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Knowledge Transfer Characteristics of Construction Workers Based on Social Network Analysis

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Abstract: Effects of traditional training methods are not obvious when transferring competent knowledge to construction workers to allow them to deal with new technology and intelligent equipment. The purpose of this study was to explore knowledge transfer paths and transfer characteristics within worker groups and to provide a theoretical basis for formulating new measures to improve knowledge and skills in worker groups. Firstly, we analyzed and verified the group characteristics of workers. Then, the social network analysis (SNA) method was used to study the knowledge transfer characteristics of worker groups, and the following conclusions were drawn: (1) construction workers have obvious group closure and regional concentration, which have significant impacts on knowledge transfer; (2) team leaders are the core and authority of knowledge transfer within entire networks, so improving the knowledge and skills of team leaders has a significant impact on promoting the overall knowledge and skills of workers; (3) it is very difficult for expatriate technical instructors with high levels of education but no blood or geographical relationships with other workers to establish knowledge authority among workers; and (4) due to the large gaps in knowledge and skills among workers, one-way flows of knowledge occur easily within groups.

Keywords: construction workers; group characteristics; knowledge transfer; social network analysis; team leaders

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1. Introduction

Labor intensity and low productivity have always been vexing issues entrenched in China's construction industry [1]. In recent years, on the one hand, the Chinese government has promoted serious measures to transform the construction industry from extensive to intensive in order to enhance the applications of advanced technology and to mitigate the dependence on labor. These measures consider building industrialization [2] and construction informatization [3] as new ways to improve traditional construction due to their potential to increase construction efficiency and sustainability [4]. On the other hand, low-carbon ecological and durable building materials have been developed to alleviate labor dependence and to reduce environmental pollution [5,6]. The application of industrialization and information technology has effectively reduced the need for on-site skilled workers [7]; however, conditions and circumstances external to worker knowledge and skills are crucial [8]. This raises new requirements for worker knowledge and skills because of the higher intelligence needed to operate construction equipment and the rapid development of construction technology [9]. The knowledge and skills of construction workers play important roles in improving construction productivity and project quality within the labor- and knowledge-intensive construction industry [10].

In China, most construction workers are rural migrants without professional training. According to data from the National Bureau of Statistics of China, in 2021, the construction industry employed about 19.0% of the total migrant workers, a total of 55.58 million people [11]. Most migrant workers are less educated, and their knowledge levels are generally low [9]. Improving the learning ability and knowledge levels of construction workers is one of the key factors for promoting the transformation and upgrade of the construction industry. However, the group closure and frequent mobility of migrant workers have been great obstacles for re-education and skills training because worker knowledge from one project cannot be fully reused for different projects due to high turnover rates and frequent reassignment [12]. To improve the knowledge levels and labor skills of this special group, the government has introduced training measures performed through formal classes and on-the-job training [13]. However, the willingness of construction workers to participate in this skills training is very low, and the training effects are not obvious [14]. Traditional methods and techniques are ineffective at transferring enough knowledge for construction workers to eliminate many common mistakes, and thus, new methods for knowledge transfer are urgently needed [15]. Therefore, it is crucial to identify the deep-seated reasons that affect the willingness of construction workers to learn and the characteristics of knowledge transfer among them in order to develop measures to promote learning enthusiasm and efficiency. Several researchers have addressed the importance of the knowledge levels of construction workers for the development of the construction industry. Wang et al. (2016) [16] used structural equation modeling (SEM) to identify the critical factors and paths that influence workers' safety risk tolerance and to explore how they contribute to accident causal models from a system thinking perspective. Chen et al. (2017) [17] used the social network analysis method to analyze safety knowledge dissemination among construction workers and put forward suggestions to promote the effective dissemination of safety knowledge. Zhang et al. (2017) [18] analyzed the factors that influence construction workers sharing safety knowledge and found that an organizational atmosphere has the greatest influence. Previous studies have mainly focused on safety knowledge transfer, and very few studies have addressed the importance of the comprehensive knowledge and skills of construction workers and the influence of worker group characteristics on knowledge transfer. In addition, significant benefits could be reaped by improving the comprehensive knowledge levels of workers for both companies and the workers themselves. The merits for companies include decreased construction costs, safer work sites, improved quality of projects, etc. The positive impacts on workers include improvements in employment prospects, income, job competency, etc. [19]. Considering these factors, the objectives of this paper were set out as follows:

- To analyze the group characteristics of construction workers and their influence on knowledge transfer;
- To explore the knowledge transfer characteristics and paths of construction workers and the influence of workers with different roles on knowledge transfer networks;
- To provide a useful reference to help decision-makers to formulate effective policies and measures to improve the knowledge and skills of construction workers.

2. Group Characteristics and Types of Knowledge

The individual and group characteristics of construction workers have direct impacts on the dissemination and transfer of knowledge; therefore, understanding the group characteristics of construction workers is an important step toward identifying the characteristics of knowledge transfer and common learning approaches. Migrant workers account for the largest proportion of construction workers within the Chinese construction industry. Migrant workers are a specific group of rural farmers who forsake their land and migrate to cities in the hope of increasing their opportunities and receiving higher incomes; they have the common characteristics of having less education [20], regional concentration, group closure and frequent migration [21].

2.1. Regional Concentration

Before migrant workers migrate to cities, most of their contacts are confined to relatives or villagers in the same village. When they move to work in cities, they are usually guided by a familiar leader who contracts work from a larger contractor and lives a collective life on construction sites. Most of the construction workers within the same construction group have the same regional characteristics, such as consanguinity, fellow countrymen, friendship, etc. Zhang and Feng (2015) [22] divided the social relations of migrant workers into kinship (i.e., blood relationships, such as parents, spouses and other relatives), geographic relationships (such as fellow townsmen) and friendship without consanguinity. These three types of relationships form links between migrant workers and can even replace formal labor contracts.

2.2. Group Closure

Han et al. (2015) [23] divided the group closure of Chinese construction workers into structural closure and relational closure. Construction workers live semiclosed lives on construction sites and have less contact with the outside world. They are mostly led by their group leaders and the construction groups are their basic units. Because they work and live together, the members of the same group are closely related and contact between different groups is rare. Group leaders have more contact with ordinary workers and become the core figures within construction groups. Most migrant workers migrate for work for the sole purpose of earning money, without considering integration into local societies [24]. They have full confidence in the group leaders and tend to communicate with workers with similar geographical and family backgrounds, adopting their suggestions both on work and life [25].

2.3. Frequent Migration

A clear majority of migrant workers move to work in cities to make money to improve the lives of their families in their hometowns. At the same time, they need to take responsibility as part of the family. When their family members encounter problems, they need to give up their jobs in the cities and return home to assume their responsibilities and obligations, which leads to job instability. Construction workers generally belong to different labor subcontracting companies, but there are no fixed personnel relationships within these labor companies. Workplaces change according to different project schedules, which causes frequent migration between jobs. According to the research of Sun et al. (2018) [26], 82% of construction workers in China have abnormal mobility, 73.3% of construction workers have changed jobs within the industry and the turnover rate of construction workers is at the forefront of all industries. The frequent migration of construction workers not only affects the willingness of government and enterprises to offer training, but also their willingness to upgrade industrial structures and the sustainable development of the construction industry [27].

2.4. Types of Knowledge

Individuals complete the effective transfer of knowledge through interpersonal communication, inquiry, theory and practice. Knowledge types have important impacts on knowledge transfer [26]. Knowledge can be generally classified into two types: explicit and tacit. Explicit knowledge is knowledge that can be formalized and stored, including standard operating procedures, best practice guides, reports and manuals [28,29]. Explicit knowledge is usually summarized and refined using language or pictures and other easy-to-understand communication forms to make the knowledge clear and easy to disseminate [30]. In contrast, tacit knowledge refers to personal context-specific knowledge that resides within people's minds and is difficult to formalize, express or articulate to other people [31]. Because tacit knowledge is based on the skills, experience and talent of individual people, it is difficult to code in order for it to be shared, as with explicit knowledge [32]. The transfer of tacit knowledge can only be achieved by the knowledge acquirer learning from the knowledge owner through the interpersonal interactions or common practice of the knowledge owner and the knowledge acquirer [31]. We studied the comprehensive knowledge and skills that construction workers need in their daily work, as well as their ability to learn to use new technology and equipment in a timely manner.

Because of their low educational levels and their group characteristics being different from general organizations, it is difficult for construction workers to acquire knowledge through systematic and formal textbook learning or professional training. Conversely, they rely more extensively on informal guidance and experience to acquire knowledge and skills; thus, "one-on-one" skills teaching between teachers and apprentices is considered to be the most effective way of learning skills on construction sites [33]. Learning while doing is a major feature of construction workers obtaining knowledge, which is greatly influenced by the people and environments around them. Therefore, the knowledge of construction workers comes largely from the working experience of group leaders and workmates, which is mainly tacit knowledge. The way workers acquire knowledge and the amount of knowledge obtained are greatly influenced by group characteristics and the roles and status of individuals within knowledge transfer networks.

3. Methodology

Social network analysis (SNA) is a structural analysis method that analyzes the structure and attributes of social relationships formed by different social units, such as individuals, groups or societies. It can provide quantitative tools for exploring various relationships within networks, accurately analyzing individual attributes and overall network attributes and building bridges between micro-relationships and macro-social systems [34]. Chen et al. (2017) [17] studied the influence of social networks on safety knowledge dissemination among construction workers in subway projects and concluded that the effect of safety knowledge dissemination among construction workers is positively related to the degree of centrality within the social network. Li et al. (2017) [35] used SNA to build a relationship network model for various unsafe behaviors among construction workers and studied their structural characteristics, node attributes, influences and clustering levels. Wang et al. (2018) [36] applied SNA to construct a network communication model of unsafe behavior among construction team members and analyzed the characteristics of the communication paths of unsafe behaviors among construction workers. The above research shows that SNA is an effective method for studying the behavior and knowledge transfer of workers. Construction workers are not only independent individuals, but they are also embedded into the networks of their groups and are affected by these networks. The group characteristics of construction workers show the characteristics of the social network; thus, social network analysis can be applied to model worker knowledge transfer networks and analyze knowledge transfer characteristics.

Considering that a significant number of construction workers in China are poorly educated and some are even illiterate [14], a two-step investigation based on a questionnaire survey was developed to achieve the three objectives of this paper, which were set out in Section 1. The first step of the investigation was to analyze and verify the regional concentration, group closure and frequent mobility of construction workers. The second step of the investigation was to build a social network model of worker knowledge transfer according to group characteristics and study the knowledge transfer features of the workers and the effects of different roles within the network. A flow chart of the research [37] is shown in Figure 1. The questionnaire was designed according to the following two basic principles:

- The language was easy for the construction workers to understand. Limited by their educational levels and knowledge, construction workers tend to refuse to answer questions that they do not understand or answer them indiscriminately, which results in the invalidity of questionnaires. Therefore, using easy-to-understand language for questionnaires could enhance the validity of the results.
- The questionnaire was simple and the number of items was small. Most construction workers work long hours and highly labor-intensive jobs, and therefore, they are unwilling to spend too much time on other things. If there were too many items on the questionnaire, it would have occupied the working and rest time of the workers

and they would have easily become tired of completing them, thus affecting the authenticity of the results of the survey.

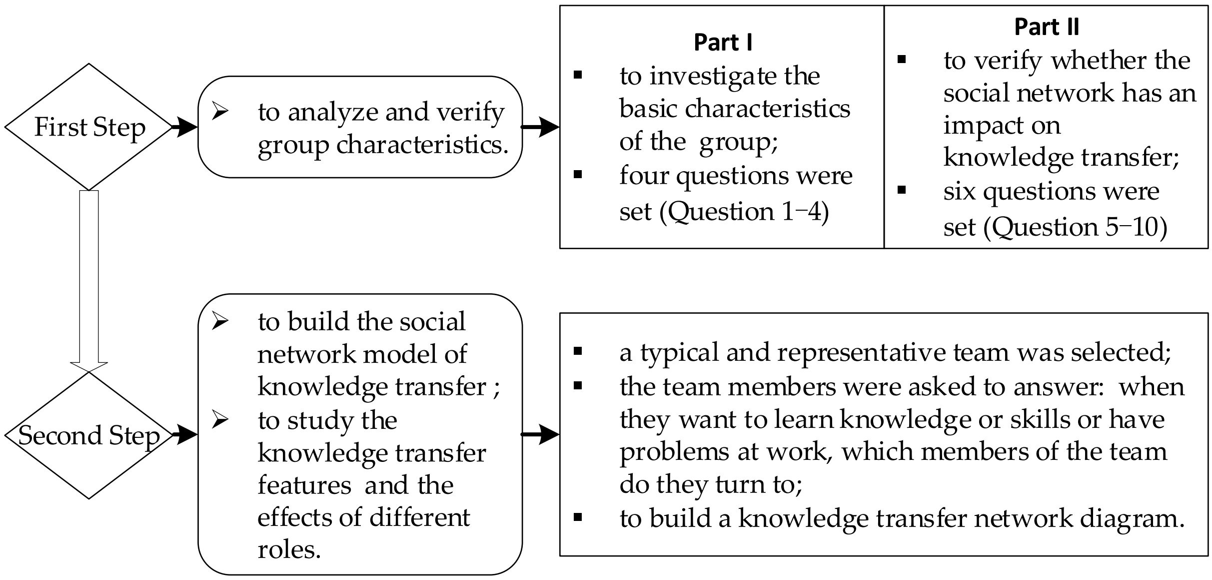

Figure 1. The flow chart of the research.

The questionnaire in the first step of the investigation consisted of two parts. The first part investigated the basic characteristics of the construction worker group. The second part evaluated the structural closure, relational closure, mobility and collaboration of the construction worker group and the personal experiences of the construction workers in the social network to verify whether the social network formed among members of the same team had an impact on knowledge transfer. This provided a research basis for using SNA in the second step of the investigation. In the first part of the questionnaire, four questions were set, as shown in Table 1. The second part contained six questions, as shown in Table 2.

Table 1. Questions to investigate the basic characteristics of the workers.

Q1	Please select your age: under 30 ( ); 30–40 ( ); 40–50 ( ); over 50 ( ).
Q2	Please select your length of service: less than 5 years ( ); 6–10 years ( ); 11–20 years ( ); more than 20 years ( ).
Q3	Please select your education background: primary school and below ( ); junior middle school or senior middle school ( ); junior college ( ); bachelor's degree or above ( ).
Q4	Please select your position: group leader ( ); technical instructor ( ); common worker ( ).

Questions 5–7 in Table 2 were included to verify whether the group characteristics of the workers met the requirements of social network characteristics; in particular, Q5 was used to verify the group's structural closure, Q6 was used to verify the group's relational closure and Q7 was used to verify the internal cooperation of the workers. Questions 8–10 were included to verify whether the social network formed among members of the same team had an impact on knowledge transfer among the construction workers by studying the effect of knowledge transfer among them. Cummings and Teng (2003) [38] pointed out that knowledge transfer not only impacts the enhancement of knowledge mastery, but also the activity and satisfaction of individual construction workers involved in the knowledge exchange. Based on the above research and combined with the group characteristics of worker networks, this questionnaire studied the effects of social networks on knowledge transfer from three aspects: the degree of knowledge accumulation, the degree of benefit and the degree of satisfaction among construction workers. The degree of accumulation

was mainly reflected by whether personal life or work problems could be solved reliably by the team, as measured by Q8. The degree of benefit was reflected by communication within the team, helping workers to master and understand all aspects of information and knowledge, as measured by Q9. Satisfaction was expressed on the form and effect of communication within the team, as measured by Q10.

Table 2. Questions to verify the group characteristics of workers and their impact on knowledge transfer.

Q5	I have close contact with my team members.
Q6	I have kinships or geographical relationships with closely connected workers on my team.
Q7	I cooperate with members of my team and learn from them to complete tasks.
Q8	My life problems and work problems can be solved by my team and I seldom turn to people outside my team.
Q9	Communicating with my team members helps me to master and understand all aspects of the required information and knowledge.
Q10	I am very satisfied with the form and effect of communication among my team members.

A 5-point Likert scale from “strongly disagree” to “strongly agree” was adopted to express the perceived importance of the questions among the respondents.

In the second step of the investigation, a typical and representative team was selected; the team members were required to learn some new knowledge related to their daily work and then go to their work site for practical operation. If they encountered problems in this process, they could ask other members of the team for help, according to their daily habits. After that, they needed to answer the following question on the questionnaire: when you want to learn knowledge or skills or have problems at work, which members of the team do you turn to? This was to determine the knowledge transfer relationships among the workers. To protect the privacy of the workers, they were labeled according to their positions: “L” represented “group leader”, “T” represented “technical instructor” and “C” represented “common worker”. As shown in Table 3, the respondents were asked to provide the labels of people who provided work assistance.

Table 3. The question to build the knowledge transfer network of workers.

Member Code	Who to Ask for Help
L1	
T1	
T2	
. . .	
Tn	
C1	
C2	
. . .	
Cn	

4. Data Research and Analysis

4.1. Data Survey and Basic Information

The questionnaire was distributed in four provinces: Shandong, Sichuan, Jiangxi and Hainan. This was to ensure that the collected data comprehensively reflected the overall characteristics of Chinese construction workers. In each province, different construction sites were selected to conduct the research at in order to avoid the homogeneity of the questionnaire, which could be caused by having too many respondents from the same site.

From November 2017 to August 2018, our research team visited eight construction sites across the four provinces, distributed 340 questionnaires and recovered 307 completed questionnaires. Finally, 19 ambiguous or incomplete questionnaires were eliminated and 288 valid questionnaires were obtained for the data analysis. The response rate was 84.7%.

The Statistical Package for Social Sciences (SPSS26.0) software was applied for the data analysis. The basic information of the surveyed workers is shown in Table 4.

Table 4. The basic information of the surveyed workers.

Age				Service Years				Educational Levels		
≤30 years	31–40 years	41–50 years	>50 years	≤5 years	6–10 years	11–20 years	>20 years	Primary school or below	Junior or senior high school	Junior college
9	15	138	26	87	112	72	17	63	217	8

The age of the construction workers was mainly between 30–50 years old, accounting for 88% of the total number of respondents. The number of workers under 30 years old was the lowest (only nine), accounting for 3% of the total number of respondents. There were 26 construction workers over 50 years old, accounting for only 9% of the total number of surveyed workers. Most of the workers had worked for 6–20 years, accounting for 64% of the total number of respondents. Only 30% of the respondents had worked for less than 5 years and 6% had worked for more than 20 years. Most of the respondents had a junior high school or senior high school education (217), accounting for 75% of the total number of respondents. There were 63 people with a primary school education or below, accounting for 22% of the total number of respondents, and there were only 8 people with a junior college education, accounting for 3% of the total number of respondents. None of the workers had a bachelor's degree or above.

Of the 288 construction workers surveyed, 26 were team leaders, 40 were technical instructors and 223 were common workers. The number of common workers was nine times that of team leaders and six times that of technical instructors, which was in line with the actual structure of worker groups on construction sites.

The lack of young people and the low levels of education accorded with the overall situation of Chinese construction workers [11], which showed that the selected survey samples were very representative and could truly and objectively reflect the research content of this paper. Meanwhile, the work experience of the workers in these samples was relatively long; therefore, the workers had a good understanding of knowledge transfer and could provide objective and real data for the research.

4.2. Verification of the Effects of Social Networks on Knowledge Transfer

Cronbach's alpha and corrected item-total correlation (CITC) were used to measure the internal consistency and interrelatedness among the initial variables. According to the results calculated using SPSS, as shown in Table 5, the Cronbach's alpha of the group closure of construction workers was 0.714, which was higher than 0.70, indicating that the internal reliability of this scale was high. Generally speaking, when the CITC is less than 0.3, this indicates that the test item has a weak correlation with other items and needs to be deleted [2]. In this test, the CITC of all items was greater than 0.3 and the coefficient after deleting items was less than the original coefficient, which showed that the internal consistency and reliability of the items were high. In addition, the average score for each item was greater than 3.7, indicating that the survey samples showed obvious group closure and internal cooperation. In particular, the average score for Q7 reached 3.94, indicating that cooperation within the groups of workers was very significant. The above results proved that the group characteristics of the workers conformed to the characteristics of social networks, meaning that the use of SNA would be effective for studying the internal mechanisms of knowledge transfer by constructing the connections between construction workers on the same team.

Table 5. The reliability analysis of group closure of construction workers.

Items	Cronbach's Alpha	CITC	Cronbach's Alpha If the Item Deleted	Mean Value
Q5	0.714	0.499	0.655	3.74
Q6		0.504	0.651	3.88
Q7		0.527	0.637	3.94

According to the results calculated using SPSS, as shown in Table 6, the Cronbach's alpha of the knowledge transfer effect was 0.829, which was higher than 0.80, indicating that the internal reliability of this scale was very high [39]. The CITC of all items was greater than 0.3 and the coefficient after deleting items was less than the original coefficient, which showed that the internal consistency and reliability of the items were high. In addition, the average score for each item was greater than 3.7, indicating that the team members had a high recognition of knowledge transfer within the network. In particular, the average score for Q9 reached 3.99, indicating that the team members had a high degree of recognition of knowledge and benefits within the network. The above results proved that the social network formed among team members had a positive effect on knowledge transfer among construction workers.

Table 6. The reliability analysis of the learning effects within the network.

Items	Cronbach's Alpha	CITC	Cronbach's Alpha If the Item Deleted	Mean Value
Q8	0.829	0.674	0.778	3.79
Q9		0.696	0.754	3.99
Q10		0.696	0.755	3.81

5. Social Network Analysis of Knowledge Transfer among Workers

5.1. Building the Social Network Model of Knowledge Transfer

A representative reinforcement team was selected from the respondents to build the social network model. The reinforcement team is a typical team running through the whole process of project construction, which is the team with the largest number of members and demands out of all the different kinds of teams. The representative team could comprehensively reflect the network relationships and knowledge transfer characteristics of construction workers. In addition, all 22 workers in this reinforcement team were educated, able to understand the content of this survey and make objective answers, and had a positive willingness to participate in this survey. Of the 22 workers in the team, 6 were between 26–35 years old, 9 were between 36–45 years old and 7 were 46 years old or above. The age distribution was relatively balanced, which fully represented the situation of the three generations of construction workers, namely, the young, middle-aged and older workers. There were five workers who had worked for less than 5 years, eight workers who had worked for 6–10 years, eight workers who had worked for 11–20 years and one worker who had worked for more than 20 years. In total, 77.3% of the workers had over 5 years of service and could objectively reflect on the knowledge transfer characteristics of the workers in their network. In addition, in this team, there was a team leader, two technical instructors and nineteen ordinary workers, which was in line with the general structure of construction worker teams. The two technical instructors were assigned by a labor company to provide technical guidance to the workers.

Firstly, all team members were gathered in a conference room at the construction site. With the help of a video, a technician explained the steel bar binding technology of a laminated plate for a prefabricated building, which was new knowledge for all members. Then, they were asked to go to the construction site and carry out the actual operation of steel bar binding a laminated plate. When all members had completed this work, they were asked to return to the conference room and answer the last question, as shown in Table 3. UCINET 6.0 software was used for the data analysis and to obtain a knowledge transfer network diagram of the reinforcement team, as shown in Figure 2.

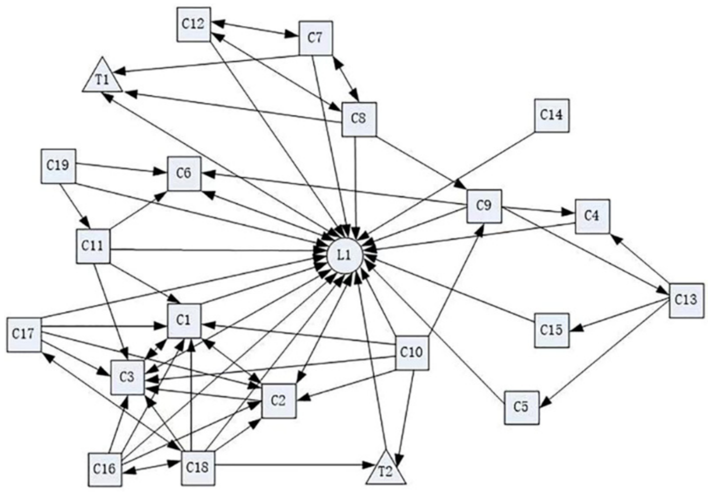

Figure 2. The knowledge transfer network of the reinforcement team.

5.2. Network Density Analysis

The nodes in the network diagram represent the team members and the connecting edges between the nodes represent the knowledge transfer relationships between members [40]. Network density refers to the ratio of the number of connections between nodes within the social network to the number of connections within theoretical networks. The network density determines the degree of knowledge transfer among participants. The value is between 0 and 1, which reflects the connection degree of the whole network. The closer the network density is to 1, the higher the frequency of connections and interactions between the nodes and the more frequent the knowledge transfer. The network density of the team members in this study was 0.1472, indicating that the overall network density of the team was relatively low and that the knowledge transfer connections between members was not close enough.

The network of construction workers had geographical relationships, blood relationships and work relationships, but the density of the knowledge transfer network was very small. According to the survey, most workers did not pay attention to improving their knowledge and skills: they just wanted to complete the task as soon as possible and be paid. They had a weak sense of responsibility over the project quality and project objectives and lacked the motivation to learn new knowledge and skills. This was also related to the fact that there is no clear responsibility for construction workers within the current quality responsibility system.

5.3. Network Centrality Analysis

The network centrality degree (CD) is used to evaluate the position of a node within a network and its influence on other nodes by calculating the number of connections between the node and other nodes. It generally includes three specific indicators: degree centrality (DC), closeness centrality (CC) and between centrality (BC). DC includes out-degree centrality (OC) and in-degree centrality (IC). OC refers to the number of connections that a node sends to the whole network, i.e., the number of direct connections between one member and the other members. IC refers to the number of connections sent from the whole network to a node, i.e., the number of connections that one member receives directly from the other members. The higher the CD of a node, the more connections it has with other nodes and the greater the power and influence it has on other nodes. UCINET 6.0

software was used to calculate the DC, CC and BC of each network node. The calculation results are shown in Table 7.

Table 7. The index values of network centrality.

Node	OC	IC	CC	BC
L1	23.810	95.238	95.455	69.571
T1	4.762	14.286	52.500	0.000
T2	4.762	9.524	52.500	0.095
C1	14.286	33.333	60.000	1.222
C2	14.286	28.571	58.333	0.429
C3	4.762	38.095	60.000	1.222
C4	4.762	9.524	53.846	1.452
C5	4.762	4.762	52.500	1.452
C6	4.762	19.048	55.263	0.667
C7	19.048	9.524	53.846	0.159
C8	23.810	9.524	56.757	1.159
C9	19.048	9.524	58.333	5.167
C10	28.571	0.000	58.333	1.810
C11	19.048	4.762	55.263	0.952
C12	14.286	9.524	52.500	0.000
C13	14.286	4.762	41.176	1.190
C14	4.762	0.000	50.000	0.000
C15	4.762	4.762	52.500	1.452
C16	23.810	4.762	55.263	0.000
C17	23.810	4.762	55.263	0.000
C18	33.333	9.524	58.333	1.048
C19	14.286	0.000	52.500	0.000

The team leader L1 had both a high OC value and a high IC value, which indicated that he was closely connected with other members and had a great influence on others, demonstrating that the team leader disseminated knowledge with reputation and authority among the team. C18, C8, C10 and C19 had high OC values but low IC values, which meant that they often took the initiative to learn from other members but other members seldom learnt from them. Through further investigation, we found that these four members had relatively short periods of work experience, especially C18 with only 2 years of experience. At work, they lacked knowledge and experience, and thus, they needed to constantly seek the help of other members. C1, C2 and C3 had high IC values but low OC values, which meant that these three members often provided knowledge and skills to other members but seldom learnt from other members. Through the investigation, we found that these three members had long working lives and rich experience and skills; thus, they could provide other members with the knowledge and skills that they needed. At the same time, these three members were more enthusiastic and willing to teach others very patiently; therefore, there were more members who sought help from them.

CC was used to measure the distance between a member and other members. When the distance between members is closer, the information transfer speed is faster. The CC value of team leader L1 was the highest at 95.455, indicating that the average path of knowledge transfer between L1 and the other members was the shortest and the speed of knowledge transfer was very fast. The CC value of all other members, except C13, was greater than 50, which indicated that the members of the network did not rely on others when disseminating information and that the knowledge transfer speed of the whole network was fast.

BC refers to the ability of a member to act as an intermediary between other members to help them transmit information and master resources. The higher the BC value of a member, the larger the intermediary role that the member plays and the more information and resources the whole network obtains. Team leader L1 had the highest BC value at 69.571, demonstrating that he was the most important intermediary for the other members in the whole network in terms of knowledge transfer. Compared to that of L1, the BC values of the other members were very low. The main reason for this was the large gaps in knowledge and skills between different workers, which caused some workers to mainly take the role of information input, whereas other workers mainly took the role of information output. Few members could achieve a balance between information input and information output, and thus, it was difficult for the members to play intermediary roles in knowledge transfer.

5.4. Structural Hole Analysis

In a social network, when there is no direct relationship or indirect redundancy relationship between two individuals or groups, then the gap between them is called a structural hole. Structural holes are used to measure the cohesion of a network and the influence of individuals within the network [41]. Freeman (1977) [42] applied BC to describing structural holes. Ronald (2004) [43] proposed to measure structural holes using the indices of constraint (CT), effective size (ES), efficiency (EF) and hierarchy (HI). Han et al. (2016) [44] analyzed different factors that affect seven existing structural hole measurements in social networks and pointed out that BC is relatively more effective among these seven methods and that the measurement results of structural holes are more accurate when multiple indices are used. BC was discussed in Section 5.3; therefore, in this section, ES, EF and CT (which are not related to BC) were used to measure the structural holes in this study.

ES is an index used to measure the overall influence of nodes and can measure the importance of structural holes to a certain extent. EF is usually used to describe the influence degree of a node on other nodes, and the nodes in structural holes are more efficient. CT is used to measure the dependence of a node on other nodes. The larger the value, the stronger the CT and the less likely the node is to cross a structural hole. The calculation results are shown in Table 8.

Table 8. The index values of structural holes.

Node	ES	EF	CT
L1	17.380	0.869	0.152
T1	1.750	0.583	0.575
T2	2.167	0.722	0.422
C1	4.500	0.563	0.383
C2	3.556	0.508	0.420
C3	4.444	0.556	0.378
C4	1.833	0.611	0.487
C5	2.000	1.000	0.500
C6	2.100	0.525	0.484
C7	2.250	0.563	0.639
C8	3.286	0.657	0.525
C9	4.667	0.778	0.304
C10	3.833	0.639	0.343
C11	3.000	0.600	0.440
C12	1.600	0.533	0.671
C13	3.500	0.875	0.321
C14	1.000	1.000	1.000
C15	2.000	1.000	0.500
C16	2.233	0.467	0.462
C17	2.233	0.467	0.462
C18	4.389	0.627	0.390
C19	1.333	0.444	0.637

From the calculation formulae of the indices, it can be seen that ES and EF are linear, whereas CT has a negative correlation with ES and EF. The larger the value of ES and EF and the smaller the value of CT, the greater the overall influence of nodes within a network [44].

The ES of L1 was the largest at 17.380, indicating that L1 had the greatest influence on the whole network and that he was also the most important structural hole member among the team. The EF values of C1, C3, C9 and C18 were also greater than 4.0, indicating that these four members had some influence on the network. At the same time, their CT values were less than 0.4, which indicated that they were not strongly dependent on other members; therefore, these four members could be regarded as the structural holes of the network and played important roles in knowledge transfer among the whole network. The EF value of C13 was very high, but his CT value was very low; thus C13 could be considered as having an important impact on knowledge transfer in this network.

The CT values of C7, C12, C14 and C19 were very high and their BC values were very low, which showed that these four members were highly dependent on the network and found it difficult to cross the structural hole, especially C14 and C19, whose IC and BC values were both 0.0, indicating that their knowledge transfer ability was very weak and that they were at the edges of the network. According to the survey, these workers were all older and were slow to accept new knowledge and skills; thus, their contributions to knowledge transfer were very small.

6. Results and Discussion

Through network analysis, the following results could be obtained:

- Team leaders are the core of the whole team, are closely connected with other members and have a great influence on others in terms of knowledge transfer. At the same time, team leaders are also the most important hubs of knowledge transfer within whole networks. Team leaders are authoritative in knowledge transfer and the transfer paths are short and the transfer speed is fast; therefore, their knowledge and skills are easily spread to whole networks. This means that they play great guiding roles in the promotion of the knowledge and skills of the other members. On the contrary, if the knowledge or skills of team leaders is defective, this has significant negative effects on the whole team. Therefore, the government and enterprises should give full support to the core role of team leaders and provide stable working environments, development spaces and sustainable incomes for them. At the same time, through training from team leaders and the core members of teams, the levels of knowledge and skills of the workers could be improved. This method could not only reduce the costs of training, but also the mobility of workers.
- In this study, C1, C3, C18 and C9 were all structural holes, but their connections were quite different. From Figure 2, it can clearly be seen that the network composed of L1, C1, C2, C3, C16, C17 and C18 was denser than the network composed of the other members and that the connections between these seven members were more frequent, indicating that there were smaller knowledge transfer groups within the team. Due to the large gaps in knowledge and skills among the workers, one-way flows of knowledge occurred easily within the group. Common workers form internal, small groups according to the intimacy of their relationships, which creates barriers to knowledge transfer within networks. Thus, it is necessary to pay attention to the training and guidance of workers who are on the edges of networks and cannot acquire new knowledge and skills in a timely manner. According to the above, managers should pair workers with active personalities who are good at communication and workers who are on the edge of the network so that the former can improve the knowledge and skills of the latter. At the same time, technical instructors should strengthen the help and supervision provided for workers at network edges and find and solve their problems with work processes in a timely manner to ensure their work quality and efficiency.
- In this study, the technical instructors T1 and T2 did not fully participate to in the knowledge transfer within the network. From the results of our network analysis, the OC and IC values of T1 and T2 were low, indicating that they had little knowledge-based interaction with the other workers. The BC values of T1 and T2 were very small,

especially the BC value of T1 at 0.0, which meant that T1 and T2 could hardly play the role of a "bridge" in knowledge transfer. Compared to education and knowledge levels, workers pay more attention to work experience and intimacy; therefore, if highly educated technical instructors lack practical experience and cannot form close relationships with the workers, then they cannot be the "bridge" role in the knowledge transfer among the team, and ultimately, only make few contributions to improvements in the team's knowledge and skills. Technical instructors can only play guiding roles for a few people, but not for the promotion of the overall knowledge and skills of the network. Therefore, when selecting technical instructors, enterprises should not only pay attention to educational background and skill level, but also to close relationships with other workers.

Compared to previous research, the main innovation of this paper is reflected in the following three aspects:

- Most previous studies have focused on the transfer of safety knowledge among construction workers. This research focused on the transfer characteristics and transfer rules of comprehensive, professional knowledge among construction workers and provided targeted suggestions to improve knowledge transfer efficiency and the professional skills of construction workers in order to lessen the learning and efficiency weaknesses of traditional construction workers in the professional and intelligent development of the construction industry.
- Due to the limitations of environments and methods, many research studies on the learning abilities and learning efficiency of construction workers have used volunteers to replace construction workers as experimental objects [45–48]. This study used a construction worker group to conduct research and obtained objective data that could accurately reflect the characteristics of knowledge transfer among construction workers, thereby providing a scientific basis for formulating strategies to improve the knowledge and skills of construction workers.
- From this study, we found that traditional construction workers were still most affected by blood and geographical relationships in terms of knowledge transfer and that different roles within the worker group had different characteristics in the process of knowledge transfer. Therefore, adopting unified training or technical guidance is not an effective way to improve the professional skills of construction workers.

7. Conclusions

By using the SNA method to study knowledge transfer among construction workers, we found that the knowledge transfer network of the workers also had the following characteristics:

- Compared to other groups, the willingness of construction workers to transfer knowledge is very low. Most individuals do not learn from each other well and the exchange of knowledge and skills is not sufficient. They only focus on the current work and lack the motivation to improve their skills and work efficiency.
- Team leaders, based on blood and geographical relationships, are the cores of teams and have greater impacts on knowledge transfer among construction workers than technical instructors without blood and geographical relationships, even if they have a higher level of education.
- It is very difficult for expatriate technical instructors with high education levels but no blood or geographical relationships with workers to establish knowledge authority among the workers.
- Construction worker groups lack internal knowledge transmission networks with close contacts and frequent interactions. There are big gaps between the workers at the center of a networks and those at the edges in terms of knowledge transfer channels and knowledge transfer efficiency, which means that one-way flows of knowledge occur easily within the group.

This study verified that group characteristics, such as regional concentration, group closure and frequent mobility, have important impacts on the transfer of knowledge and skills among construction worker groups. At the same time, the study explored the knowledge sources and knowledge acquisition channels of construction workers and provided a scientific basis for formulating targeted measures to improve the efficiency of construction worker skills. There were some deficiencies in this study. Due to many factors, such as the high mobility and low participation willingness of the construction workers, it was difficult to collect data. Only one representative team was selected for testing, which reduced the comprehensiveness of the research conclusions. In addition, the research object of this study was only workers on construction sites, not industrial construction workers. We will address and improve the above problems in future research.

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