each category. Betweenness centrality and closeness centrality were also frequently adopted, especially in Category I. However, structural hole was less used in interindividual level studies than in interorganizational level studies. This may result from the characteristics of construction projects; organizations within a temporary project are more fragmented with the disparate perception of stakeholders towards objectives [118]. Thus, researchers were motivated to investigate the structural holes to facilitate organizational communication and coordination [56, 118, 125]. Structural equivalence measures the competitiveness of a relationship while it was rarely used in the selected studies. Loosemore [19] found the concept of structural equivalence useful to investigate communication efficiency. Studies in other related fields suggest that actor's adoption decision towards new technologies can be affected through structural equivalence [41, 148, 149]. Future research in the construction domain can leverage structural equivalence to better disentangle how social contagion influences the diffusion of innovative technologies (e.g., BIM) among industry organizations and professionals. Network-level constructs capture the overall compactness and distributions of relations in the whole network. The most frequently used construct in the network level was network density. Nonetheless, network cohesion and degree distribution were

Table 7: Distribution of publications by data sources and categories of network analysis.

	Category I	Category II	Category III	Category IV
Surveys and interviews	18 (48.65%)	13 (81.25%)	20 (47.62%)	1 (7.69%)
Databases	8 (21.62%)	3 (18.75%)	3 (7.14%)	12 (92.31%)
Mixed	7 (18.92%)	0 (0.00%)	15 (35.71%)	0 (0.00%)
Others	4 (10.81%)	0 (0.00%)	4 (9.52%)	0 (0.00%)

Note: percentages are based on the amount of publications in each category.

Table 8: Distribution of publications by SNA constructs and categories of network analysis.

	Node level						Network level		
	Degree centrality	Betweenness centrality	Closeness centrality	Eigenvector centrality	Structural hole	Structural equivalence	Network density	Network cohesion	Power-law degree distribution
Category I	30 (81.08%)	25 (67.57%)	13 (35.14%)	3 (8.11%)	1 (2.70%)	4 (10.81%)	19 (51.35%)	2 (5.41%)	1 (2.70%)
Category II	4 (25.00%)	3 (18.75%)	4 (25.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	4 (25.00%)	1 (6.25%)	0 (0.00%)
Category III	29 (69.05%)	16 (38.10%)	11 (26.19%)	7 (16.67%)	3 (7.14%)	1 (2.38%)	19 (45.24%)	5 (11.90%)	0 (0.00%)
Category IV	10 (76.92%)	5 (38.46%)	5 (38.46%)	3 (23.08%)	1 (7.69%)	1 (7.69%)	7 (53.85%)	1 (7.69%)	5 (38.46%)

Note: percentages are based on the amount of publications in each category.

less adopted. Compared with intraproject level and corporate-level studies, industry-level studies (38.46%) used degree distribution mostly for unveiling the uneven distribution of interproject collaborations [3, 9, 11, 53, 139].

The quantitative analysis methods can be summarized into five categories, including descriptive analysis, correlation analysis, regression analysis, and simulation. Descriptive analysis was adopted to summarize the basic network characteristics. Correlation and linear regression analysis were used to uncover the relationships between network constructs and safety climate [78, 104, 105], project performance [7, 60, 115], management efficiency [69], individual performance [111, 129], company's profit [66], organizational competitiveness [51], and individual coordination [74, 75, 86]. However, considering that social actors are embedded within the social environment [150], the observed correlation in linear regression analyses may result from the inherently interdependent nature of social relations [151]. To address this methodological gap, several simulation methods were introduced in the construction domain, including the quadratic assignment procedure (QAP) [9, 113, 137], the exponential random graph model (ERGM) [97, 109], and the stochastic actor-based model (SAOM) [3, 11, 53].

Based on the permutations test that repeated a considerable number of times, the QAP is a promising statistical method to control for dependence among variables [151]. As a stochastic rather than a deterministic approach, the EGRM treats the links of a network as endogenous and random [152]. The hypothesis embodied in the EGRM is based on dyadic dependence, which permits possible homophily effects among actors [152]. The SAOM can be regarded as an actor-oriented simulation model in which actors evaluate the network structure and change their outgoing ties for myopically optimizing an objective function [153]. While these three simulation models have considered the interdependence of social relations, the detailed differences need to be pointed out. First, both the QAP and the ERGM can be applied to cross-sectional data while the SAOM can be used for analyzing longitudinal data [154]. Second, the QAP does not allow the specification of endogenous effects (structure-based effects); only the EGRM and the SAOM do [155]. Apart from these, the SAOM can also model the coevolution of both networks and behaviors [156].

The trends of these quantitative analysis methods are displayed in Figure 7. The bar graph depicts the absolute quantity of each method, and the line graph represents the relative percentage (based on the total number of publications in each time slice). The bulk of SNA-based studies only conducted descriptive analyses, analyzing the visual sociogram or calculating several network constructs. It suggests that network research in the construction domain has been a relatively immature field receiving most attention paid to understand the network structures among organizations or individuals. It is worth noting that the relative percentage of descriptive analysis has decreased since 2013 together with the increase of correlation analysis, regression analysis, simulation, and other methods (e.g., structural equation modeling (SEM), data envelopment analysis (DEA), and semantic analysis). The distribution of publications by quantitative analysis methods and categories of network analysis is further reported in Table 9. The majority of studies in Categories I and III only employed descriptive analysis (54.05% and 76.19%, resp.) while many studies in Categories II and IV adopted inferential statistics, especially simulation analysis (18.75% and 38.46%, resp.). This implies that project-level studies mostly focused on revealing how the networks are arranged and who the influential actors are.

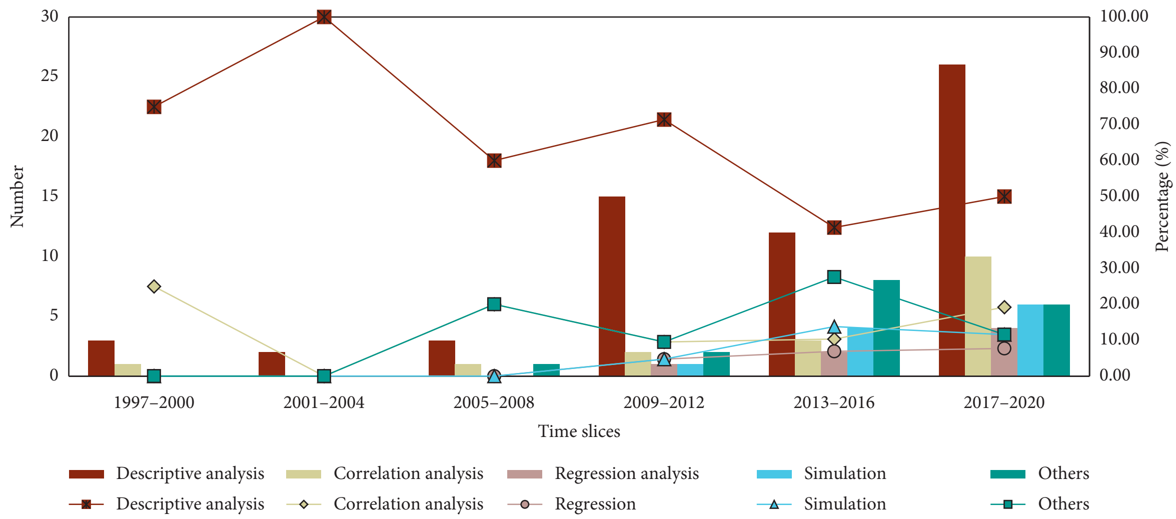

Figure 7: Trends in quantitative analysis methods across years (1997–2020).

Table 9: Distribution of publications by quantitative analysis methods and categories of network analysis.

	Category I	Category II	Category III	Category IV
Descriptive analysis	20 (54.05%)	6 (37.50%)	32 (76.19%)	3 (23.08%)
Correlation analysis	7 (18.92%)	3 (18.75%)	5 (11.90%)	2 (15.38%)
Regression analysis	3 (8.11%)	1 (6.25%)	0 (0.00%)	3 (23.08%)
Simulation analysis	2 (5.41%)	3 (18.75%)	1 (2.38%)	5 (38.46%)
Others	8 (21.62%)	3 (18.75%)	5 (11.90%)	1 (7.69%)

Note: percentages are based on the amount of publications in each category.

However, corporate-level and industry-level studies mostly further explored the relationships between network structures and actors' behaviors as well as project outcomes.

4. Discussion and Future Research Directions

4.1. Discussion of Findings. Through combining bibliometric analysis and content analysis, this study identified the research trends and developed an integrated framework for previous SNA-based studies, which enabled deeper and more systematic insights into the research topics, research designs, and research instruments of network studies in the construction domain. The findings of bibliometric analysis indicate that research keywords of the reviewed literature are generally veering away from a static focus to a more dynamic perspective. The results of content analysis further illustrate that increasing scholarly interests have been attracted to examine more macronetworks such as interproject relationships and most of these studies were conducted longitudinally. Taken together, these results tend to suggest that the research foci of network studies in the construction domain are generally moving towards addressing the complexity and dynamics of project-related relations at more diversified levels. A plausible explanation for this trend is that, with the evolution of organizational and process paradigms in the construction industry, it is increasingly recognized that the performance of construction activities is not only impacted by the relationships within corresponding projects at the short term but also shaped by how individuals and organizations interact with each other across projects in the long term [51]. The development of construction-related databases and data analytics also enables researchers to conduct related analyses from more macro- and dynamic perspectives.

Another noteworthy finding of this study is that, compared with corporate-level and industry-level studies, the vast majority of project-level studies only conducted descriptive analyses to characterize the characteristics of relation networks among project stakeholders but infrequently employed inferential statistics to further explore the associations between network structures and organizational behaviors as well as project outcomes. One plausible explanation for this finding might be that project-level networks are generally more stable than industry-level and corporate-level networks in nature [3]. As a result, project-level studies tend to focus more on the structure of the networks in which stakeholders are embedded. In contrast, a critical point of departure for corporate-level and industry-level studies is to improve organizational competitiveness or the performance of the construction industry. Thus, this stream of network studies generally pays more attention on whether and how the behaviors and outcomes of construction organizations impact or are impacted by their relationship networks [3, 51]. Another plausible explanation can be that corporate-level and industry-level network data, which can be retrieved from public databases in many cases, might be more easily collected as compared with project-level network data which are generally obtained through

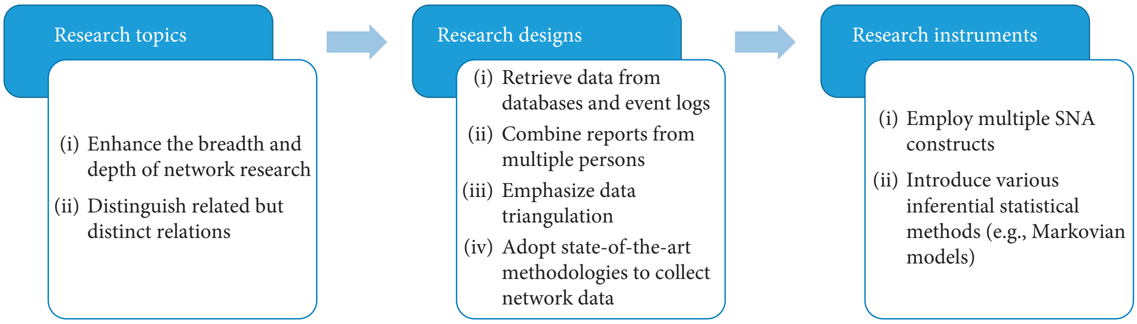

Figure 8: Future directions for network research in construction.

survey and interview. Nevertheless, the debates over how individuals shape the networks within which they are embedded and how these networks influence individuals' characters and performance have been at the heart of organizational social network research [18, 157]. These results tend to suggest that more efforts need to be paid in project-level studies to deepen our understandings of how relationship networks within construction projects interact with related organizational or project behaviors and outcomes.

4.2. Future Research Directions. Previous review studies have suggested several potential directions from the perspectives of SNA constructs [6] and stakeholder management [17] for future network research in the project organization domain and the complex project management domain. However, considering the multiplex levels and manifold relation types of networks in the construction domain, it would be significant to further discuss the limitations of extant studies and the directions for future research based on a more systemic perspective. As shown in Figure 8, future research can be enriched from the perspectives of research topics, research designs, and research instruments. Regarding the lack of corporate- and industry-level research, as well as longitudinal network research, future research can investigate multiple types of dynamic interproject relationships, such as advice, trust, and influence relations, as shown in Figure 5. Previous scholars have also suggested future studies to conduct longitudinal research to better reveal how different relationship networks evolve within a project or across projects over time [16]. Another gap is that a paucity of studies has clearly distinguished related but distinct relations; for instance, communication, information exchange, and knowledge exchange relations are easily confused with each other. As suggested by Chinowsky et al. [73], communication is a more general interaction among actors while information exchange specifies related tasks and knowledge exchange emphasizes why tasks are done in this way and how to achieve higher performances. Considering the difficulties for interviewees to distinguish the differences among several relations, researchers can explore well-defined relations by specifying the situations.

Concerning research designs, more attention should be paid to network boundary specification and network data triangulation to conduct compelling studies. However, as mentioned in previous studies, the boundary of a network is often difficult to effectively identify. Retrieving data from online databases and mining data from event logs can serve as promising alternative sources because methodologically defining the network boundary is more objective and scientific. Considering that investigating interorganizational relations through surveys and interviews is prone to involving an individual's activities, future research can combine reports by multiple representative persons for determining organizational ties [115]. In viewing the difficulty in data triangulation, some state-of-the-art methodologies, such as wearable sensors and emotional facial recognition, can be employed [40]. These methods could help to collect other types of objective relationship data and can thus have a potential to be combined with surveys or archives for data triangulation.

Given that the use of SNA is still in its infancy in the construction domain, additional efforts are needed to leverage multiple SNA constructs [6] and inferential statistical methods to capture the complexity and dynamics of construction projects. Many of the identified SNA studies, especially corporate-level research, do not fully use SNA constructs to unravel the underlying complexity of construction projects. For instance, structural equivalence can be used to better disentangle how social contagion influences the diffusion of innovative technologies (e.g., BIM) [41, 148, 149]; however, this is less used in the identified studies. As discussed earlier, project-level studies mostly focused on depicting the networks while corporate-level and industry-level studies explored the relationships between network structures and actors' behaviors as well as project outcomes. Thus, future SNA-based research, especially for project-level studies, needs to focus on leveraging various inferential statistical methods to explore how individuals shape the project networks in which they are embedded and how these networks influence organizational or individual behaviors and project performance [17], which have attracted great interests in organizational social network research [157]. For example, Markovian models yield new insights into analyzing longitudinal data and examining how social networks can coevolve and interact with actors' behaviors [42]. These models may extend our knowledge on how various types of interindividual or interorganizational networks can associate with innovation implementation behaviors from a longitudinal view [3, 51, 55, 158, 159].

5. Conclusions

As an attempt to develop an integrated framework for SNA-based studies at different levels related to construction activities, this study is the first of its kind to conduct a bibliometric-qualitative review that systematically maps and critically identifies the research topics, research designs, and research instruments of different categories of network research in the construction domain. Based on a three-stage data retrieval process, 106 papers were identified from nine top-ranked and qualified journals. The results of keyword cooccurrence analysis revealed the research foci and enlightened the research trends of SNA-based research in the construction domain. The findings indicated that the research foci in the construction domain are generally moving towards characterizing and addressing the complexity and dynamics of interproject relations. Also, the results of bibliometric analysis provided an intriguing insight that SNA-based research conducted in the construction domain can be placed into a categorization framework with two dimensions, including the type of network node and the level of network analysis.

Content analysis was carried out in terms of research topics, research designs, and research instruments based on the integrated categorization framework. The results of content analysis revealed that corporate- and industry-level research did not receive much attention compared to project-level research. Through reviewing the boundary specification methods and data sources, this study contributes to deepened understandings of how SNA was used in the construction domain. The results revealed that the exogenously defined method was widely used in the identified studies (except for industry-level research). Although surveys and interviews were the predominant data sources, mixed sources and databases have gained increasing popularity in recent years. Several novel insights also came to light by reviewing the research instruments of the selected studies. The results indicated that network research in the construction domain is still at an infant stage, with the vast majority of the investigations still primarily focusing on descriptively analyzing the structural characteristics of related networks. By contrast, scant attention has been paid to further characterize the dynamics and influences of the network structures using inferential statistical or simulation methods.

Compared with previous studies that focus on characterizing the application of SNA in construction research in specific domains such as project organization or complex project management, this study developed an integrated framework for the network research in the construction domain at project, corporate, and industry levels and provided future research suggestions from the perspectives of research topics, research designs, and research instruments. In the future, attention should be paid to enhance the breadth and depth of network research in the construction domain by investigating multiple types of dynamic interproject relations. By specifying the research situations, researchers can well distinguish related but distinct networks. Additionally, more attention should be given to methodologically defined boundary specification method and data triangulation with the help of online databases and state-of-the-art methodologies. It is also worth noting that multiple network constructs and Markovian models can create fertile opportunities for further research. Despite the promising findings and contributions of this study as discussed, this study is also subjected to the following limitations: first, it only included publications written in English. Future studies can extend to other languages; for instance, researchers can review the research interests and trends of Chinese publications and compare these with English language publications. Also, the identified 106 studies may not cover all relevant studies limited by problems such as diversity in terminology [31]. However, through conducting an additional manual search, the limitation of the database search can be mitigated. Besides, content analysis may be prone to cognitive biases. Nonetheless, this limitation can be mitigated through independently dual-coding and measuring the reliability of data collection.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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