Journal of Civil Engineering and Management
ISSN 1392-3730 / eISSN 1822-3605
2019 Volume 25 Issue 3: 228–240
https://doi.org/10.3846/jcem.2019.8137

PATENT COOPERATIVE PATTERNS AND DEVELOPMENT TRENDS OF CHINESE CONSTRUCTION ENTERPRISES: A NETWORK ANALYSIS

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Received 06 June 2018; accepted 13 December 2018

Abstract. Despite the rapid development of Chinese construction industry, there has been little research effort directed towards exploring patent cooperative patterns and evolution trends of construction enterprises, especially from the perspective of the patent development network. This paper extracts implicit collaborative information and introduces Social Network Analysis (SNA) method to conduct the patentometric analysis based on patent data from the "Top 500 Chinese Construction Enterprises" sourced from PatSnap database. The enterprise-enterprise networks and enterprise-university networks are analyzed quantitatively. The results reveal that: 1) there is a rising trend in the number of patents and patentees; 2) state-owned enterprises play a dominant role in patent development; 3) most of patents are classified as International Patent Classification E04G21; 4) the cooperative relationships are mainly within enterprises and their subsidiaries; 5) when enterprises choose to cooperate with universities, in addition to professional qualification, geographical factors should also be considered. Finally, the development and patent evolution trends are discussed. Some useful suggestions are proposed. The contribution lies in: (a) providing a visualization of the implicit collaboration information of patents in Chinese construction enterprises; (b) revealing cooperative patterns of construction enterprises on patents; and (c) providing enterprises some useful suggestions for patent cooperation.

Keywords: Chinese construction enterprises, patentometric analysis, cooperative patterns, enterprise-university cooperation, Social Network Analysis, visualization.

Introduction

The Chinese construction industry faces increasing resource and environmental constraints, leading to increasing labor and production costs that can impact on competitiveness and productivity. To address these pervasive challenges and remain competitive, many construction enterprises have proactively embraced technological innovation to achieve sustainable development. As an output of the Research and Development (R&D) process, patents reflect an enterprise's level of innovation to some extent (Semih Akçomak & Weel, 2009). Thus patent makes it possible not only to conduct quantitative analysis by providing standardized information on the technologies, but also to provide important information to relevant enterprises in charge of R&D or technology policies (Yoon & Park, 2004). Therefore, patent analysis is suitable for understanding an enterprise's activities in patent cooperation.

Despite extensive use of patent analysis outside the construction domain (Yang, Xu, & Neuhäusler, 2013; R. Zhao, L. Zhao, Deng, & Zheng, 2015; Kroll, 2016), there has been few examples to explore patent cooperative patterns and evolution trends of construction enterprises, especially from the perspective of the patent development network. This is particularly relevant in the context of the large-scale Chinese construction market. Despite the size of this market, according to the National Bureau of Statistics of China (2017), construction development growth has tended to flatten over the past five years. This research extracts implicit collaborative information from patent data for mining patent collaborative networks. As a reflec-

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tion on an enterprise's level of innovation, it is worthwhile to analyze patent development of Chinese construction enterprises, to identify collaborative patterns of enterprises, and further to give suggestions for construction enterprises in China and other developing countries.

Therefore, this paper will effectively ascertain the structure of the patent cooperative network and development trends of Chinese construction enterprises. Patent application numbers, patentees and IPC codes are analyzed quantitatively to explore patent development trends. Enterprise-enterprise and enterprise-university cooperation on patent activities are analyzed using Social Network Analysis (SNA) to reveal patent cooperative patterns of construction enterprises and technical knowledge diffusion. Three patent maps are drawn based on quantitative analysis and SNA, using patent data derived from PatSnap. Broadly, PatSnap covers the patent data from more than 90 regions and organizations, including the World Intellectual Property Organization, China, and Taiwan.

An enterprise's level of innovation diffusion and business sustainability can align with its patent activities. The results of this study help provide a basis for better understanding enterprises' patent cooperative patterns, indicate levels of technological innovation related to the Chinese construction industry, and contribute to future patent research development.

1. Related research

1.1. Patent data analysis

Several studies had applied patent data to explore various patenting activities in different fields. Yoon, Park, and Kim (2013) analyzed technological competition trends by patent analysis. Kim and Bae (2017) forecasted promising technology in the field of wellness care using patent analysis. Nakamura, Suzuki, Kajikawa, and Osawa (2015) investigated the effect of patent families using cases from automobile drivetrain technology. Burhan, Singh, and Jain (2017), Kessler and Sperling (2016) and Pantano, Priporas, Sorace, and Iazzolino (2017) found that granted patents were better proxies for measuring innovation in different fields. Moreover, Qiao, Ju, and Fung (2014) argued that innovation has a positive effect on enterprise performance using patent analysis. Patel and Ward (2011) used patent citation patterns to estimate competition in innovation markets and found that an enterprise's market value increased when its patent portfolio was cited.

1.2. Social Network Analysis in patent analysis

Previous patent analysis such as regression analysis and correlation analysis are limited, because it provides only partial information on knowledge diffusion. To examine the knowledge diffusion process from a comprehensive perspective, more studies have turned to network theory (Choe, Lee, Kim, & Seo, 2016). SNA is a useful approach for analyzing network structures, and provides a series of methods to quantitatively analyze and reveal the overall structure of a network (Otte & Rousseau, 2002). It can be used to present relationships visually.

Rowley (1997) constructed a theory of stakeholder influences and predicted how organizations respond to the simultaneous influence of multiple stakeholders based on SNA. Moussa and Varsakelis (2017) used SNA to visually examine patent data to identify the behavior of patenting abroad. Ding and Liu (2011) constructed a network based on SNA to compare the different organizational structure schemes in the supervision of a large-scale construction project. They predicted the trend of the project governance structure and investigated risk based on this structure. Pering and Huang (2016) used patent data from shading devices to investigate technological trends based on SNA. The results provided a clear picture of, and evidence for, the citation between shading device technology.

1.3. Social Network Analysis in cooperation research

Collaboration studies have attracted increasing attention and SNA is offen applied to identify and analyze relationships in collaborative organizations (Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006; Hatala & Lutta, 2009). Zhang and Ashuri (2018) discovered social networks in BIM-based collaborative design practices and examine the relationship between the characteristics of the design social network by SNA. Adopting patent bibliometrics and SNA, Wang, Sung, Chen, and Huang (2017) examined structures of semiconductor companies' R&D cooperative networks and channels of knowledge spillovers. Ye, Yu, and Li (2013) analyzed 36,731 enterprise-enterprise cooperative patents and found that the most prominent subgroup has small-world features and supports patent data as a useful indicator for measuring enterprise performance. In a similar way, applying SNA to conduct patent analysis can provide a clear picture of stakeholders and their networked relationships and present the structure of the related network visually.

Despite the application of SNA in other research fields, there remains limited construction specific research using SNA method. Such research topics are mainly confined to three aspects: large-scale project organization controlling mechanisms, project stakeholder relations and safety management (Pan, Zheng, & Li, 2017; Yang & Zou, 2014). For example, Le, Chong, and Cao (2010) used SNA to construct the social network model of an engineering project organization and the quantitative analysis of the risk network model. The results showed that SNA was feasible in the organization and management of an engineering project.

Therefore, this paper applied SNA to explore construction enterprises' cooperative activities, especially in the context of the Chinese construction industry. The objectives of this study were to explore 1) the developing situation of patent applications in China; 2) the relationships between enterprises and universities in the patent cooperative networks; and 3) the cooperative patterns of construction enterprises in China using SNA.

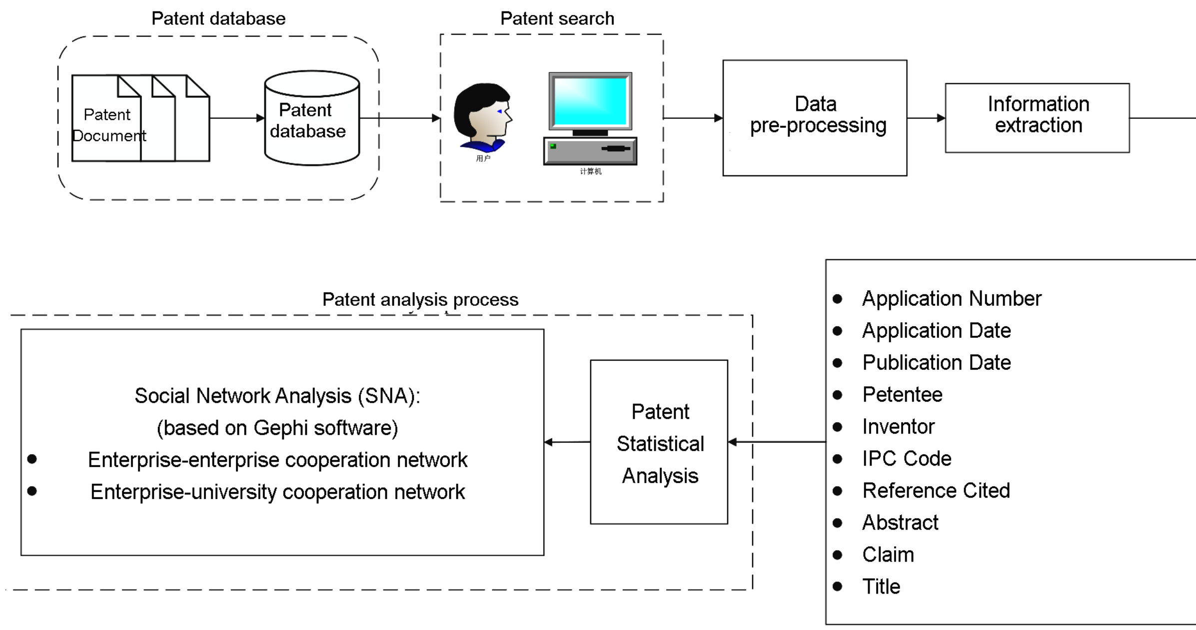


Figure 1. Research framework

2. Methodology

The research framework is shown in Figure 1, comprising patent searching, data pre-processing, and quantitative patent analysis. Relevant patent information was obtained from the PatSnap Global Patent Database, using a comprehensive data search on the subject area. A manual review was then conducted to remove duplicate and unsuitable patents. Then, social network analysis was adopted to conduct an in-depth analysis of patents using the software named Gephi.

2.1. Patent data collection and preprocessing

Patents of "Top 500 Chinese Construction Enterprises" retrieved from PatSnap Global Patent Database were selected to explore recent patent activities in China. The time span of these patents ranged from 2000–2015 to capture a stable and reliable set of patent data across the defined fifteen year period. This patent data was deemed to represent the general development of patent activities in China by analyzing a large set of reliable data. Following this, duplicates and non-construction field patents, such as patents in the petrochemical, transportation and biological medicine areas, were manually removed to improve the reliability of the data. Finally, 39,810 patents were analyzed. The information sourced from these patent records includes the following: patent number, patent name, patent abstract, application year, granted year, IPC classification number, reference relationship and details of the applying enterprise.

2.2. Social Network Analysis

Broadly, SNA is a methodology for network structure analysis, which originated in sociology and anthropology. SNA provides a series of methods for quantitative analysis to reveal the overall structure of the network. The value of SNA lies in its ability to map networks and illustrate linkages, interactions, and behavioral patterns. It has been extensively used in the field of sociology, economics, and management. In recent years, this method had been increasingly applied in the engineering management domain.

As the core concept of SNA, the network represents associated relationships, which exist between multiple interaction units (Freeman, 2005). SNA has become a unique research method in its own right and has guided research and application of relevant theories (Wasserman & Faust, 1994). According to Newman (2003), the network (or graph) is represented as a set of nodes (or vertices) connected by edges. The key identifying features of social networks is the users and their interrelated connections (Nickerson, Steiny, & Oinas-Kukkonen, 2014). These connections establish the structure of the network. While not without its inherent problems, as noted by Batool and Niazi (2014), structural and topological characteristics have been used in various studies to understand the nuances of human behavior in social networks. In an organizational context, nodes typically represent individuals, and the edges correspond to relationships (e.g. trust, knowledge) between nodes. As such, SNA software can help identify, analyze, visualize, or simulate these nodes and edges (Ryan & Creech, 2012). Further, such software can also identify subgroups in a network, clustering of actors or individuals, or emphasize isolated nodes of the network (Logica & Magdalena, 2015). Network visualization facilitates the understanding of how communication took place, while statistical analyses allows a quantitative assessment of how a network was functioning relative to a desired set of indicators (Kunz, Kastelle, & Moran, 2017). Therefore, SNA can provide an in-depth enterprise cooperative analysis and reveal their cooperative patterns.

Table 1. An example of data excerpts: cooperative enterprises or universities

Enterprise-Enterprise		Enterprise-University	
Node *i*	Node *j*	Node *i*	Node *j*
China State Construction (CSC)	The First Construction CO., LTD of CSC	Zhejiang University	Zhejiang Zhancheng Construction CO., LTD
China State Construction (CSC)	China Construction Eighth Engineering Division CO., LTD	Zhejiang University	Offshore Oil Engineering CO., LTD
China State Construction (CSC)	CSC Engineering Construction International	Zhejiang University	Zhejiang Beili Construction CO., LTD
Chian Railway Tunnel Group	Beijing Urban Engineering Design & Research Institute CO., LTD	China Three Gorges University	China Gezhouba (Group) CORP.

After data pre-processing, cooperative enterprises or universities are listed in Excel (presented in Table 1), and then convert it to CSV format. Finally, SNA software Gephi is used to visualize the two networks. Gephi is an interactive visualization and exploration platform for all kinds of networks and complex systems. According to Bastian, Heymann, and Jacomy (2009), this application implements the most frequently used algorithms in descriptive statistics for networks. The networks in this study are undirected (when all the links between the nodes are bidirectional, the social network is 'undirected') in which the nodes represent enterprises or universities and the edges represent cooperative relationships. The SNA indicators can reveal the structure of the network as follows.

(1) Density

Density (D) can measure the count of the number of links to other nodes in a directed or undirected network, as shown in Eqns (1) and (2), respectively. This measure is useful for assessing the overall relationships within a network of n nodes. It can be used to identify the completeness of the network (Yoon et al., 2013). A network with high density is highly connected.

$$D=\frac{L}{N(N-1)}; \tag{1}$$

$$D=\frac{L}{N(N-1)/2}, \tag{2}$$

where L is the total number of links and N is the total number of nodes in a network.

(2) Degree centrality

Degree centrality (C_D) is used to measure the number of directed or undirected relationships that a node has with other nodes in a network, as shown in Eqn (3). This indicator can be used to calculate a node's number of directly connected neighbors in a network. A node with a higher degree of centrality indicates that it had more influence and importance than other nodes in a network.

$$C_D\left(P_k\right)=\sum_{i=1}^{N} a(P_i,P_k), \tag{3}$$

where P_k is a given node; N is the total number of nodes; $a(P_i,P_k)$ = [1 if and are connected by a line, 0 otherwise].

(3) PageRank

PageRank, is an algorithm developed by Google founders, Larry Page and Sergey Brin, as shown in Eqn (4). It works by measuring the number and quality of links to a node to determine a rough estimate of how important the node is. The underlying assumption is that more important nodes were likely to receive more links from other nodes (Google, 2014). It can be used to find the most influential node in the network (Google, 2001). Various studies had tested different damping factors, but it was assumed that the damping factor would be approximately 0.85 (Brin & Page, 1998; Brookes & Huynh, 2018).

$$PR\left(P_i\right)=\frac{1-d}{N}+d\left(\frac{PR(B)}{L(B)}+\frac{PR(C)}{L(C)}+\frac{PR(D)}{L(D)}+\ldots\right), \tag{4}$$

where d is a damping factor, d = 0.85 (we consider the top 15% enterprise nodes to be important); N is the total number of nodes; $L(B)$ is the number of edges that B linked to P_i.

(4) Cohesive subgroups index

Blondel, Guillaume, Lambiotte, and Lefebvre (2008) proposed an algorithm named Cohesive subgroups index to partition a network into communities of densely connected nodes as shown in Eqn (5). This indicator reflects the dispersion of a network. The low value of this indicator means high discreteness of a network, which indicates that there are some closed connected subgroups within it. It can help to capture the community structure of large networks. It is a heuristic method that is based on modularity optimization.

$$Q=\frac{1}{2m}\sum_{i.j}\left(A_{ij}-\frac{K_iK_j}{2m}\right)\delta\left(C_i,C_j\right), \tag{5}$$

where A_{ij} represents the weight of the edge between i and j, $K_i=\Sigma_j A_{ij}$ is the sum of the weights of the edges attached to vertex i, C_i is the community to which vertex i is assigned, the δ-function = [1 if u = v, 0 otherwise], $m=\frac{1}{2}\Sigma_{ij}A_{ij}$.

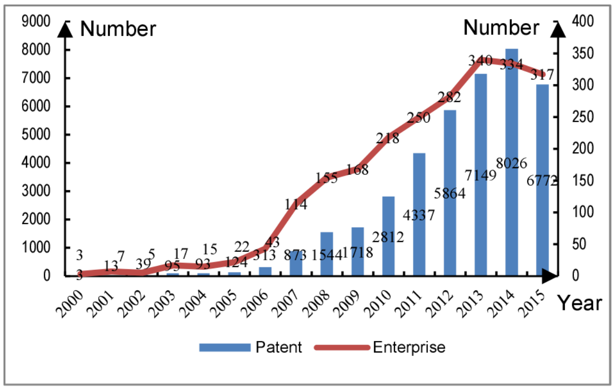


Figure 2. The number of applied patents and enterprises from 2000 to 2015

3. Patent activity trend and core technology

3.1. Patent application trends

Information extracted from patents is specific indicators for forecasting industry development trends. This research tracked patent applications in time by capturing the application year instead of the granting year. Since the granting process usually takes a long time, the application year is closer to the point in time when the invention is first developed (Albino, Ardito, Dangelico, & Petruzzelli, 2014). The number of patent applications and patentees began to increase sharply from 2007 as shown in Figure 2. This number then increased gradually every year. This increase highlights a rising trend in the number of patents and patentees in China, and indicates increasing attention on patent application and development by Chinese construction enterprises.

According to statistical results, the number of utility model patents accounts for 65.08% of granted patents, followed by 34.15% for invention patents and 0.78% for design patents (as shown in Figure 3). Utility model patents are more practical and less innovative than invention patents. This suggests these enterprises place importance on the practicability of the applied patents.

3.2. Analysis of enterprises

In this research, the Research & Development (R&D) pattern of patents can be characterized into two classifications:

1. Independent R&D pattern: referring to patents developed by only one enterprise.
2. Joint R&D pattern: referring to patents developed by two or more enterprises.

Most of the patents retrieved from the database were developed by a single enterprise, totaling 29,637. The top 10 enterprises with the most number of independent R&D patents are shown in Figure 4.

China Metallurgy Communications Construction (MCC) 17 Group Co., Ltd. was the leading enterprise from the list, having been granted 1653 patents, which accounts for 5.53% of the total number of granted patents. China Construction Eighth Engineering Division. CORP. Ltd was ranked second. China National Petroleum Corporation (CNPC) Bohai Drilling Engineering Company Limited followed in third place. Interestingly, the results show that the leading companies by the most number of independent R&D patents were state-owned enterprises.

3.3. International Patent Classification (IPC) analysis of core technology

Although IPC was initially designed as a shelf-location tool for paper search-files, the classification has certain

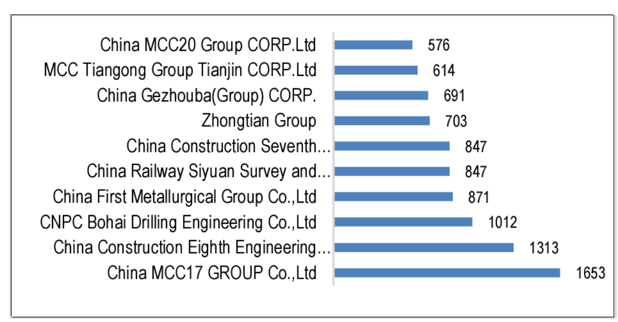
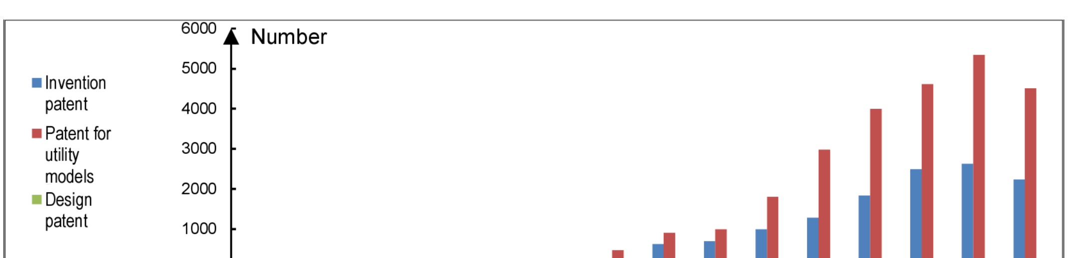


Figure 4. The top 10 enterprises with most number of independent R&D patents



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Invention patent	1	6	24	49	57	78	182	193	626	700	994	1278	1837	2491	2629	2238
Patent for utility models	2	7	15	46	36	46	128	470	901	994	1800	2979	3999	4614	5338	4508
Design patent	0	0	0	0	0	0	3	10	17	24	18	80	28	44	59	26

Figure 3. The number of different types of patent from 2000 to 2015

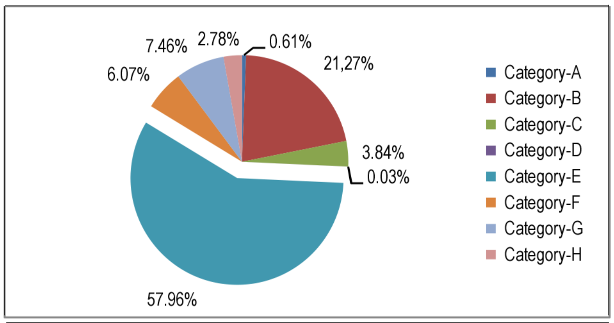


Figure 5. Proportion of patents in different areas

features which make it an attractive option for subject-based patent searching and analyzing of electronic databases (Adams, 2000). According to the standard of International Patent Classification, patents are divided into eight categories (Category A to H). Traditionally, the statistics on patents in the construction domain has been captured under Category E, Fixed Buildings. However, in recent years, with the rapid development of construction technology (especially emerging technology), an interdisciplinary trend across categories has emerged, where Category E cannot adequately represent the breath of current construction industry patents (Kim et al., 2009). The proportion of patents across different categories is shown in Figure 5.

According to the statistical results, patents in Category E account for more than half the proportion of the total patents. The top ten technology fields of the entire Chinese construction industry are presented in Table 2.

From these results, most of the granted patents (2429 patents, which account for 6.15% of the total number) were classified as E04G21 according to IPC. The second leading classification was E01D21 with 1273, followed by E04B1 with 1260. Thus, the top ten technology fields covered 24.89% of the patents. The core technology fields relating to the Chinese construction industry are identified where technological development is primarily classified in E04G21, which refers to the preparation, handling, or processing of building materials or building components on the construction site. The result indicates that in the construction domain, many patents are developed to overcome practical problems during construction processes.

4. Cooperative patterns and evolution

4.1. Enterprise-enterprise cooperative network

In this section, some SNA indicators such as Degree, PageRank, and Cohesive Subgroups Index were applied to explore the cooperative relationships between enterprises using the Gephi software. An informal cooperative relationship was established when multiple enterprises jointly developed the patents. An enterprise-enterprise cooperative network (mapped by Gephi) including 1834 nodes (enterprises) and 3423 links (cooperative relations), is shown in Figure 6 (in order to read easily, the graph only shows nodes whose degree were over 15). The average degree of such a network was 3.282, and the average density was 0.002. This also implies that enterprises' relationships were not highly cooperative.

The top ten enterprises with a high Degree and PageRank were shown in Table 3. China State Construction had the highest PageRank and degree, which indicates it is more active, influential and important than other enterprises within the construction technology domain. In this

Table 2. Top 10 technology fields in Chinese construction industry

Rank	IPC	Description	Number of patents	Percent of patents	Cumulative percentage
1	E04G21	The preparation, handling, or processing of building materials or building components; Other methods and equipment used in construction	2429	6.15	6.15
2	E01D21	Method and apparatus for erecting or assembling bridges	1273	3.22	9.37
3	E04B1	General structure; not limited to the wall, for example, partition wall, ceiling or roof	1260	3.19	12.56
4	E21D11	Tunnels or other underground caverns, for example, lining of underground large-scale chambers and their lining	835	2.12	14.68
5	E04B2	The walls of the building, for example, partition wall; isolation of wall structure; wall connections	740	1.87	16.55
6	E02D5	Sheet pile walls special for foundation engineering, piles or other structural components	735	1.86	18.41
7	B66C1	A load hanging element or device attached to a crane lifting, lowering, or traction mechanism or used to connect with these mechanisms for transferring lifting force to an object	677	1.72	20.13
8	E04G17	A connector or other accessory for a shell, a falsework, or a template	671	1.70	21.83
9	E02D17	The edge of the building excavation; excavation; embankment	627	1.59	23.42
10	E04G3	Scaffolding supported mainly by housing structure	579	1.47	24.89

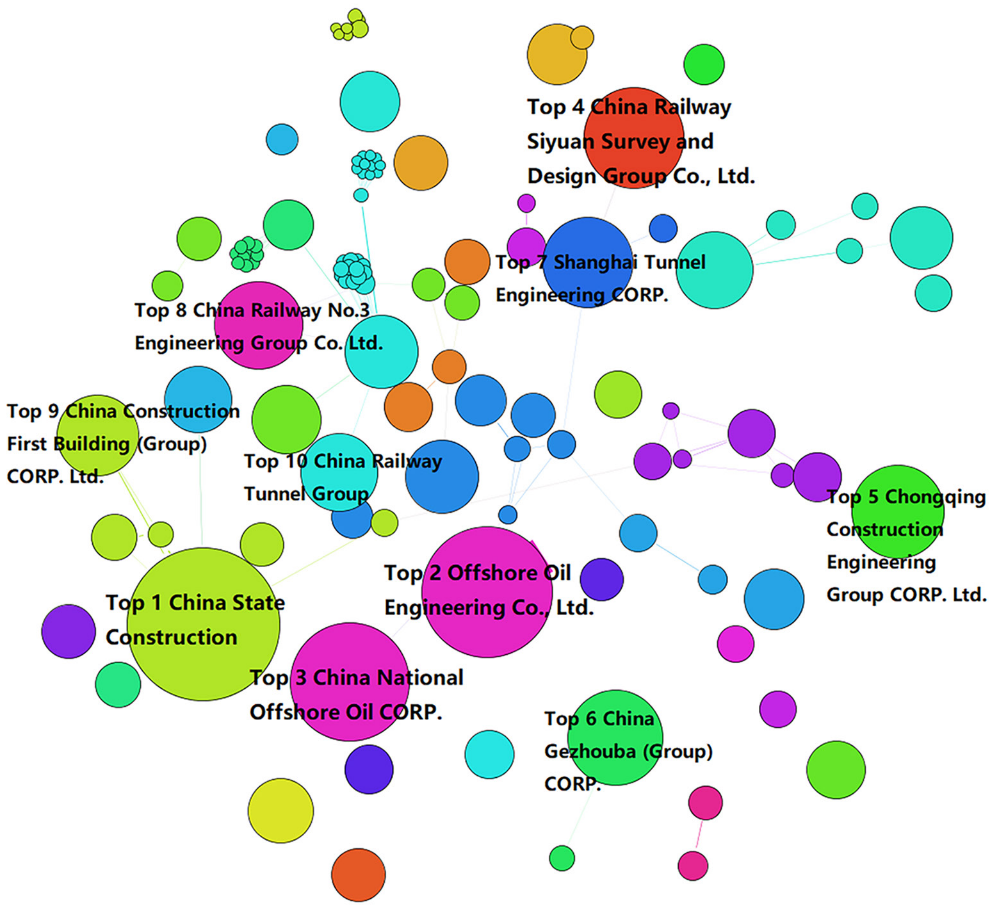


Figure 6. Enterprise-enterprise cooperative network

Table 3. Top 10 enterprises applying for patents with high Degree and PageRank

Enterprise	Degree	Enterprise	PageRank
China State Construction	58	China State Construction	0.007963138
Offshore Oil Engineering Co., Ltd	58	Offshore Oil Engineering Co., Ltd	0.006809093
China National Offshore Oil CORP.	54	China National Offshore Oil CORP.	0.006193574
China Gezhouba (Group) CORP.	41	China Railway Siyuan Survey and Design Group Co., Ltd	0.005246614
China Railway GROUP Ltd	39	Chongqing Construction Engineering Group COPR. Ltd	0.004974293
China Construction First Building (Group) CORP. Ltd	38	China Gezhouba (Group) CORP.	0.004839276
China Railway Siyuan Survey and Design Group Co., Ltd	33	Shanghai Tunnel Engineering CORP.	0.004707034
Shanghai Tunnel Engineering CORP.	31	China Railway No. 3 Engineering Group Co., Ltd	0.004598046
China Railway No.3 Engineering Group Co., Ltd	26	China Construction First Building (Group) COPR. Ltd	0.004249329
China Railway Major Bridge Engineering Group Co., Ltd	26	China Railway Tunnel Group	0.004036742

Table 4. Top 10 most closely linked enterprises

Source	Target	Weight
Offshore Oil Engineering Co., Ltd	China National Offshore Oil CORP.	987
MCC TianGong Group COPR. Ltd	Shanghai MCC13 Group Co., Ltd	314
China Communications 2nd Navigational Bureau 2nd Engineering Co., Ltd.	CCCC Second Harbor Engineering Co., Ltd.	302
CCCC Fourth Harbor Engineering Co., Ltd	CCCC Second Harbor Engineering Co., Ltd	140
CCCC Fourth Harbor Engineering Co., Ltd	China Communications 2nd Navigational Bureau 2nd Engineering Co., Ltd.	140
The Second Engineering Company of CCCC Fourth Harbor Engineering Co., Ltd.	CCCC Second Harbor Engineering Co., Ltd.	140
The Second Engineering Company of CCCC Fourth Harbor Engineering Co., Ltd.	China Communications 2nd Navigational Bureau 2nd Engineering Co., Ltd.	140
China National Offshore Oil CORP.	OFFSHORE OIL ENGINEERING Co., Ltd (Qingdao)	132
China State Construction	China Construction-Baili Engineering Technology Development Co., Ltd.	130
The Second Engineering Company of CCCC Fourth Harbor Engineering Co., Ltd.	CCCC Fourth Harbor Engineering Co., Ltd.	129

respect, the top three enterprises were China State Construction, followed by Offshore Oil Engineering Co., Ltd and China National Offshore Oil Corp. The result of degree analysis in this study shows that the top three enterprises had more than 50 relations in the above network. In summary, these large companies had cooperative relationships with more than 50 other companies and were identified to play an important role in the innovation knowledge diffusion process.

The frequency of cooperation is a key indicator of the level of relationship strength, referred to as the formal or informal contact in the development of the business, and sharing of technical knowledge and other resources (Li, 2015). In general, frequent formal or informal communication can help to improve the strength of the relationship between enterprises and their partners. Table 4 presents the most closely linked enterprises. The higher weight in Table 4 indicates a more stable and linked connection. According to Table 4, Offshore Oil Engineering Co., Ltd. and China National Offshore Oil CORP. were the most closely connected enterprises by a significant margin, followed by MCC TianGong Group Co., LTD. and Shanghai MCC13 TianGong Group Co., Ltd. China Communications 2nd Navigational Bureau 2nd Engineering Co., Ltd. (CSNEC). China Communications Construction Company (CCCC) Second Harbour Engineering Company Ltd was the third most closely linked enterprise. This result highlights that the most closely connected enterprises were operating in the same field. As expected, the majority of these enterprises were parent companies and their closely connected subsidiaries.

4.2. Evolution of enterprise-enterprise cooperative networks

This research analyzed the cooperative network from 2007, considering that patent number sharply increased from that year. According to degree analysis, there were extra-ordinary core enterprises identified in the network. In 2007 and 2008, China State Construction and its subsidiary China Construction First Building (Group) CORP. Ltd were at the center of the network. In 2009, several enterprises emerged to actively participant in patent activity, such as China Railway Construction Co., Ltd and Shanghai Urban Construction Co., Ltd. In 2010, China National Offshore Oil Corporation (CNOOC) was at the center of the patents cooperative network, with previously active enterprises still playing important roles in patent activities during 2011 to 2015.

In the evolution of enterprise-enterprise cooperative networks, the number of nodes, the number of subgroup and subgroup size are increasing and there are three types of cooperative groups in the network: cooperative groups with a large number of nodes, cooperative groups with a fewer nodes, and small groups with two or three nodes. Moreover, the number of large-scale groups is relatively small. Some of the large groups were within a stable structure and some of the small groups were not stable. In each year, new groups would appear, and some groups would subside.

As shown in Table 5, the density of the enterprise-enterprise cooperative network presents a downward trend. The central networks became smaller, with a rising number of cooperative network groupings. From the perspective of cohesive subgroups index, the evolution of enterprise-enterprise cooperation represents a small-world network trend. The cooperative relationships mainly concentrate on inter-group cooperation and parent-subsidiary cooperation.

4.3. Enterprise-university cooperative network

Industry-University-Research Collaboration can integrate social, scientific and technological resources, which can

Table 5. The parameter of enterprise-enterprise cooperative network from 2007 to 2015

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Average degree	1.608	2.072	2.274	2.103	2.221	2.589	2.277	2.126	2.199
Density	0.011	0.009	0.008	0.006	0.006	0.005	0.004	0.004	0.005
Cohesive subgroups index	0.935	0.900	0.911	0.924	0.966	0.965	0.934	0.944	0.909
Group number	52	56	67	84	93	110	116	113	93

address the enterprise-level technological innovation barriers and provided market orientation and financial support for university research and development activities. At present, Industry-University-Research Collaboration had become a new mode of technological innovation development, which had received significant research attention by scholars all over the world. Joint patent applications have become a common outcome of Industry-University-Research Collaboration (Levy, Roux, & Wolff, 2009). In the process of joint patent applications, an informal cooperative network is formed between the university and the enterprise. This informal cooperative network can facilitate the transfer of knowledge from the universities to the enterprises (Ponds, Oort, & Frenken, 2009).

The research results highlight some universities began to cooperate with enterprises to conduct patent applications from 2004, and from then on, a greater number of

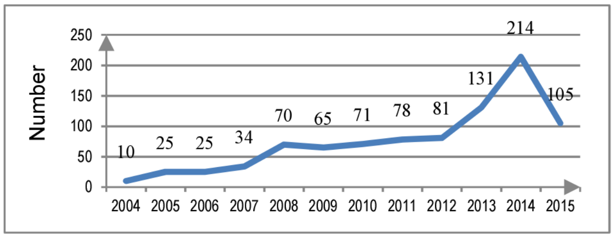


Figure 7. The number of patents developed by enterprise-university from 2004 to 2015

universities began to work with enterprises in patent applications. There was a rising trend of patents, which were jointly developed by enterprises and universities, as shown in Figure 7 (in order to read easily, the graph only shows nodes whose degree were over 5). Through this cooperative research and patent development, enterprises obtain

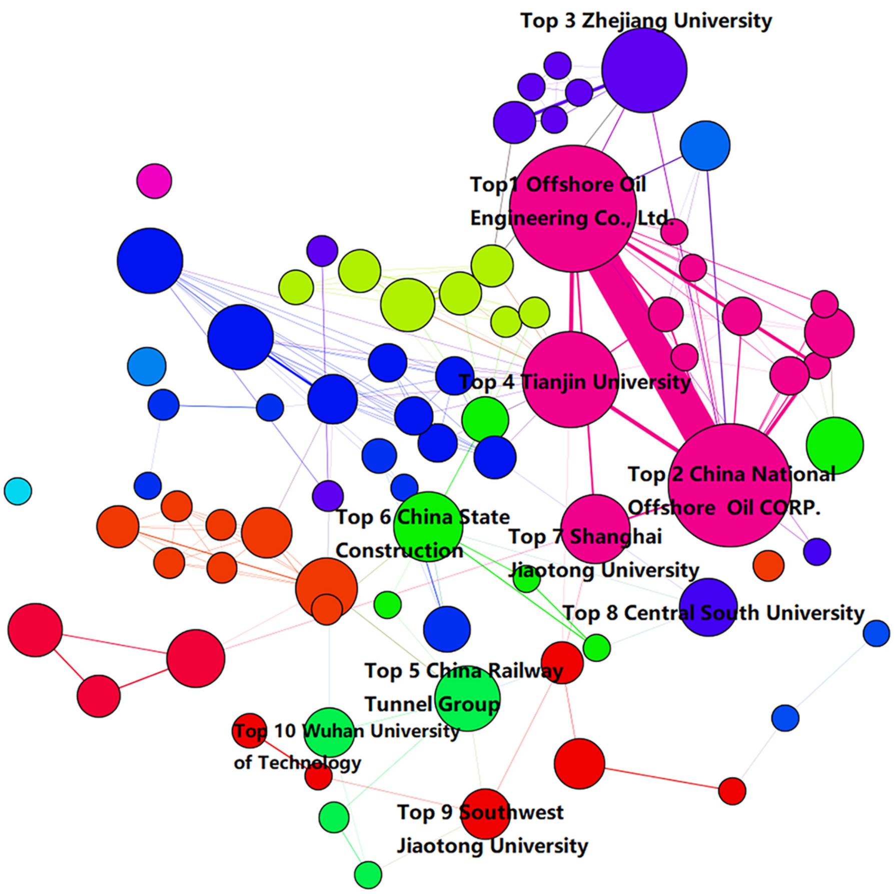


Figure 8. Enterprise-university cooperative network

Table 6. Top10 most influential enterprises and universities

Enterprise or university	Degree	PageRank
Offshore Oil Engineering Co., Ltd	31	0.015348821
China National Offshore Oil CORP.	30	0.014784663
Zhejiang University	20	0.012814655
Tianjin University	23	0.01064786
China Railway Tunnel Group	15	0.010551283
China State Construction	16	0.009778453
Shanghai Jiaotong University	16	0.009638186
Central South University	13	0.008808706
Southwest Jiaotong University	11	0.008638638
Wuhan University of Technology	11	0.008583339

and diffuse new knowledge and develop innovative ideas for mutual benefit to contribute to enhancing China's international competitiveness.

The enterprise-university cooperative network comprised 1834 nodes and 3423 links, as shown in Figure 8. The average degree of each node was 3.415, and the average density was 0.009. The average density in the enterprise-university cooperative network was higher than that in the enterprise-enterprise cooperative network, which implies that it was a higher connected network.

Table 6 presents the top ten most influential enterprises and universities, with the ranked top four comprising Offshore Oil Engineering Co., Ltd, CNOOC, Zhejiang University and Tianjin University. These enterprises and universities were most active in Industry-University-Research Collaboration activities and played an important role in the innovation knowledge diffusion process.

Table 7. Top 10 most closely linked enterprises and universities

Enterprise or university	Enterprise or university	Weight
Harbin Engineering University	China National Offshore Oil CORP.	72
Harbin Engineering University	Offshore Oil Engineering Co., Ltd	72
China National Offshore Oil CORP.	Tianjin University	32
Tianjin University	Offshore Oil Engineering Co., Ltd	32
China National Offshore Oil CORP.	China University of Petroleum-Beijing	27
Offshore Oil Engineering Co., Ltd	China University of Petroleum-Beijing	27
Zhejiang University	Zhejiang Zhancheng group	27
China National Offshore Oil CORP.	China University of Petroleum-Beijing	26
Offshore Oil Engineering Co., Ltd	China University of Petroleum-Beijing	26
Sinohydro Bureau 7 Co., Ltd	Wuhan University	18

The more stable connections are presented in Table 7. From the perspective of cooperative relationships, when enterprises and universities choose to cooperate with each other, in addition to professional qualification, geographical factors also need to be considered. Based on the geographical locations of the enterprises and universities, the results highlight that enterprises and universities located in the same geographical region cooperated more closely on patents.

5. Discussion

According to the results presented above, state-owned enterprises played a dominant role in patent activities in the Chinese construction industry. In general, state-owned enterprises gain more favor from government and their R&D investments are high (Gao & Zhao, 2015; Wu & Tian, 2000). For example, according to the research results, China State Construction was the most heavily influential enterprise with more than 40 subsidiaries in total. One of its subsidiaries is China Construction Eighth Engineering Division. CORP. Ltd, owned 1313 granted patents between 2000 and 2015, accounting for 4.39% of the total number of patents in the entire construction industry. The results also indicate that this enterprise had cooperative relations with more than 50 companies and played an important role in the knowledge diffusion process. Also, China State Construction was identified as a major investor in scientific research and heavily involved in enterprise-university cooperative ventures. It had undertaken 108 national scientific research tasks supported by the state with total funding reportedly at 520 million yuan. Such strong financial support contributes significantly to an enterprise's technological innovation (Bronzini & Piselli, 2016).

In the evolution of enterprise-enterprise cooperative network, there are three types of cooperative groups identified in the network: cooperative groups with a large number of nodes, cooperative groups with fewer nodes, and small groups with two or three nodes. Further, the number of large-scale groups is small. Some of the large cooperative groups were within a stable structure and some small groups were not stable. In each year, some new groups would appear, and some groups would subside. It is suggested a primary reason for this phenomenon is that most of the patents in construction field were utility model patents, which are developed during the process of specific projects. Large-scale enterprises undertake many construction projects and the duration of their projects are long. This allows funds to be invested into technical innovation each year. In comparison, small-scale enterprises have fewer projects and less innovation investment funds at their disposal, and their annual innovation investment can heavily depend on their earnings each year (Xiao, 2013).

Further, the evolution of enterprise-enterprise cooperation represents a small-world network trend. Such cooperative relationships were mainly concentrated on inter-group cooperation and parent-subsidiary cooperation. It is suggested a primary reason for this phenomenon is that, due to fierce competition, construction enterprises aim to maintain their competitive edge and improve their technological innovation by developing patents in cooperation within closely linked groups (Akis, 2015), such as a parent-subsidiary group.

The SNA-based patent analysis method proposed in this paper is expected to be useful. The proposed method visually presents critical enterprise-enterprise cooperative networks and enterprise-university cooperative networks to be analyzed quantitatively. This method allows the analysis of the network features to reveal potential relationships between stakeholders (e.g. enterprises, universities, and patents) in the construction industry context without expert opinion or peer review. Moreover, the proposed approach has the potential to be applied to other domains to visually present cooperative networks in patent development. After the graph is developed, controls can be applied to select nodes or edges, to view their implications on the network structure, or to measure average access and identify the groups with most frequent access. The graph can be undirected, representing only symmetric relations, or directed, for asymmetric and symmetric relations and weight, representing intensities, distances or cost of relations.

Conclusions and future work

This paper extracts implicit collaborative information from patent data and introduces a SNA method to conduct the patentometric analysis. Patents developed between 2000 and 2015 by the "Top 500 Chinese Construction Enterprises" are collected from PatSnap database, and analyzed using SNA. Then, the enterprise-enterprise and enterprise-university cooperative networks are analyzed. The contributions of this study lie in: (a) providing a visual representation for better understanding of the implicit collaborative information; (b) revealing cooperative patterns of construction enterprises on patents; and (c) providing some useful suggestions for patent cooperation for enterprises.

The results indicate a rising trend in the number of patents and patentees in China, and highlights increasing attention on patent application and development by Chinese construction enterprises since 2007. The results also highlight the dominant role played by state-owned enterprises in patent activities. The number of utility model patents accounts for 65.08% in the granted patents, which reveals that most enterprises focus on the practicability of the patents. According to IPC analysis, the majority of patent technology focuses on the E04G21 classification, which refers to the preparation, handling, or processing of building materials or building components on the site. IPC analysis result shows that many patents are developed to overcome practical problems during construction processes. According to the SNA results, the cooperative relationships are mainly limited to inter-group cooperation and parent-subsidiary cooperation. Further, the evolution of enterprise-enterprise cooperation presents a small-world network trend. Within the small-world network, the efficiency of knowledge diffusion is high (Latora & Marchiori, 2001). When enterprises choose to cooperate with universities, in addition to professional qualification, geographical factors are also identified as important. Enterprises and universities located in the same geographical region cooperate more closely on patents.

In summary, the results presented in this paper reveal construction enterprises' patent cooperative patterns and indirectly provides enterprises a basis for improved decision-making in the development of their technical strategy: (a) Enterprises are encouraged to develop innovation patents to enhance innovative ability; (b) Enterprises can seek help from universities to develop patents, and the geographical factor of universities should be taken into consideration; (c) Enterprises, especially large-scale enterprises, are encouraged to cooperate with others that are not their subsidiaries to facilitate knowledge diffusion. Further, results also provide direction for government policy development to promote enterprise and industry-level sustainability: (d) Financial support is one of the driving forces of technological innovation in an enterprise.

Despite the benefits in providing insight into patent development trends, the research has some limitations for future work to address, and thus, further contribute to the patent management research. A limitation is that the research only analyzed patents developed by the "Top 500 Chinese Construction Enterprises". In the future work, it is recommended that patents from small enterprises be taken into account, as small enterprises are acknowledged to play an important role in national patent activities. Further, the research is limited to enterprises operating in the Chinese construction industry. Results indicate the proposed method could be applied to analyze patent cooperative patterns and evolution trends of construction enterprises in other industries and countries. This would offer the opportunity to further validate the proposed method and compare differences in patent activity within and across industry boundaries. In the future work, taking enterprise attributes (e.g. funds, qualifications or professionals) into consideration based on the findings of this paper, more meaningful findings will be concluded.

Acknowledgements

This research is partly supported by "National Natural Science Foundation of China" (No. 51878311, No. 71732001).

Funding

This work was supported by the National Natural Science Foundation of China under Grant [number 51878311 and number 71732001].

Author contributions

Botao Zhong and Hanbin Luo conceived the study and were responsible for the design and development of the data analysis. Botao Zhong and Yongjian Hei were responsible for data collection and analysis. Heng Li and Botao Zhong were responsible for data interpretation. Yongjian Hei and Botao Zhong wrote the first draft of the article. Timothy Rose revised the article and polished language.

Disclosure statement

We have no competing financial, professional, or personal interests from other parties.

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