

Collaboration Networks for Megaprojects: The Case for Skyscrapers

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Abstract: This study aims to investigate the dynamics of project networks composed by megaprojects (i.e. skyscrapers) and their collaborations of stakeholders, and to analyze the influence attributed by past collaboration experience, locations, and roles of stakeholders. In particular, a dynamic network model that includes key project features and stakeholder characteristics was developed based on 43 completed skyscrapers taller than 300 meters in China. Based on the project network, the quantifiable network relationships, the dynamic evolution, and its influence by different geographic locations were analyzed. The findings suggest a growing trend of the collaboration and help AEC companies make better decisions in selecting future collaborators.

Keywords: Collaboration networks; Megaproject management; Dynamic network; Network analysis; Project organizations; Social Network Analysis

INTRODUCTION

Megaprojects can be viewed as complex networks of actors, or heterogeneous stakeholders, including owners, designers, contractors, and so on. Lack of previous cooperation experience and dynamic organizational relationship over time within a megaproject team may further increase the risk of project failure (Flyvbjerg, 2014; Han et al., 2009; Lundrigan, Gil, & Puranam, 2015; Ruuska, Artto, Aaltonen, & Lehtonen, 2009). Therefore, how to construct an efficient collaborative team and an effective organizational network have become critical to improve megaproject performance (P. S. Chinowsky, Diekmann, & O'Brien, 2009; Ruuska et al., 2009). Meanwhile, identifying and retaining competitive in the emerging markets have become important strategies of architecture, engineering, and construction (AEC) companies, owing to the increasing competition in the AEC industry. Those strive to enhance their market competitiveness by building flagship megaprojects, developing strategic partnerships with other organizations, and increasing social capitals (Castro, Galan, & Casanueva, 2009; P. S. Chinowsky et al., 2009; Skaates, Tikkanen, & Alajoutsijärvi, 2002). Therefore, clients, design firms, contractors, and sub-contractors may form inter-organizational partnerships and

collaboration networks for short-term project-based performance targets and long-term market competitiveness (Dubois & Gadde, 2000; Sedita & Apa, 2015).

Nevertheless, the formation process of an inter-organizational network is rather complicated. The network evolves dynamically over the course of project plan, design, and execution. Current research primarily focuses on stand-alone projects or cross-project collaborations of a single organization, as well as social network, communication network, and information sharing in static and homogeneous networks (Bygballe, Jahre, & Swärd, 2010; P. Chinowsky & Taylor, 2012). More research is needed to empirically analyze the dynamic networks in the AEC industry from larger inter-project and inter-organizational perspectives, in order to understand the formation mechanisms and evolution characteristics of inter-organization collaboration networks of the megaprojects under different influences.

Therefore, a case study of skyscraper projects (more than 300 meters in height) was selected to investigate the formation process and dynamic evolution of inter-organizational collaboration networks in megaprojects. Skyscraper projects are challenging due to the heavy investment, tight construction schedule driven by return on investment, applications of new technologies, and so on, and also involve hundreds of organizations that demand tremendous organization and coordination, thus is typical of the megaproject (Ireland, 1985; Kaming, Olomolaiye, Holt, & Harris, 1997; Le & Li, 2013; Wood, Tsang, & Safarik, 2014). So this study attempt to investigate the formation process and evolution characteristics of the inter-organizational collaboration network in skyscrapers.

LITERATURE REVIEW

Inter-organizational project teams or coalitions are commonly formed in the AEC industry in order to accomplish the project target. For larger projects, such temporal inter-organizations may involve a number of stakeholders. The successful delivery of an AEC project is dependent on two fundamental elements: the ability to plan and manage the technical components, and the ability of project participants to effectively form a high-performance team (P. S. Chinowsky et al., 2009). Effective communication, coordination, and information sharing are also important between each project sub-teams.

In order to reduce the trust risk and shorten the learning curve for a collaborated project, organizations expect to cooperate with competent teams with more collaboration experience. Organizational capability and collaboration experience are the key factors that influence the complexities of a megaproject. Lack of competence is a common barrier to adopt and implement relational transaction practices (Erik Eriksson, Nilsson, & Atkin, 2008), which may subsequently cause delays and cost overruns (Bosch-Rekveltdt, Jongkind, Mooi, Bakker, & Verbraeck, 2011). To the organizations that seek for collaboration, previous alliances can be considered active information exchange networks in which the organizations understand the reliability and specific abilities of their

present and potential partners. Moreover, previous empirical findings confirmed that the form of coalitions in the AEC industry is principally based on past collaboration experience in order for better commitment and trust (Bygballe et al., 2010; Castro et al., 2009). Research has also demonstrated that trust, including companion trust, competence trust, and commitment trust, is one of the most important social factors in inter-organizational collaborations (P. S. Chinowsky et al., 2009; Newell & Swan, 2000). Repeated collaboration practices among coalition members that are likely to share the same objectives, working methods and values. Over time, these members are able to build a collaborative community, eventually reinforced by co-location and collaborative intensity. Inter-organizational relationships between project network actors, developed over the course of multiple projects, may also lead to opportunities for learning, reduced supervisory costs and a reduced risk of project failure (Sedita & Apa, 2015). Therefore, repeated collaborations have become industry norms and best practices in constituting effective project organizations.

However, no AEC project is carried out in a vacuum situation without consideration of specific project contexts (Engwall, 2003). There may be different connections between projects, while companies are not only involved in a single project (Engwall & Jerbrant, 2003). Thus, the cross-project and inter-organizational collaboration research at macro-level is equally important as a project-based micro-level study (Phua, 2004). Such greater perspective of inter-organizational collaboration has shaped the specific supply chain relationships in AEC industry. Comparing to a supply chain in the manufacturing industry, a construction supply chain is more complex, highly specialized, and involves a larger number of key participants, such as project clients, consultants, the main and specialist contractors, and various suppliers. As the core of the project organizations, their competencies, and interests to put resources in the process and carry responsibilities are essential are successful project deliveries (Meng, 2012; Ruuska et al., 2009).

METHODOLOGY

Inter-organizational collaboration relationship is more complicated as the project become more complex. As a result, the network features of such project networks become more representative. Skyscrapers are clearly complex and large-scale projects that involve many organizations and vast financial investments. Therefore, we choose skyscraper projects as representatives of complex megaprojects in this study, to analyze the characteristics of the inter-organizational collaboration network.

We firstly created a skyscraper dataset that contains all the built skyscrapers over 300 meters in China. Over the last several years, the build of skyscraper has become an emerging megaproject market in China. Council on Tall Buildings and Urban Habitat (CTBUH) reported that 13 skyscrapers that are over 300 meters were completed in the year of 2015 globally, while 9 of them were built in China. In 2016, 6 of 10 skyscrapers that are expected to erect are from China, all of which are above

300 meters' tall. For each skyscraper project, project attributes (height, geographical location, start and complete time, etc.), core project organizations (project client or investor, design company, general contractor, specialty sub-contractor, engineering supervisor, etc.), and organization attributes (headquarter location and organization ownership property) were collected. Secondly, different network models were built based on the dataset. Using the completion date of individual skyscraper projects as the longitudinal time stamp to indicate the different formation stage of the network, the dynamic change of the whole network and individual networks were modelled and calculated through SNA. Network density, network centralization, and centralization index were examined in the whole network.

Parameters of whole networks and individual networks of SNA are usually used to study inter-organizational network. For the analysis of whole networks, indices such as density, network centralization, and centralization index are used to measure the proportion of all possible ties that are actually present, quantifies the dispersion or variation among individual centralities and betweenness centralities, and some other structural properties of whole networks. The collaboration index R_d is also proposed as follows to measure the level of collaborations based on previous performance.

$$R_d(n) = (\sum_{i=1}^n \sum_{j=1}^m S_{i,j} - S'_n) / S'_n \quad (1)$$

Where, n represents the year; m represents the number of projects; $S_{i,j}$ represents the number of construction organizations for project j in a given year i; S'_n represents the real accumulated number of construction organizations until the year n.

The data used in the study is resourced from Skyscraper Centre of CTBUH and the Mega Projects Case Study and Data Center (MPCSC) database developed by the Research Institute of Complex Engineering & Management (RICEM) of the Tongji University in China. Design organizations include architectural firms, structural firms, and mechanical and electrical firms, while contractor organizations consist of general contractors, curtain wall sub-contractors, steel structure sub-contractors, and mechanical and electrical subcontractors.

RESULT AND DISCUSSION

Collaboration Based on Past Experience

Collaboration index R_d of different types of organizations from 1996 to 2015 is shown in Figure 1. Experienced organizations started to award another skyscraper project until the fifty year. On average, the collaboration index that based on previous experience increased gradually. The characteristics of design firms, contractors, and supervisors are different despite their similar overall growth trends. Contractors have the highest index, almost twice as high as designers and supervisors. This indicates that experienced contractors have a higher chance to win new projects in Chinese skyscraper AEC market, making more difficult for new contractors to enter in the market. On the

contrary, designers and supervisors have a similar trend of slow progress, indicating that there is still room for newcomers to enter the market. For instance, foreign designers constantly participate in the design competition for skyscrapers in China, reflecting the intense competition in this market.

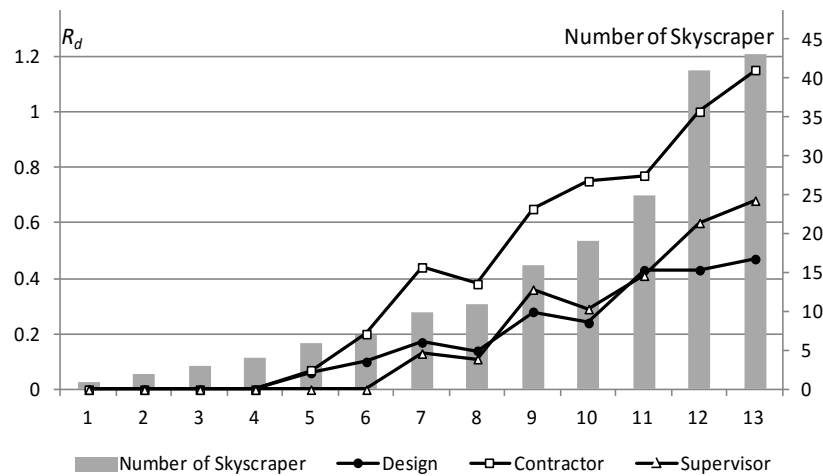


Figure 1. Collaboration index (R_d) of different types of organizations from 1996 to 2015.

In addition, the relationship of the collaboration index R_d and the number of skyscrapers shows certain correlation. The result of linear regression demonstrates that the repeated collaboration indices and the number of skyscrapers are linearly correlated, with R^2 values 0.8995, 0.9113, and 0.9547 (p-value less than 0.001), respectively. Such correlation denotes that organizations with similar project experience are easier to acquire new project opportunities as skyscraper projects increase.

Inter-organizational Collaboration Network

Typical parameters including density, network centralization, and centralization index are used to analyze the formation process, main characteristics and network evolution in the whole network. Figure 2 illustrates the trends of network centralization and centralization index over time. Network centralization of the whole network reached 7.84% in the second year and the peak 11.97% in the seventh year (Year 2009). It stayed at 8.75% averagely with a standard deviation of 0.0203 despite small fluctuations, showing the smaller differences between individuals of the whole network. This result of network centralization is reasonable when compared with other megaprojects. It is smaller than inter-organizational collaboration networks in a stand-alone megaproject, like 23.23% in the Shanghai Expo construction (Li et al., 2011), but larger than in a wider range of metropolises or megacities, such as 6.75% in a three-year (2008 to 2010) inter-organizational collaboration network of infrastructure projects in a major city of China (Li, et al., 2013). On the other hand, centralization index reflects the degree of dependence on an intermediate in the whole network. Such indicator has an overall upward trend with larger fluctuations. The peak value of the centralization index is 24.05% in this study, similar to the value in the study of Shanghai Expo (23.59%) (Y. Li, Lu, Kwak, Le, & He,

2011). The most recent value of 18.99% in this study is slightly higher than the value of 17.18% in a city-level infrastructure megaprojects in China (Y. k. Li, Chong, He, & Guo, 2013). Due to the high dependence on an intermediate in the network, the network may have “structural holes” that emerge when two separate clusters possess non-redundant information (Burt, 2009). Thus, a network that bridges structural holes can provide additional value to the network as well as the social capitals in the network.

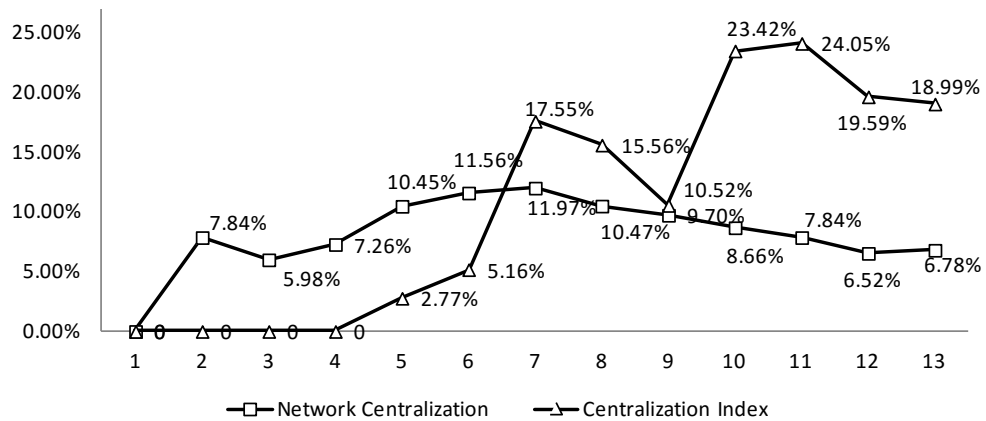


Figure 2. Trends of network centralization and centralization index of in the skyscraper case study.

We further analyzed the relationship of the number of skyscrapers with network centralization, centralization index, and network density, and the results are shown in Figures 3, 4, and 5. As the number of skyscraper projects grew, network centralization increased during the first several years, and decreased after reaching the peak number in the seventh year (year 2009), showing a polynomial function ($R^2=0.86$) between the two variables (Figure 3). Centralization index and the number of skyscrapers also correlate with a polynomial function shown in Figure 4 ($R^2=0.88$). The centralization index drops after the eleventh year (Year 2013) in which the maximum value was 25%. In Figure 5, network density and the number of skyscrapers shows an exponential relationship ($R^2=0.96$). The density value reached a stable 0.07 as project number increased. However, the density value of the whole network is lower than aforementioned two reference parameter, 0.3106 of Shanghai Expo and 0.1332 of infrastructure network, respectively (Y. Li et al., 2011; Y. k. Li et al., 2013), possibly owing to the loose connection between participated organizations and the disperse geographical locations of skyscrapers in China.

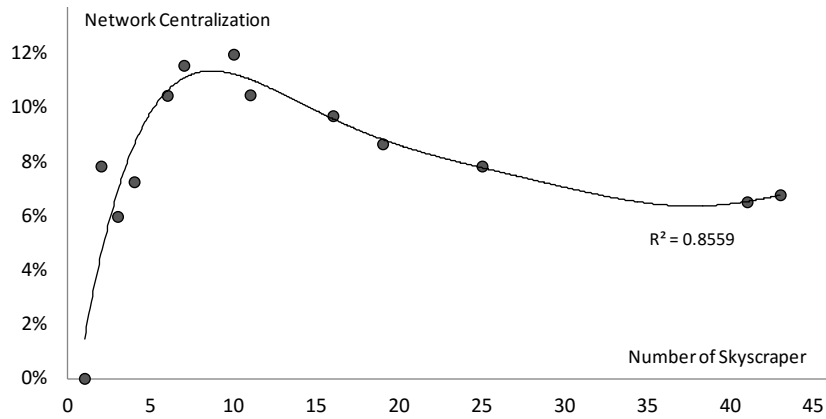


Figure 3. The relationship between network centralization and the number of skyscrapers.

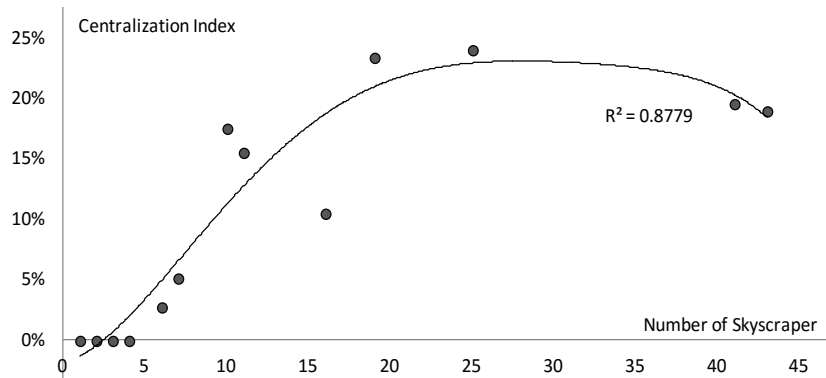


Figure 4. The relationship between centralization index and the number of skyscrapers.

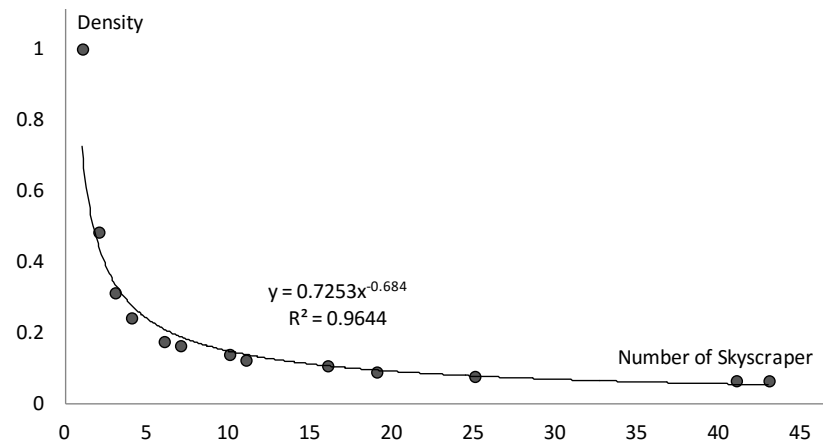


Figure 5. The relationship between network density and the number of skyscrapers.

CONCLUSION

In a specific kind of megaprojects, inter-organizational collaboration networks are gradually formed. Previous experience not only help organizations to possess important positions in the network, but also provide a better opportunity to accumulate social capitals and to increase market competitiveness. Owners and clients of megaprojects tend to choose their collaborators that have

strong past experience, leading to a “winner takes all” phenomenon. At the same time, contractors are easier to be connected to better network positions comparing to design firms and supervisors which have more competitive markets.

Although several key organizations exist in the inter-organizational collaboration network of a specific kind of megaprojects, there are not much centrality differences among individual organizations and no significant change of network centralization over time, indicating that new organizations are constantly entering the market and striving to become strong competitors. However, centralization index of the whole network demonstrates an upward trend, and positively correlates with the number of the skyscraper projects, signaling possible structural holes in the network that need to be carefully examined to avoid information manipulation.

This study of inter-organization collaboration networks extends the previous emphasis on static networks and limitation of a stand-alone engineering project, to dynamic and evolutionary collaboration network. The research findings help to further understand the form and evolution of inter-organization collaboration networks in megaprojects. It will not only provide suggestions to project clients on how to constitute high efficient project team, but also offer guidance to AEC firms on how to enter and remain competitive in the megaprojects market.

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