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Exploring the Project-Based Collaborative Networks between Owners and Contractors in the Construction Industry: Empirical Study in China

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Abstract: In the project-based construction industry, organizations build collaborative relationships through specific projects. The owners and contractors who are the key project stakeholders have gradually formed a complex project-based industry-level collaborative network in many different projects, closely related to knowledge exchange and industry development. Based on the data set of the National Quality Engineering Award (NQEA) projects in China from 2013 to 2021, we empirically analyze the characteristics and evolution of project-based collaborative networks between owners and contractors in the construction industry by using social network analysis (SNA) and network motif analysis (NMA) method. The results show that (1) the owner–contractor collaborative network exhibits small-world network characteristics. The island effect caused by small groups in the network makes the overall connectivity of the network low. During the study period, the collaborative network became more compact. (2) State-owned construction companies, such as China Construction Third Engineering Bureau Corporation Limited, China Construction Eighth Engineering Bureau Corporation Limited, and China Construction Second Engineering Bureau Corporation Limited, with high degree centrality and betweenness centrality, are the core companies in the collaborative network. In China, state-owned construction enterprises are favored by owners and have established collaborative relationships with many owners and contractors. (3) There are two local collaborative patterns in the collaborative network: motif and anti-motif. Motifs include some triangle-based tight collaborative patterns, while anti-motifs involve some loose binary collaborative patterns. The results help understand the structure and evolution of the industry-level collaborative relationship network between owners and contractors and can provide references for owners and contractors to develop relationship cultivation strategies more effectively.

Keywords: social network analysis (SNA); network motif analysis (NMA); collaborative relationship; owner; contractor

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1. Introduction

The construction industry is a project-based industry. Construction projects are complex and usually involve multiple stakeholders. Among them, the project owner is the initiator of the construction project, and the contractor undertakes the construction tasks of the project [1,2]. The owner and the contractor collaborate on a specific project, and the collaborative relationship between them is essential to the success of the construction activity [3,4]. Due to the temporary nature of construction projects, an owner or a contractor constantly develops new collaborative relationships with new owners or contractors in new projects. The number of construction projects in China has grown substantially over the past decade. The contract value of new projects in 2021 was USD 5.12 trillion, three times that of 2011 [5]. The massive increase in the number of projects has involved more and more owners and contractors. Lee et al. [6] believed that owners and contractors had gradually formed a complex collaborative relationship network based on their intertwined collaboration in different projects. An organization's position in this collaborative network reflects its competitiveness in the construction market and its influence on the industry and determines its ability to access external resources and information [3,7].

As new projects are implemented, new participants and relationships are continuously embedded into the network. Therefore, the collaborative relationship network is dynamic, and this change will affect the exchange of information between owners and contractors and their future collaborative relationships [8,9]. According to the Industrial Marketing and Procurement (IMP) group, organizations should build long-term collaborative relationships to achieve mutual benefits and enhance competitiveness [10]. Studying the characteristics and evolution of the relationship network formed by owners and contractors in a certain period from a dynamic perspective helps understand their collaboration mechanism and the change of an organization's position in the construction market to provide a basis for formulating future collaboration strategies.

However, previous studies mainly focused on the one-time and short-term collaborative relationship between owners and contractors in particular projects [11,12]. There is a lack of industry-level exploration of the structural characteristics and evolution of the collaborative networks formed by numerous owners and contractors when they are involved in different projects. Although some studies on collaborative networks formed by different types of stakeholders in various projects involved owners and contractors, they focused on specific types of projects, such as skyscraper projects, BIM projects, and green building projects [13–15]. In fact, owners and contractors have formed intricate collaborative relationships based on their involvement in different types of construction projects. Studies based on broader boundaries can provide a more comprehensive insight into their collaboration.

Collaborative relationship network analysis is the foundation of organizational network governance, which is a long-term, selective, structured, and autonomous collection of organizations [16,17]. Unlike an organization concerned with maximizing its interests, organizational network governance focuses on the interactions between organizations and their performance in the network. Social network analysis (SNA) is a commonly used method to explore the macro-structural features of complex collaborative networks [18]. Meanwhile, the network motif analysis (NMA) method can be applied to analyze the local topology and micro-structural features of collaborative networks [19]. To bridge the knowledge gap in industry-level owner–contractor collaborative network research, we combined SNA and NMA to study the structural characteristics and dynamic evolution of the collaborative networks, which were established based on thousands of collaborative relationships among owners and contractors in the construction projects that won China's National Quality Engineering Award (NQEA) from 2013 to 2021.

This study aims to characterize the macro-structure and micro-structure of the collaborative networks formed by numerous owners and contractors involved in different projects and how they evolved over time by using the data of NQEA projects in China and combining SNA and NMA methods in order to help owners and contractors clarify their position in the partnership network and provide a reference for them to formulate future relationship cultivation strategies. The remainder of this study is organized as follows. In Section 2, the literature on the owner–contractor relationship and the collaborative network analysis in the construction field are reviewed. Section 3 presents the research methodology, and Section 4 explains the analytical procedures and data collection. In Section 5, the characteristics and evolution of the collaborative network formed by owners and contractors are analyzed based on SNA and NMA, followed by a discussion and some managerial implications.

2. Literature Review

2.1. Owner–Contractor Relationships

The collaborative relationship between owners and contractors affects the implementation of construction projects. Previous studies have analyzed the relationship between the owner and the contractor from three aspects.

First, some scholars explored the owner–contractor relationship in different delivery systems adopted for construction projects. For example, Li and Feng [20] explored the strategies for enhancing the trust relationship between owners and contractors in project management contracting (PMC) projects. Sun et al. [21] argued that effective collaboration between owners and general contractors improved the level of BIM adoption in engineering, procurement, and construction (EPC) projects. Collecting questionnaires from 243 Chinese project professionals, Zhang et al. [22] demonstrated that the level of design provided by the owner had an impact on the quality of the contractor's design in the design–build (DB) projects.

Second, some scholars explored the factors that influenced collaborative relationships between owners and contractors. For example, Suprapto et al. [23] revealed that relational attitudes, collaborative practices, and teams' joint capability influenced the collaborative relationship between the owner and the contractor. Jiang et al. [24] found that reputation, competence, honesty, communication, reciprocity, and contracts effectively influenced the establishment of trust relationship between owners and contractors. Zhang and Qian [25] analyzed how the mediated power influenced opportunism in owner–contractor relationships. Tai et al. [26] analyzed the factors influencing owners' trust in contractors in construction projects. Suprapto et al. [27] found that shared team responsibility, execution-focused teams, common capability and structures, and senior leadership pair can be effective in improving the relationship between owners and contractors.

Finally, the interaction mechanism between the owner and the contractor is also one of the research focuses. For example, Zhang et al. [28] discussed the combined influence of the owner's power and contractual mechanism on the behavior of contractors in China. Qian et al. [29] emphasized that there is both cooperation and competition in the relationship between the owner and the contractor and that when the two are balanced against each other, greater value can be created in the project for maximum benefit. Based on a contract management perspective, Nasir and Hadikusumo [30] developed an integrated model to manage the relationship between the owner and the contractor. Zhao et al. [31] believed that there was a strong reciprocity relationship between the owner and the contractor, and the parties accepted and maintained specific cooperation.

Although previous studies support understanding the collaborative mechanism between the owner and the contractor, their relationships were typically regarded as a binary structure or explored in the context of a specific project. A construction project is implemented by a temporary organizational alliance, which forms a temporary collaborative network [32]. The owners and contractors are constantly expanding into new project-based partnerships as they engage in new projects. From an industry perspective, they gradually form a long-term organizational network with a specific structure in project-based collaboration [33]. Project-based industry-level collaborative networks are more complex and dynamic than project-level networks, which characterize collaborative relationships within a single project. Analysis of project-based industry-level collaborative networks not only helps to understand an organization's position in the industry and its competitiveness in the construction market, but also reveal the organization's collaboration preferences, which can provide a basis for the organization to choose partners [34,35]. However, there is still a lack of research on the characteristics of owner–contractor industry-level collaborative relationship networks and the evolution of the network structures.

2.2. Collaborative Network Analysis in the Construction Field

In today's business environment, collaboration is seen as a way for organizations to acquire new business opportunities and facilitate the formation of a networked society [36].

Organizations can improve their market competitiveness by strengthening their position in the network [9]. As a result, the strategic focus of organizations has shifted from focusing solely on their operational performance to network-based collaboration and competition [37,38]. It is increasingly important to understand the relationship structure of the collaboration network and the position of the organization in the network.

Some scholars have adopted the social network analysis (SNA) method to study the collaborative network in the construction field from the industry perspective. The collaborative network formed by multiple different types of stakeholders is one of the research focuses. For example, Han et al. [13] studied the structural characteristics of the collaboration network formed by different owners, general contractors, design firms, and project managers involved in 422 skyscraper projects worldwide from 1990 to 2010. Tang et al. [14] explored the collaborative relationship network formed by owners, design consultants, and major contractors in Hong Kong's BIM projects from 2002 to 2017. Qiang et al. [15] explored how the collaborative networks formed by owners, contractors, and designers in the implementation of multiple green building projects evolve over time based on the SNA method. In addition, some scholars have studied the collaborative network formed by one or two kinds of stakeholders (such as the contractor–subcontractor collaboration network and the contractor–contractor collaboration network). For example, Tang et al. [35] studied the collaborative relationship between contractors and subcontractors in China's construction industry based on the data set of projects that won the China Construction Engineering Luban Prize, and the results provided a reference for contractors to choose subcontractors. Akgul et al. [39] used the SNA method to investigate the collaborative relationship of contractors in Turkey while participating in overseas projects based on the data from 449 projects in 46 countries. Liu et al. [40] used some indicators of the SNA method to characterize the collaborative network among contractors in China's construction industry. Liu et al. [41] analyzed the characteristics of the collaborative network among China's construction firms using the SNA method based on 251 international construction projects constructed by China's 156 construction firms in cooperation. Park et al. [42] investigated the collaborative networks of Korean construction firms formed in 389 overseas projects using the SNA method.

The above studies used the SNA method to describe the complex relationship and macro-structure characteristics of the collaborative network in the construction field. The research results can clarify the organization's influence in the owner–contractor collaborative network and provide a reference for organizations to develop cooperation strategies. The existing research mainly focuses on contractor–subcontractor collaborative networks, contractor–contractor collaborative networks, and collaborative networks among multiple types of stakeholders. The owner and the contractor are the main stakeholders in the construction project. They gradually form a certain relationship network by participating in multiple projects. Understanding the characteristics of the relationship network between the two is helpful for the owner to select contractors and the contractor's bidding decision. Although previous studies on collaborative networks of multiple types of stakeholders involved owners and contractors, they focused on a specific project type. At present, there is still a lack of research on the relationship network of owners and contractors at the industry level based on extensive project data. Moreover, the collaborative networks studies based on SNA focus on exploring the macro-structural features of the network but cannot reveal the local patterns of collaboration.

To explore the micro-structure of complex networks more deeply, researchers shift their attention from focusing on the global properties of the network to local properties. Milo et al. [43] proposed network motifs to reflect a particular local pattern of network interactions, providing new insights for understanding the network structure and relational characteristics. Network motif analyses (NMA) have been applied to explore biochemical networks, ecological networks, neurobiological networks, traffic networks, and energy networks [44–47]. There are also a few scholars who use it to explore the local structural characteristics in organizational networks [48]. It would be meaningful and interesting to explore the local relationship patterns of owner–contractor collaboration networks based on the method of NMA to discover the evolution of their collaborative patterns from a local network perspective. The introduction of NMA can overcome the limitation of SNA, which focuses on exploring the macro-structure characteristics of the network rather than the local properties. Therefore, we will combine SNA and NMA to analyze the owner–contractor collaboration network and to reveal the characteristics and evolution of the macro-structure of the overall network and the micro-structure of the local network.

3. Methods

The collaborative relationship between owners and contractors based on different projects involves a complex network connecting different organizations. To fully understand this relationship's structural characteristics and evolution laws, SNA and NMA are applied in the study. Specifically, SNA is used to capture the overall structural characteristics and node locations of the owner–contractor collaborative network from a macro-level. MNA is applied to discover the structure of subgroups in networks and reveal local collaborative patterns from a micro-level.

3.1. Social Network Analysis (SNA)

The measurement for the macro-structure of the owner–contractor collaborative network based on SNA includes the network-level and the node-level indicators.

3.1.1. Network-Level Measurement

In the SNA method, four network indicators, including density, average degree, average distance, and clustering coefficient, are generally used to analyze the characteristics and evolution of the network.

(1) Density

Density refers to the ratio of the actual number of connections to the maximum possible number of connections in the network and can measure the degree of interconnection between nodes in the network [49,50]. The value of density is between 0 and 1. When all nodes in the network are connected to each other, the value of density is 1. When the nodes in the network are all isolated, the density value is 0 [51]. The calculation formula of density D is as follows.

$$D = \frac{2E}{N(N-1)} \tag{1}$$

where E refers to the number of connections between these nodes, and N refers to the number of all nodes in the network.

(2) Average degree

The average degree refers to the average number of connections to a node in the network, reflecting the network's tightness [34]. The larger the value of the average degree in the collaborative network, the tighter the network is [52]. The average degree AD is formulated as follows.

$$AD = \frac{E}{N} \tag{2}$$

(3) Average distance

In the undirected network, the number of connections in a path between two nodes is defined as the length of the path, and the length of the shortest path is defined as the distance between the two nodes [53]. The average distance of a network is the average of the shortest path length between pairs of nodes in the network, and it is used to measure the ease of communication between nodes [54]. The average distance L is calculated as follows.

$$L = \frac{\sum_{i \geq j} d_{ij}}{N(N+1)/2} \tag{3}$$

where d_{ij} represents the shortest path length from node i to node j.

(4) Clustering coefficient

The clustering coefficient of a node is the ratio of the number of actual connections between the node and its neighbors to the number of the maximum possible connections between those nodes. The clustering coefficient of the whole network is the average of the clustering coefficients of all the nodes [55]. The clustering coefficient is used to describe the extent to which a node is embedded in the network's local group and reflects the aggregation extent of networks [56]. The value of the clustering coefficient ranges from 0 to 1. The clustering coefficient (CC) is 1 when all nodes are interconnected in the network, while CC is 0 when all nodes are not connected. CC is expressed as follows.

$$CC = \sum_{i=1}^{N} \frac{2e_i}{k_i(k_i - 1)} \tag{4}$$

where k_i is the number of neighbors of the ith node, and e_i refers to the number of connections between these neighbors.

3.1.2. Node-Level Measurement

In the network, the transmission of information is affected by the location of nodes. Centrality is a commonly used indicator to measure the location and status of nodes in the network, which helps figure out the core nodes, i.e., nodes that are relatively more connected with other nodes [57]. Betweenness centrality and degree centrality are two indicators commonly used for centrality analysis [58,59].

(1) Degree centrality

Degree centrality refers to the number of direct connections a node has to other nodes [60]. Additionally, the normalized degree centrality is defined as the ratio of the number of direct connections of a node and the total number of connections in the network [61]. Generally, the higher the degree centrality a node has, the greater its influence is on the network [62]. The normalized degree centrality $C_D(i)$ is calculated as follows.

$$C_D(i) = \frac{\sum_{j=1}^{N} e_{i,j}}{N - 1} \tag{5}$$

where $e_{i,j}$ is the number of connections between node i and node j, and N is the total number of nodes in the network.

(2) Betweenness centrality

Betweenness centrality reflects the extent to which a node is located on the shortest paths between pairs of other nodes [63]. The greater the betweenness centrality of a node, the more it can influence the connections between other nodes [64]. The normalized betweenness centrality $C_B(i)$ can be calculated as follows.

$$C_B(i) = \sum_{j<k} \frac{g_{jk}(i)}{g_{jk}} / \frac{(N-1)(N-2)}{2} \tag{6}$$

where $g_{jk}(i)$ refers to the number of shortest paths traversing node i, and g_{jk} is the total amount of the shortest paths between node j and node k.

3.2. Network Motif Analysis (NMA)

Network motifs are small connected subgraphs of 3–7 nodes that occur in real networks, the number of which is significantly higher than that in random networks [65,66]. Conversely, subgraphs that appear less frequently than in random networks are defined as anti-motifs [43]. The Z-Score is a statistical significance indicator, which is often used to determine the network motif and assess the importance of the motif structure in the network [67]. The Z-Score for each subgroup is represented as follows.

$$Z_i = \frac{N_{real_i} - N_{rand_i}}{\sigma_{rand_i}} \quad (7)$$

where N_{real_i} represents the number of occurrences of subgraph i in the real network; N_{real_i} represents the mean of the number of occurrences of subgraph i in the iterated random network; σ_{rand_i} represents the standard deviation of the number of occurrences of subgraph i in the random network.

Typically, $Z_i > 0$ represents that the number of occurrences of subgraph i in the owner–contractor collaborative network is greater than that in the corresponding random network. In this case, subgraph i is defined as a motif; otherwise, i is an anti-motif [43].

3.3. Analytical Procedures

We collected a longitudinal data set of the projects that won the National Quality Engineering Award (NQEA) in China and used the SNA and NMA methods to study the structural characteristics and evolutionary laws of owner–contractor collaborative relationship networks. Figure 1 depicts the analytical procedures, which consist of four steps: (i) Obtain the information on the owners and contractors of NQEA award-winning projects, (ii) Construct the owner–contractor relationship matrix based on the processed data and develop the owner–contractor snapshot network, (iii) Analyze the macro-structural characteristics of owner–contractor collaborative networks by using SNA, (iv) Discover the local collaborative patterns by using NMA.

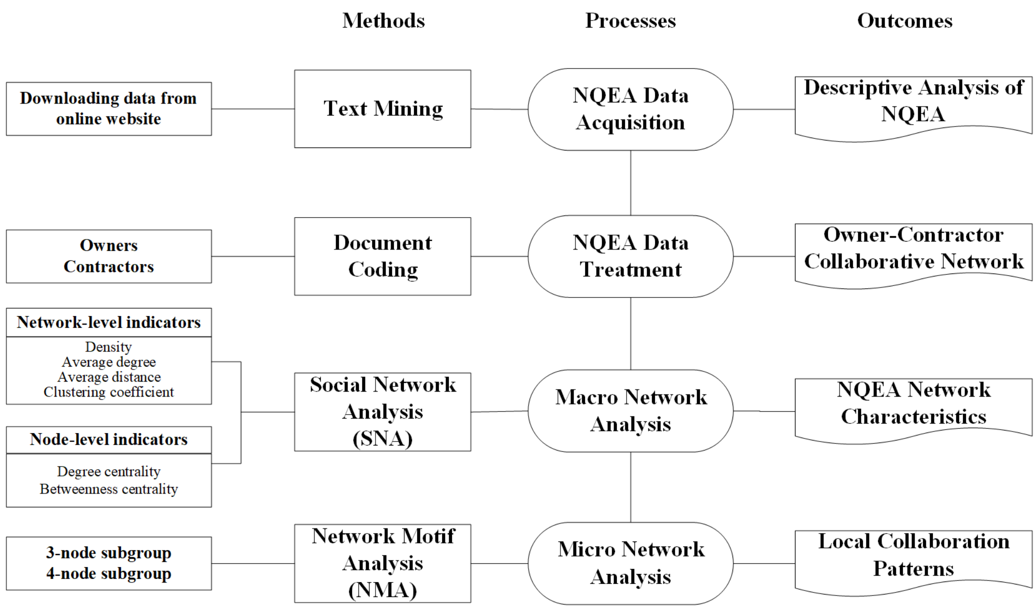


Figure 1. Analytical procedures.

3.4. Data Collection and Processing

China's NQEA is an award established to encourage construction companies to improve project quality. It was established in 1981 as China's construction industry's earliest and highest level national quality award. Generally, NQEA is awarded annually. The applicants include owners, contractors, designers, and some other enterprises participating in projects. The award projects must meet requirements such as excellent design, high construction quality, effective management, advanced technology, energy saving, and environmental protection. Projects in seven fields, including construction engineering, industrial engineering, traffic engineering, water conservancy engineering, and municipal engineering, are involved in NQEA. Among them, construction engineering projects account for 70% of the total number of award projects. The information on award projects, including project name, project type, year of winning the award, and project participants, is available on the official website (http://www.cacem.com.cn/ (accessed on 15 July 2022)) of the China Association of Construction Enterprise Management.

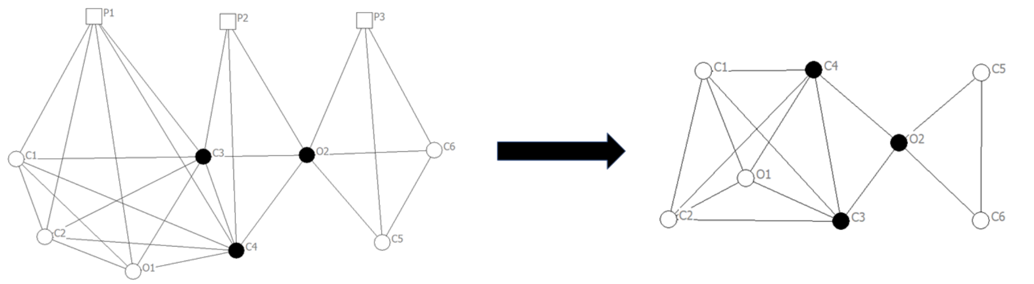
The NQEA project information provides a valuable data set for exploring the owner–contractor collaborative network. In this study, the data of 1371 construction projects that won NQEA from 2013 to 2021 were used to analyze the characteristics and evolution of the owner–contractor collaborative network in China's construction industry. These projects involved 1283 owners and 1560 contractors. The number of owners is smaller than that of projects because some NQEA projects have the same owners. In total, 1560 contractors are all the contractors included in the NQEA projects data set. Since some projects involve multiple contractors, the number of contractors is greater than that of projects. The descriptive statistics of the projects are shown in Table 1.

Table 1. Basic information on awarded projects.

Year	Number of Awarded Projects	Number of Awarded Owners	Number of Awarded Contractors
2013	104	105	185
2014	108	109	194
2015	133	135	256
2016	130	127	245
2017	164	161	301
2018	179	178	378
2019	173	173	342
2020	182	188	402
2021	198	201	452

We processed the project information collected in accordance with the following principles. First, for some large contractors with multiple tiers of subsidiaries, only the first-level subsidiaries were regarded as network nodes in this study. For example, China Construction Second Engineering Bureau Ltd., China Construction Third Engineering Bureau Ltd., China Construction Seventh Engineering Bureau Ltd., and China Construction Eighth Engineering Bureau Ltd. are all first-tier subsidiaries of China State Construction Engineering Corporation, one of China's largest construction companies. Therefore, they were displayed as different nodes in the collaborative relationship network. Second, we regarded the collaborative network between owners and contractors as an undirected and unweighted network. In other words, we only considered whether there was a collaborative relationship between an owner and a contractor, regardless of how many times they had collaborated. Third, we coded the enterprises in the network with an "O" for owners and a "C" for contractors and used different numbers to represent different enterprises. For example, C1446 represented China Construction Third Engineering Bureau Co., Ltd., and O68 represented Beijing Wangjing Souhou Real Estate Co., Ltd.

To understand the evolution of the network, a dynamic analysis of the network is required. For analyzing longitudinal networks, it is crucial to determine the optimal window size, which refers to the time interval between two snapshots. The NQEA is awarded annually, so we set each year as a time window to generate nine network snapshots over the study period from 2013 to 2021. Each network snapshot contains the awarded projects and the owners and contractors involved in that year. We constructed a two-mode network at each snapshot point. The network nodes were divided into two different sets in a two-mode network: the project set and the organization set. Figure 2a shows a schematic diagram of a two-mode network, where the square nodes represent the awarded projects, and the round nodes represent the awarded organizations. If a circular node is interconnected with a square node, the award-winning organization is involved in the construction project. Since project implementation depends on the organizations' collaboration, there are interconnections between the organizations involved in the same project. In addition, an organization may be involved in multiple projects and form a complex network of relationships with other organizations through different projects. For example, the black node C3 in Figure 2a is involved in both projects P1 and P2. Since this study aims to explore the collaborative relationship network between organizations, we converted the two-mode network consisting of the project set and organization set into the one-mode network containing only the organization set (see Figure 2b). Then, we established nine owner–contractor collaborative relationship matrices with the row and column 290 × 290, 303 × 303, 391 × 391, 372 × 372, 462 × 462, 556 × 556, 515 × 515, 590 × 590, 653 × 653, respectively. If there was a collaborative relationship between company i and company j at the snapshot time point, $r_{ij} = 1$; otherwise $r_{ij} = 0$.



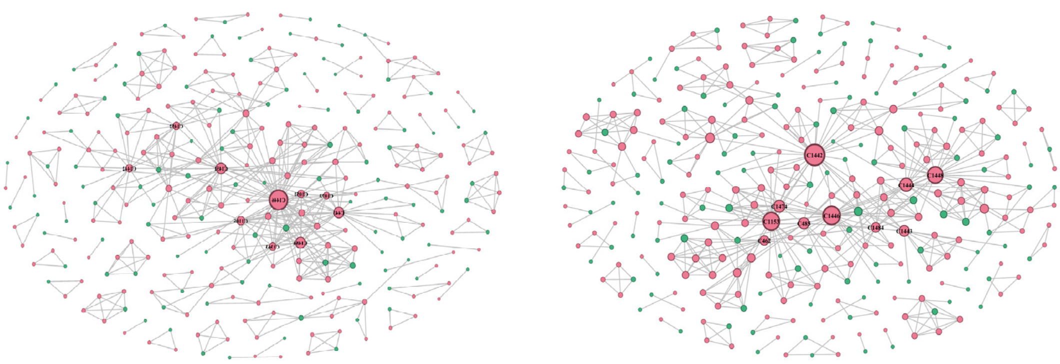
(a) (b)

Figure 2. Schematic diagram of project organization network: (**a**) two-mode network; (**b**) one-mode network.

4. Results and Discussion

4.1. Whole Network Topology

According to the established owner–contractor adjacency matrix, the topological diagrams of the collaborative relationship in nine snapshots are produced by Gephi software to show the evolution of the collaborative network (as shown in Figure 3). In Figure 3, the color of the nodes represents the type of companies, with green nodes representing the owners and pink nodes representing the contractors. The size of the node reflects the number of connections to this node. Specifically, the larger the node, the higher the number of connections to this nod, and vice versa. We can see from Figure 3 that the network structure at different snapshots is quite different. The number of nodes and connections in the collaborative network increases over time, which results in a larger network size. Furthermore, several significant components with many connected nodes can be found in each network.



2013 2014

Figure 3. *Cont.*

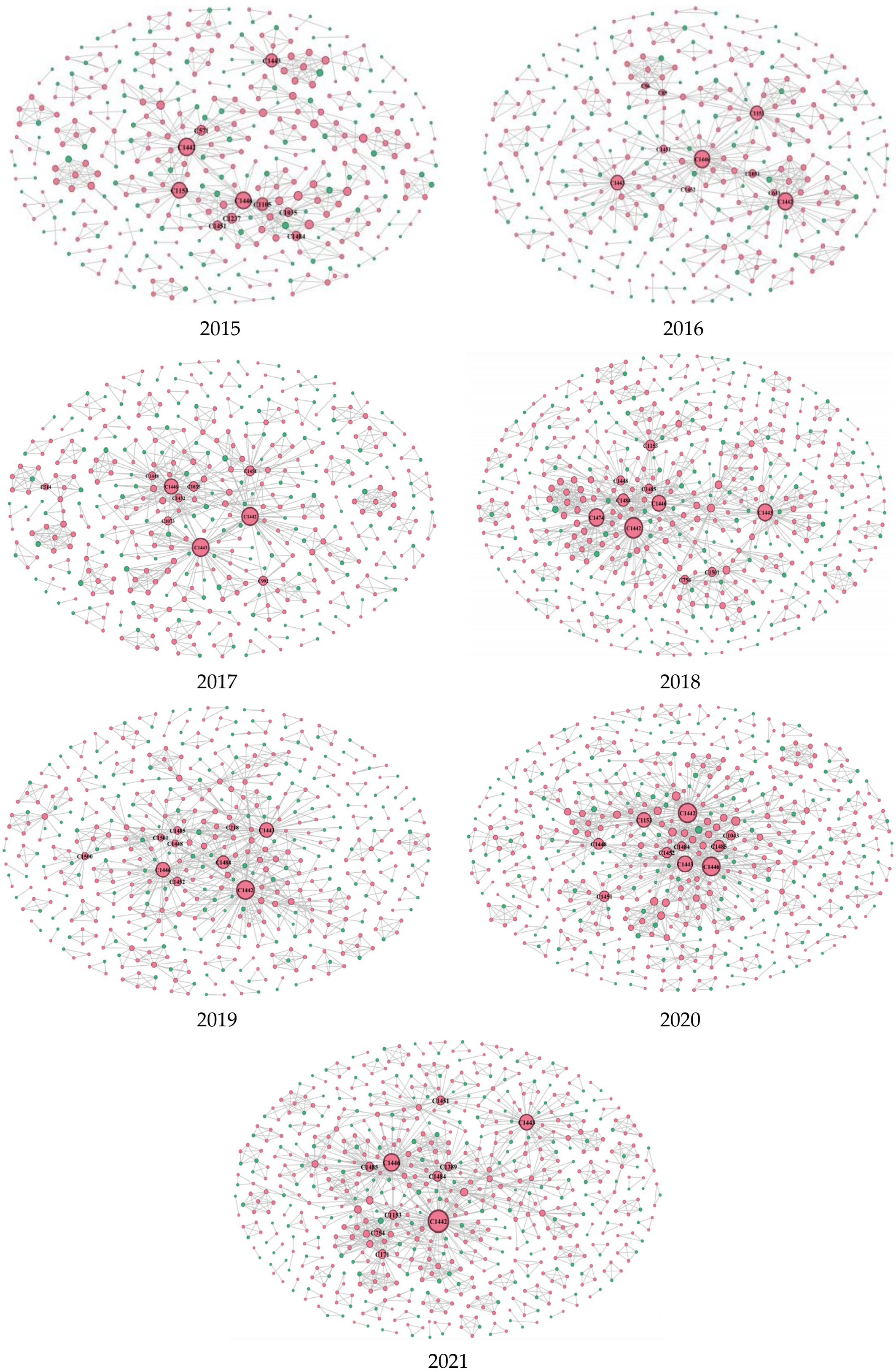


Figure 3. The topology diagram of different network snapshots.

4.2. Network-Level Analysis

4.2.1. Density

As an important indicator of the SNA method, network density reflects the connectivity of the network [51,52]. Figure 4 displays the evolution of the density of the owner–contractor collaborative relationship network over time. It can be seen that the density values for 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, and 2021 are 0.013, 0.013, 0.010, 0.011, 0.008, 0.008, 0.008, 0.008, and 0.007, respectively, indicating that the density was low and decreased during the study period. This is different from some research conclusions on the collaborative network [8,34,35]. For example, Tang et al. [34] studied the collaborative relationships between contractors and subcontractors, and the results showed that during the study period, the contractor–subcontractor collaborative network became denser and more connected between nodes. This may be because it is more flexible for contractors and subcontractors to establish collaborative relationships, and it is easy to collaborate multiple times. However, the owners of different projects are often different, and the contractors are usually selected by means of bidding, which makes establishing a collaborative relationship between the owners and the contractors more restricted. Therefore, the value of density of the owner–contractor collaborative network did not increase over time. A low network density indicates that some owners and contractors have little communication, which is not conducive to exchanging information and sharing knowledge in the collaborative network [58]. The gradual decrease in network density reflects the worsening of network connectivity. This is because some groups have appeared in the evolution of the network. The organizations within the group are closely connected, but they are less connected with the organizations outside the group, causing an island effect, which results in low connectivity of the network. Most of these groups with island characteristics are composed of medium-sized contractors that won few NQEA. Organizations in the island group should fully understand their dilemmas and strengthen cooperation with other organizations to improve the overall connectivity of the collaborative network.

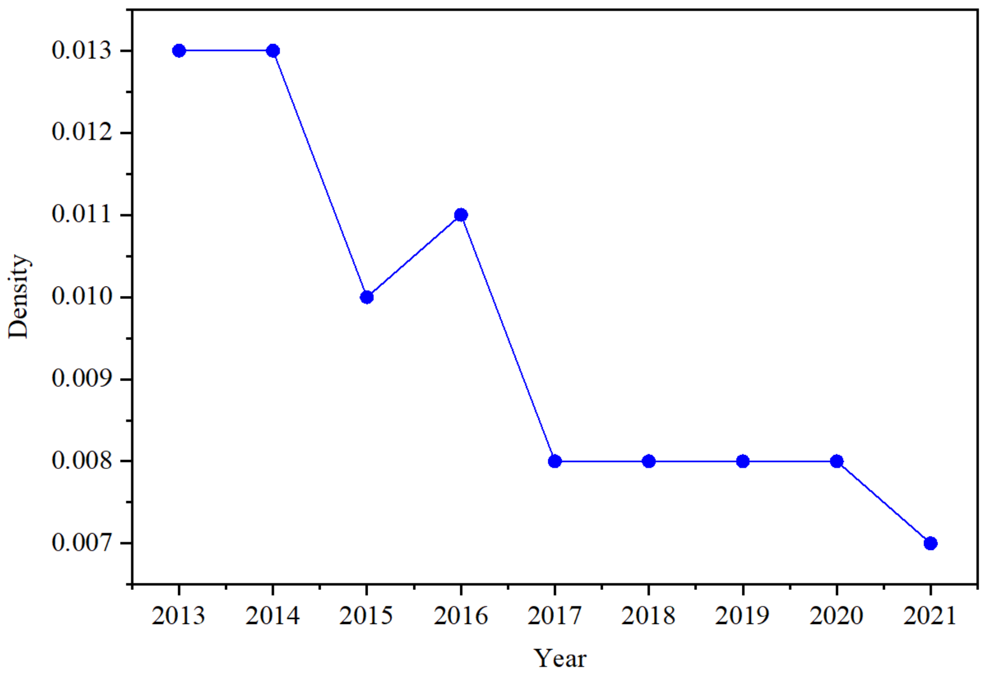


Figure 4. The density of the collaborative networks in 2013–2021.

4.2.2. Average Degree

The average degree is an indicator, which describes the compactness of the network and is the average number of connections (collaborative relationships) of a node (owner or contractor) in the collaborative network [68]. The higher the average degree, the more compact the network [69]. Figure 5 depicts the number of owners, contractors, and connections in the collaborative network from 2013 to 2020. During the study period, the number of nodes (contractors and owners) and connections in the network had increased, and the number of connections had increased more than that of nodes. This may be because the connection between nodes involves not only the collaboration between the newly joined contractors and owners but also the collaboration between the existing contractors in the collaborative network and the newly joined owners.

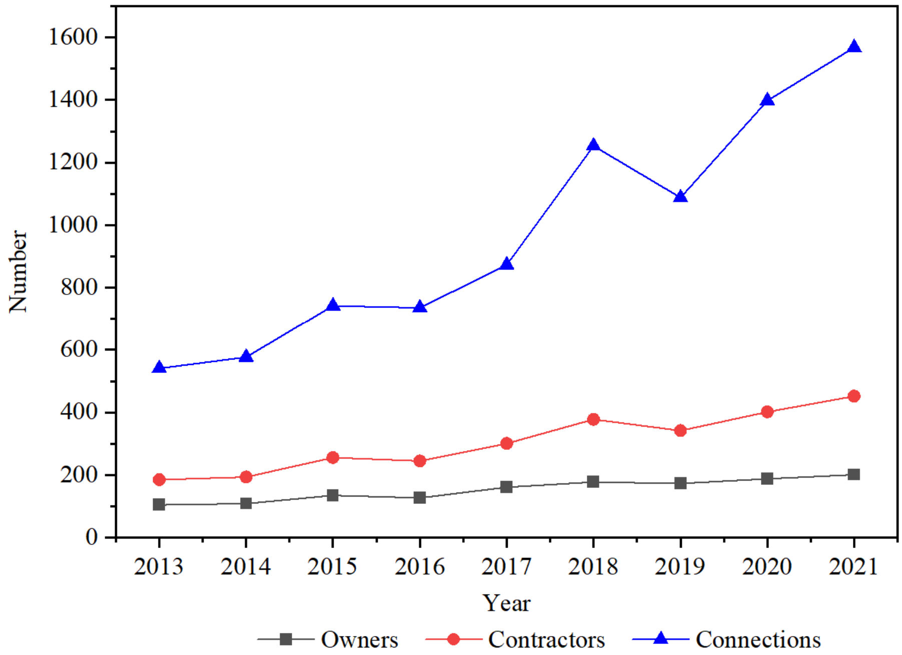


Figure 5. The number of owners, contractors, and connections in 2013–2021.

Figure 6 shows the change in average degree during the study period. It can be seen that the average degree of the collaborative network had increased over time, indicating that the collaborative network was becoming more and more compact. In 2021, the average degree of the owner–contractor collaborative network was 4.802, indicating that each node collaborated with at least four nodes, on average. Liu et al. [40]'s study on the collaborative relationships between contractors showed that the average degree of contractors' collaborative network in 2011 was 11.20, which is higher than the average degree of the owner–contractor collaborative network obtained in this study. Generally, a contractor can undertake several projects simultaneously or participate in a project together with other contractors. With the increase in the number of projects, the number of connections between different contractors also increased. Therefore, the average degree of the collaborative network of contractors is relatively high. However, for the collaborative network of owners and contractors, although the contractors of different projects may be the same, the owners are often different. This results in a relatively small number of relationships embedded in the collaborative network between owners and contractors, with a low average degree of the network.

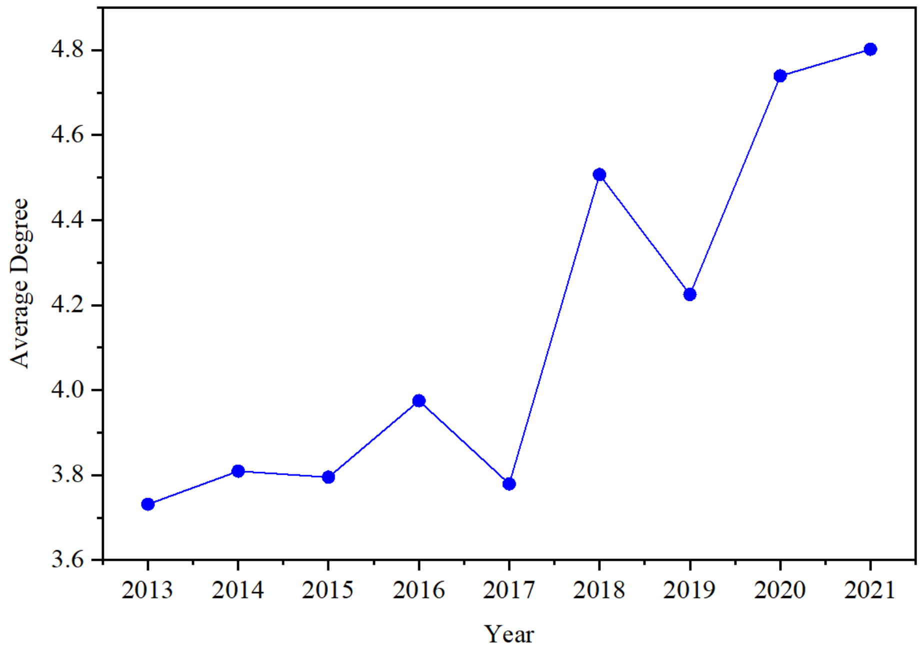


Figure 6. The average degree of the collaborative networks in 2013–2021.

4.2.3. Average Distance

In the organization network, the average distance refers to the average of the shortest path length between two organizations, which reflects the difficulty in communication between the two organizations and the possibility of information exchange [70]. Figure 7 depicts the variation of the average distance in the collaborative relationship network, as shown by the black line. In 2021, the average distance of the network was 3.719, which meant that it took about four steps from one node to another node. We can see from Figure 7 that the average distance of the collaborative network between owners and contractors in 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, and 2021 was 3.298, 3.269, 3.864, 3.230, 3.615, 3.557, 3.580, 3.389, 3.719, respectively. The value of the average distance in 2021 is greater than that in 2013, which means that compared to 2013, more intermediate nodes are needed to establish connections between two companies in the collaborative network in 2021. This is because some newly joined companies in the collaborative network happened to be located on the shortest communication path between the other two companies, resulting in the need for the two companies to communicate through more intermediaries.

4.2.4. Clustering Coefficient

The clustering coefficient can be used to reflect the degree to which nodes in the network are clustered. In general, nodes clustered in a group can communicate and collaborate more effectively [71]. Figure 8 depicts the change in the clustering coefficient of the collaborative relationship network during the study period. The clustering coefficient gradually increased from 2013 to 2021. In 2021, the clustering coefficient value was 0.935, which meant that the owner–contractor network was highly clustered. This is because most of the NQEA projects are large in scale, and the owners usually contract out the construction tasks to several contractors to complete together, which makes them form a closely collaborative group, and many highly aggregated groups improve the aggregation degree of the whole network.

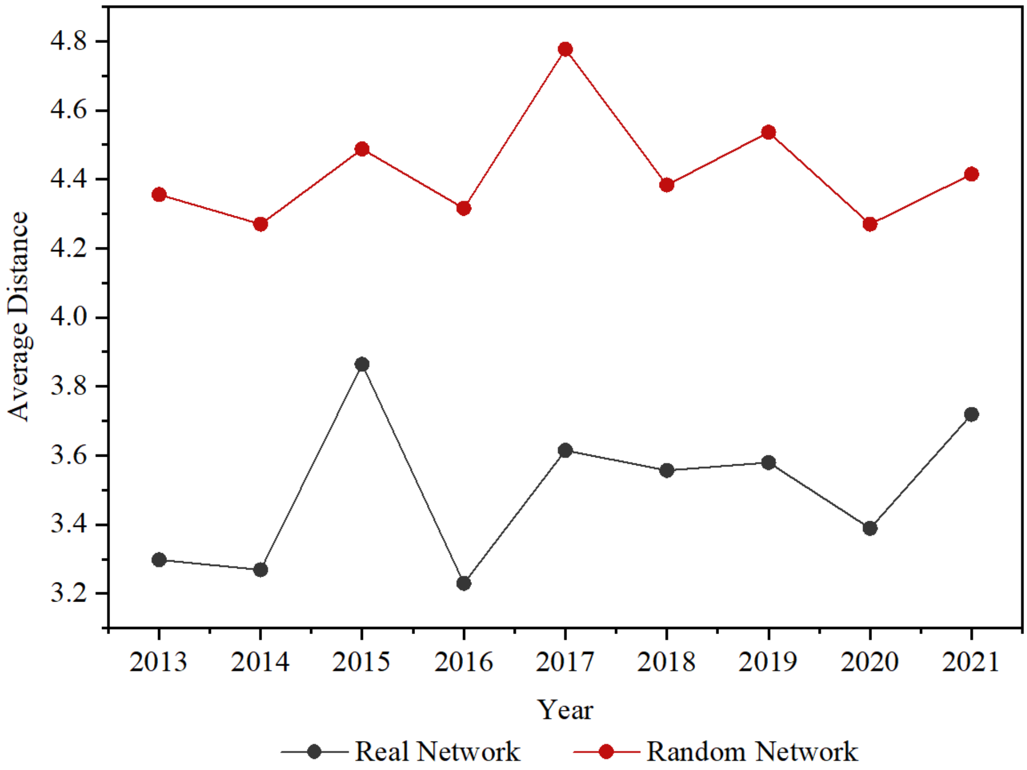


Figure 7. Evolution of the average distance of the collaborative networks in 2013–2021.

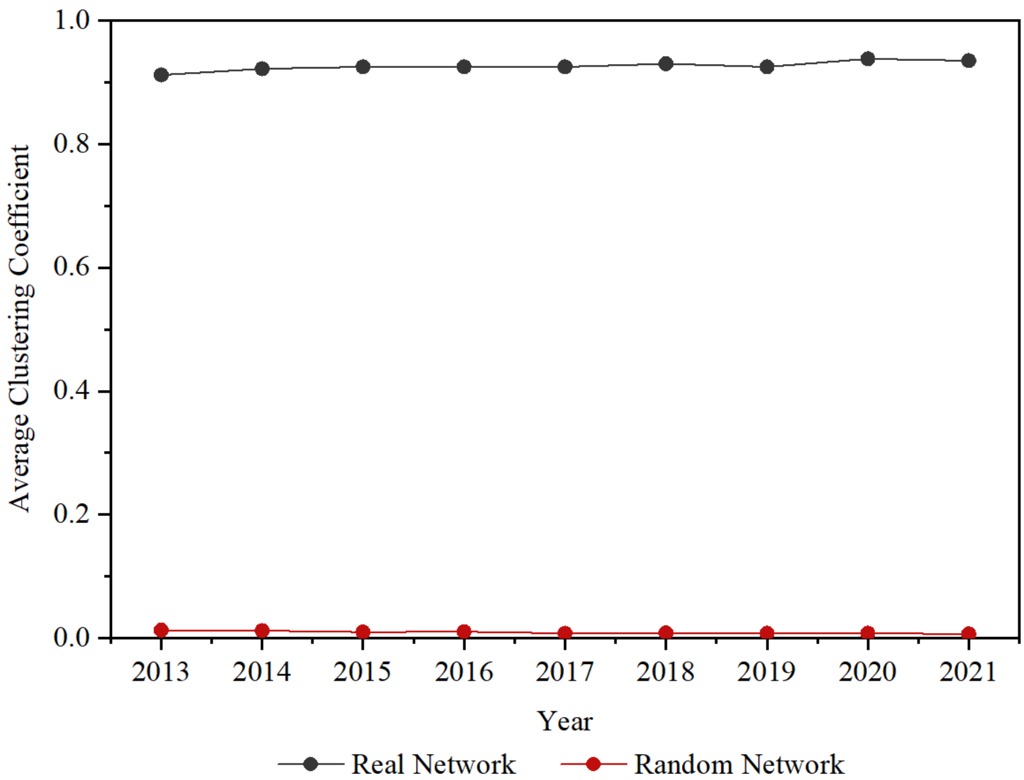


Figure 8. Change of the clustering coefficient of the collaborative networks in 2013–2021.

We further analyzed whether there was a small-world network in the owner–contractor collaborative network. Watts and Strogatz [72] and Neal [73] pointed out that if a network formed based on a specific rule had a larger clustering coefficient and a lower average distance than those of a random network with the same number of connected nodes and density, this indicated that the network had small-world characteristics. We randomly generate 100 networks with the same nodes and density as the owner–contractor collaborative network and calculate their average distances and clustering coefficients. Figures 7 and 8 show the mean distance and clustering coefficients of these 100 random networks, respectively, as shown by the red line. It can be seen that compared to random networks, the owner–contractor collaborative networks have lower average distances and higher clustering coefficients, that is, the collaborative networks have the characteristics of a small-world network. In a small-world network, the connection between two organizations requires only a few intermediary organizations, facilitating technology dissemination, capital accumulation, and personnel collaboration between the owners and contractors.

4.3. Node-Level Analysis

4.3.1. Degree Centrality

Degree centrality is the number of adjacent connections a node has in the network, reflecting the direct connection between nodes and other nodes [74]. In a collaborative network, the node with a high degree centrality has robust interactivity, significant influence, high participation degree, and it is at the core of the network [75].

Table 2 shows the top 15 companies ranked by the degree centrality of the collaborative network in nine snapshots. It can be seen from Table 2 that the degree centrality of C1442, C1446, and C1443 has consistently been ranked in the top three during the study period. This indicates that they are at the network's core and can be called core nodes. Compared with the other contractors, they have more experience in collaborating with owners and contractors. These companies exhibit the preference attachment effect, i.e., contractors who have won the NQEAs are more likely to acquire new projects and form partnerships with new owners.

Table 2. Top 15 companies ranked by degree centrality (DC).

No.	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	C1446	C1442	C1442	C1446	C1443	C1442	C1442	C1442	C1442
2	C1451	C1446	C1446	C1442	C1442	C1474	C1446	C1446	C1446
3	C1443	C1153	C1153	C1443	C1446	C1443	C1443	C1443	C1443
4	C1484	C1448	C1443	C1153	C1451	C1446	C1484	C1153	C1484
5	C1105	C1444	C1105	C1051	C1035	C1484	C1452	C1485	C1153
6	C1051	C1474	C1237	C1451	C992	C1153	C1485	C1452	C1451
7	C1442	C485	C571	C641	C1073	C1485	C1501	C1448	C1485
8	C1452	C1443	C1451	C96	C1448	C1501	C1500	C1451	C171
9	C1363	C1484	C1484	C85	C1452	C1448	C1448	C1043	C1389
10	C1073	C462	C1035	C1452	C514	C754	C218	C1484	C754
11	C1410	C1069	C1410	C1035	C1484	C628	C1405	C588	C1474
12	C238	C782	C517	C1039	C1501	C1451	C1451	C1389	C1452
13	C1159	O68	C83	C1105	C13	C1452	C1073	C41	C588
14	O353	C573	C1363	O403	C750	C1449	C664	C1474	C750
15	C57	C992	C803	C508	C1438	C1511	C998	C750	C714

C1446, C1442, and C1443 refer to China Construction Third Engineering Bureau Corporation Limited, China Construction Eighth Engineering Bureau Corporation Limited, and China Construction Second Engineering Bureau Corporation Limited, respectively, all of which are the subsidiaries of China State Construction Engineering Corporation Ltd. (CSCE). CSCE is one of the largest construction contractors in China, ranking seventh in ENR's 2021 Top 250 International Contractors list. C1446, C1442, and C1443 are the three subsidiaries with the most potent comprehensive competitiveness of CSCE. In 2021, the newly signed contract values of C1446, C1442, and C1443 were around USD 88 billion, USD 94 billion, and USD 59 billion, respectively, and the operating income was around USD 44 billion, USD 53 billion, and USD 30 billion, respectively. The three companies have branches in many cities in China, which provide conditions for extensive participation in project bidding and establishing collaborative relationships with owners. They all have advanced technology and excellent R&D talents and have won many high-quality engineering awards. From 2013 to 2021, C1446, C1442, and C1443 have won 106, 116, and 112 NQEAs, respectively.

4.3.2. Betweenness Centrality

Betweenness centrality is an indicator, which measures the degree to which a node acts as an intermediary, that is, the degree to which a node influences the flow of information between other nodes [76]. The higher the betweenness centrality of a node, the greater its influence on the information flow between other nodes [77].

Table 3 lists the top 15 organizations in terms of betweenness centrality at each snapshot point. It can be seen from Table 3 that C1442, C1443, and C1446 always had a high value of betweenness centrality over time. This means that these companies act as bridges in the owner–contractor collaborative network. It is worth noting that C1153 (Suzhou Golden Mantis Building Decoration Co., Ltd.), as a private company, also had a high betweenness centrality in the owner–contractor collaborative network. In 2015, C1153 had the most significant betweenness centrality. C1153 (Suzhou Golden Mantis Building Decoration Co., Ltd.) is a large listed company with building decoration and renovation as its primary business. It has been ranked as one of the top 100 building decoration companies in China for 19 consecutive years, and its business has spread to various cities in China and many overseas markets. From 2013 to 2021, the number of NQEA won by C1153 has increased yearly, totaling 41 awards. This is due to its continuous development in building decoration with a large team of interior designers and excellent decoration and renovation construction teams. These advantages increase C1153′s bidding competitiveness and make it easy to be favored by owners.

Table 3. Top 15 companies ranked by betweenness centrality (BC).

No.	2013	2014	2015	2016	2017	2018	2019	2020	2021
1	C1446	C1442	C1153	C1446	C1442	C1442	C1442	C1442	C1442
2	C1451	C1446	C571	C1442	C1443	C1443	C1484	C1443	C1446
3	C1443	C1448	C1442	C1153	C1446	C1446	C1446	C1446	C1443
4	C1410	C1153	C714	C1443	C1451	C1153	C1443	C1452	C1451
5	C1442	C1069	C1446	C1451	C1448	C1474	C1501	C1153	C1389
6	C1363	C485	C1105	C1452	C992	C1485	C1452	C1451	C1452
7	C1051	C1474	C750	C85	C1452	C1452	C1063	C1448	C1474
8	C1073	C1443	C1410	C1501	C1501	C754	C1500	C588	C1485
9	O250	C1445	C83	C1051	C64	C1448	C664	C750	C1484
10	C1452	C573	C1237	C1039	C1035	C1451	C750	C1474	C74
11	C1105	C819	C1484	C951	C1073	C1501	C430	C1405	C1512
12	C1237	C1484	C803	C540	C238	C992	C1512	C1043	C171
13	C1064	C1451	C517	C1105	C1153	C1484	C1485	C1485	C1153
14	C962	C1534	C1363	C641	C754	C1389	C1100	C737	C1448
15	C533	C171	C785	C96	C996	C540	C1405	C1389	C1258

We further analyze the attributes of the top 15 contractors ranked by degree centrality and betweenness centrality, as shown in Table 4. As can be seen from Table 4, among the top 15 contractors, there are more state-owned enterprises (SOEs) than private enterprises (PEs). This indicates that SOEs play a dominant and critical role in the owner–contractor collaborative network. Han et al. [78] also found that SOEs have high centrality and are the primary carrier of technological innovation in China's construction industry in the study on the collaborative innovation network of China's construction industry. State-owned construction enterprises often have substantial financial resources, government support, and extensive experience in contracting large-scale engineering projects. These advantages make it easier to develop collaborative relationships with owners and often collaborate with other subcontractors as a general contractor.

Table 4. Number of SOEs and PEs in the top 15 contractors in terms of degree centrality and betweenness centrality in 2013–2021.

No.	Degree Centrality		Betweenness Centrality	
	SOEs	**PEs**	**SOEs**	**PEs**
2013	8	7	8	7
2014	10	5	8	7
2015	5	10	4	11
2016	8	7	9	6
2017	11	4	10	5
2018	11	4	11	4
2019	12	3	10	5
2020	11	4	10	5
2021	10	5	10	5

4.4. Subgroup-Level Analysis

A network consists of several subgroups. Exploring the subgroup structure based on the NMA method helps gain a deeper understanding of the characteristics and evolution of the owner–contractor collaborative network. Unlike SNA, which focuses on the overall network structure and the role of nodes, NMA focuses on investigating the subgroup structure of the network. According to the number of award-winning projects and the number of organizations involved in the network, an average of three to four organizations (owners and contractors) are involved in each project. Therefore, we focus on the three-node subgroups and four-node subgroups of the owner–contractor collaborative network.

For the undirected unweighted network, there are two structural forms for the three-node subgroup and six structural forms for the four-node subgroup. Their topologies are shown in Figure 9.

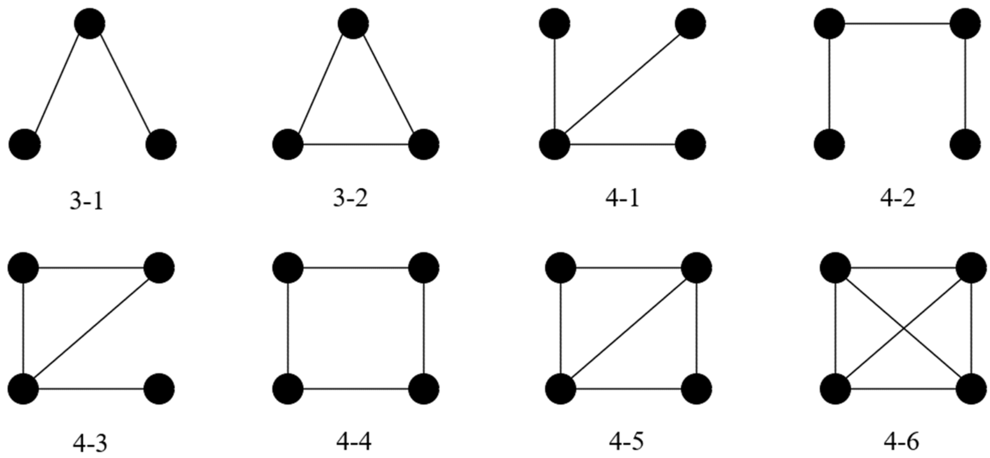


Figure 9. Topology of three-node and four-node subgroups.

We imported the data for each snapshot point into the Mfinder 1.2 software and performed 100 iterations, producing motif results for different subgraphs. The number of occurrences of a certain type of subgroup in the real network and the random network is shown in Figure 10. The Z-Scores of the three-node subgroups and the four-node subgroups in different snapshots are shown in Table 5.

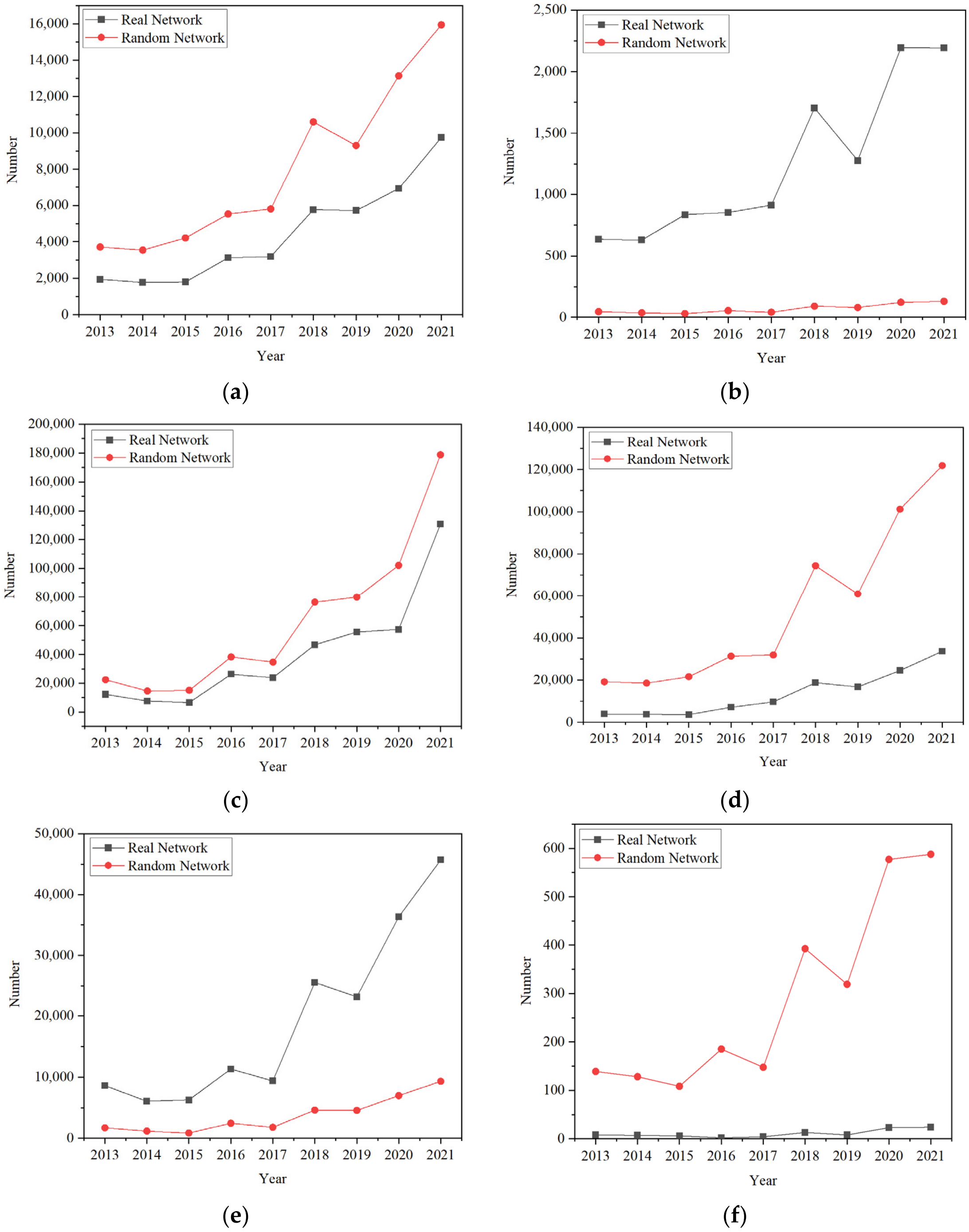


Figure 10. *Cont*.

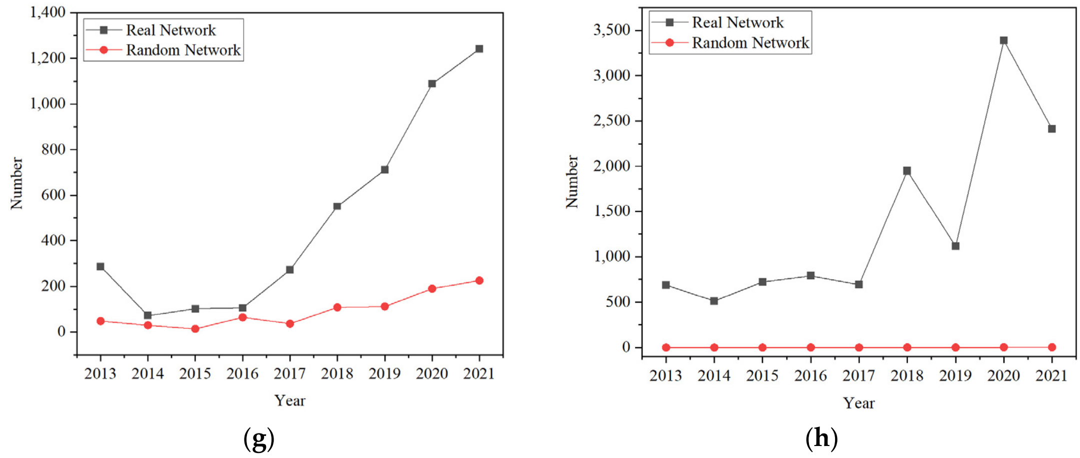


Figure 10. The number of three-node subgroups and four-node subgroups in real networks and random networks: (**a**) subgroup 3-1; (**b**) subgroup 3-2; (**c**) subgroup 4-1; (**d**) subgroup 4-2; (**e**) subgroup 4-3; (**f**) subgroup 4-4; (**g**) subgroup 4-5; (**h**) subgroup 4-6.

Table 5. Z-Score of all three-node subgroups and four-node subgroups in different snapshots.

ID	2013	2014	2015	2016	2017	2018	2019	2020	2021
3-1	−82.31	−80.88	−131.20	−86.88	−114.53	−154.19	−109.40	−131.68	−148.79
3-2	82.31	80.88	131.20	86.88	114.53	154.19	109.40	131.68	148.79
4-1	−31.39	−29.44	−46.49	−24.22	−25.65	−40.14	−27.96	−38.11	−30.86
4-2	−26.09	−29.19	−35.16	−25.84	−19.73	−31.30	−29.99	−34.85	−28.43
4-3	24.26	22.93	31.94	19.79	19.62	31.42	24.01	28.21	26.05
4-4	−7.45	−7.38	−6.75	−8.05	−6.96	−9.78	−9.78	−11.17	−10.56
4-5	11.75	3.10	11.13	1.54	12.60	12.18	12.97	14.08	12.83
4-6	921.86	850.89	2458.93	673.29	841.17	1098.79	614.04	971.35	674.41

It can be seen in Figure 10 that the number of three-node subgroups and four-node subgroups both increased in the real network and the random network during the study period. This means that the structure of owner–contractor collaborative networks in China's construction industry is becoming increasingly complex, and the collaboration between organizations is becoming more and more diverse. For the three-node subgroup, subgroup 3-1 always appeared more frequently in the random network than in the real network, while subgroup 3-2 is on the contrary. Table 4 shows that the Z-Score of subgroup 3-2 is positive, while that of subgroup 3-1 is negative. Thus, subgroup 3-2 is the network motif, while subgroup 3-1 is the network anti-motif. For the four-node subgroups, subgroup 4-1, subgroup 4-2, and subgroup 4-4 always appeared more frequently in the random network than in the real network, while subgroup 4-3, subgroup 4-5, and subgroup 4-6 appeared much more frequently in the real network than in the random network. It can also be seen in Table 5 that the Z-Scores of subgroup 4-3, subgroup 4-5, and subgroup 4-6 are all greater than 0, while those of subgroup 4-1, subgroup 4-2, and subgroup 4-4 are all less than 0. Therefore, for the four-node subgroup, subgroups 4-3, 4-5, and 4-6 are network motifs, and subgroups 4-1, 4-2, and 4-4 are network anti-motifs.

Motifs are fundamental patterns that recur in networks, and their frequency in real networks is significantly higher than in random networks with the same number of nodes and connections. Anti-motifs are just the opposite. The above results show that subgroups 3-2, 4-3, 4-5, and 4-6 are the motifs in the owner–contractor collaborative relationship network, that is, there are many local collaborative relationships of these forms in the network. Among them, subgroups 3-2 have the largest Z-Score in the three-node subgroup, and subgroups 4-6 have the largest Z-Score in the four-node subgroup. That is, subgroups 3-2 and 4-6 are the two most dominant subgroup structures in the owner–contractor collaborative network. As seen in Figure 9, these four forms are all generated based on the complete collaboration of the three organizations (containing at least one triangle). This subgroup structure facilitates the organization's efficient collaboration and the network's development. Subgroups 3-1, 4-1, 4-2, and 4-4 are anti-motifs in the owner–contractor collaborative relationship network. As can be seen in Figure 9, these four forms are mainly binary cooperation between organizations (containing no triangle) and do not have the basis for multiple collaborations. They are undesirable because they reduce the connectivity and cohesiveness of the network.

4.5. Managerial Implications

Based on the above results, the structural characteristics of the collaborative networks formed by owners and contractors involved in projects that won NQEA and the evolution of each organization's position in the network from 2013 to 2021 can be identified. Accordingly, the following management insights can be proposed for organizations to improve their collaborative relationships and thus contribute to the development of the organizations and the industry.

(1) The results regarding centrality indicated that some contractors, such as C1442, C1443, and C1446, always had a high degree centrality and betweenness centrality during the study period. These contractors are all subsidiaries of CSCE, one of China's largest contractors. The high value of degree centrality indicates that these large contractors have a lot of experience in collaborating with owners or other contractors and are at the core of the collaborative relationship network, while high betweenness centrality means that they have a significant impact on the owner–contractor collaborative relationship network. It can be seen that these organizations have played an essential role in the construction of high-quality projects in China. In the future, they should further play their leading role in developing the construction industry. Specifically, they can make efforts from the following three aspects. First, since new technology, such as blockchain and artificial intelligence, can effectively promote the high-quality development of construction industry, these companies can positively explore the application of these new technologies in construction projects. Second, completing high-quality projects requires constant materials and construction techniques innovation. Therefore, these companies need to increase the R&D efforts of new technologies and new materials and promote their application in construction. Third, these leading enterprises can actively participate in formulating relevant industry norms and technical standards to promote the industry's overall development.

(2) The results of density, average degree, average distance, and clustering coefficient showed that the collaborative relationship network became more and more compact during the study period. A compact collaborative network is beneficial for sharing new policies, technologies, and ideas, promoting industrial upgrading and high-quality development. Thus, more frequent interaction is required for the owners and contractors in China's construction industry to develop strong collaborative relationships. To this end, construction industry associations can often hold some technology-sharing activities to provide a good platform for promoting exchanges, giving small and medium contractors more opportunities to collaborate with owners and large contractors.

(3) As previously mentioned, some contractors who have won NQEAs in the past, such as C1142 and C1143, showed a preference attachment effect, which means that contractors who have won NQEAs were more likely to obtain new projects and establish partnerships with new owners. NQEA-winning collaboration projects must satisfy some requirements, including reliable quality, leading design ideas, and significant technological innovation achievement. Therefore, contractors who have won this award generally have good management capability, technical innovation ability, and construction levels. Awarding the NQEA further enhances the credibility of companies, which in turn helps the companies obtain new construction projects. This virtuous cycle can promote the development of enterprises. Consequently, construction

companies should pay special attention to improving their management capabilities and technical levels and follow the principle of excellence when undertaking projects to establish their industry reputation and lay the foundation for market expansion and collaborative relationship establishment.

(4) The results of NMA indicate that there are two local collaborative patterns in the network, i.e., motif and anti-motif. Motifs are mainly triangle-based collaborative patterns, and anti-motifs are binary collaborative patterns. Generally, project organizations can reduce the uncertainty in the search for collaboration and increase the likelihood of successful collaboration based on previous collaboration experience (relational embeddedness) and common third collaborator (structural embeddedness) [79,80]. The triangle-based collaborative pattern is beneficial for the organization to obtain information about indirect partners and can help the organization to establish contacts with indirect partners through direct partners, thus effectively expanding the scope of collaboration. Triangle-based motifs reflect collaborative patterns with structurally embedded features. The owners and contractors can deepen their partnership with more indirect partners to create opportunities to participate in more large-scale projects.

5. Conclusions

Collaboration between the owners and contractors is key to the success of a construction project. Recently, with the increase in construction projects in China, a complex collaborative relationship has formed between the owners and contractors. It is necessary to systematically and deeply understand the complexity and dynamics of this collaborative relationship. Based on the data of NQEA projects from 2013 to 2021, we adopted the SNA and NMA methods to establish a collaborative network between the owners and contractors in China's construction industry and analyzed the structural characteristics and dynamic evolution of the collaborative network.

The main findings of the study are as follows. (1) The collaborative networks formed by owners and contractors that have won NQEA in China became larger and more complex in structure during the study period. This indicates that the large number of construction projects in China has led to the involvement of an increasing number of owners and contractors who have formed an intricate network of relationships. In the evolution of the network, there have been island-like groups, where the organizations within the group are closely connected, but they are less connected to organizations outside the group. This result can help organizations in the isolated groups to understand their dilemma and suggest that they need to expand their cooperation with other organizations. (2) The results of the centrality analysis indicate that most of the organizations at the core of the network are large state-owned contractors who have rich resources and strong power. Their central position in the network indicates that they have had cooperative relationships with many owners and other contractors and have a large industry influence. There is a need to strengthen the driving role of these state-owned contractors in the development of China's construction industry. In addition, the results of centrality also show that most of the organizations at the core of the network have repeatedly won NQEA, such as China Construction Third Engineering Bureau, China Construction Eighth Engineering Bureau, and China Construction Second Engineering Bureau. This suggests that there is a preference attachment effect in the construction market, i.e., winning NQEAs for quality construction work gives them more opportunities to undertake new projects and form new partnerships with new owners and other contractors. (3) The results of NMA show that the collaboration patterns between owners and contractors have become complex and diverse over time, consisting mainly of sparse binary collaboration patterns and tight multiparty collaboration patterns. Multiparty collaboration patterns are increasingly present in the network, making the network more locally clustered. This indicates that more and more organizations form multiparty collaboration networks with other organizations when participating in new projects, laying the foundation for future participation in the fierce competition in the construction market. Organizations with only a binary cooperation model can also draw inspiration from this finding that they need to establish broader cooperative relationships with other organizations by contracting more projects.

This study brings the following knowledge contributions. First, this study enriches the existing body of knowledge on owner–contractor collaborative relationships by shifting the focus from one-off and short-term cooperation in a specific project to the collaborative relationship network at the industry level. Second, the evolution mechanism of the owner–contractor industry-level network is studied from a dynamic network perspective, which expands the study of the organizational network in the construction field and fills the gap in the research on the owner–contractor collaborative network. Third, the findings provide valuable insights into understanding the evolution of China's owner–contractor collaborative relationship and provide a basis for collaborative network governance and organizational collaboration strategy formulations. Fourth, this study proposes a method, which combines SNA and NMA to reveal the characteristics and evolution of the network's overall macro-structure and local micro-structure, providing a research idea for mining cooperation information from industry-level project-based social networks. The interdisciplinary network motif concept is introduced to characterize the local relationship patterns of the network and collaboration mechanisms of subgroups, and SNA is used to explore the network's overall characteristics and nodes' position. SNA and NMA complement each other and advance the understanding of the network properties and structural embeddedness. The method and ideas in this study can also be used to explore the collaborative relationships between stakeholders in the construction industry of other countries.

Although the study brings the above contributions, there are still some limitations. First, we only studied the collaborative network of owners and contractors based on the data of the NQEA project in China. In the future, data sources can be expanded for more in-depth research. Second, we only focused on the collaborative relationship between owners and contractors. However, a construction project involves many participants, such as subcontractors and designers. Future studies can include these stakeholders to better understand the collaborative relationships between different stakeholders. Third, we only discovered the three-node subgroups and four-node subgroups; however, some large projects may involve more owners and contractors. The structure of more node subgroups can be further explored in the future.

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