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Current Trends and Future Directions in Knowledge Management in Construction Research Using Social Network Analysis

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Abstract: The growing interest in Knowledge Management (KM) has led to increased attention to Social Network Analysis (SNA) as a tool to map the relationships in networks. SNA can be used to evaluate knowledge flows between project teams, contributing to collaborative working and improved performance. Similarly, it has the potential to be used for construction projects and organisations. This paper aims at identifying current trends and future research directions related to using SNA for KM in construction. A systematic review and thematic analysis were used to critically review the existing studies and identify potential research areas in construction specifically related to research approaches and explore the possibilities for extension of SNA in KM. The findings revealed that there are knowledge gaps in research approaches with case study-based research involving external stakeholders, collaborations, development of communication protocols, which are priority areas identified for future research. SNA in KM related to construction could be extended to develop models that capture both formal and informal relationships as well as the KM process in pre-construction, construction, and post-construction stages to improve the performance of projects. Similarly, SNA can be integrated with methodological concepts, such as Analytic Hierarchy Process (AHP), knowledge broker, and so forth, to improve KM processes in construction. This study identifies potential research areas that provide the basis for stakeholders and academia to resolve current issues in the use of SNA for KM in construction.

Keywords: Knowledge Management; Social Network Analysis; construction; future research directions

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1. Introduction

Knowledge Management (KM) has grasped the attention in academia as well as industry. KM is identified as "the discipline of creating a thriving work and learning environment that fosters the continuous creation, aggregation, use, and re-use of both organisational and personal knowledge in the pursuit of new business value" [1]. KM ensures effective dissemination of knowledge throughout an organisation to the point of requirement within a particular project [2]. The effective management of project knowledge assists in proactive and timely decision-making and contributes to project performance in terms of time, cost, and quality [3]. According to Allen et al. [4], although the internal knowledge assets of an organisation are vital in driving its commercial performance, it is believed that success is conditional on the way in which these are effectively exchanged and exploited.

KM practices in organisations focus on knowledge creation and knowledge transfer activities [5]. According to Alavi and Leidner [6], knowledge can be considered as (1) an object, which considers building and managing knowledge stocks, or (2) a process, which focuses on knowledge flow and processes of creation, sharing, and distribution of knowledge. Knowledge as a process includes creation, storage, retrieval, transfer, and

application [7]. These processes could be sub-divided to create internal knowledge, acquire external knowledge, store knowledge in documents or routines, and update and share knowledge internally and externally [6].

The construction industry is known as one of the knowledge-based value creating sectors of the economy [8]. Knowledge-intensive construction organisations rely on professional knowledge or expertise related to a specific technical or functional domain [9,10] and heavily rely on tacit knowledge [11,12]. Tacit knowledge is stored in a construction professional's head [13], for example, knowledge on estimating and tendering; while explicit knowledge is stored as written documents or procedures, for example, drawings, specifications, and so forth. The construction industry involves several stakeholders that exchange knowledge through various modes. Hence, knowledge sharing is strongly affected by the relationship between the people or their social interactions [14]. Argote and Ingram [15] found that strong ties enable tacit knowledge sharing.

Social Network Analysis (SNA) is a novel tool that was introduced to monitor and rigorously analyse the relationships between actors. Studying the relationships in KM flows in construction networks through SNA could assist construction organisations to nurture stronger networks and enable better knowledge management processes. There is a growing tendency of using SNA as a tool to measure knowledge flows in KM research in construction and other sectors [16]. A recent systematic review into SNA in sustainable construction found that SNA can be effectively used to map networks in different disciplines such as project management, risk management, KM, and among others [17]. However, there is a lack of reviews and understanding of SNA for KM in construction research. Therefore, this study reviews existing literature and identifies knowledge gaps and future research directions related to using SNA for KM in construction. This paper aims at reviewing existing literature and identifying current trends and future research directions related to using SNA for KM in construction. This study answers the following research questions (RQs):

1. What are the research approaches that could be used to explore SNA for KM?
2. What are the current trends for using SNA in construction?
3. What are the research gaps related to using SNA for KM in construction?

The terminology and concepts on SNA have been discussed in Section 2 followed by Section 3, which provides the methodology adopted. Section 4 presents the findings of the paper, along with the identified potential research areas that could be explored in future to resolve issues in KM in construction. Section 5 presents the conclusion of the paper.

2. SNA as a Tool for Analysing Social Relationships

The social network of a project refers to "the combination of all project relationships that exist between the project actors" [3]. According to Wasserman and Faust [18], a social network is a set/sets of actors (discrete individual, corporate, or collective social units) and the relationships between them. Networking is a social communication process that encourages communities to share knowledge. The social relations that knot the modern world together can have multiple effects, where a change in one area of the world could affect the rest [19,20]. The same impact can be observed within an organisation as well. Hence, it is important to have a precise understanding of the relationships between actors in terms of knowledge sharing in a formal as well as informal surrounding in an organization [21].

SNA is a method that is used to analyse people and their relationships with each other [22]. It maps and measures formal and informal relationships to understand, what facilitates or impedes the knowledge flows; for example, who knows whom, who shares what information/knowledge with whom by what media [23]. The data collected to carry out SNA provides baseline information, which could be analysed to improve knowledge flows, i.e., social connections with increased productivity [23].

SNA provides both a visual and mathematical analysis of human relationships [24]. The visual aid is provided by "sociograms", and mathematical analysis is provided with the

use of matrices and statistical models. These mathematical and graphical techniques in SNA assist in representing the networks compactly and systematically, while allowing to derive patterns of social relationships that connect the actors instead of words [25]. The results of an SNA assist in identifying the actors, who play central roles, identify bottlenecks and structural holes, identify opportunities to accelerate knowledge flows, strengthen efficiency and effectiveness of existing communication channels, raise awareness of the importance of informal networks to enhance organisational performance, leverage peer support, and improve innovation learning among others [23]. In social networks, individuals could be seen as nodes or actors and, similarly, a social network approach could be observed between organisations [26,27].

To identify the nature of relationships between various construction stakeholders/actors SNA tool uses different measures such as degree centrality, closeness centrality, betweenness centrality, and tie strength, among others, which are used in SNA-related studies when analysing the relationships between actors in social networks.

- Degree centrality indicates the influence or power of network members [28]. Kim et al. [7] stated that degree refers to the number of relationships maintained by each member in a network. In-degree refers to incoming connections while out-degree refers to outgoing connections. In-degree connections indicate a member's popularity (prominence), while a person with a high out-degree is considered as an influential member in the network [29].
- Closeness centrality indicates the integration or isolation of network members [28]. According to Kim et al. [7], it is measured as the sum of distances between members. Nodes that are at a comparatively shorter distance would receive information sooner than other nodes that are away from others [30]. High closeness centrality signifies the greater autonomy of an individual member due to the ease of reaching out to other members [28]. On the other hand, low centrality denotes higher individual member dependency on other members.
- Betweenness centrality indicates the extent to which a member sits between others in the network [7]. It refers to the role played by a member as an intermediary and determines whether a member plays an important role as a broker or a gatekeeper within a network [28]. Structurally important nodes are well positioned to control information flows and create bottlenecks that slow the network down [30].
- Tie strength assists in assessing the degree of connectivity of members in a network and the likelihood that information flows between members [7]. Tie strength is measured by the number of relationships between members [28]. When the tie strength between 2 members is high, they are more motivated to provide information to the other member.
- Density presents the overall linkage between network members. Density is measured by dividing the total number of ties by the total number of possible ties [28]. According to Chinowsky et al. [31], if the density is high, it indicates that the number of relationships that exist in the network is high.

3. Research Methodology

The methodological approach followed in this study consisted of a qualitative research approach, including a systematic literature review and thematic analysis. The systematic literature review was carried out on the use of SNA for KM to understand the terminology and concepts and to give an overview of previous studies and their research outputs. Scopus, Web of Science, and Google Scholar databases were used to carry out the searches using the keywords "Knowledge Management" AND "Social Network Analysis" AND "Construction". Scopus identified 2285 papers, Web of Science identified 398 papers, while Google Scholar identified 10,600 results. This initial search was done considering all fields and this could be misleading as it considers the whole content of the article including the reference list. Therefore, in the next step, the search was limited to title, abstract, and keywords only. As a result, 43 papers from Scopus, 15 papers from Web of Science, and

135 papers from Google Scholar were identified. Subsequently, all identified suggestions were evaluated in detail, avoiding repetitions to refine the most suitable articles. Finally, a total of 42 articles, including journals, conference papers, and book sections, between 1998 and 2020 were considered for the systematic review as illustrated in Figure 1.

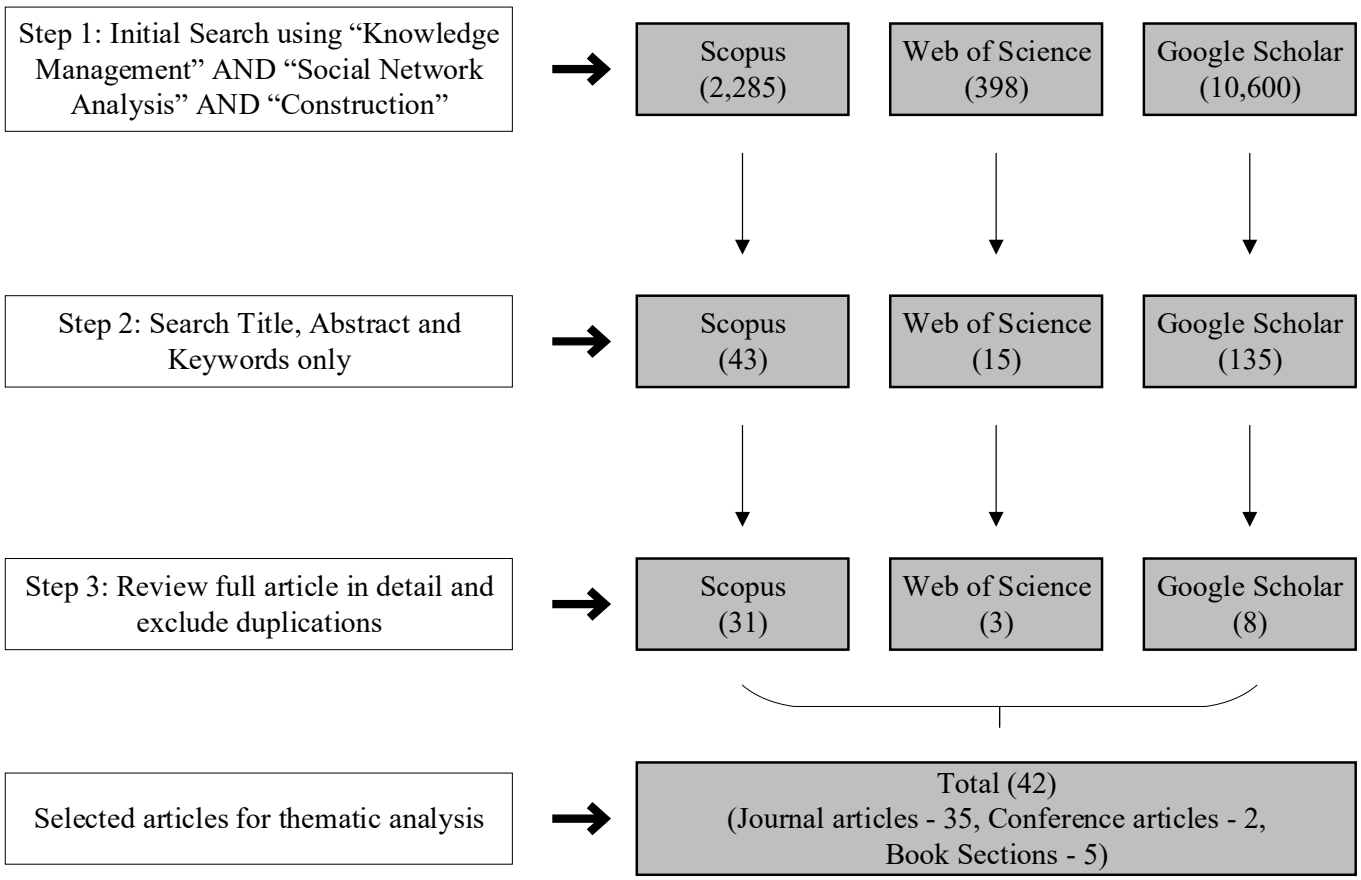

Figure 1. Selection of articles for systematic review.

After selecting the papers for the systematic review, the thematic analysis was carried out as presented in Figure 2.

Thematic analysis is used in qualitative research to examine themes by identifying and reporting patterns (themes) within the research topic. Therefore, thematic analysis was selected to define the themes, Knowledge Management, and Social Network Analysis (KM-SNA) research approaches and extension of SNA in KM, as depicted in Figure 2. Under each theme, sub-themes were identified. This assisted in identifying the research gaps for each theme. After following these steps on all the themes, the research gaps and directions for future construction research under each theme were identified as detailed in the following section.

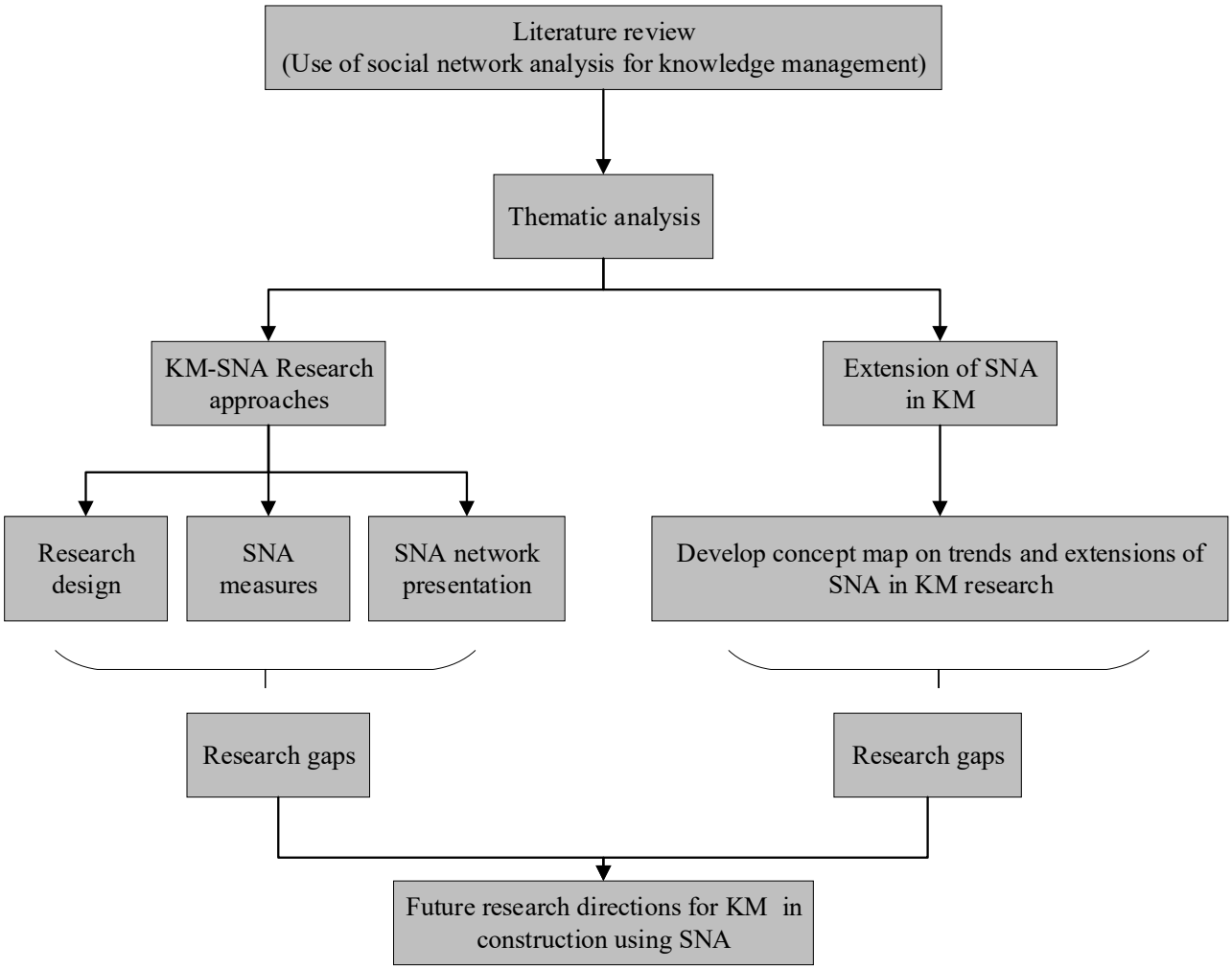

Figure 2. Thematic analysis process.

4. Findings

This section presents the findings of the systematic literature review and thematic analysis carried out in this study.

4.1. Research Approaches to Explore the Use of SNA for KM

Various studies that explore the use of SNA for KM consider different research approaches to evaluate relationships in social networks. These research approaches have been categorised into 3 areas such as research designs, SNA measures, and SNA network presentation modes.

4.1.1. SNA in KM Research Designs

Out of 15 studies that were short-listed through the systematic review, seven studies considered a single case study design, and six studies considered a multiple case study design as reported in Tables 1 and 2 while two studies used other research designs such as survey strategy, expert interviews, and meta-analysis. Some of the case study-based researches were specifically related to construction as indicated in the tables.

Table 1. Single case study research design.

Studies in Various Industries		
Study	**Description**	**Features of Case Study Design**
Kim et al. [7]	A Knowledge Brokering System (KBS) is introduced to create the link between knowledge seekers and knowledge experts. This system uses several SNA measures to calculate the expertise index, which assists in selecting experts.	A single project team consisting of 10 members in a Korean financial company were considered to collect data and validate the functions of the KBS.
Capece and Costa [32]	This study proposes an evaluation method based on SNA and team configuration indexes to measure knowledge creation in virtual teams. 4 virtual teams within a single case study have been used to collect data and evaluate the relationships between the actors using SNA.	4 independent virtual teams (each comprising of 6 members) in an Italian manufacturing company were considered and data were collected using an autoevaluation questionnaire with closed questions using likert scale or multiple-choice questions.
Studies in Construction		
Study	**Description**	**Features of Case Study Design**
Lin [33]	In this study, job-site social networks including order-management, technical-consultation, and interpersonal-social networks in the Husan dam project in Taiwan are analysed using SNA measures to discover underlying job-site management issues and potential technology interfaces.	70 participants involved in Husan dam project in Taiwan contributed to the data collection process carried out in the form of a questionnaire. These participants were from 9 organisations, including the owner company, 2 consultancy firms, and 6 subcontractors.
Almahmoud and Doloi [34]	The proposed dynamic assessment model, developed using sustainability and equity theories, was evaluated using SNA to map the relationships between stahkeholders.	20 participants engaged in 14 different roles, such as contractor, supplier, owner and so forth, in a project in Saudi Arabia were analysed using a questionnaire with a 7-point Likert scale.
Wang et al. [35]	SNA was used in this study to evaluate the suitability of the proposed multi-layered conceptual framework that incorporated social sustainability and construction.	The network participants in a turnkey building renovation project were analysed using a questionnaire.
Loosemore [36]	In this study, crisis management in the UK construction industry is explored especially focusing on interpersonal communication networks under conditions of crisis. SNA is used to analyse the management of construction crises and concluded that both quantitative and qualitative methods are needed to understand complexity of people's changing social roles, positions and behaviours.	SNA, along with an adjacency matrix, was used in a leisure centre project that involved crisis management to analyse its communication networks between various stakeholders.
Liu et al. [37]	An SNA-based method is used to investigate equipment movement between project sites and equipment shops. The study proposed a novel index, direct dispatch index, along with the coefficients of SNA to measure the equipment dispatching performance with the use of equipment logistics data collected from the equipment and project management system of a company in Alberta, Canada. The study revealed that equipment management could be enhanced through improved decision-making.	Equipment movement data was collected from an internal equipment management system of construction contractor in Alberta, Canada, between 2013 and 2016.

Table 2. Multiple case studies research design.

Studies in Various Industries		
Study	**Description**	**Features of Case Study Design**
Parise [38]	It used three case studies to explore how SNA contributes to knowledge management efforts related to human resources professionals within organisations.	3 case studies were selected to observe the relationships between actors within the networks in these 3 different organisations. Questionnaires with follow up interviews have been conducted to collect data.
Helms [39]	Knowledge Network Analysis is a novel technique which was introduced and explored using case studies to identify the bottlenecks of the technique.	Data were collected from 3 social networks in 3 different offices in the Netherlands using a questionnaire.
Cross et al. [40]	Multiple case studies were considered to observe how organisations could support work occurring in informal networks of employees. In this study, the data were collected from 40 informal networks from 23 organisations. It was revealed that informal relationships among employees provide more reflection of the way work happens in an organisation rather than relationships established by the organisational hierarchy.	40 informal networks from 23 different organisations were considered for data collection, which was conducted in the form of questionnaire and interviews.
Studies in Construction		
Study	**Description**	**Features of Case Study Design**
Pryke et al. [41]	Resource provision ego-networks are investigated structurally in this study using social network analysis.	The ego-centred personal networks of 6 small construction business owners in Greece were interveiwed.
Schröpfer et al. [42]	This study examines knowledge transfer practices in sustainable construction projects using SNA.	Questionnaires were distributed among workers in 5 construction projects that delivered sustainable office buildings in Germany and the UK. The network sizes were 125, 39, 38, 50, and 35.
Alsamadani et al. [43]	Safety communication between parties in small construction crews was explored using SNA to identify communication patterns in effective and ineffective safety netowrks.	9 small crews where their network sizes varied between 5 and 12, working in building construction projects in Denver, USA, contributed to the study through questionnaires and follow up interviews.

According to the features of case study research designs reported in the third column of the tables, the number of networks studied within a single case or multiple cases varied and also the size of the network, where some networks were as large as 125 members, and some were less than 12 members. It was seen that the studies with smaller network sizes led to in-depth investigations and analysis, whereas others were leading to generalisation. While most studies used questionnaires to collect data within the case study networks, some relied on follow-up interviews.

Two other studies deviated from a case study approach and used other research designs such as survey strategy, expert interviews, and meta-analysis. For example, Chung and Hossain [44] used cluster sampling and a survey strategy to collect data, where questionnaires collected from 110 general practititioners in 15 rural divisions in NSW were considered to evaluate their ego-centric networks. Gan et al. [45] explored the effectiveness of stakeholder collaboration for Off-Site Construction (OSC) using 13 expert interviews to identify barriers affecting the OSC adoption followed by a survey strategy to collect data from 39 respondents, which were analysed using adjacency matrix. However, the type of data that was required to be collected in these two studies were either related to a cluster or involved the need for expertise knowledge. Hence, these were special occasions, where it was a requirement in these studies to adopt such an approach. On the other hand, research approaches such as experiments and action research have not been used for SNA

related studies. Hence, it can be emphasised that the common research approach used in SNA-related studies was case studies.

4.1.2. Use of SNA Measures

The short-listed studies through the systematic review had used various SNA measures such as density, tie strength, degree centrality, closeness centrality, and betweenness centrality (see Section 2 for description of each term) when interpreting the network relationships (see Table 3).

Table 3. Summary of SNA measures used by various studies.

References	SNA Measures					
	Degree Centrality	Closeness Centrality	Betweenness Centrality	Tie Strength	Density	Other (Eigenvector Centrality, Clusters, Brokerage, Bridges etc.
Almahmoud and Doloi [34]						✓
Alsamadani et al. [43]	✓	✓			✓	
Capece and Costa [32]	✓		✓			
Chung et al. [46]	✓		✓		✓	
Gan et al. [45]	✓		✓			✓
Helms [39]	✓					✓
Kim et al. [7]	✓	✓	✓	✓		
Lin [33]	✓		✓			✓
Liu et al. [37]	✓	✓	✓			✓
Loosemore [36]	✓	✓	✓			
Parise [38]	✓				✓	✓
Pryke et al. [41]				✓	✓	
Schröpfer et al. [42]	✓		✓	✓	✓	
Wang et al. [35]	✓	✓	✓		✓	

According to Table 3, the SNA measures, degree centrality, closeness centrality, betweenness centrality, and density, were used in most of the studies. Some studies had used tie strength, eigenvector centrality, and clusters, among others, depending on the requirements of the study. Selecting SNA measures for the studies can vary based on the depth of analysis and the expected outcomes of the study. Therefore, it is difficult to derive patterns on SNA measures and presentation modes for future research. However, it is noticed that in most of the studies, SNA measures such as degree centrality and betweenness centrality are quite popular among others.

4.1.3. SNA Network Presentation

The results of the studies that used SNA in KM have been presented in various modes as demonstrated in Figure 3.

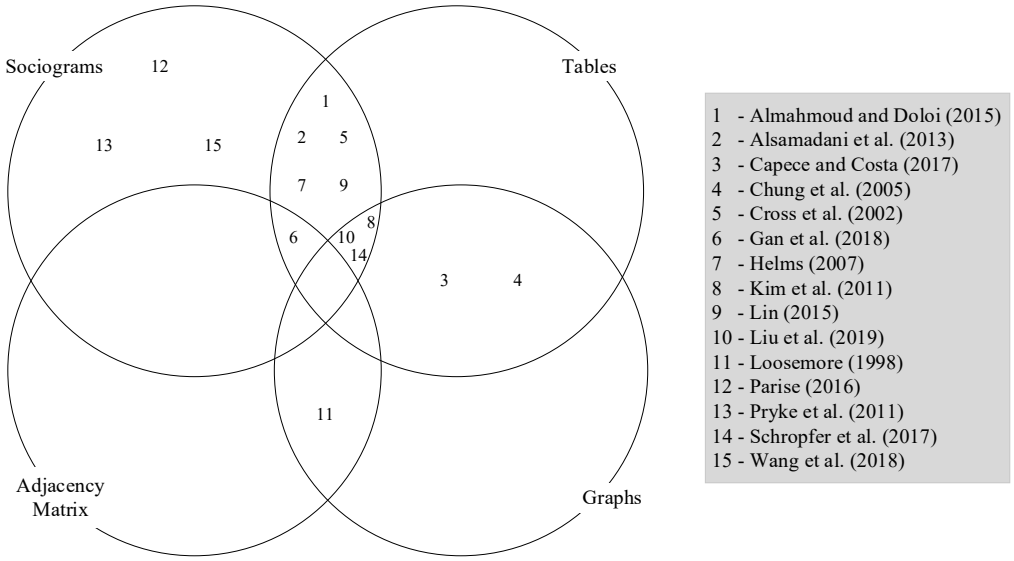

Figure 3. Presentation outputs produced in studies related to using SNA in KM.

According to Figure 3, the results have been presented using several modes such as sociograms, tables, graphs, and adjacency matrix in various studies. A sociograms provides a visual representation of the relationships between actors. Similarly, the tables and graphs represent the various values achieved for various SNA measures such as degree centrality, closeness centrality, betweenness centrality and so forth. These values have been compared against various networks within the same case study or against various case studies to derive conclusions. According to Figure 3, though sociograms and tables are quite common in most studies, graphs have been used in a few studies. It was noted that adjacency matrix has been used in two studies. An adjacency matrix connects a matrix to a graph, which provides a numerical representation of relational data within a network or graph [36]. Similar to SNA measures, selecting a mode to present results of a study, depends on the type of data that is collected and analysed, the richness and clarity of data among others.

4.2. Discussion on Findings

A qualitative analysis was carried out on existing literature along with thematic analysis to explore the current trends and extensions of SNA for KM-related research (see Section 4.2.1) and identify research gaps and future research directions for using SNA for KM in construction (see Section 4.2.2). Below sub-sections present and discuss the key findings along with pattern-matching to literature from other contexts as appropriate when proposing future directions for identified gaps.

4.2.1. Trends and Extensions of SNA in KM Research

Various researchers have developed models or frameworks based on the use of SNA for KM-related research. Some studies have integrated various concepts or methodologies with SNA to improve KM practices. Figure 4 demonstrates the concept map that was developed to illustrate trends and extensions of SNA for KM research, followed by the subsequent discussions.

As depicted in Figure 4, **knowledge brokering** was an emerging concept in KM research using SNA. A knowledge broker is an intermediary (an organisation/person) that provides knowledge sources or knowledge to organisations within the network [47]. A knowledge brokering system, K-broker, has been introduced by Kim et al. [7], which facilitates tacit **knowledge transfer** between **knowledge seekers** and **knowledge experts** without a bottleneck or members' overload excluding the intervention of a human knowledge broker. A single case study of a financial company comprising of 10 members has been used along with SNA to test and validate the functions of K-broker.

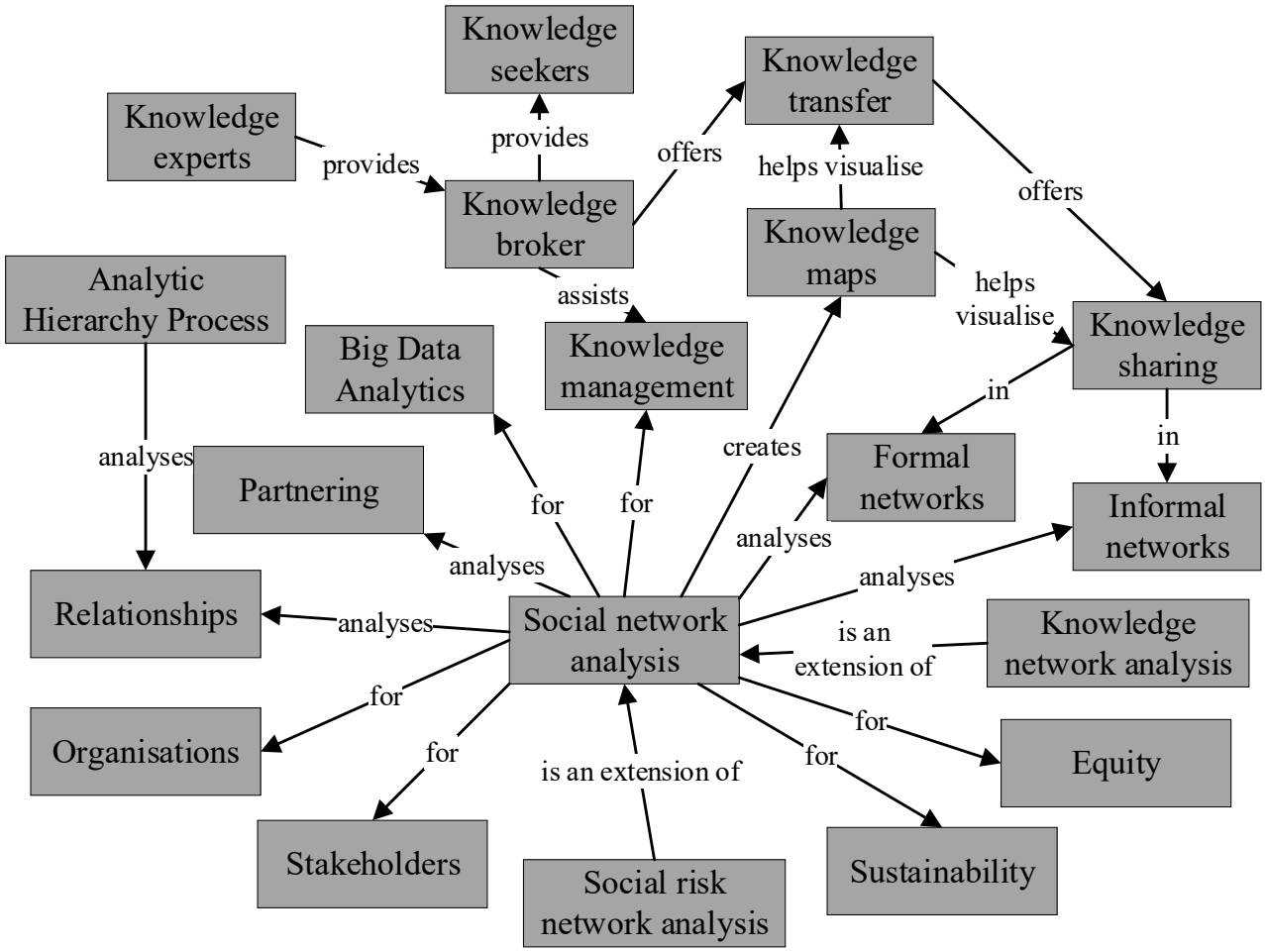

Figure 4. Concept map on trends and extensions of SNA for KM.

To identify **knowledge sharing** barriers in knowledge networks, Helms and Buijsrogge [48] introduced the **Knowledge Network Analysis** (KNA) technique, which is an extension to generic SNA measures, where properties such as knowledge velocity (speed of movement of knowledge) and viscosity (richness of the knowledge transferred) are incorporated. This was later developed to Knowledge Sharing Environmental Model (KSEM) by Helms et al. [49]. A single case study consisting of 99 employees in 17 learning networks was considered to validate the developed model, KSEM. The developed KSEM graphs identified the bottlenecks in knowledge sharing, which were compared with the SNA results to validate the findings of KSEM.

Knowledge brokering was further highlighted in the knowledge-sharing model developed by Bosua and Scheepers [50], which is named as, Bosua–Scheepers Model (BSM) and borrows similar ideas of KSEM model. This model integrates **formal and informal social networks** for knowledge sharing. BSM was validated using three case studies that explored the effectiveness and efficiency of knowledge-sharing activities in workgroups. It was revealed that a lack of facilitating mechanisms could lead to a multitude of knowledge-sharing problems and highlighted the importance of knowledge brokers to avoid delays in finding appropriate information from **knowledge experts** to **knowledge seekers** to enable better **knowledge management**.

Some studies have looked at possibilities of introducing **knowledge mapping**. Yun et al. [51] proposed a knowledge mapping model (K-mapping model) that includes criteria to identify a suitable knowledge map considering various characteristics and conditions related to personnel, processes and knowledge transfer technologies used by organisations. This study has developed 4 types of K-mapping models based on the characteristics and

conditions of construction personnel, construction processes, and knowledge transfer technologies. Liebowitz [52] has integrated SNA with **Analytic Hierarchy Process (AHP)** to develop interval measures for knowledge mapping purposes and it determines the strengths of relationships between actors rather than ordinal numbers. However, scalability might be an issue when using it for large social networks.

Some KM research using SNA extended with sustainability concepts. For example, Almahmoud and Doloi [34] introduced the Social Sustainability Health Check (SSHC) model, which is a dynamic model that considers **sustainability and equity** theories to evaluate the contributions of construction projects in a social context. It checks how a project performs and satisfies the needs of the stakeholders. SNA is used in this model to understand and map the complex patterns of **stakeholders' positions and their relationships** with each other. The SSHC model was validated using the data collected from 20 stakeholders involved in a farmer's market development, which was evaluated using SNA.

The conceptual framework developed by Wang et al. [35] could improve **social sustainability** in construction, which could be advanced through use of SNA. The conceptual framework assists in diagnosing social sustainability of internal stakeholders using SNA measures. The framework has been developed based on project-based organisations; however, it could be generalised for a broader context related to construction management.

Chinowsky et al. [31] introduced a **social network model** for construction, which emphasises team development and knowledge exchange to produce construction projects with high performance. This model includes both mechanics (knowledge exchange) and dynamics (social collaboration within the project team to motivate exchanging items/mechanics). A case study consisting of 35 individuals was used to evaluate the features identified in the model.

Another team model using SNA in KM research is from Yuan et al. [53]. It is a **social risk network analysis** that works by evaluating the inter-relationships between stakeholders and risks. A case study comprising 66 social risk cases in China was considered in the study. SNA was used to evaluate the social risk factors in detail. The study identified a further research direction to identify the cause-and-effect and nonlinear relationships between different risk factors and stakeholders by using simulation methods.

Barão et al. [5] has used an ontological-based KM tool to capture real-world entities, events, and relationships. It further explores KM and engineering prospectives for predictive analysis related to **organisational learning networks** within the workplace. There are a few studies that have explored the use of various concepts such as **partnering along with SNA** to improve construction practices. A study conducted by Akgul et al. [54] analysed the relationship between construction **organisations/stakeholders** that have partnered with an international organisation using SNA which revealed the nature of strong and weak relationships. SNA can be used for **Big Data Analytics** to improve the interactions and characterize the network through degree centrality, clustering coefficient, and the like [55]. Similarly, Bilal et al. [56] stated that SNA integrated with **Building Information Modelling (BIM)** and **Big Data** can improve project management through social data integration.

In summary, these studies explored the use of SNA with different KM concepts, sometimes extending to team, organisational, social, and sustainability perspectives. Further research directions using SNA for KM to resolve issues in the construction industry have been discussed in detail in the following section.

4.2.2. Research Gaps and Future Research Directions

Building on the above review, the research gaps and future directions related to construction have been identified in Figure 5 and discussed below.

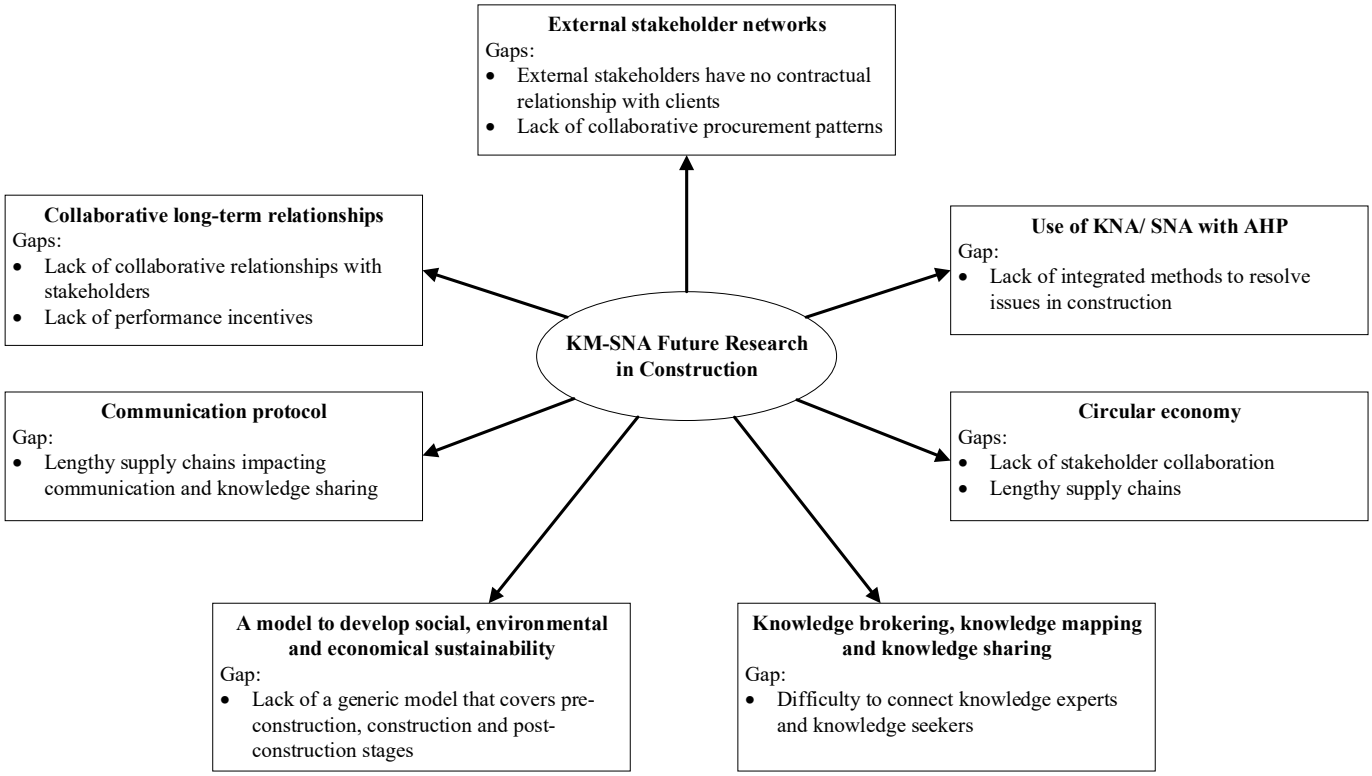

Figure 5. Gaps and future research directions for KM-SNA in construction.

Most of the current research has been focused on the impact of internal stakeholders for improving knowledge transfer and other KM-related aspects. The focus on the effects of **external stakeholder networks** on project delivery or outcomes is comparatively less [57]. The external stakeholders may not have a contractual relationship with the client. However, similar to the strong connections maintained between internal stakeholders, it is important to maintain a good relationship with external stakeholders to deliver a project within the expected time, cost, and quality parameters. According to Nunes et al. [58], lack of efficient models to manage collaboration is one of the major constraints organisations face in internal and external collaboration initiatives. On the other hand, it is believed that trust between internal and external stakeholders within the social network in the agricultural sector could be strengthened through collaboration [59]. Several studies have explored internal stakeholder relationships [60,61] or external stakeholder relationships [62] separately. There is scope for further research to explore the relationship patterns between internal and external stakeholders using a multiple case study approach with emerging relational and collaborative procurement patterns. In particular, the impact of collaborative long-term relationships towards effective and efficient project delivery could be explored using SNA. According to Pryke [63], performance incentives could contribute to productivity and project performance. This is another area that could be explored along with **collaborative long-term relationships** between construction stakeholders with the use of case studies along with SNA. The success of collaborative long-term relationships could be assessed using SNA to explore whether strong ties have an impact towards long-term relationships.

The construction industry is known for its fragmented nature, the unique nature of construction projects, and lengthy supply chains. The involvement of many stakeholders and lengthy supply chains could have a negative impact on communications and knowledge sharing within construction projects. Therefore, each project needs to have a well-defined **communication protocol** developed and implemented to avoid such issues. Communication protocols refer to the accepted method of generating, storing, processing, and communicating information among stakeholders [64]. SNA could be used effectively to develop a generic communication protocol that could be used by any construction

project with minor additions/omissions as per the requirements of the project. Improved communication assists in filling the gaps in construction supply chains and creating smooth process flows. SNA assists in identifying the strong and weak ties between stakeholders along with any influencers within a network that leads to developing an effective communication protocol. A multiple case study approach could be used to test and validate the communication protocol.

Hewa Welege et al. [17] identified that due to capabilities of SNA, there is tendency to apply SNA techniques and tools towards enhancing sustainability. SNA could be used to explore the relationships within construction teams to identify influencers that could promote sustainable practices among the team members. The SSHC model introduced by Chinowsky et al. [31] has considered sustainability and equity concepts to evaluate the performance of construction projects. It could be used by any construction stakeholder or project to explore the relationships between stakeholders. A more detailed generic model could be developed as a further research direction to cover any construction project, including pre-construction, construction, and post-construction stages, considering **social, environment, and economic sustainability** and aiming to connect construction stakeholders to create a circular economy. The importance of stakeholder collaboration in construction supply chains to create a circular economy was identified in recent research [65], which could be extended using SNA to create knowledge sharing networks between stakeholders. SNA assists in exploring relationships between network members to identify the prominent stakeholders and take necessary steps for collaboration and establish improvements towards circular economy.

Exploring current research trends, use of SNA in KM has been expanded into various areas such as **knowledge brokering, knowledge mapping, and knowledge sharing**. With the formal and informal relationships that exist between various stakeholders in construction projects, it is possible to identify knowledge brokering services for effective and efficient KM in construction. Further, KNA could be used to identify the knowledge-sharing barriers in knowledge networks within construction organisations as well as projects. Many studies have used SNA to explore the relationship between construction stakeholders and project crews. However, SNA along with AHP could provide stronger and more accurate results that could be used to derive better conclusions. The ontological approach introduced by Barão et al. [5] could be used in the construction industry to observe the nature of reality in construction by observing the entities, events, and relationships within networks. Using SNA, future research could expand to explore more dimensions such as project success, health and safety, quality assurance, and payment management in construction settings.

5. Conclusions

This paper was aimed at reviewing existing literature to identify the current trends and future research directions related to using SNA for KM in construction. A systematic literature review and thematic analysis considering the themes, KM-SNA research approaches, and extension of SNA in KM were carried out to identify the potential areas of research and to answer the research questions set out for this study. In terms of the first RQ, the main research approaches that were used to explore SNA for KM are case study research as reported in Section 4.1. The answers to the second RQ on current trends for using SNA in construction were mapped in Figure 4 and discussed in Section 4.2.1. The third RQ on the research gaps related to using SNA for KM in construction were summarised in Figure 5 and discussed in Section 4.2.2. The key contributions from this research are found in the answers to the above three RQs, which propose potential research areas for using SNA for KM in construction.

As per the key findings, most of the current research has been focused on internal stakeholders and their relationships to improve knowledge transfer and KM in construction. However, external stakeholders have a significant impact on construction projects. Therefore, a knowledge gap on the importance of external stakeholder networks using SNA to connect key stakeholders to achieve circular economy in the construction industry exists

and should be explored. Similarly, with growing collaborative practices in construction, the impact of collaborations on project delivery and knowledge transfer could be explored using SNA, which could lead to the creation of a communication protocol for a construction project and its supply chain, using multiple case studies. Research also found future research scope in expanding KM models on knowledge brokering, knowledge mapping, and knowledge sharing areas by using SNA for construction, which can be identified as a key implication for future research that contributes to an existing body of knowledge and brings novelty. Furthermore, specific implications for industry practice can be listed as follows:

- Construction organisations could consider using SNA as a tool to identify and strengthen knowledge sharing networks
- Construction project managers could use SNA as a tool to identify, classify, and prioritise key stakeholders and enhance their knowledge sharing and communication processes
- Professional bodies and relevant organisations could consider use of SNA as a tool to create industry-wide knowledge management networks
- Government and other policy makers could encourage the industry to use SNA and knowledge management networks towards circular economy in construction

There were several methodological limitations in this study. When considering Scopus, Web of Science, and Google Scholar databases, there were duplications. A manual screening process was followed to resolve this issue. Adopting a qualitative analysis method brought in biasness; however, its impact could be significantly reduced through constant pattern-matching with previous literature.

The identified research gaps and future research directions demonstrated in Figure 5 would be beneficial for stakeholders and academics in resolving the current issues related to the use of SNA for KM in construction. The identified areas of research are the future trends to be explored and adopted by the industry to improve KM in construction.

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References

1. Cross, R. Managing for knowledge: Managing for growth. *Knowl. Manag.* **1998**, *1*, 9–13.
2. Koskines, K.U. Knowledge Mangement to improve Project Communication and Implementation. *Proj. Manag. J.* **2004**, *35*, 13–19. [CrossRef]
3. Brookes, N.J.; Morton, S.C.; Dainty, A.R.J.; Burns, N.D. Social processes, patterns and practices and project knowledge management: A theoretical framework and an empirical investigation. *Int. J. Proj. Manag.* **2006**, *24*, 474–482. [CrossRef]
4. Allen, J.; James, A.D.; Gamlen, P. Formal versus informal knowledge networks in R&D: A case study using social network analysis. *R D Manag.* **2007**, *37*, 179–196.
5. Barão, A.; de Vasconcelos, J.B.; Rocha, Á.; Pereira, R. A knowledge management approach to capture organizational learning networks. *Int. J. Inf. Manag.* **2017**, *37*, 735–740. [CrossRef]
6. Alavi, M.; Leidner, D.E. Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS Q.* **2001**, *25*, 107–136. [CrossRef]
7. Kim, S.; Suh, E.; Jun, Y. Building a Knowledge Brokering System using social network analysis: A case study of the Korean financial industry. *Expert Syst. Appl.* **2011**, *38*, 14633–14649. [CrossRef]
8. Pathirage, C.P.; Amaratunga, D.G.; Haigh, R.P. The role of tacit knowledge in the construction industry: Towards a definition. In Proceedings of the CIB W89 International Conference on Building Education and Research (BEAR), Heritance Kandalama, Sri Lanka, 11–15 February 2008.
9. Egbu, C.O.; Robinson, H.S. Construction as a Knowledge-Based Industry. In *Knowledge Management in Construction*; Anumba, C.J., Egbu, C.O., Carrillo, P.M., Eds.; Wiley-Blackwell Publishing Ltd.: Oxford, UK, 2005; pp. 31–48.

10. Senaratne, S.; Ruwanpura, M. Communication in construction: A management perspective through case studies in Sri Lanka. *Archit. Eng. Des. Manag.* **2015**, *12*, 3–18. [CrossRef]
11. Senaratne, S.; Sexton, M. Managing construction project change: A knowledge management perspective. *Constr. Manag. Econ.* **2008**, *26*, 1303–1311. [CrossRef]
12. Pathirage, C.P.; Amaratunga, D.G.; Haigh, R.P. Tacit knowledge and organisational performance: Construction industry perspective. *J. Knowl. Manag.* **2007**, *11*, 115–126. [CrossRef]
13. Robinson, H.S.; Carrillo, P.M.; Anumba, C.J.; Al-Ghassani, A.M. Knowledge management practices in large construction organisations. *Eng. Constr. Archit. Manag.* **2005**, *12*, 431–445. [CrossRef]
14. Shi, Q.; Wang, Q.; Guo, Z. Knowledge sharing in the construction supply chain: Collaborative innovation activities and BIM application on innovation performance. *Eng. Constr. Archit. Manag.* **2021**. [CrossRef]
15. Argote, L.; Ingram, P. Knowledge Transfer: A Basis for Competitive Advantage in Firms. *Organ. Behav. Hum. Decis. Process.* **2000**, *82*, 150–169. [CrossRef]
16. Senaratne, S.; Jin, X.-H.; Balasuriya, K. Exploring the role of networks in disseminating construction project knowledge through case studies. *Eng. Constr. Archit. Manag.* **2017**, *24*, 1281–1293. [CrossRef]
17. Welege, N.M.H.; Pan, W.; Kumaraswamy, M. Social network analysis applications in sustainable construction and built environment management: A review. *Built Environ. Proj. Asset Manag.* **2021**, *11*, 511–528. [CrossRef]
18. Wasserman, S.; Faust, K. *Social Networks Analysis: Methods and Applications*; Cambridge University Press: Cambridge/London, UK, 1994.
19. Prell, C. *Social Network Analysis–History, Theory & Methodology*, 1st ed; SAGE Publications Ltd.: London, UK, 2012.
20. Senaratne, S.; Sexton, M.G. Role of knowledge in managing construction project change. *Eng. Constr. Archit. Manag.* **2009**, *16*, 186–200. [CrossRef]
21. Herrera, R.F.; Mourgues, C.; Alarcón, L.F.; Pellicer, E. Comparing Team Interactions in Traditional and BIM-Lean Design Management. *Buildings* **2021**, *11*, 447. [CrossRef]
22. Müller-Prothmann, T. *Leveraging Knowledge Communication for Innovation: Framework, Methods, and Applications of Social Network Analysis in Research and Development*, 1st ed; Peter Lang Publishing: New York, NY, USA, 2007.
23. Serrat, O. Social Network Analysis. In *Knowledge Solutions*; Springer: Singapore, 2017; pp. 39–43.
24. Jamali, M.; Abolhassani, H. Different Aspects of Social Network Analysis. In Proceedings of the 2006 IEEE/WIC/ACM International Conference on Web Intelligence (WI 2006 Main Conference Proceedings) (WI'06), Hong Kong, China, 18–22 December 2006.
25. Hanneman, R.A.; Riddle, M. *Introduction to Social Network Methods*; University of California: Riverside, CA, USA, 2005.
26. Camarasa, C.; Heiberger, R.; Hennes, L.; Jakob, M.; Ostermeyer, Y.; Rosado, L. Key Decision-Makers and Persuaders in the Selection of Energy-Efficient Technologies in EU Residential Buildings. *Buildings* **2020**, *10*, 70. [CrossRef]
27. Maskil-Leitan, R.; Gurevich, U.; Reychav, I. BIM Management Measure for an Effective Green Building Project. *Buildings* **2020**, *10*, 147. [CrossRef]
28. Müller-Prothmann, T. Social Network Analysis: A Practical Method to Improve Knowledge Sharing. In *Hands-On Knowledge Co-Creation and Sharing: Practical Methods and Techniques*; Kazi, A.S., Wohlfahrt, L., Wolf, P., Eds.; Knowledge Board: Stuttgart, Germany, 2007; pp. 219–233.
29. Ruan, X.; Ochieng, E.G.; Price, A.D.F.; Egbu, C.O. Time for a Real Shift to Relations: Appraisal of Social Network Analysis Applications in the UK Construction Industry. *Australas. J. Constr. Econ. Build.* **2013**, *13*, 92–105.
30. Borgatti, S.P.; Li, X. On Social Network Analysis in a Supply Chain Context. *J. Supply Chain Manag.* **2009**, *45*, 5–22. [CrossRef]
31. Chinowsky, P.; Diekmann, J.; Galotti, V. Social Network Model of Construction. *J. Constr. Eng. Manag.* **2008**, *134*, 804–812. [CrossRef]
32. Capece, G.; Costa, R. Measuring knowledge creation in virtual teams through the social network analysis. *Knowl. Manag. Res. Pract.* **2017**, *7*, 329–338. [CrossRef]
33. Lin, S.-C. An Analysis for Construction Engineering Networks. *J. Constr. Eng. Manag.* **2015**, *141*, 04014096. [CrossRef]
34. Almahmoud, E.; Doloi, H.K. Assessment of social sustainability in construction projects using social network analysis. *Facilities* **2015**, *33*, 152–176. [CrossRef]
35. Wang, H.; Zhang, X.; Lu, W. Improving Social Sustainability in Construction: Conceptual Framework Based on Social Network Analysis. *J. Manag. Eng.* **2018**, *34*, 05018012. [CrossRef]
36. Loosemore, M. Social network analysis: Using a quantitative tool within an interpretative context to explore the management of construction crises. *Eng. Constr. Archit. Manag.* **1998**, *5*, 315–326. [CrossRef]
37. Liu, C.; Ji, W.; AbouRizk, S.M.; Siu, M.-F.F. Equipment Logistics Performance Measurement Using Data-Driven Social Network Analysis. *J. Constr. Eng. Manag.* **2019**, *145*, 04019033. [CrossRef]
38. Parise, S. Knowledge Management and Human Resource Development: An Application in Social Network Analysis Methods. *Adv. Dev. Hum. Resour.* **2016**, *9*, 359–383. [CrossRef]
39. Helms, R. Redesigning Communities of Practice using Knowledge Network Analysis. In *Hands-On Knowledge Co-Creation and Sharing: Practical Methods and Techniques*; Kazi, A.S., Wohlfahrt, L., Wolf, P., Eds.; Knowledge Board: Stuttgart, Germany, 2007.
40. Cross, R.; Borgatti, S.P.; Parker, A. Making Invisible Work Visible: Using Social Network Analysis to Support Strategic Collaboration. *Calif. Manag. Rev.* **2002**, *44*, 25–46. [CrossRef]

41. Pryke, S.D.; Zagkli, G.; Kougia, I. Resource provision ego-networks in small Greek construction firms. *Build. Res. Inf.* **2011**, *39*, 616–636. [CrossRef]
42. Schröpfer, V.L.M.; Tah, J.; Kurul, E. Mapping the knowledge flow in sustainable construction project teams using social network analysis. *Eng. Constr. Archit. Manag.* **2017**, *24*, 229–259. [CrossRef]
43. Alsamadani, R.; Hallowell, M.; Javernick-Will, A.N. Measuring and modelling safety communication in small work crews in the US using social network analysis. *Constr. Manag. Econ.* **2013**, *31*, 568–579. [CrossRef]
44. Chung, K.S.K.; Hossain, L. Towards a social network model for understanding information and communication technology use for general practitioners in rural Australia. *Comput. Hum. Behav.* **2010**, *26*, 562–571. [CrossRef]
45. Gan, X.; Chang, R.; Wen, T. Overcoming barriers to off-site construction through engaging stakeholders: A two-mode social network analysis. *J. Clean. Prod.* **2018**, *201*, 735–747. [CrossRef]
46. Chung, K.K.S.; Hossain, L.; Davis, J. Exploring Sociocentric and Egocentric Approaches for Social Network Analysis. In *Exploring Sociocentric and Egocentric Approaches for Social Network Analysis*; Victoria University of Wellington: Wellington, New Zealand, 2005; pp. 1–8.
47. Hargadon, A.B. Firms as Knowledge Brokers: Lessons in Pursuing Continuous Innovation. *Calif. Manag. Rev.* **1998**, *40*, 209–227. [CrossRef]
48. Helms, R.; Buijsrogge, K. Knowledge Network Analysis: A technique to analyze knowledge management bottlenecks in organizations. In Proceedings of the 16th International Workshop on Database and Expert Systems Applications (DEXA'05), Copenhagen, Denmark, 22–26 August 2005.
49. Helms, R.; Ignacio, R.; Brinkkemper, S.; Zonneveld, A. Limitations of Network Analysis for Studying Efficiency and Effectiveness of Knowledge Sharing. *Electron. J. Knowl. Manag.* **2010**, *8*, 53–68.
50. Bosua, R.; Scheepers, R. Towards a model to explain knowledge sharing in complex organizational environments. *Knowl. Manag. Res. Pract.* **2017**, *5*, 93–109. [CrossRef]
51. Yun, G.; Shin, D.; Kim, H.; Lee, S. Knowledge-mapping model for construction project organizations. *J. Knowl. Manag.* **2011**, *15*, 528–548. [CrossRef]
52. Liebowitz, J. Linking social network analysis with the analytic hierarchy process for knowledge mapping in organizations. *J. Knowl. Manag.* **2005**, *9*, 76–86. [CrossRef]
53. Yuan, J.; Chen, K.; Li, W.; Ji, C.; Wang, Z.; Skibniewski, M.J. Social network analysis for social risks of construction projects in high-density urban areas in China. *J. Clean. Prod.* **2018**, *198*, 940–961. [CrossRef]
54. Akgul, B.K.; Ozorhon, B.; Dikmen, I.; Birgonul, M.T. Social network analysis of construction companies operating in international markets: Case of Turkish contractors. *J. Civ. Eng. Manag.* **2016**, *23*, 327–337. [CrossRef]
55. Kulcu, S.; Dogdu, E.; Ozbayoglu, A.M. A Survey on Semantic Web and Big Data Technologies for Social Network Analysis. In Proceedings of the 2016 IEEE International Conference on Big Data (Big Data), Washington, DC, USA, 5–8 December 2016.
56. Bilal, M.; Oyedele, L.O.; Qadir, J.; Munir, K.; Ajayi, S.O.; Akinade, O.O.; Owolabi, H.A.; Alaka, H.A.; Pasha, M. Big Data in the construction industry: A review of present status, opportunities, and future trends. *Adv. Eng. Inform.* **2016**, *30*, 500–521. [CrossRef]
57. Zheng, X.; Le, Y.; Chan, A.P.C.; Hu, Y.; Li, Y. Review of the application of social network analysis (SNA) in construction project management research. *Int. J. Proj. Manag.* **2016**, *34*, 1214–1225. [CrossRef]
58. Nunes, M.; Abreu, A.; Bagnjuk, J.; Tiedtke, J. Measuring project performance by applying social network analyses. *Int. J. Innov. Stud.* **2021**, *5*, 35–55. [CrossRef]
59. Wu, Y.; Wu, Y.; Shang, Y.; Guo, H.; Wang, J. Social network efficiency of multiple stakeholders on agricultural drought risk governance—A southern China case study. *Int. J. Disaster Risk Reduct.* **2020**, *51*, 101772. [CrossRef]
60. Eray, E.; Haas, C.T.; Rayside, D. Interface Health and Workload between Stakeholders in Complex Capital Projects: Assessment, Visualization, and Interpretation Using SNA. *J. Manag. Eng.* **2021**, *37*, 04021006. [CrossRef]
61. Martini, U.; Buffa, F. Local networks, stakeholder dynamics and sustainability in tourism. Opportunities and limits in the light of stakeholder theory and SNA. *Sinergie* **2015**, *33*, 113–130.
62. Argyris, Y.A.; Monu, K. Corporate Use of Social Media: Technology Affordance and External Stakeholder Relations. *J. Organ. Comput. Electron. Commer.* **2015**, *25*, 140–168. [CrossRef]
63. Pryke, S.D. *Social Network Analysis in Construction*, 1st ed; John Wiley & Sons Ltd.: West Sussex, UK, 2012.
64. Ahuja, V.; Yang, J. Communication Protocol for Building Project Management—The Potential of I.T. Enhanced Approaches for the Indian Building Practice. In *BEAR 2006: Construction Sustainability and Innovation, Proceedings of the CIB W89 International Conference on Building Education and Research, Hong Kong, China, 10–13 April 2006*; Hong Kong Polytechnic University: Hong Kong, China, 2006.
65. Senaratne, S.; Abhishek, K.C.; Perera, S.; Almeida, L. Promoting stakeholder collaboration in adopting circular economy principles for sustainable construction. In Proceedings of the 9th World Construction Symposium 2021, Colombo, Sri Lanka, 9–10 July 2021.