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

Botao ZHONG1, 2, Yongjian HE1, 2, Heng LI3, Timothy ROSE4, Hanbin LUO1, 2*

1Department of Construction Management, School of Civil Engineering and Mechanics, Huazhong University of Science and Technology, Wuhan 430074, Hubei, China
2Hubei Engineering Research Centre for Virtual, Safe and Automated Construction, Wuhan, Hubei, China
3Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong, China
4Faculty of Civil Engineering and Built Environment, Queensland University of Technology, Queensland, Australia

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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-
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 often applied to identify and analyze relationships in collaborative organizations (Boccaletti, Latora, Moreno, Chavez, & Hwong, 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.
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.
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.

\[
D = \frac{L}{N(N-1)}; \quad (1)
\]

\[
D = \frac{L}{N(N-1)/2}, \quad (2)
\]

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.

\[
C_D(B_k) = \sum_{i=1}^{N} a(P_i, P_k), \quad (3)
\]

where \( P_k \) is a given node; \( N \) is the total number of nodes; \( a(P_i, P_k) = \begin{cases} 1 & \text{if and are connected by a line}, \\ 0 & \text{otherwise} \end{cases} \).

(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).

\[
PR(P_j) = \frac{1-d}{N} + d \left( \frac{PR(B)}{L(B)} + \frac{PR(C)}{L(C)} + \frac{PR(D)}{L(D)} + \ldots \right), \quad (4)
\]

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 \( P_c \).

(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.

\[
Q = \frac{1}{2m} \sum_{i,j} \left( A_{ij} - \frac{K_i K_j}{2m} \right) \delta(C_i, C_j), \quad (5)
\]

where \( A_{ij} \) represents the weight of the edge between \( i \) and \( j \). \( K_i = \sum_{j} A_{ij} \) 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 \( \delta \)-function = \( \begin{cases} 1 & \text{if } u = v, \\ 0 & \text{otherwise} \end{cases} \), \( m = \frac{1}{2} \sum_{i} A_{ii} \).
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
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 breadth 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 3.28, 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>
<thead>
<tr>
<th>Rank</th>
<th>IPC</th>
<th>Description</th>
<th>Number of patents</th>
<th>Percent of patents</th>
<th>Cumulative percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E04G21</td>
<td>The preparation, handling, or processing of building materials or building components; Other methods and equipment used in construction</td>
<td>2429</td>
<td>6.15</td>
<td>6.15</td>
</tr>
<tr>
<td>2</td>
<td>E01D21</td>
<td>Method and apparatus for erecting or assembling bridges</td>
<td>1273</td>
<td>3.22</td>
<td>9.37</td>
</tr>
<tr>
<td>3</td>
<td>E04B1</td>
<td>General structure; not limited to the wall, for example, partition wall, ceiling or roof</td>
<td>1260</td>
<td>3.19</td>
<td>12.56</td>
</tr>
<tr>
<td>4</td>
<td>E21D11</td>
<td>Tunnels or other underground caverns, for example, lining of underground large-scale chambers and their lining</td>
<td>835</td>
<td>2.12</td>
<td>14.68</td>
</tr>
<tr>
<td>5</td>
<td>E04B2</td>
<td>The walls of the building, for example, partition wall; isolation of wall structure; wall connections</td>
<td>740</td>
<td>1.87</td>
<td>16.55</td>
</tr>
<tr>
<td>6</td>
<td>E02D5</td>
<td>Sheet pile walls special for foundation engineering, piles or other structural components</td>
<td>735</td>
<td>1.86</td>
<td>18.41</td>
</tr>
<tr>
<td>7</td>
<td>B66C1</td>
<td>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</td>
<td>677</td>
<td>1.72</td>
<td>20.13</td>
</tr>
<tr>
<td>8</td>
<td>E04G17</td>
<td>A connector or other accessory for a shell, a falsework, or a template</td>
<td>671</td>
<td>1.70</td>
<td>21.83</td>
</tr>
<tr>
<td>9</td>
<td>E02D17</td>
<td>The edge of the building excavation; excavation; embankment</td>
<td>627</td>
<td>1.59</td>
<td>23.42</td>
</tr>
<tr>
<td>10</td>
<td>E04G3</td>
<td>Scaffolding supported mainly by housing structure</td>
<td>579</td>
<td>1.47</td>
<td>24.89</td>
</tr>
</tbody>
</table>
Table 3. Top 10 enterprises applying for patents with high Degree and PageRank

<table>
<thead>
<tr>
<th>Enterprise</th>
<th>Degree</th>
<th>Enterprise</th>
<th>PageRank</th>
</tr>
</thead>
<tbody>
<tr>
<td>China State Construction</td>
<td>58</td>
<td>China State Construction</td>
<td>0.007963138</td>
</tr>
<tr>
<td>Offshore Oil Engineering Co., Ltd</td>
<td>58</td>
<td>Offshore Oil Engineering Co., Ltd</td>
<td>0.006809093</td>
</tr>
<tr>
<td>China National Offshore Oil CORP.</td>
<td>54</td>
<td>China National Offshore Oil CORP.</td>
<td>0.006193574</td>
</tr>
<tr>
<td>China Gezhouba (Group) CORP.</td>
<td>41</td>
<td>China Railway Siyuan Survey and Design Group Co., Ltd</td>
<td>0.005246614</td>
</tr>
<tr>
<td>China Railway GROUP Ltd</td>
<td>39</td>
<td>Chongqing Construction Engineering Group CORP. Ltd</td>
<td>0.004974293</td>
</tr>
<tr>
<td>China Construction First Building (Group) CORP. Ltd</td>
<td>38</td>
<td>China Gezhouba (Group) CORP.</td>
<td>0.004839276</td>
</tr>
<tr>
<td>China Railway Siyuan Survey and Design Group Co., Ltd</td>
<td>33</td>
<td>Shanghai Tunnel Engineering CORP.</td>
<td>0.004707034</td>
</tr>
<tr>
<td>Shanghai Tunnel Engineering CORP.</td>
<td>31</td>
<td>China Railway No. 3 Engineering Group Co., Ltd</td>
<td>0.004598046</td>
</tr>
<tr>
<td>China Railway No.3 Engineering Group Co., Ltd</td>
<td>26</td>
<td>China Construction First Building (Group) CORP. Ltd</td>
<td>0.004249329</td>
</tr>
<tr>
<td>China Railway Major Bridge Engineering Group Co., Ltd</td>
<td>26</td>
<td>China Railway Tunnel Group</td>
<td>0.004036742</td>
</tr>
</tbody>
</table>
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. China Communications 2nd Navigational Bureau 2nd Engineering Co., 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 participate 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
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 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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average degree</td>
<td>1.608</td>
<td>2.072</td>
<td>2.274</td>
<td>2.103</td>
<td>2.221</td>
<td>2.589</td>
<td>2.277</td>
<td>2.126</td>
<td>2.199</td>
</tr>
<tr>
<td>Density</td>
<td>0.011</td>
<td>0.009</td>
<td>0.008</td>
<td>0.006</td>
<td>0.006</td>
<td>0.005</td>
<td>0.004</td>
<td>0.004</td>
<td>0.005</td>
</tr>
<tr>
<td>Cohesive subgroups index</td>
<td>0.935</td>
<td>0.900</td>
<td>0.911</td>
<td>0.924</td>
<td>0.966</td>
<td>0.965</td>
<td>0.934</td>
<td>0.944</td>
<td>0.909</td>
</tr>
<tr>
<td>Group number</td>
<td>52</td>
<td>56</td>
<td>67</td>
<td>84</td>
<td>93</td>
<td>110</td>
<td>116</td>
<td>113</td>
<td>93</td>
</tr>
</tbody>
</table>

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

Figure 8. Enterprise-university cooperative network
Operation represents a small-world network trend. Such a phenomenon is common in large-scale networks, where a small number of nodes have a high connectivity degree, and the majority of nodes have low degrees. For example, in an enterprise-enterprise cooperative network, a few nodes (enterprises or universities) have a high degree, indicating a high level of cooperation, while most nodes have a low degree, indicating less frequent cooperation.

Table 6. Top 10 most influential enterprises and universities

<table>
<thead>
<tr>
<th>Enterprise or university</th>
<th>Degree</th>
<th>PageRank</th>
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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.

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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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