Collaborative Innovation in Construction Project: A Social Network Perspective

Xiaolong Xue* *Ph.D., Professor*

School of Management, Harbin Institute of Technology, Harbin, China; Email: xlxue@hit.edu.cn

Ruixue Zhang Ph.D. Lecturer

School of Business Administration, Liaoning Technical University, Liaoning, China, Email: asnow1860@163.com

Liang Wang Ph.D. Candidate

School of Management, Harbin Institute of Technology, Harbin, China, Email: 14b910008@hit.edu.cn

Hongqin Fan, PhD., Associate Professor

Department of Building and Real Estate, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China, Email: bshfan@polyu.edu.hk

Rebecca J. Yang Ph.D., Senior Lecturer

RMIT University, School of Project, Construction and Property Management, Australia Email: rebecca.yang@rmit.edu.au

Jason Dai Ph.D., Benchmarking Analyst

ConocoPhillips Company, Houston, Texas, USA, Email: jiukun.dai@gmail.com

ABSTRACT: Successful innovation requires effective cooperation and working relationships among different parties within construction projects. In order to promote construction innovation performance, it is important to shed light on the internal mechanism of innovation through investigating collaborative relationships from a network perspective. In this case, the formation of collaborative relationship can be viewed as a potential generator of innovation processes, and relationship network indicates information exchanges among organizations. This article investigates the collaborative relationship network in a commercial complex by using social network method and in-depth quantitative data analysis. Social network method is widely applied in innovative research. Combined with quantitative data, it is able to quantify and visual the interaction relations of innovation stakeholder. The analytical results will be more objective and reliable. The results illustrate the relatively dense collaborative relationship networks and highlight the roles that the key members played in the innovation process. The decomposition of collaborative relationship with network analysis contributes to a better understanding of innovation process in construction projects. In particular, key nodes which influence construction innovation through collaborative relationships are revealed and analyzed.

Keywords: Collaborative relationship; Innovation; Construction project; Social network analysis; Relationship network

1. Introduction

Innovation makes great contribution to curtailing duration and spending, improving quality, and being environmentally-friendly in construction (Slaughter, 1998). It is essential for any industry progress (Gambatese and Hallowell, 2011). Construction is a project-based, service-enhanced industry (Gann and salter, 2000; Zhang, 2011). Most construction innovations activities are carried out at project level and need cooperation among different participants (Barret, 2007) which make their analysis more important. Construction project team is a project-based temporary coalition，involving multiple parties. Although, to encourage innovation，the different parties have their own separate responsibilities and roles, relationships and interactions among them are critical factors which determine the success of innovative projects (Widén et al. 2014; Liu et al.2016). Innovation needs to combine new and existing knowledge (Fleming, 2001), which is inherent in these social interactions. Many scholars have proved that the effective cooperation relationships among participants are prerequisites for successful innovation within projects (Kumaraswamy et al. 2004). Shan et al. (1994) stated that collaborative relationship's quantity in a corporation positively affected its innovative outcomes. Collaborative interaction, acting as a channel to strengthen the understanding of cooperation and acquiring a better konwledge about client demands which is proved to be an important factor in innovation, is beneficial to improve the information flow from the supply side to the demand side (Laursen et al., 2012). The positive impact of collaborative relationship on innovation can be traced back to the participants who can gather and recombine knowledge from those industries and hence be innovative. Despite the importance of collaborative relationship, there is a challenge of what collaborative relationship is likely to improve innovation performance. Hence, this study aims to investigate the associations between collaborative relationship and innovation within construction project, thus identify the key factors which influence the construction innovation.

Coordination in construction often involves a large number of participants and subsequent interconnections. These interconnections are multilayered, including multiple relationships, conceptualized as a relationship network (Pryke, 2012). Through the network relationship, participants are able to secure a stable flow of resources (Thorelli, 1986) and tap into their partners 'opportunities' (Inkpen, 1996). However, it is the accelerated opportunities for information and knowledge sharing coupled with the information flow provides the greatest advantage within networks (Conway, 1995; Powell et al., 1996). In previous studies, it was commonly agreed that collaboration network plays the role of medium in resource exchange and makes the information source more informal. They are two key factors in innovation (e.g., Fleming *et al*, 2007). These findings provide theoretical foundations to investigate collaborative relationships on construction innovation from a network perspective. It is meaningful to apply network analysis to investigate the features of relationship network and the effect of relationship network on construction innovation. This study aims to identify the key factors which influence the construction innovation through the analysis of relationship network. This study will answer the following research questions:

- What formal and informal information networks are formed through the collaborative works on construction innovation?
- What roles do participants play in relationship networks during innovation process?
- How to improve innovation output by proposing suggestions on collaborative relationship?

A case study on a commercial complex project in China is conducted in this study to obtain in-depth understanding of the relationship networks during innovation process. This paper is structured as follows: First, previous research on construction collaborative innovation, the main elements of network structure and the effects of networks are identified and discussed. A description of the case study and discussions on research findings of the empirical investigation follow. Finally the implications for future research on project networks are explored.

2. Literature Review

2.1. Collaborative relationships in construction

Collaboration is viewed as a reciprocal process where individuals or organizations work together. Generally, participants would like to form a collaborative relationship where they can share knowledge and resources to increase benefits rather than working alone (Son and Eddy, 2011). To improve the construction development process, many collaborative arrangements can be adopted such as partnering, prime contracting, joint venture, supply chain management and public private partnerships. Some collaborative approaches are used, such as e-Commerce technology(Castro, et al., 2003), DSS(Chau, et al., 2002) and 4D/VR (Dawood, et al., 2003)and so on. However, not all of the collaborative arrangements are effective (Akintoye, 2007). Construction involves a large number of key stakeholders that need close collaboration, for instance, the main contractor and specialist contractor or project client, various suppliers or consultants including partnerships, project or long term strategic alliances or joint ventures. In construction, the upstream is the collaboration between main contractor and client while the downstream is the collaboration between main contractor and specialist.

Loraine (1994) stated that, in the management of traditional construction projects, the lack of rapid responsiveness in the vertical organizational relationship framework hinders innovation. Partnering management aims to convert the adversarial relationship among the participants in traditional projects into a relationship with common benefits. Therefore, creating a win-win situation by avoiding or reducing the dispute and claim and ensure the interests of all participants in the project (Kumaraswamy, 2000). Partnering in construction is widely recognized as a collaborative relationship (Beach et al., 2005). The partnering can be divided into two kinds: project partnering dealing with a single project and strategic partnering focused on multiple projects. They can both describe collaborative relationship and separately be short-term and long-term (Meng, 2012). The participants in construction projects establish a project-based temporary coalition through partnering. Pryke(2005) defined coalition in construction as a multilayer of interdependent networks, such as contractual relationships, performance incentives, and information exchange. The short-term collaborative relationship among participants determines the nature of their cooperation experience and that they will never work together again. Paulraj et al. (2007) regard inter-organizational communication as a relational competency to generate various relationships. Favorable relationships could take place through effective communication and coordination among collaborative partners.

Inter-organizations collaborative ties act as channels of communication provide more opportunities for learning, knowledge transfer and hence innovation. So, to some extent, collaborative relationships are formed by informal communication and social mechanisms. However, construction management practice is often described as having inadequate coordination and inefficient communication (Costa and Tavares, 2012).

Collaborative relationship network and its effects on innovation have been reviewed in prior research. The networks affect innovation, starting with possible of inter-organizational collaboration which stimulates knowledge sharing and interactive learning among partners (Powell and Koput, 1996). Innovative behavior is the process of knowledge recreation, and the external sources are usually the necessary elements of the input through inter-organizational collaboration. Research in the field of inter-organizational cooperation and innovation is often categorized as 'network research'. Scholars identified a strong correlation between knowledge transfer among organizations and the innovative process in relation to networks and collaborative relationships (Liebeskind et al., 1996). Networks can be regarded as a new kind of organization within knowledge production: they encourage learning inside the firm, complement the resources that the firm already has through interaction with the others and make the exploration of synergies possible by combining different competences. Thus, collaboration networks bring a range of resources, create opportunities for knowledge flow and stimulate innovation (Liu, 2011). Previous research has examined how network ties and structure affect innovation (e.g., Tsai, 2001; Obstfeld, 2005).

Network structure is interpreted as the pattern of relationships among a series of actors, and network composition is interpreted as the kinds of actors in a network distinguished for their stable traits, characteristics, or resource endowments (Wasserman and Faust, 1994).

2.2. Social Network Analysis

Social network analysis (SNA) analyzes the interactions and interrelationships of a series of actors and adopts a methodology to explore the conditions of social structures (Hu and Rachera 2008). This helps understand the network relationship through describing, visualizing, and statistical modeling (Van Duijn and Vermunt, 2006). It has been used on the exploration of diseases spread (Klovdahl, 1985) and innovation diffusion (Abrahamson and Rosenkopf, 1997). Also in the graphs or sociograms created by the SNA, the nodes represent individuals and the links between the nodes represent the relationships between the individuals, like information exchange (Chinowsky et al., 2008). SNA places more emphasis on the measure of relationship between individuals than the features of individuals' behavior.

SNA has been used to investigate the various relationships among individuals and organizations and knowledge diffusion in the social sciences and economics. Many researchers have studied the relationship between a global inter-firm innovation and adopt the quantity of patents as the measure of the firms' innovation and knowledge diffusion in the different industries including chemistry, wireless telecommunications and high-technology manufacturing, such as automotive bodies, computer and office equipment, and aerospace equipment (Ahuja 2000; Cowan et al. 2007; Schilling and Phelps 2007; Leiponen 2008). SNA views the relationships between construction organizations as a multi-layered independent network structure. It can visualize the collaboration in construction project coalition. As such scholars begin to adopt SNA to investigate the network relationship among construction organizations (Taylor and Bernstein, 2009), for instance, Loosemore (1998) investigates the interpersonal relationships in construction projects under the crisis condition of The United Kingdom construction industries and stresses the importance of contractual relationship. Based on the researches on diplomatic relations among countries and the features of construction projects, Pryke (2006) divided the relationship network among organizations in the construction project into information exchange relationship networks, contractual relationship networks and performance incentive relationship network.

Prior research has been undertaken on the social network analysis in the field of construction. Thorpe and Meade (2001) investigated every frontline supervisor on two questions: who did he/she communicate with and how often did he/she communicate with the others in the same project team. They adopted social network analysis to figure out key members of the team in accordance with communication and concluded that the effectiveness of project management systems will be quickly lost as soon as one of the key members quit. Social networks are supposed to contribute to the improvement of the communication performance of supervisors' groups. Di Macro et al. (2010) surveyed two cross-cultural project teams that execute complex, reciprocally interdependent engineering design projects. They demonstrated the communication patterns by SNA and make both quantitative and qualitative analysis about the interactions among different cultures. They figured that individuals expelled from Indian act as the character of cultural boundary spanning reducing the conflicts in knowledge system among different cultures and improving the effectiveness of collaboration.

Many research works focused on organizational collaboration in complex engineering tasks. SNA is also widely applied in this field. Heedae Park and Seung (2011) analyzed collaboration in the construction field and proved the applicability of SNA. They also discussed many collaboration patterns and the effect that they have on performance. Pryke (2004) believed that SNA is a significant tool in analyzing the inter-firm relationships which contain construction project collaborations. Hossain and Wu (2009) discussed the relationship between network centrality and project-based coordination. They used SNA techniques to explore the correlation among the network positions and coordination through an email dataset. In their analysis, it depicts how communication and information exchanges between actors. They found that, in the network, the capability of coordination positively affect the actors' centrality.

Collaboration networks' effect on innovation has received less attention in the construction industry. The way the project managers act on cooperation is critical for success in innovation. This study will demonstrate a collaborative network to identify the detailed properties of the network affecting innovation and study how collaboration patterns contribute to knowledge and information sharing performance and hence to innovation.

2.3. Network Properties

Density

Density describes the extent of how densely and cohesively the nodes in a network are interconnected (Pryke, 2004). It calculates the number of existing relationships in a network as a proportion of the maximum possible number of relationships. Density reflects the close relationship between nodes in a network. The density and number of relationships which exist between the network actors have a positive correlation. Therefore, a network with higher density has closer relationships, which eventually contributes to information sharing, knowledge diffusion, resource delivery and innovation. It also can be deduced that it is associated with greater cooperation and information sharing (Sparrowe et al.2001). Density has been regarded as the indicator that is the most widely used in the network’s connectivity, as shown in the following equation:

$$Density = l/(n^*(n-1))/2 \qquad (1)$$

l represents the number of existent lines and n represents the number of existent nodes.

Centrality

Centrality reflects the distribution of relationships though the network (Chinowsky et al., 2008). It is the indicator that describes the extent of how important an individual node in a network. An individual who has higher centrality than the others occupies an extraordinary socioeconomic position and significantly affects the behaviors of the others (Mizruchi, 1994). The centrality of an individual determines his social position (Freeman, 1979), reputation (Burt, 1982), and power (Coleman, 1973).

There are different types of centrality measures. The most popular ones are degree centrality, closeness centrality, and betweenness centrality. Degree centrality indicates the number directly linked to the nodes. InDegree is the number of connections each node has from other nodes, and OutDegree is the number of connections each node has to other nodes. A high degree centrality node has greater connectedness than other nodes. Degree centrality is used to analyze descriptive views of networks at the macro level (Park et al., 2011). Closeness centrality describes the degree of closeness of a node to the others in a network (De Nooy et al. 2005). It is a measure of a node's autonomy or independence. A high closeness centrality node has less restraint effects on the others, at the same time it also reflects the ability to acquire information through the other nodes. Betweenness centrality describes to the extent to which a node lies between every pair of the remaining nodes. It represents the potential control and impact of a node in the network (Marsden, 2002). A high betweenness centrality node has more control over resource, and greater capacity to influence the other nodes. The following Eqs(2)-(4) describe the mathematical centrality forms.

$$\text{Degree centrality} C_i = \frac{\sum_{j=1}^{n}(z_{ij}+z_{ji})}{\sum_{i=1}^{n}\sum_{j=1}^{n}(z_{ij})} (0 \leq C_i \leq 1) \quad (2)$$

In which Z_{ij} represents the number of degree that a node i receives from a node j and n represents number of existent nodes.

$$\text{Betweenness centrality (of node i)} = \sum_{s,t;s\neq t\neq i} \frac{\sigma_i(s,t)}{\sigma(s,t)} \quad (3)$$

In which $\sigma_i(s,t)$ represents the number of shortest paths from node s to node t that pass through node i.

$$Closeness\ centrality\ (\ of\ node\ i) = \frac{n-1}{\sum_{k\in N} d(i,k)} \quad (4)$$

Here n represents the number of nodes; N represents total number of nodes; k is the k node in the network; and $d(i,k)$ represents the length of the shortest path between node i and k .

2.4. Role of key individuals in the innovation

Many researchers have emphasized the importance of key individuals in the innovation process. The key individuals should be identified in the innovation process(Widén et al., 2014). The key individuals play different roles such as gatekeeper, coordinator, and champion, and different functions in the innovation process. Table 1 summarizes the characteristics of these roles.

Gatekeeper: Allen (1970) pointed that "gatekeepers" is the individuals that acquire information from external sources and then transfer the information internally. The major function of the gatekeepers is that they can create an access to the outside and make the purpose of obtaining important external resources possible (Aldrich and Herker, 1977). Therefore, in the organizations, gatekeeper should be regarded as a significant channel to gain access to important external information. In relationship networks, the gatekeeper links the external project environment to the internal network and always shows a more peripheral position in the network. In the internal network, it also rests on the place that has the most connections to the external world and consequently has high density and high InDegree.

Coordinator: The coordinator has the ability to lead or guide the other members. It is usually important to coordinate and negotiate among the parties as needed when acts as a leader and make key decisions in the period of innovation application (Nam and Tatum, 1997). In a word, this character can develop/implement innovation by coordinating resources and activities. A coordinator's network position always indicates two high centralities, the degree centrality and betweeness centrality.

Champion: The term 'champion' is used to designate individuals who lead the innovation process. The champion is critical to assure innovation and creativity in organizations. This character can encourage, promote and protect innovation, facilitates open discussion of innovative ideas and thus is necessary to every organization(Ozorhon et al. 2014). In the relationship network, the champion has much easier access to resources, information, methods and processes greater power, higher position and stronger influence on the stakeholders. This role has a high betweeness centrality and closeness centrality.

Table 1. Roles in innovation

Role	Activities characteristic	Network positions
Gatekeeper	Creating channels from the inside to the outside	High density and high indegree
Coordinator	Coordinating resources and movements to develop or achieve innovation	High degree centrality and High betweeness centrality
Champion	Encourage, protect, promote innovation	High betweeness centrality and closeness centrality

3. Case Study

A case study design was chosen in line with the aim to investigate the network of relationships in construction projects. In this context, a qualitative in-depth analysis was needed. The study is focused on the late stage of a project. Most actors had not worked together before. Project communication channels and practices were established. The relationship network was basically stable. This provided the opportunity to investigate the way the actors construct and create the relationship network to implement innovation in construction project.

3.1 Project background

The selected case project is a commercial complex integrating shopping, dining, culture, entertainment, business, leisure and other functions. Commercial complex has many characteristics, such as functional cooperation, large-scale, and multi-functions. Innovation becomes essential to the success of a commercial complex project and also creates possibilities for achieving competitive advantages for the project. It involves multiple participants. Close collaboration and efficient information sharing are often prevented between individuals who have differing priorities. This project lasted nearly two years from November 2011 to July 2013. The total investment of this project is 5 billion yuan (790 million US$), the total land use area of this project is about 71084 square meters. The project environment is complex because of the interdependencies and newness of the task and the heterogeneity of the relevant actors. Approximately 2,000 people work on the site, ranging from owner, designer, general contractor, subcontractors, supervising engineers, and suppliers.

The general department (GD) coordinates the contract awards to outside providers. It was supported by a construction site management (CM) from the client who were mainly in charge of the operations. The remaining actors were supervised by the CM, such as the equipment, material suppliers. Fig. 1 shows the formal organization of the construction project.

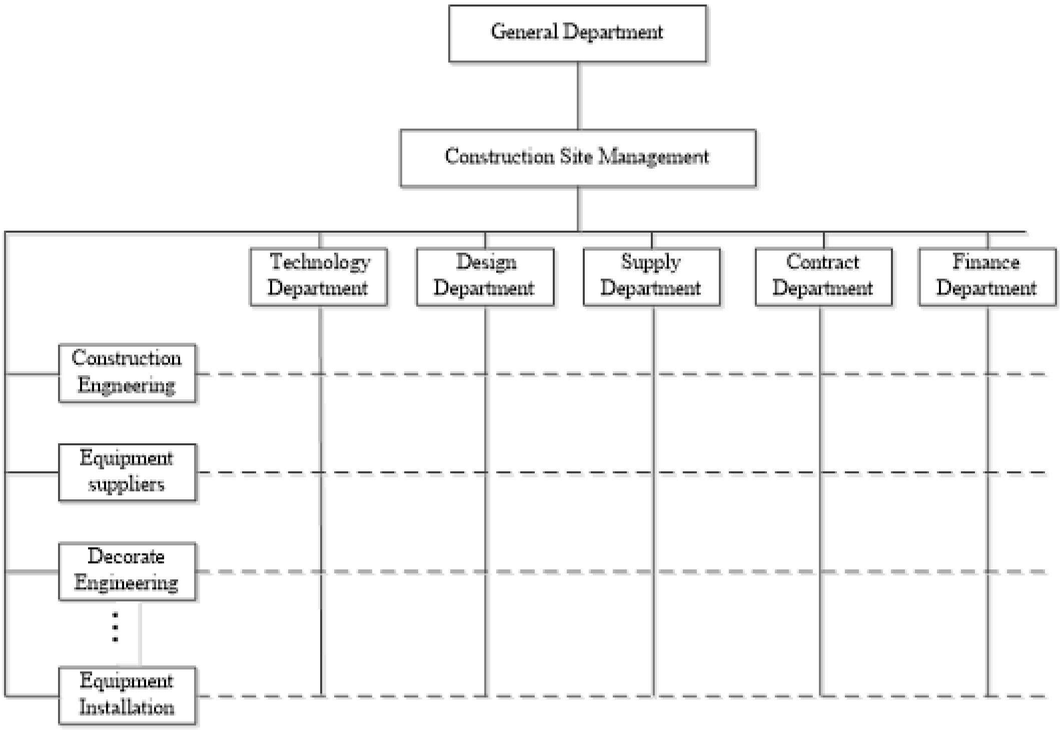

Fig.1. The formal organizational structure of the case project

3.2 Data collection

In the relationship networks, actors are the participants or stakeholders of the construction projects. These individuals are called nodes in a network model. In order to ensure the validity and accuracy of the data, the source of the individuals in this model will be confined to the owner, the architect, general contractor, subcontractor and supervising engineers. In the analysis of social network, Tie represents the specific communication content or how the substantive relationship occurs in reality and Arcs represent the contact between the individuals based on the project.

Data were collected through interviewing project managements and a structured questionnaire distributed to individuals involved in the project. There are 7 managers attend to the interview. Their specializations rang from owner, designer, general contractor, subcontractors, supervising engineers, and suppliers. According to the prominent role for the project, persons which are more active and important in the project are identified. Cases are chosen to show the different organizations involved in the project. The individual who create, maintain and develop networks, show how information exchanges among organizations. Based on a structured questionnaire, we conducted interviews with an average of 2 hours long. A structured questionnaire is more beneficial to control and more feasible to determine the relationship between variables, quantify and statistical processing of data. The foundation of map network is quantitative data. The prior interviews with the representative of general department have found those individuals that currently play the most active and the most important roles in the project. In the next round of interview, important participants are requested to list all their contact persons who provide important information on project work. According to the information from the prior expert interviews, the name list and some sources of data such as internal documents of the project plan, decision-making procedures, meeting minutes and financial data, we developed a standardized questionnaire involving a name generator and a web survey designed for important actors from May 18, 2013 to June 23, 2013.

In total, 16 individuals who are the important actors were finally confirmed, which come from the category of owner (5 persons), architect (2 persons), general contractor (2 persons), subcontractor (6 persons), and supervising engineer (1 person). The relationship network of the project is drawn from the data collected in the questionnaire, through analysis of the condition of information flow in the relationship network and identification of the key members. According to the data collected from questionnaires and further in-depth interviews, a comprehensive list of the contact people was created, each of them provided important information about the project work and drew an ego-centered network. Analysis of the relevant network index and confirmation of the roles and functions of the key members in the innovation process of construction was also undertaken.

4. Results and Discussion

4.1 The completed relationship network

To measure the overall network, we analyze network structure and characteristics according to the data of overall network structure, depicting the connection among multi-stakeholder. Through calculating the index of centrality and filtrating important node, the basis for a personal network measurement is provided. Questionnaires were sent to 16 key project members. These individuals form a network consisting of 135 ties between the individuals (see Figure 2). The size of nodes depicts how many people the member has contact with. The larger the node, the more the member is in contact with the others. Different node shapes indicate the different organizations in which the participants worked during the case. The arrows in Fig. 2 represent that it can be either bidirectional or unidirectional when the information flows. It shows how complex the collaborative patterns were during the project and key participants as a part of this network. The following section provides a more in-depth analysis of the nature of relationship networks with the selected measures. Table 2 shows the results of the social network measures.

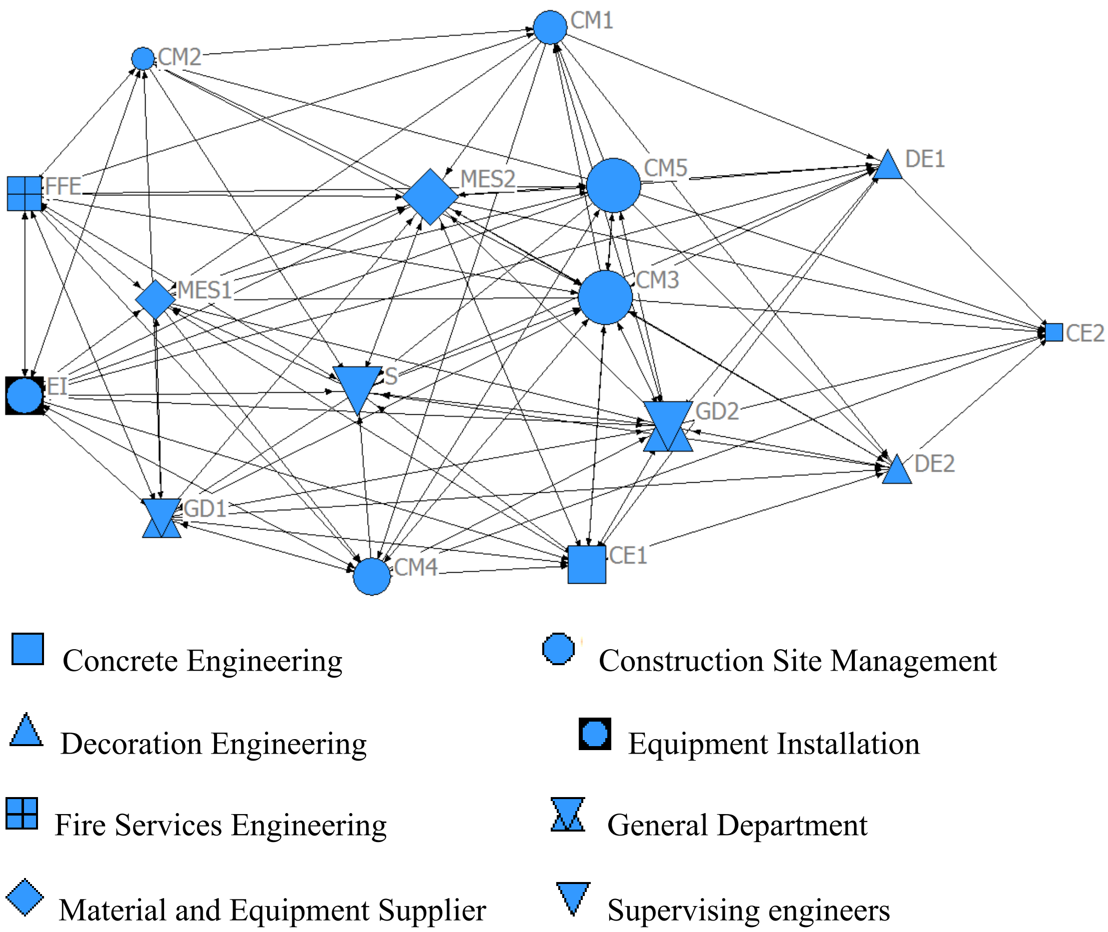

Fig.2 The complete relationship network

Table2 Centrality measures for the complete relationship network

No.	Organization	Indegree	Outdegree	Betweenness	Closeness
GD2	General Department (Architect)	0.10	0.11	20.32	78.947
MES2	Material and Equipment Supplier (Subcontractor)	0.10	0.09	9.365	71.429
CM3	Construction Site Management (Owner)	0.09	0.10	15.94	88.235
S	Supervising engineer	0.09	0.07	8.168	71.429
CM4	Construction Site Management (Owner)	0.08	0.10	9.245	68.182
CE1	Concrete Engineering (General Contractor)	0.08	0.08	7.007	75.000
FFE	Fire Services Engineering (Subcontractor)	0.08	0.08	6.944	75.000
DE1	Decoration Engineering (Subcontractor)	0.08	0.04	1.676	62.500
EI	Equipment Installation (Subcontractor)	0.08	0.10	5.881	75.000
GD1	General Department (Owner)	0.07	0.10	5.486	75.000
CM1	Construction Site Management (Owner)	0.07	0.07	2.958	68.182
CM2	Construction Site Management (Architect)	0.07	0.07	2.467	62.500
CE2	Concrete Engineering (General Contractor)	0.07	0.01	1.337	48.387
MES1	Material and Equipment Supplier (Subcontractor)	0.07	0.04	9.372	60.000
CM5	Construction Site Management (Owner)	0.05	0.10	7.740	83.333
DE2	Decoration Engineering (Subcontractor)	0.05	0.04	1.626	62.500

The density of the network is 56.25%. This indicates that the overall integration of the directed network is adequate, because the value of network density in the range

0.0-0.5 is considered to be lower (Friedkin, 1981). No actors are isolated in the network which suggests that through direct connect or intermediaries every member involved can reach each other. In short, the project process contains a variety of members that are closely linked. To further decipher the positions of individual nodes in the network, personal level measures of the results should be complemented. Finally, it is possible to determine whether a relationship network is beneficial to innovation.

The selected personal level measures used to scrutinize the collaborative relationship network can find out the people who are communicated to the most (InDegree) and the most communicative ones (OutDegree). It can also identify the people in the most central positions in the information flow. CM3, GD2, CE1, MES2 are the most central people according to the result of the degree centrality measure. To achieve further understanding of the roles of individual people and determine the key members, the betweenness value is analyzed. The results show that GD2, CM3 and CE1all have higher betweenness. It illustrates that they exert substantial stress on information flow. Through the information flow, the individuals with higher betweenness possess considerable power in the network, because of their extensive potential to control the information flow. In other words, they play key roles in the collaborative network.

4.2 The ego-centered networks

Individuals get knowledge, technology and resources when they choose partners, depending on a personal network, which could be developed in the meanwhile. Through a personal network, which is an informal organization structure, one could find the corresponding knowledge. According to the analysis of the complete relationship network, key members are identified and the ego-centered network of these members is drawn. An ego-centered network (sometimes called a personal network) is a network centered on a specific individual (generically “actor”)，whom we call the ego (Wasserman and Faust, 1994; Killworth et al., 1990). The network represents the set of relationship related to focal ego. Ties indicate the individuals with whom the focal ego has some sort of relationship. Density describes the frequency of network members have contact with the focal ego. Table 3 summarizes the major network measures for the ego-centered networks.

Table 3 Network measures for the ego-centered networks

Remember	Organization	Size	Ties	Density
CM5	Construction Site Management	14	99	54.40
MES2	Material and Equipment Supplier	14	98	53.85
S	Supervising engineers	13	93	59.62
GD1	General Department	13	68	61.82
CM3	Construction Site Management	11	93	51.10
GD2	General Department	11	84	53.85
CM4	Construction Site Management	11	62	54.40
CE1	Concrete Engineering	11	68	61.82
MES1	Material and Equipment Supplier	11	75	68.18
EI	Equipment Installation	11	64	58.18
CM1	Construction Site Management	10	47	52.22
FFE	Fire Services Engineering	10	53	58.89
DE1	Decoration Engineering	9	44	61.11
DE2	Decoration Engineering	9	44	61.11
CM2	Construction Site Management	8	37	66.07
CE2	Concrete Engineering	7	27	64.29

Note: The “ties”, the second column, show the number of ties in the network.

The largest ego-centered networks are the heating ventilation air conditioning engineer (CM5，14 nodes), material and equipment suppliers (MES2,14 nodes), the representative of the general department (GD1,13 nodes), and supervisor (S,13nodes). The highest density of the ego-networks is 68.18%. This is higher than the density of the complete relationship network. It revealed the existence of closely connected small groups in the network. The information flows fast in these small groups, therefore benefit the innovation. In the general department, GD1 with higher density (61.82) and InDegree (10) is supposed to act as the gatekeeper of the general department. For the same reason, CM3, CE2 also play the role of gatekeeper. The sparsest ego-centered network (CM3) was compared with the densest network (MES1). Fig.3 shows a subset of the whole complete relationship network, which is a single actor's (MES1) social network. The ego network is a network consisting of ego (MES1) together with the actors they are connected to (alters) and all the links among those alters. The black node identifies the ego, and red nodes recognize other actors. In addition, the participants from different organizations are shown with the different shapes of the nodes.

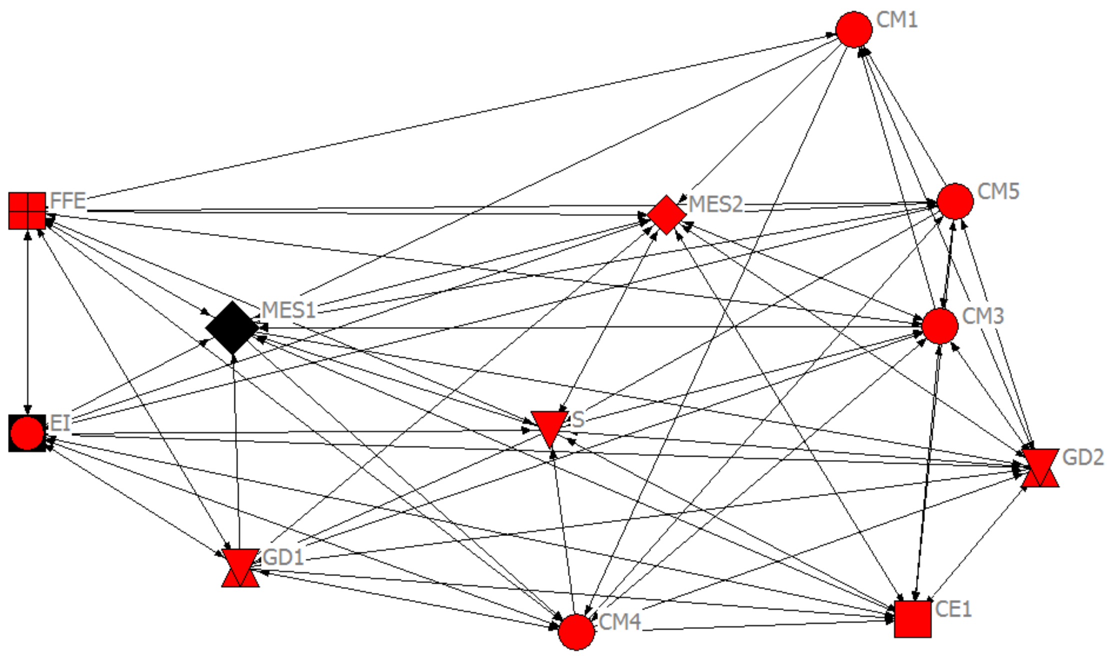

Fig. 3. Ego-centered networks(MES1)

Fig.4 represents another ego network (CM3) in the same method. Though the two networks have nearly the same size (11), a participant's network of material and equipment supplier - MES1 (see in Fig.3) is much denser than that of CM3 (see in Fig.4). It indicates that the amount of information separately received by the two individuals is different although CM3 and MES1 can both draw information from ten people. Therefore, the information of the ego-centered network (MES1) is bigger than that of the ego-centered network (CM3). The ego-centered network (MES1) provides a more conducive environment to achieve innovation. Meanwhile，MES1 has a higher betweenness centrality (9.372), so MES1 plays the role of coordinator. CM3 is the node with relatively high betweenness (15.94) and closeness(88.235). CM3 is also in charge of construction site management. While CM3 acts as a champion that encourages innovation, high quality innovation output can be expected. GD2 is the representative of the general department, the high score of betweenness (20.32) and closeness (78.947) suggests that their position in network determines their role as Champion.

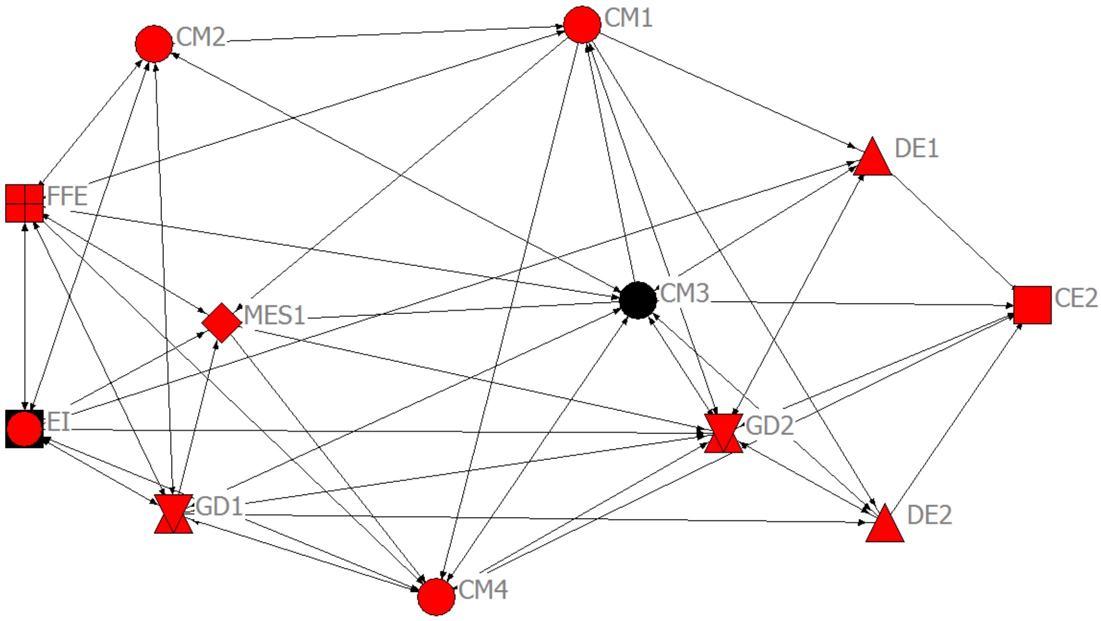

Fig. 4. Ego-centered networks(CM3).

5.Conclusion

Research in construction innovation indicates that collaboration is a critical factor for construction innovation (Holmen et al., 2005; Rutten et al., 2009). Compared with the other industries, construction industry involves multiple participants and its collaborative relationship is more complex. The network method can be adopted to clarify the relationships. Based on the empirical research of the complete relationship network in a project, the study applied network analysis to identify the key factors which influence the construction innovation. The analysis of the collaborative relationship network is performed by applying social network analysis measures. The social network analysis measures used are: density, degree centrality, closeness centrality, and betweenness centrality. The results presented in this paper indicate that the collaborative relationship network formed during the construction project process is dense. Due to the large number of participants involved, the role of collaborative works is considerable. However, it seems that a small group of people plays a substantial role in the relationship network. The information flowing among these key individuals has the greatest impact on the important new knowledge creation. Further, communication between these key individuals has the greatest impact on the efficiency of collaborative relationships in the project, encouraging innovation.

Considering the principal of innovation, three roles were identified: gatekeeper, coordinator and champion that correspond to specific network positions. The process of distinguishing these roles enhances the understanding of the function of the project members in the information exchange network, and reveals who controls, stimulates and hinders the information flows. The information exchange in a project can be coordinated by the development of different roles management strategies to stimulate innovation. For example, gatekeepers act as system integrators and information diffusers for potential innovation, and the frequency of knowledge exchange between they and their direct contact. So, the number of direct contact with gatekeepers determines the opportunities to collaborate and exchange knowledge, leading to innovation; Network structures influence how information flows around the whole environment, and the network structure is becoming more centralized, depending on one coordinator, therefore, having short paths to coordinator, might control the efficiency of the flow of information transmitted in a network; Champions occupy network position should correspond to the formal project organization, keeping contact with them to improve the validity of information.

In accordance with the results of this study, the approach is directly relevant to construction innovation management practice. This study demonstrated the potential application and application scenarios of SNA in the field of construction project innovation management. It is noted that this study is limited to a single case study and the proposed conclusions cannot be generalized to all cases. In this paper, the conclusion is based on the analysis data of specific case. Although the conclusion does not apply to other cases, quantitative analysis method has been shown to applicability through case analysis. Further research should add more cases of different project types that may offer more information to support the implications. Another limitation of this study is the static approach adopted. The study focuses specifically on the late phase of the project, and thus nothing can be concluded in the early project phases. The scope of relationship networks seems to change over time. So future research should investigate the dynamics of collaborative relationship networks to completely reveal the mechanisms of information exchange and hence contribute to a better understanding of innovation in construction projects.

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