Knowledge Management Research in the Construction Industry: A Review

Abstract

Purpose - Knowledge management (KM) is important to the knowledge-intensive construction industry. The diversified and changing nature of works in this field warrants us to stocktake, identify changes and map out KM research framework for future exploration.

Design/methodology/approach - The study involves three aspects. First, three stages of KM research in construction were distinguished in terms of the time distribution of 217 target publications. Major topics in the stages were extracted for understanding the changes of research emphasis from evolutionary perspective. Second, the past works were summed up in a three-dimensional research framework in terms of management organization, managerial methodology and approach, and managerial objective. Finally, potential research orientations in the future were predicted to expand the existing research framework.

Findings - It was found that (1) KM research has significantly blossomed in the last two decades with a great potential; (2) major topics of KM were changing in terms of technology, technique, organization, attribute of knowledge and research objectives; (3) past KM studies centred around management organization, managerial methodology and approach, and managerial objective thus a three-dimensional research framework was proposed; (4) within the research framework, team-level, project-level and firm-level KM were studied to achieve project, organizational and competitive objectives by integrated methodologies of information technology, social technique and KM process tool; and (5) nine potential research orientations were predicted corresponding to the three dimensions. Finally, an expanded research framework was proposed to encourage and guide future research works in this field.

Research limitations/implications – The paper only focused on the construction industry. The findings need further exploration in order to discover any possible missing important research works which were not published in English or not included in the time period.

Originality/value – The paper formed a systematic framework of KM research in construction and predicted the potential research orientations. It provides much value for the researchers who want to understand the past and the future of global KM research in the construction industry.

Keywords: Knowledge management; Construction industry; Literature review; Research; Prediction

Introduction

The iead of knowledge management (KM) was firstly raised in the monograph of Horton (1979). In the 1980's, researchers such as Rogers, Sveiby and Edvinsson began to recognize the importance of knowledge

resources (Edvinsson, 1987; Rogers, 1987; Sveiby, 1988). In general, it is identified that KM was established as an discipline since 1991(Nonaka, 1991). Then, KM started to attract broad attention when it was systematically discussed once again (Nonaka and Takeuchi, 1995). From then on, knowledge was known as one of the most important resources, capabilities or assets for organizations to maintain their sustainable competitive advantages (Bruton *et al*, 2007). As a significant and emerging managerial tool, KM was witnessed an explosive growth of research on it in last two decades. Currently KM is a major field of academic publications.

The construction industry is one of the main pillars of many countries' economy boom. KM in the construction industry, which is now characterized by intensive knowledge (Kim, 2014), is essential to improving business performance. The importance of KM is increasingly recognised in this industry and many KM research achievementsin the special field have been published by past researchers (McRea and Langdon, 2003; Senaratne and Sexton, 2009).

However, the reporting of the research achievements is often ad hoc, fragmental and disorganised. The diversified and changing nature of past works in this field warrants us to stocktake, identify research framework and predict research trends for theoretical improvement and practical implementation in the future. A summary of past research can contribute to systematic thinking and better judgement of the past research achievements. Prediction of potential research orientations can provide significant information for new researchers to conveniently identify new clues and avoid "reinventing the wheel".

Hence, this study was set to answer two questions: what has been studied in the past, and what are the potential research orientations in the future? To answer these questions, major topics and research framework were summarized and future research orientations were predicted in this paper on the basis of literature review.

The remainder of this paper is thus organized as follows. Methodology of literature retrieval and paper selection is explained in Section 2. The major topics in three stages which are distinguished in terms of the number of papers are discussed in Section 3 from evolutionary perspective. The research framework in the past is summarized in Section 4. Prediction of potential research orientations is proposed in Section 5 to improve the past research framework. Finally, conclusions, limitations and future work are presented in Section 6.

Methodology

Since KM research began to flourish from 1995, a document study of a three-phase literature review (Ke *et al*, 2009; Yi and Yang, 2014) of KM in the construction industry over last two decades (from 1995 to 2015, 2015 being an incomplete year when this study was completed) was conducted. The data were collected up to 10 August 2015.

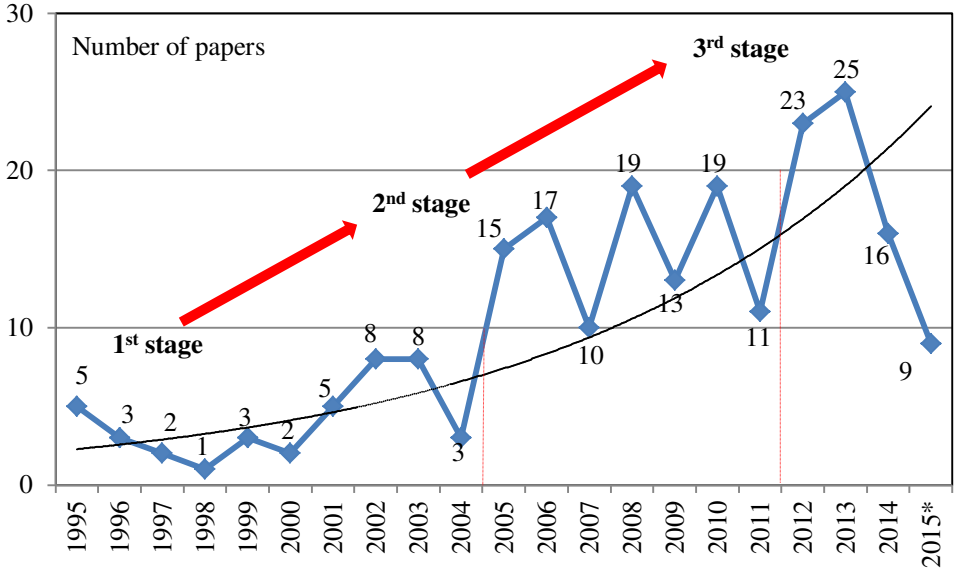
The three phases of literature review were respectively designed as follows: (1) papers were searched through a search engine in the first phase; (2) subject areas were limited and target papers were manually selected by examination of titles to look for papers highly related to the topic of study in the second phase; and (3) publications were visually examined in terms of abstract and keywords to ensure that the selected papers are valid representations in the third phase. In addition, journals that have published most of the papers were double checked according to the bibliography to ensure no potential papers were missed.

Scopus is one of the leading search engines and is popular among construction researchers (Yi and Yang, 2014). In addition, Falagas *et al* (2008) proposed that Scopus has better performance than other engines such as PubMed, Web of Science and Google Scholar in terms of coverage and accuracy. Hence, in the first phase, the Scopus search engine was adopted by the authors to go through "titles".

The complete search code is listed as follows: (TITLE(construction*) AND TITLE(knowledge*)) AND DOCTYPE (ar OR re) AND SUBJAREA (mult OR ceng OR chem OR comp OR eart OR ener OR engi OR envi OR mate OR math OR phys OR mult OR arts OR busi OR deci OR econ OR psyc OR soci) AND PUBYEAR >1994 AND LIMIT TO (LANGUAGE, "English").

Major topics

The three-phase literature retrieval yielded 217 papers that were published in last two decades. The significant exponential increasing trend (see **Figure 1**) of the number of papers indicates that the theory of KM in construction is of potential and many researchers started to pay attention to the research in the field. Suggested by the **Figure 1**, the development of KM research in construction can be divided into three stages. In the first stage which is from 1995 to 2004 less than ten papers were published per year.A dozen of papers were published in the second stage from 2005 to 2011. The third stage started from 2012. The number of papers broke through twenty in 2012 and 2013, although it briefly reduced to sixteen in 2014. The number of papers in 2015 was only nine because it was incompletely counted. It can be expected that KM in construction will be a hot research field in the future.



*As of August 2015

Figure 1. Number of papers published in last two decades

Summary of major topics is beneficial to the comprehensive understanding of KM research in the construction industry. Furthermore, discussion of major topics in the three stages in terms of time series helps us to better understand the research emphases in the past and the change of research themes from evolutionary perspective. Hence, after going through "titles/abstracts/keywords" of the target papers, major topics were summarized as follows.

Topics in the first stage (1995 - 2004)

According to the statistics, forty papers were published in the first stage. That is, only four papers were reported per year. The major topics in the first stage can be significantly reflected on the three following themes.

Knowledge-based system. In the earliest years, especially in 1995, researchers paid the greatest attention to research of knowledge-based system in construction from technological perspective. Different knowledge based systems were developed for multifarious applied functions such as construction planning (Shaked and Warszawski, 1995), construction-site organization (Sauce and Mommessin, 1995), contractor pre-screening (Taha *et al*, 1995), contractor proposal evaluation (Kuprenas and Madjidi, 1996) and decision-making support (Shalomygin *et al*, 1999). Expert knowledge base and information technology supported these systems.

KM skill and approach. In the following years, researchers gradually diverted their attention to the development of KM skills and approaches from management science perspective. Egbu (1999) distinguished the six most important skills such as leadership, communication and motivation for managing construction refurbishment works among 75 types of management skills. Briscoe *et al* (2001) explored knowledge, skills and

attitudes for achieving better supply chain integration in SME companies. Mohamed (2001) and Tah and Carr (2001a) respectively developed a knowledge based approach for productivity adjusted construction schedule and project risk management.

Knowledge generation and acquisition. Along with the development of KM theory, KM activities, especially the knowledge generation and acquisition, began to receive attention. Nakajima (1998) developed a knowledge-based system to generate nonnumerical information such as the assembly order and activity procedures for building members. Soibelman and Kim (2002) further proposed a series of data preparation processes for knowledge generation through knowledge discovery in databases. Palaneeswaran and Kumaraswamy (2003) then explored some emerging technologies and tacit knowledge sources for structuring knowledge mining strategy. In addition, Yu and Skibniewski (1999) described a neuro-fuzzy computational approach for constructability knowledge acquisition of construction technologies.

In the late period of the first stage, the diverged topics indicated that researchers began to be interested in more research themes in the field. The KM theory in the construction industry was expected to be rapidly improved from then on. It is thus not surprising that a new stage which is characterized by boom of publications was coming.

Topics in the second stage (2005 - 2011)

The period from 2005 to 2011 has witnessed a boom of KM research in construction. One hundred and four papers were published in the seven years and about 15 papers were published per year. The knowledge-based system as well as information technology was also mainstream theme in this stage (Arun and Rao, 2007; Pan *et al*, 2005). Some other new topics which were summarized through keyword analysis function provided by Scopus were listed as follows.

Ontology. The ontology is a specific conception in computer science. It is one of the main components of semantic web (El-Diraby and Kashif, 2005). The ontology theory began to be employed in KM research in construction since 2005 (Ei-Diraby *et al*, 2005). KM activities started to be more networked, dynamic and global. More efficient KM tools relied on semantic web were developed to manage increasing knowledge resources from more distributed knowledge sources (Svetel and Pejanović, 2010). It is a great progress of KM technology.

Tacit knowledge. Tacit knowledge was always thought to be more valuable than explicit knowledge in organizations (Styhre, 2009). The relationship between tacit knowledge and organizational performance in the construction industry was firstly analysed by Pathirage *et al* (2007). Under the inspiration, Teerajetgul and

Chareonngam (2008) explored the utilization of tacit knowledge in executing construction projects, and found that four factors of tacit knowledge utilizations were inherently embedded in management practices for organizational creativity and competitiveness.

Knowledge learning and sharing. On the basis of knowledge generation and acquisition, researchers began to focus on interactive KM activities such as knowledge learning (Fu *et al*, 2006), sharing (Chen, 2008) and transfer (Ekambaram *et al*, 2010; Wynn *et al*, 2008) in organizations. The research works around this theme were to explore the mechanism and influential factors of and tools for knowledge learning and sharing among construction projects.

Safety knowledge management. Comparing to the early researchers focusing on "how to manage knowledge", pragmatic researchers began to pay more attention to "how to solve specific problems using KM tools". Safety knowledge management as well as risk knowledge management is an important direction of KM application in construction. While Edwards and Holt (2008) and Fargnoli *et al* (2011) engaged in integrative research on KM and occupational health and safety systems in the construction sector, information technologies for safety knowledge sharing were also developed (Li and Poon, 2009, 2011).

KM modelling. Along with the deep development of KM theory, the research trended to be more integrative and modelled. Kinds of KM models such as knowledge-based diagnosis model (Wang *et al*, 2007), knowledge sharing model (Chen, 2008), integrative KM model (Kanapeckiene *et al*, 2010; Yin *et al*, 2008), ontology-based design knowledge model (Gao *et al*, 2011) and knowledge map model (Ping Tserng *et al*, 2010; Yun *et al*, 2011) were developed in succession. KM modelling is an indicator which suggests the primary maturity of KM theory in construction.

Value and performance. After the implementation of KM in construction practices, more researchers concerned for its value or performance. In fact, the early KM practice was not so effective. Tombesi (2006) critically argued that the socialization of knowledge was a good thinking but with poor value. Fortunately its effectiveness was recognizedwithin many aspects including enhancing collaboration (Dave and Koskela, 2009), improving innovation (Wynn *et al*, 2008), managing project change (Senaratne and Sexton, 2008, 2009) and promoting sustainable construction (Moore and Rydin, 2008). A few of researchers thus began to develop evaluation models or systems for KM performance appraisal (Lin *et al*, 2011; Park *et al*, 2010).

Of course not all the research works in the second stage were involved in the above topics. Some other topics also received attention, for example, knowledge-based process (El-Gohary and El-Diraby, 2010; Fong

and Choi, 2009), ITs (Information Technologies) for KM (Bigliardi *et al*, 2010) and influential factor analysis (Ma *et al*, 2008; Teerajetgul *et al*, 2009).

Topics in the third stage (2012 - present)

In the short period from 2012 to present, 73 papers have been published. More publications can be expected in the near future. Many major topics in the above stages, for example, knowledge sharing, safety KM and knowledge-based system, were also popular, and even widely and deeply discussed in the third stage. The new topics were summarized as follows.

BIM and big data technology. When kinds of information technologies were applied to the development of KM systems, the enriched KM technologies played a more important role in value creation for the construction industry. However, it is also meaningful that RFID (Radio Frequency Identification Devices) technology was firstly tried to use for the development of KM tools in big data era (El Ghazali *et al*, 2012). Furthermore, it is fortunately that a useful KM tool – BIM (Building Information Modelling) was developed and widely used in many construction projects all over the world (Ho *et al*, 2013; Lin, 2014).

KM process. When KM activities such as knowledge sharing and knowledge learning became popular themes of KM research, the integration of fragmental KM activities was finally focused (Ruan *et al*, 2012). The impacts of influential factors on KM activities (Idris *et al*, 2015) and of KM activities on construction outcomes (Venkateswaran and Aundhe, 2013) were also embedded in construction process (Akhavian and Behzadan, 2014). KM process was gradually improved as an effective KM technique for direct value creation.

Social techniques. In fact, the application of social techniques to KM has been proposed in the second stage (Kazi, 2005; Simões and Soares, 2006). However, the social techniques were widely developed and used for KM in recent years. Javernick-Will (2012) studied the power of social motivation to motivate knowledge sharing in construction organizations. Abdul-Rahman *et al* (2012) studied the role of social psychology in knowledge acquisition. Furthermore, Ruan *et al* (2012) and Le *et al* (2014) employed social network analysis approach to research collaborative KM in construction projects.

Collaborative KM. In recent years, collaborative KM or KM for collaborative engineering received increasing attention. As an effective tool, KM was used for increasing efficiency of collaborative design (Lee and Jeong, 2012), promoting collaborative working in construction projects (Ruan *et al*, 2012) and even improving collaborative relationship in construction supply chain (Shi and Wu, 2013). Several researchers engaged themselves in the development of information technologies for collaborative KM among multi organizations (Costa and Lima, 2014; El Ghazali *et al*, 2012).

The change of research topics from evolutionary perspective

From the above analysis the change of research topics can be summarizedas follows from evolutionary perspective.

Change of managerial technology. In the first stage, knowledge-based systems were strongly developed on the basis of information technologies. In the second stage, ontology methodology and semantic web technology were employed to solve problems about management of distributed knowledge resources. Up to recent years, BIM was deeply studied and became a relatively mature tool for KM in construction. To overcome the challenges inthe big data era, big data technologies are expected to be widely used for KM in the future.

Change of managerial technique. In the early stages, most of researchers paid more attention to the development of technology. The early KM was actually like information management. Only a few of researchers tried to graft traditional management theories to explore KM skills and approaches. Up to the beginning of the 21st century, researchers began to emphasize the important role of socio-techniques. Social network, social psychologyand social behaviour were employed to explain KM principles in the third stage.

Change of organizational management. Knowledge generation and acquisition were focused in the first stage. However, the research emphases changed to knowledge learning and sharing in the second stage. Based on the research works about knowledge activities, comprehensive KM models were developed. And then in the third stage, researchers naturally began to be interested in KM process studies. In recent years, collaborative KM, as a high-level and more complex organizational technique, received great attention.

Change of the attribute of knowledge. In the first stage, the subject matter of KM mainly included data, information and expert experience. In the later period, KM was refined, and it focused on the management of specific knowledge resources in the construction sector such as tacit knowledge, risk knowledge and health and safety knowledge.

Change of research objective. In the early period, researchers considered much "what is KM and how to implement KM in the construction sector", so they focused on the development of KM technologies and skills. Later researchers considered more "how to create value and enhance performance of KM". Hence, many research works about value creation mechanism, performance evaluation model and influential factors of KM performance were published.

Research framework

Dimensional representation and framework construction

Though hundreds of papers have been published for the construction of KM theory in the construction industry, only a few of researchers systematically considered the framework of KM in construction. Rezgui (2001) conclusively discussed knowledge categories, managerial technologies and management systems involving in KM practices in the construction industry. Rezgui *et al* (2010) firstly proposed a systematic framework of KM in construction that it could be divided into three generations from evolutionary perspective which were differentiated in terms of four distinctive criteria including underpinning ICT, socio-technique, lifecycle and knowledge. They also indicated that KM research in construction mainly focused on three dimensions including socio-technical dimension, socio-organizational dimension and learning process dimension. Fang and Le (2012) summarized the factors of knowledge sharing among construction organizations from three dimensional levels, that is, individual, organizational and technology. However, the above review works did not cover all of the past research achievements and they were lack of systematic thinking of "how KM theory and tools contribute to the management of the construction industry".

Based on a thorough review of the KM literature, the authors defined KM in construction from an integrative perspective. The integrative view emphasizes "how to embed KM principles and methodologies in managerial practices of the construction industry". Consequently, the KM research achievements would be re-viewed from the three following dimensions.

Management organization dimension. Currently KM theories are widely used to instruct managerial practices of different level construction organizations such as team, project and firm. Research on team-level KM focused on knowledge learning mechanismand the intention, attitude and behaviour of knowledge sharing. In addition to knowledge learning and sharing, research on project-level KM was much more fruitful and it also paid attention to other KM activities such as knowledge creation, acquisition, transfer, diffusion, integration and mapping. From intra-organizational perspective, more macro issues such as the objective, implementation, influential factor and effect of KM were always in consideration. Furthermore, a few of researchers studied inter-organizational KM since practices in the construction industry are often collaborative among different firms (Costa and Lima, 2014; Shi and Wu, 2013). Even several researchers took the whole construction industry into consideration. The research contents included creating enterprises (Goh, 2006), developing knowledge based systems (Kaetzel and Clifton, 1995) and booming construction economy(Ofori, 2003).

Managerial methodology and approach dimension. KM methodologies and approaches including knowledge process tools, information technologies, and social techniques were always employed to study and implement the KM in construction. A logical process of KM includes activities such as knowledge creation or

discovery, knowledge acquisition or learning, knowledge sharing or transfer, knowledge integration, and knowledge applicationor exploitation. Information technologies, for example, BIM technology (Lin, 2014) and expert based system (Kaetzel and Clifton, 1995), were developed to promote the implementation of KM in the construction industry. Social factors such as culture, trust and relationship were often thought as important influential factors of KM practices. Hence, many socio-technical approaches to KM have been initiated in many construction organizations (Ruan *et al*, 2012; Simões and Soares, 2006).

Managerial objective dimension. KM was generally accepted by practitioners as a new technique for gaining core competence or sustainable competitive advantage (Egbu, 1999; Ruan *et al*, 2012). As a kind of resource, asset or capital, knowledge in organizations was usually managed for capability development (Rezgui *et al*, 2010). More concretely, KM was employed to realize practical objectives such as supporting design, controlling risk, managing project change, coordinating investment, improving preparation of construction projectsand enhancing inter-organizational collaboration.

Hence, the research framework of KM in construction can be described in terms of the three dimensions. **Figure 2** provides an illustration of the research framework using two axes. The horizontal axis provides the gradually extensive organizations which are served by KM. The vertical axis illustrates the evolutionary managerial objectives of KM in the construction sector. The integration of three types of KM methodologies and approaches is essential to the effectiveness and performance of KM implementation in construction organizations. ICT technologies and social techniques support the development and application of knowledge processing tools.

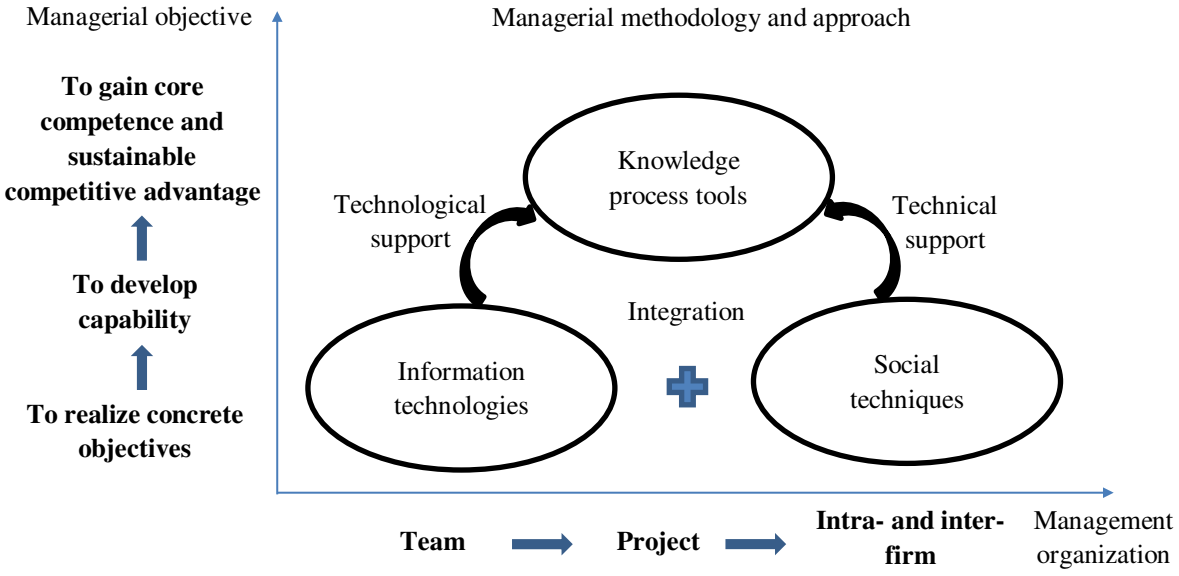


Figure 2. The research framework of KM in construction

Management organization dimension

KM serves different level organizations in the construction industry. Hundreds of KM research works have been completed for construction teams, projects and firms.

Team-level KM. Researchers focused on knowledge sharing in construction teams. The most important contribution for team-level KM is the TPB (Theory of Planed Behaviour) model of knowledge sharing which was constructed by Zhang and Ng. The model revealed the knowledge sharing mechanism in construction teams: attitude toward knowledge sharing significantly influences knowledge sharing intention and in turn individual knowledge sharing behaviour (Zhang and Ng, 2012a, b). Furthermore, they suggested that in construction teams professional's knowledge sharing intention is determined by attitude toward and perceived behavioural control over knowledge sharing (Zhang and Ng, 2013).

*Project-level KM.*It received sustainable attention in a long period since the beginning of the 21st century. Many themes about project-level KM were studied to realize different objectives in construction projects. The most special applications areproject risk KM (Tah and Carr, 2001b), project change KM (Senaratne and Sexton, 2008) and KM for project complexity and success (Chou *et al*, 2013; Cooke, 2013). In addition, project-level KM activities including sharing (Kivrak *et al*, 2014), transfer (Ekambaram *et al*, 2010) and mapping (Yun *et al*, 2011) were also popular themes. Because of the attribute of project, knowledge of previous projects is valuable to the management of later projects. Hence, the live capture and reuse of project knowledge is especially important (Tan *et al*, 2006). Finally, several integrative project-level KM models are worth noting (Ruan *et al*, 2012; Tah and Carr, 2001b; Yu and Skibniewski, 2010).

Firm-level KM. Case study was always employed to summarize the experience and problems of KM practices in different kinds of construction firms (Kale and Karaman, 2012; Lu and Sexton, 2006; Tan *et al*, 2012). The influential factors of KM success often attracted researchers' interests (Khalifa and Jamaluddin, 2012). Concretely they paid considerable attention to knowledge sharing among individuals, teams, projects in construction firms (Javernick-Will, 2012). The knowledge transfer from previous projects to later projects was repeatedly concerned (Tan *et al*, 2006; Udeaja *et al*, 2008). Cross-organizational-boundary and cross-culture KM was emphasized for promoting collaboration between different firms (Chou *et al*, 2013; Demaid and Quintas, 2006; Neff *et al*, 2010). Culture was thought as one of the most important factors of inter-firm KM practices (Kivrak *et al*, 2014).

Managerial methodology and approach dimension

Methodology and approach of KM in construction is threefold: socio-technique, IT and knowledge process tool. Socio-technique and IT support the development of KM systems for construction projects, while knowledge process is directly embedded in construction process for improvement of managerial efficiency.

Socio-techniques for KM. The performance of some interactive KM activities including knowledge sharing, knowledge transfer, knowledge integration and collaborative innovation is depended on the structure and function of social networks of construction project teams (Le *et al*, 2014). In human terms, social motivation (Javernick-Will, 2012), mutual trust (Olomolaiye and Egbu, 2005) and organizational culture (Idris *et al*, 2015) are effective influential factors that can encourage people in construction organizations to share and create knowledge.In addition, the existing theory of social psychology was successfully used to examine knowledge sharing behaviour in the construction sector (Zhang and Ng, 2013).

ITs for KM. As proposed by Rezgui *et al* (2010), construction KM technology has witnessed an evolutionary experience in order of design and office automation tools, document management systems, BIM, ontology based ICT and ubiquitous e-construction. Various knowledge-based systems were developed (Lin, 2014; Mosa *et al*, 2011; Sauce and Mommessin, 1995). KM activities were promoted through product data modelling initiatives such as STEP, IFCs and BIM (Rezgui *et al*, 2010). The advent of the semantic web underpinned by ontologies widely boosted the development of ITs for KM. In the future, the application of emerging big data technologies (El Ghazali *et al*, 2012) and the synthesis of previous ITs (Park *et al*, 2013) into a KM portal system will be of potential.

Knowledge process tools. The tools are developed to create, collect, share, transfer and use valuable knowledge in construction organizations. They follow the principles of knowledge flow and managerial theory, and are supported by ITs. Hence, these tools, for example, knowledge capture awareness tool (Hari *et al*, 2005) and knowledge-based risk mapping tool (Yildiz *et al*, 2014), are always effective for some specific functions such as promoting knowledge capture, learning and mapping. Taking integration of KM activities into consideration, serval complete KM process models were proposed to build knowledge flow cycle for sustainable knowledge-based competitive advantage in construction organizations (Ruan *et al*, 2012; Venkateswaran and Aundhe, 2013). Furthermore, the integration of KM process and construction process was focused to enhance the value creation capability of construction projects.

Managerial objective dimension

According to the KM practices in many construction organizations, KM is beneficial to project objectives and organizational capability, and in turn core competence and sustainable competitive advantage for construction firms.

KM for project objectives. The construction industry is characterized by fragmental structure and project management. KM was widely employed to solve concrete problems in different kinds of construction projectssuch ashighway construction project (El-Diraby and Wang, 2005). The importance of knowledge exchange between construction design teams to collaborative design was repeatedly emphasized (Demian and Fruchter, 2006; Kocaturk, 2010; Ugwu *et al*, 2003). Several authors suggested that lively captured knowledge through a structure method helps project managers to predict changes in project team, product and process and in turn reduce project risk (Senaratne and Sexton, 2008, 2009). Furthermore, Cooke (2013) suggested knowledge sharing can mitigate the effect of construction project complexity. Finally, KM was also found to be advantageous to overcoming challenges to green construction (Hwang and Ng, 2013) and sustainable construction (Pietrosemoli and Rodríguez Monroy, 2013).

KM for organizational capability. Knowledge was often known as resource as well as capability in construction organizations. KM was famous for promoting organizational capabilities in terms of technology, innovation, organization and decision-making. Previous research works proved that: (1) knowledge based system and platform enhances technological capability to better manage data, information and knowledge in many construction organizations (Kivrak *et al*, 2008); (2) KM has an important role in improvement of innovation capability (Egbu, 2004); (3) KM is essential to the organization of collaborative construction project teams (Costa and Lima, 2014); and (4) knowledge/expert based system is usually used to support decision-making of construction organizations (Al-Jibouri and Mawdesley, 2002). In addition, the capability of knowledge learning from failures impacts on the adaption and success of many construction projects in the future (Gressgård and Hansen, 2014).

KM for industrialcompetition. It is without doubt that knowledge is an important source of core competence and sustainable competitive advantage for most of the knowledge-based construction organizations. KM is a useful technique to manage this kind of important resource. For one thing, KM improves technological capability through knowledge innovation and then enhances the core competence of construction organizations (Goh, 2006). For another, a range of KM issues such as organizing collaboration cross professions and building informal networks with partners and subcontractors influence the implementation of construction solutions in the context of specific markets (Grubbauer, 2015). Furthermore, knowledge cooperation in construction supply

chain changes the competitive relationship (Guang-dong, 2013), and makes a few of organizations advantageous to coopetition.

Prediction

The changes of major topics from the first stage to the third stage indicate the new research orientations in the future. The research framework structures the important research themes of KM in construction. In addition, previous publications also suggested the research limitations and future works. A complete examination of these discussions provides the ability to synthesise previous authors' recommendations and highlight potential research areas for KM research in construction. Consequently, taking the above three aspects of information into consideration, the authors predict potential research orientations of KM in construction in terms of the three dimensions, as presented below.

Organization-dimensional future research orientations

Comparatively speaking project-level KM and firm-level KM attracted too much attention, but individual KM in construction teams and KM system for the whole industry were lack of deep study. In addition, most of research works were involved in regular building engineering projects. However, it was suggested that KM studies need to expand to special engineering fields such as green construction and sustainable construction. Of course, some potential research orientations in the past (e.g. cross-culture KM and project change KM) also need to be deeply improved through more research works in the future.

Individual KM. Individual KM mechanism is required to be explored for better managing knowledge, skills and experience of designers, professionals, salesmen and project managers, etc. Topics including motivators of individual knowledge leaning and sharing, influential factors of individual KM performance and socialization mechanism transforming individual knowledge to organizational knowledge constitute research emphases. In addition, individual KM tools and systems need to be developed. Tacit knowledge stored in human brain is especially expected to be developed and managed for increasing of KM value.

KM for special construction. KM research should be extended to the other domains such as roads, bridges, tunnels and traffic control, etc. It also should be expanded to specialised construction projects such as sustainable building development, green construction design and post-disaster reconstruction. Furthermore, comparative studies of KM practices in different construction project teams are also expected.

Industrial KM. Industrial KM systems are required to be developed from perspectives of construction supply chain and construction markets. Knowledge exchange mechanism needs to play a role in communication

among designers, contractors, suppliers and customers. A complete technological platform is required for sharing knowledge of most of the past projects in the whole industry. Research on knowledge-based economic development of the construction industry is also stimulated to improve KM theory.

Methodology-and-approach-dimensional future research orientations

It is no doubt that the mainstream of KM research for construction is to develop KM tools using integrated methodology of ITs and socio-techniques. Of course, the technologies and techniques also need to be continuously developed along with the change of technological level and managerial demand. From technological perspective, big data technologies are expected to be widely used in the whole economic field in the future. From technical perspective, more social factors will be considered to better manage construction knowledge. Certainly old topics such as knowledge-based system, impact of culture on knowledge sharing and knowledge activity management will also receive much attention.

Application of big data technology. Big data technologies such as RFID, distributed cache and distributed database based on MPPare expected to be widely used for knowledge acquisition, live capture of knowledge, knowledge mining, knowledge discovery, knowledge generation and knowledge mapping in construction organizations. Research on application of big data technologies surely needs to integrate mature information technologies such as semantic web underpinned by ontologies.

Social network analysis and theory of social psychology. Knowledge sharing and transfer research should take place in social network context. Social network analysis in terms of structure, relationship and behaviour is an effective methodology of knowledge sharing mechanism research. In addition to social factors such as social culture, trust and social environment, social psychology is necessary to be employed to explain the attitude toward and intention of knowledge sharing. Mechanism of interactive knowledge activities in which theory of social psychology is embedded is inspired to be deeply studied.

*Integrated use of technologies and techniques.*The mutual support relationship and interactive impact of information technologies and socio-techniques are extremely important to enhance the effectiveness of KM tools for construction organizations. More KM models and systems are encouraged to be developed through integrated use of ITs and techniques. Balance of information technologies and organizational techniques needs to be more considered in KM practices.

Objective-dimensional future research orientations

The previous research focused on KM for concrete project objectives (e.g. risk control and change management) and knowledge process management for capability development. There was lack of consideration on the management of knowledge/intellectual capital, knowledge-based corporate strategyand knowledge value chain which would bring more value to construction organizations.

KM to accumulate capital. KM is beneficial to capital accumulation in terms of social capital and intellectual capital. Different levels (team, project or firm) of collaborative KM in the context of social networks foster social capital by building human relationship, trust system and behaviour norm. The role of KM in improvement of technological innovation reflects on the growth of knowledge talent, technological achievements and innovative products. Management measures for accumulation of social capital and intellectual capital need to be developed to upgrade resource and capability to capital.

KM to form strategy. As a kind of knowledge-based organization, construction firm should build its corporate strategy on the basis of KM theory for gaining core competence and sustainable competitive advantage through systematic implementation of KM practices. Issues such as "how to implement KM practices", "how to create value through integration KM in organizational functions" and "how to make KM sustainable" should be taken into consideration of corporate strategy. Developing tools to aid and control KM strategy implementation or evaluate its performance also will constitute future research topics.

KM to create value in a chain. The theory of value chain management needs to be employed to improve KM in construction. Relationship between KM and value creation is required to be explored and verified. Mechanism of embedding knowledge networks in construction value chain is also expected to be developed. Furthermore, KM practices in the construction industry should be designed for enhancement of competitive advantage over the complete industrial chain. Future research may focus on knowledge value chain management instead of knowledge resource management in single organizations.

The expanded research framework in the future

Through the above analysis the future potential research orientations were proposed to expand and improve the past research framework. The research framework will be more fruitful and complete when the potential research orientations are integrated in the past framework involving in management organization, managerial methodology and approach, and managerial objective. The expanded framework will indicate development trend of the theory of KM in construction, and suggest research hotpots for new researchers in the future. **Figure 3** illustrates the expanded research framework. The italic items reflect the potential research orientations in the future.

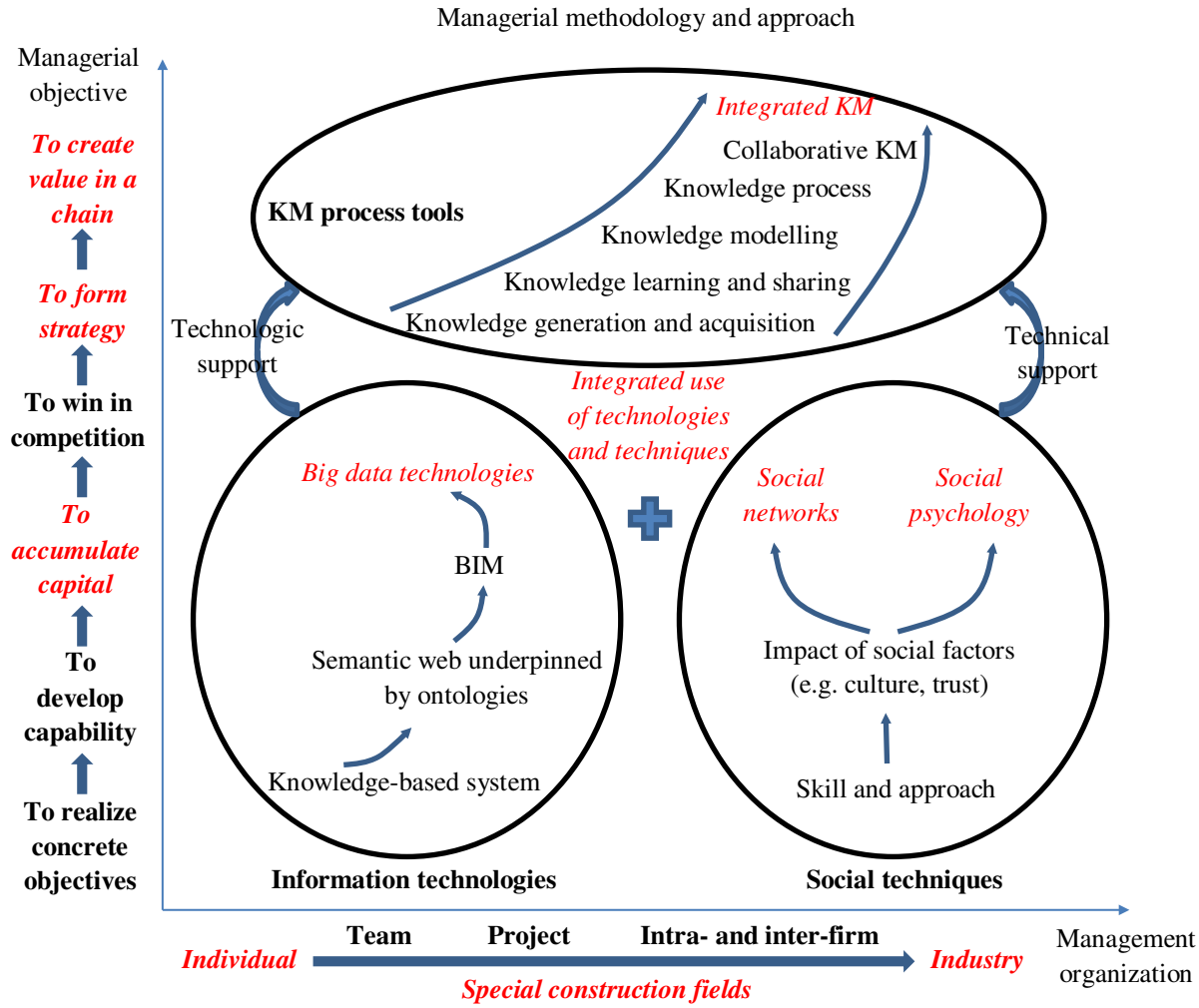


Figure 3. The expanded research framework including potential research orientations

Conclusion remarks

As noted in the introduction section, the paper addresses the following research questions: what has been studied and what will be researched involving in KM in construction? Based on the evidence gathered by the authors through a literature review of 217 papers published in the period from 1995 to present, the authors summarized the major topics from evolutionary perspective, the research framework in terms of three dimensions, and predicted the potential research orientations in the future to expand the research framework.

It is expected that KM research for construction is of considerable potential since the number of papers was significantly increasing in the last two decades. According to the number of papers, the KM research for construction was divided into three stages: the first stage is from 1995 to 2004, the second stage is from 2005 to 2011 and the incomplete third stage is from 2012 to present. The major topics in the first stage included knowledge-based system, knowledge skill and approach, and knowledge generation and acquisition. The research in the second stage was involved in topics such as ontology, tacit knowledge, knowledge learning and

sharing and safety knowledge management etc. Researchers focused on BIM and big data technology, knowledge process, social technique and collaborative KM in recent years. Furthermore, the significant changes in terms of managerial technology, managerial technique, organizational management, attribute of knowledge and research objective were summarized to show the evolution of construction KM research emphases.

Three dimensions are used to define the research framework of KM in construction from an integrative perspective, namely: management organization, managerial methodology and approach, and managerial objective. In view of organizational dimension, KM research covered organizational fields including construction team, project and intra- and inter-firm. The KM methodology and approach was catalogued into three categories: IT, social technique and KM process tool. Generally speaking, the KM was usually applied to realization of concrete project objectives, development of organizational capability, and gaining core competence and sustainable competitive advantage. The IT and social technique support development of the KM process tools.

Taking the evolution of major topics, the three-dimensional research framework and the future research works proposed by previous authors into consideration, the authors predicted the potential research orientations in this paper to expand and improve the research framework of the construction KM theory. The organizational-dimensional future research orientations include individual KM, KM for special construction and industrial KM. The methodology-dimensional future research orientations cover application of big data technology, social network analysis and theory of social psychology, and integrated use of technologies and techniques. Finally, the objective of KM in the construction industry is expanded to accumulating capital, forming strategy and creating value in a chain.

According to the expanded research framework, five possible research trends in the future can be speculated concretely. First, from theoretical perspective, more emerging KM theories will be employed in research of the construction industry. Researchers will focus on develop more integrative KM models to be applied to construction practices. Second, from technological perspective, more advanced ICTs, especially technologies related to big data and internet of things, will be used to develop KM tools for construction management. Third, KM evolving in social fields will attract more attention. Social networks and social psychology are expected to be heavily used in the research of KM in construction organizations. Fourth, enriched KM processes and actions will be discovered in practical construction management work. And then, KM also will be employed to solve more various problems and realize more kinds of objectives in the construction industry. Finally, the range of KM research will be broaden. On the basis of past research works

which centred around team, project and organization, KM research in the future will illustrate more from individual or industrial perspectives.

All in all, this paper provides two views for comprehensive understanding the research works in the past, namely: the major research topics in three stages from evolutionary perspective and the research framework in terms of management organization, managerial methodology and approach, and managerial objective. Meanwhile, the authors suggest several potential research orientations for future research. Hence, the study is valuable for readers who wish to gain a deeper understanding of this intriguing and long lasting field of research.

Limitations do exist in this study. The paper only focused on the construction industry. A few of papers may be omitted because of the limitation of Scopus search engine and the criteria of time period or language. The thoroughly proposed potential research orientations were limited in the three-dimensional research framework. Previous popular research orientations and other new directions may also of potential in the future.

References

Abdul-Rahman, H., Wang, C., Siong, E.K. (2012), "Knowledge acquisition using psychotherapy technique for critical factors influencing construction project layout planning", *Project Management Journal,* Vol. 43 No. 1, PP. 50-64.

Akhavian, R., Behzadan, A.H. (2014), "Evaluation of queuing systems for knowledge-based simulation of construction processes", *Automation in Construction,* Vol. 47 No., PP. 37-49.

Al-Jibouri, S.H., Mawdesley, M.J. (2002), "A knowledge based system for linking information to support decision making in construction", *Electronic Journal of Information Technology in Construction,* Vol. 7 No., PP. 83-100.

Arun, C., Rao, B.N. (2007), "Knowledge based decision support tool for duration and cost overrun analysis of highway construction projects", *Journal of the Institution of Engineers (India): Civil Engineering Division,* Vol. 88 No. AUG., PP. 27-33.

Bigliardi, B., Dormio, A.I., Galati, F. (2010), "ICTs and knowledge management: An Italian case study of a construction company", *Measuring Business Excellence,* Vol. 14 No. 3, PP. 16-29.

Briscoe, G., Dainty, A.R.J., Millett, S. (2001), "Construction supply chain partnerships: Skills, knowledge and attitudinal requirements", *European Journal of Purchasing and Supply Management,* Vol. 7 No. 4, PP. 243-255.

Bruton, G., Dess, G., Janney, J. (2007), "Knowledge management in technology-focused firms in emerging economies: caveats on capabilities, networks, and real options", *Asia Pacific Journal of Management,* Vol. 24 No. 2, PP. 115-130.

Chen, J.H. (2008), "KNN based knowledge-sharing model for severe change order disputes in construction", *Automation in Construction,* Vol. 17 No. 6, PP. 773-779.

Chou, J.S., Irawan, N., Pham, A.D. (2013), "Project management knowledge of construction professionals: Cross-country study of effects on project success", *Journal of Construction Engineering and Management,* Vol. 139 No. 11.

Cooke, T. (2013), "Can knowledge sharing mitigate the effect of construction project complexity?", *Construction Innovation,* Vol. 13 No. 1, PP. 5-9.

Costa, R., Lima, C. (2014), "Knowledge representations with ontology support for collaborative engineering in architecture engineering and construction", *Journal of Information Technology in Construction,* Vol. 19 No., PP. 434-461.
Dave, B., Koskela, L. (2009), "Collaborative knowledge management-A construction case study", *Automation in Construction,* Vol. 18 No. 7, PP. 894-902.
Demaid, A., Quintas, P. (2006), "Knowledge across cultures in the construction industry: Sustainability, innovation and design", *Technovation,* Vol. 26 No. 5-6, PP. 603-610.
Demian, P., Fruchter, R. (2006), "An ethnographic study of design knowledge reuse in the architecture, engineering, and construction industry", *Research in Engineering Design,* Vol. 16 No. 4, PP. 184-195.
Edvinsson, L. (1987), "The new business focus", *Service Industries Journal,* Vol. 7 No. 7, PP. 195-206.
Edwards, D.J., Holt, G.D. (2008), "Construction workers' health and safety knowledge: Initial observations on some test-result data", *Journal of Engineering, Design and Technology,* Vol. 6 No. 1, PP. 65-80.
Egbu, C.O. (1999), "Skills, knowledge and competencies for managing construction refurbishment works", *Construction Management and Economics,* Vol. 17 No. 1, PP. 29-43.
Egbu, C.O. (2004), "Managing knowledge and intellectual capital for improved organizational innovations in the construction industry: An examination of critical success factors", *Engineering, Construction and Architectural Management,* Vol. 11 No. 5, PP. 301-315.
Ei-Diraby, T.A., Lima, C., Feis, B. (2005), "Domain taxonomy for construction concepts: Toward a formal ontology for construction knowledge", *Journal of Computing in Civil Engineering,* Vol. 19 No. 4, PP. 394-406.
Ekambaram, A., Langlo, J.A., Johansen, A. (2010), "Knowledge transfer - a study on construction projects in a Norwegian public sector organisation", Proceedings of the European Conference on Knowledge Management, ECKM, Famalicao, PP. 345-353.
El-Diraby, T.E., Kashif, K.F. (2005), "Distributed ontology architecture for knowledge management in highway construction", *Journal of Construction Engineering and Management,* Vol. 131 No. 5, PP. 591-603.
El-Diraby, T.E., Wang, B. (2005), "Society portal: Integrating Urban highway construction projects into the Knowledge City", *Journal of Construction Engineering and Management,* Vol. 131 No. 11, PP. 1196-1211.
El-Gohary, N.M., El-Diraby, T.E. (2010), "Dynamic knowledge-based process integration portal for collaborative construction", *Journal of Construction Engineering and Management,* Vol. 136 No. 3, PP. 316-328.
El Ghazali, Y., Lefebvre, E., Lefebvre, L.A. (2012), "The potential of RFID as an enabler of knowledge management and collaboration for the procurement cycle in the construction industry", *Journal of Technology Management and Innovation,* Vol. 7 No. 4, PP. 81-102.
Falagas, M.E., Pitsouni, E.I., Malietzis, G.A., Pappas, G. (2008), "Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses", *FASEB Journal,* Vol. 22 No. 2, PP. 338-342.
Fang, J., Le, Y. (2012), "Organizational culture and knowledge sharing in construction project organization: A review", *Advances in Information Sciences and Service Sciences,* Vol. 4 No. 19, PP. 122-131.
Fargnoli, M., De Minicis, M., Di Gravio, G. (2011), "Knowledge management integration in Occupational Health and Safety systems in the construction industry", *International Journal of Product Development,* Vol. 14 No. 1-4, PP. 165-185.
Fong, P.S.W., Choi, S.K.Y. (2009), "The processes of knowledge management in professional services firms in the construction industry: A critical assessment of both theory and practice", *Journal of Knowledge Management,* Vol. 13 No. 2, PP. 110-126.
Fu, W.K., Lo, H.P., Drew, D.S. (2006), "Collective learning, collective knowledge and learning networks in construction", *Construction Management and Economics,* Vol. 24 No. 10, PP. 1019-1028.

Gao, Z., Ji, X., Guo, H. (2011), *An ontology-based design knowledge model for the construction machinery*, Key Engineering Materials, pp. 271-276.
Goh, B.H. (2006), "Creating intelligent enterprises in the Singapore construction industry to support a knowledge economy", *Building and Environment,* Vol. 41 No. 3, PP. 367-379.
Gressgård, L.J., Hansen, K. (2014), "Knowledge exchange and learning from failures in distributed environments: The role of contractor relationship management and work characteristics", *Reliability Engineering and System Safety,* Vol. 133 No., PP. 167-175.
Grubbauer, M. (2015), "Circulating knowledge, marketization and norm-making: International developers and construction firms in Eastern Europe since 2000", *Global Networks,* Vol. 15 No. 3, PP. 288-306.
Guang-dong, W. (2013), "Joint investment decision on knowledge cooperation innovation for construction supply Chain", *International Journal of Applied Mathematics and Statistics,* Vol. 44 No. 14, PP. 88-95.
Hari, S., Egbu, C., Kumar, B. (2005), "A knowledge capture awareness tool: An empirical study on small and medium enterprises in the construction industry", *Engineering, Construction and Architectural Management,* Vol. 12 No. 6, PP. 533-567.
Ho, S.P., Tserng, H.P., Jan, S.H. (2013), "Enhancing knowledge sharing management using BIM technology in construction", *The Scientific World Journal,* Vol. 2013 No.
Horton, F.W. (1979), *Information resources management: concept and cases*. Association for Systems Management Press, Ohio.
Hwang, B.G., Ng, W.J. (2013), "Project management knowledge and skills for green construction: Overcoming challenges", *International Journal of Project Management,* Vol. 31 No. 2, PP. 272-284.
Idris, K.M., Nita, A.K., Godwin, A.U. (2015), "Impact of organizational culture on knowledge management process in construction", *Asian Social Science,* Vol. 11 No. 9, PP. 281-288.
Javernick-Will, A. (2012), "Motivating knowledge sharing in engineering and construction organizations: Power of social motivations", *Journal of Management in Engineering,* Vol. 28 No. 2, PP. 193-202.
Kaetzel, L.J., Clifton, J.R. (1995), "Expert/knowledge based systems for materials in the construction industry: State-of-the-art report", *Materials and Structures,* Vol. 28 No. 3, PP. 160-174.
Kale, S., Karaman, E.A. (2012), "A diagnostic model for assessing the knowledge management practices of construction firms", *KSCE Journal of Civil Engineering,* Vol. 16 No. 4, PP. 526-537.
Kanapeckiene, L., Kaklauskas, A., Zavadskas, E.K., Seniut, M. (2010), "Integrated knowledge management model and system for construction projects", *Engineering Applications of Artificial Intelligence,* Vol. 23 No. 7, PP. 1200-1215.
Kazi, A.S. (2005), "Knowledge management in the construction industry: A socio-technical perspective", *Information Management,* Vol. 18 No. 1-2, PP. 21-22.
Ke, Y., Wang, S., Chan, A.P.C., Cheung, E. (2009), "Research trend of public-private partnership in construction journals", *Journal of Construction Engineering and Management,* Vol. 135 No. 10, PP. 1076-1086.
Khalifa, Z.A., Jamaluddin, Y. (2012), "Key success factors affecting knowledge management implementation in construction industry in Libya", *Australian Journal of Basic and Applied Sciences,* Vol. 6 No. 5, PP. 161-164.
Kim, S.B. (2014), "Quantitative evaluation on organizational knowledge implementation in the construction industry", *KSCE Journal of Civil Engineering,* Vol. 18 No. 1, PP. 37-46.
Kivrak, S., Arslan, G., Dikmen, I., Birgonul, M.T. (2008), "Capturing knowledge in construction projects: Knowledge platform for contractors", *Journal of Management in Engineering,* Vol. 24 No. 2, PP. 87-95.
Kivrak, S., Arslan, G., Tuncan, M., Birgonul, M.T. (2014), "Impact of national culture on knowledge sharing in international construction projects", *Canadian Journal of Civil Engineering,* Vol. 41 No. 7, PP. 642-649.

Kocaturk, T. (2010), "A web-based teaching/learning environment to support collaborative knowledge construction in design", *Electronic Journal of Information Technology in Construction,* Vol. 15 No., PP. 271-290.
Kuprenas, J.A., Madjidi, F. (1996), "A knowledge based construction contractor proposal evaluation system", *Computing in Civil Engineering (New York),* Vol. 10 No. 4, PP. 247-253.
Le, Q.T., Lee, D.Y., Park, C.S. (2014), "A social network system for sharing construction safety and health knowledge", *Automation in Construction,* Vol. 46 No., PP. 30-37.
Lee, J., Jeong, Y. (2012), "User-centric knowledge representations based on ontology for AEC design collaboration", *CAD Computer Aided Design,* Vol. 44 No. 8, PP. 735-748.
Li, R.Y.M., Poon, S.W. (2009), "Future motivation in construction safety knowledge sharing by means of information technology in Hong Kong", *Journal of Applied Economic Sciences,* Vol. 4 No. 3, PP. 457-472.
Li, R.Y.M., Poon, S.W. (2011), "USing web 2.0 to share knowledge of construction safety: The fable of economic animals", *Economic Affairs,* Vol. 31 No. 1, PP. 73-79.
Lin, L.K., Chang, C.C., Lin, Y.C. (2011), "Structure development and performance evaluation of construction knowledge management system", *Journal of Civil Engineering and Management,* Vol. 17 No. 2, PP. 184-196.
Lin, Y.C. (2014), "Construction 3D BIM-based knowledge management system: A case study", *Journal of Civil Engineering and Management,* Vol. 20 No. 2, PP. 186-200.
Lu, S.L., Sexton, M. (2006), "Innovation in small construction knowledge-intensive professional service firms: A case study of an architectural practice", *Construction Management and Economics,* Vol. 24 No. 12, PP. 1269-1282.
Ma, Z., Qi, L., Wang, K. (2008), "Knowledge sharing in Chinese construction project teams and its affecting factors: An empirical study", *Chinese Management Studies,* Vol. 2 No. 2, PP. 97-108.
McRea, A., Langdon, D. (2003), "Knowledge management in construction", *Structural Engineer,* Vol. 81 No. 13, PP. 14.
Mohamed, A.N. (2001), "Knowledge based approach for productivity adjusted construction schedule", *Expert Systems with Applications,* Vol. 21 No. 2, PP. 87-97.
Moore, S., Rydin, Y. (2008), "Promoting sustainable construction: European and British networks at the knowledge-policy interface", *Journal of Environmental Policy and Planning,* Vol. 10 No. 3, PP. 233-254.
Mosa, A.M., Rahmat, R.A.O.K., Taha, M.R., Ismail, A. (2011), "A knowledge base system to control construction problems in rigid highway pavements", *Australian Journal of Basic and Applied Sciences,* Vol. 5 No. 6, PP. 1126-1136.
Nakajima, M. (1998), "Knowledge-based generation of the activity process in wooden construction systems", *Computer-Aided Civil and Infrastructure Engineering,* Vol. 13 No. 3, PP. 163-177.
Neff, G., Fiore-Silfvast, B., Dossick, C.S. (2010), "A case study of the failure of digital communication to cross knowledge boundaries in virtual construction", *Information Communication and Society,* Vol. 13 No. 4, PP. 556-573.
Nonaka, I. (1991), "The knowledge creating company", *harvard Business Review,* Vol. 69 No. 6, PP. 96-104.
Nonaka, I., Takeuchi, H. (1995), *The knowledge creating company*. Oxford University Press, Oxford, U.K.
Ofori, G. (2003), "Preparing Singapore's construction industry for the knowledge-based economy: Practices, procedures and performance", *Construction Management and Economics,* Vol. 21 No. 2, PP. 113-125.
Olomolaiye, A., Egbu, C. (2005), "Trust and knowledge management in the construction industry", 6th European Conference on Knowledge Management, ECKM 2005, Limerick, Ireland, Academic Conferences Ltd, PP. 375-382.

Palaneeswaran, E., Kumaraswamy, M.M. (2003), "Knowledge mining of information sources for research in construction management", *Journal of Construction Engineering and Management,* Vol. 129 No. 2, PP. 182-191.
Pan, N.F., Hadipriono, F.C., Whitlatch, E. (2005), "A fuzzy reasoning knowledge-based system for assessing rain impact in highway construction scheduling: Part 2. Development and validation of the system", *Journal of Intelligent and Fuzzy Systems,* Vol. 16 No. 3, PP. 169-179.
Park, M., Jang, Y., Lee, H.S., Ahn, C., Yoon, Y.S. (2013), "Application of knowledge management technologies in Korean small and medium-sized construction companies", *KSCE Journal of Civil Engineering,* Vol. 17 No. 1, PP. 22-32.
Park, M., Lee, H.S., Kwon, S. (2010), "Construction knowledge evaluation using expert index", *Journal of Civil Engineering and Management,* Vol. 16 No. 3, PP. 401-411.
Pathirage, C.P., Amaratunga, D.G., Haigh, R.P. (2007), "Tacit knowledge and organisational performance: Construction industry perspective", *Journal of Knowledge Management,* Vol. 11 No. 1, PP. 115-126.
Pietrosemoli, L., Rodríguez Monroy, C. (2013), "The impact of sustainable construction and knowledge management on sustainability goals. A review of the Venezuelan renewable energy sector", *Renewable and Sustainable Energy Reviews,* Vol. 27 No., PP. 683-691.
Ping Tserng, H., Yin, S.Y.L., Lee, M.H. (2010), "The use of knowledge map model in construction industry", *Journal of Civil Engineering and Management,* Vol. 16 No. 3, PP. 332-344.
Rezgui, Y. (2001), "Review of information and the state of the art of knowledge management practices in the construction industry", *Knowledge Engineering Review,* Vol. 16 No. 3, PP. 241-254.
Rezgui, Y., Hopfe, C.J., Vorakulpipat, C. (2010), "Generations of knowledge management in the architecture, engineering and construction industry: An evolutionary perspective", *Advanced Engineering Informatics,* Vol. 24 No. 2, PP. 219-228.
Rogers, D.M.A. (1987), "Opening remarks - roundtable on critical issues: "Management of Knowledge Assets into the 21st Century"", *Journal of Technology Transfer,* Vol. 11 No. 2, PP. 75-79.
Ruan, X., Ochieng, E.G., Price, A.D.F., Egbu, C.O. (2012), "Knowledge integration process in construction projects: a social network analysis approach to compare competitive and collaborative working", *Construction Management and Economics,* Vol. 30 No. 1, PP. 5-19.
Sauce, G., Mommessin, M. (1995), "Knowledge-based system for construction-site organization", *Microcomputers in civil engineering,* Vol. 10 No. 3, PP. 187-197.
Senaratne, S., Sexton, M. (2008), "Managing construction project change: A knowledge management perspective", *Construction Management and Economics,* Vol. 26 No. 12, PP. 1303-1311.
Senaratne, S., Sexton, M. (2009), "Role of knowledge in managing construction project change", *Engineering, Construction and Architectural Management,* Vol. 16 No. 2, PP. 186-200.
Shaked, O., Warszawski, A. (1995), "Knowledge-based system for construction planning of high-rise buildings", *Journal of Construction Engineering and Management,* Vol. 121 No. 2, PP. 172-182.
Shalomygin, M.V., Osadchiy, E.P., Babiak, A.A. (1999), "On a method for construction of knowledge bases for expert monitoring systems for technical facilities", *Engineering Simulation,* Vol. 17 No. 1, PP. 127-132.
Shi, W., Wu, G.D. (2013), "Dynamic decision model for knowledge collaborative cooperation in construction supply Chain", *Metalurgia International,* Vol. 18 No. 11, PP. 39-43.
Simões, D., Soares, A.L. (2006), *The socio-technical design of a SME knowledge community in the construction industry*, IFIP International Federation for Information Processing, pp. 361-370.
Soibelman, L., Kim, H. (2002), "Data preparation process for construction knowledge generation through knowledge discovery in databases", *Journal of Computing in Civil Engineering,* Vol. 16 No. 1, PP. 39-48.
Styhre, A. (2009), "Tacit knowledge in rock construction work: A study and a critique of the use of the term", *Construction Management and Economics,* Vol. 27 No. 10, PP. 995-1003.
Sveiby, K.E. (1988), *Managing knowhow*. Trafalgar Square, London.

Svetel, I., Pejanović, M. (2010), "The role of the semantic web for knowledge management in the construction industry", *Informatica (Ljubljana),* Vol. 34 No. 3, PP. 331-336.
Tah, J.H.M., Carr, V. (2001a), "Knowledge-based approach to construction project risk management", *Journal of Computing in Civil Engineering,* Vol. 15 No. 3, PP. 170-177.
Tah, J.H.M., Carr, V. (2001b), "Towards a framework for project risk knowledge management in the construction supply chain", *Advances in Engineering Software,* Vol. 32 No. 10-11, PP. 835-846.
Taha, M.A., Park, S.C., Russell, J.S. (1995), "Knowledge-based DSS for construction contractor prescreening", *European Journal of Operational Research,* Vol. 84 No. 1, PP. 35-46.
Tan, H.C., Carrillo, P., Anumba, C., Kamara, J.M., Bouchlaghem, D., Udeaja, C. (2006), "Live capture and reuse of project knowledge in construction organisations", *Knowledge Management Research and Practice,* Vol. 4 No. 2, PP. 149-161.
Tan, H.C., Carrillo, P.M., Anumba, C.J. (2012), "Case study of knowledge management implementation in a medium-sized construction sector firm", *Journal of Management in Engineering,* Vol. 28 No. 3, PP. 338-347.
Teerajetgul, W., Chareonngam, C. (2008), "Tacit knowledge utilization in Thai construction projects", *Journal of Knowledge Management,* Vol. 12 No. 1, PP. 164-174.
Teerajetgul, W., Chareonngam, C., Wethyavivorn, P. (2009), "Key knowledge factors in Thai construction practice", *International Journal of Project Management,* Vol. 27 No. 8, PP. 833-839.
Tombesi, P. (2006), "Good thinking and poor value: On the socialization of knowledge in construction", *Building Research and Information,* Vol. 34 No. 3, PP. 272-286.
Udeaja, C.E., Kamara, J.M., Carrillo, P.M., Anumba, C.J., Bouchlaghem, N., Tan, H.C. (2008), "A web-based prototype for live capture and reuse of construction project knowledge", *Automation in Construction,* Vol. 17 No. 7, PP. 839-851.
Ugwu, O.O., Kumaraswamy, M., Ng, T., Lee, P.K.K. (2003), "Agent-based collaborative working in construction: understanding and modelling design knowledge, construction management practice and activities for process automation", *HKIE Transactions Hong Kong Institution of Engineers,* Vol. 10 No. 4, PP. 81-87.
Venkateswaran, V., Aundhe, S. (2013), "Managing knowledge in a construction company-A process model", *Knowledge and Process Management,* Vol. 20 No. 2, PP. 59-70.
Wang, C.H., Tsai, C.H., Cheng, Y.Y. (2007), "Knowledge-based diagnosis model for PCM executing problems in public construction", *Construction Management and Economics,* Vol. 25 No. 2, PP. 129-142.
Wynn, M., Jones, P., Roberts, C., Little, E. (2008), "Innovation in the construction and property management industries: Case studies of the knowledge transfer partnership scheme", *Property Management,* Vol. 26 No. 1, PP. 66-78.
Yi, H., Yang, J. (2014), "Research trends of post disaster reconstruction: The past and the future", *Habitat International,* Vol. 42 No., PP. 21-29.
Yildiz, A.E., Dikmen, I., Birgonul, M.T., Ercoskun, K., Alten, S. (2014), "A knowledge-based risk mapping tool for cost estimation of international construction projects", *Automation in Construction,* Vol. 43 No., PP. 144-155.
Yin, S.Y.L., Tserng, H.P., Tsai, M.D. (2008), "A model of integrating the cycle of construction knowledge flows: Lessons learned in Taiwan", *Automation in Construction,* Vol. 17 No. 5, PP. 536-549.
Yu, W.D., Skibniewski, M.J. (1999), "A neuro-fuzzy computational approach to constructability knowledge acquisition for construction technology evaluation", *Automation in Construction,* Vol. 8 No. 5, PP. 539-552.
Yu, W.D., Skibniewski, M.J. (2010), "Integrating neurofuzzy system with conceptual cost estimation to discover cost-related knowledge from residential construction projects", *Journal of Computing in Civil Engineering,* Vol. 24 No. 1, PP. 35-44.
Yun, G., Shin, D., Kim, H., Lee, S. (2011), "Knowledge-mapping model for construction project organizations", *Journal of Knowledge Management,* Vol. 15 No. 3, PP. 528-548.

Zhang, P., Ng, F.F. (2012a), "Analysis of knowledge sharing behaviour in construction teams in Hong Kong", *Construction Management and Economics,* Vol. 30 No. 7, PP. 557-574.
Zhang, P., Ng, F.F. (2012b), "Attitude toward knowledge sharing in construction teams", *Industrial Management and Data Systems,* Vol. 112 No. 9, PP. 1326-1347.
Zhang, P., Ng, F.F. (2013), "Explaining knowledge-sharing intention in construction teams in Hong Kong", *Journal of Construction Engineering and Management,* Vol. 139 No. 3, PP. 280-293.