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# Enhancing Knowledge Management for Engineers Using Mind Mapping in Construction

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## 1. Introduction

Knowledge management (KM) is the collection of processes governing the creation, storage, reuse, maintenance, dissemination and reuse of knowledge. KM refers to the collection of processes controlling the creation, storage and usage of experience in a particular situation or problem solving context. To transfer knowledge between experienced engineers, construction professionals have traditionally used techniques ranging from formal annual meetings to face-to-face interviews. Construction KM focuses on the acquisition and management of important issues and experience from participating engineers.

To enhance the quality of KM gained by engineers involved in construction projects, this study proposes a knowledge flow approach integrated with mind mapping to achieving KM solutions in the construction industry. Combined with web-based technology and mind mapping, this study proposes a Construction Web Topic-based Knowledge Management (CWTKM) system enabling engineers to reuse domain knowledge and experience by dynamically exchanging and managing knowledge during the construction phase of a project. In the proposed CWTKM system, the topic-based experience exchange environment in the mind map enables engineers to illustrate and share their experience with other engineers effectively. Engineers are, thus, invited to exchange and share their knowledge based on their previous experience.

By integrating web-based technology and mind mapping, engineers can obtain problem solutions and experience directly from senior engineers, decreasing the time and reducing the cost of on-the-job training. By exchanging and sharing previous experiences among engineers, similar and related experiences used to execute similar projects can clarify domain knowledge and enable the exchange of knowledge through web KM. The CWTKM system provides a web-based platform for users who can request assistance from selected or all engineers in the enterprise who have relevant experience. The user can also submit knowledge description using mind mapping in CWTKM system. Moreover, senior and junior engineers can effectively and easily exchange knowledge and experience regarding a specific aspect of their current construction project. In this study of a Taiwan construction building project, the survey (questionnaire) results indicated that the CWTKM system, integrated with mind mapping approach is effective for construction knowledge exchange and management.

## 2. Problem statement

When completing projects, these engineers and experts typically accumulate domain knowledge and valued knowledge, but share little or no knowledge with others. In view of KM, these significant issues and experiences of construction engineers and experts are particularly valuable due to associated factors such as manpower, significant cost and time. The complicated nature of the construction industry makes it an important field for KM, particularly regarding knowledge gained from experienced engineers. Sharing knowledge between engineers can improve construction management during the construction phases of projects, thus helping avoid mistakes that past projects have already encountered. Transferring construction knowledge between projects can significantly contribute to achieving project objectives such as cost, schedule, quality and safety (Reuss and Tatum, 1993). Learning from experience, also, avoids problem-solving from scratch, i.e., problems that have already been solved need not be solved repeatedly. However, no effective platforms are available to assist engineers or experts in exchanging and sharing their know-how and experiences when contractors execute construction projects. The inability to share the knowledge of engineers and experts represents a major loss for contractors in the construction industry.

The primary problems derived from the questionnaire survey of twenty junior and senior engineers from five participating construction building projects, in the sharing and exchanging of knowledge, specifically during the construction phase of projects, are as follows: (1) difficulty in determining which engineers and experts have helpful and relevant knowledge; (2) limited efficiency and quality when using only document-based media for knowledge management; (3) difficulty in finding engineers with relevant knowledge in similar projects; and (4) unease with illustrating knowledge in current commercial information management systems. Documenting and applying knowledge may avoid problem-solving from the outset, i.e., problems already solved need not be solved repeatedly. However, few suitable design platforms have been developed to assist engineers in illustrating and sharing their knowledge when needed. Although enterprises in the A/E/C industry have begun to collect and store explicit information in KM databases, they have not always been successful at retrieving and sharing tacit knowledge (Woo et al., 2004). Sharing and using previous tacit knowledge in construction projects is, therefore, the primary and significant challenge of this study.

## 3. Research objectives

This study proposes a novel and practical methodology for capturing and representing the knowledge and project knowledge of engineers by utilizing mind mapping and topic-based maps (TBM) approach. Furthermore, this study develops a construction topic-based Maps Knowledge Management (CWTKM) system for engineers. The CWTKM provides a knowledge exchange and management service in the construction phase of a project for the reuse of domain knowledge and experience (see Fig. 1). Contractors often execute similar projects; accordingly, the problems encountered in like projects can provide a reference for comparable projects in the future. To be competitive, a contractor needs to make innovative use of knowledge, accumulate knowledge through previous projects and apply it in relevant projects. Senior engineers that participate in projects act as knowledge workers; they facilitate the collection and management of knowledge from previous projects.

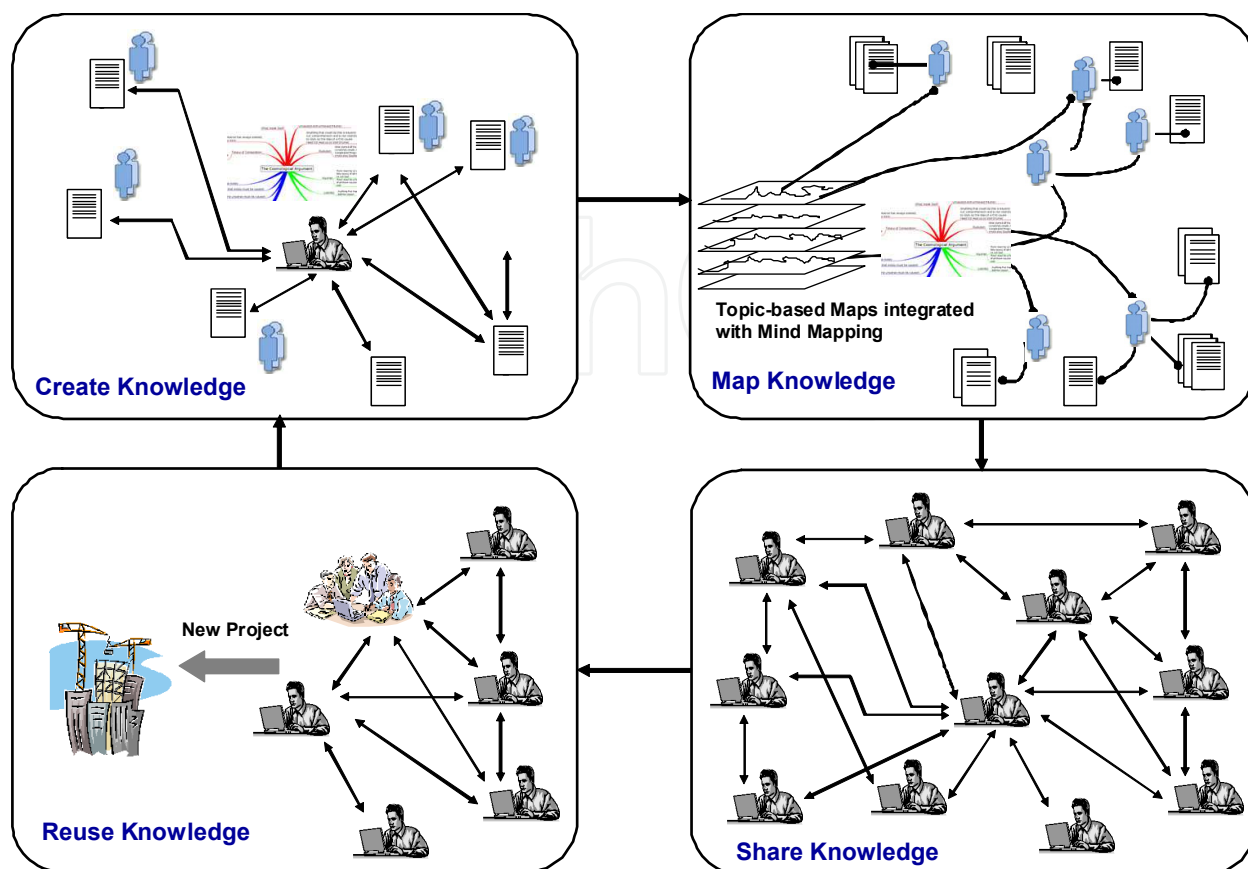


Fig. 1. The application of CWTKM in construction projects.

This study concentrates on new approaches for managing and reusing past specific knowledge for a construction project framework. With the newly proposed TBM approach and integration of mind mapping techniques, service engineers and practitioners can exchange original ideas, experience, knowledge and commands. By integrating TBM and mind mapping techniques, engineers can obtain problem solutions and experience directly from senior engineers, decreasing the time and reducing the cost of on-the-job training. By exchanging and sharing previous knowledge among engineers, similar and related knowledge used to execute similar projects can clarify domain knowledge and enable the exchange of knowledge through web-based KM platform.

To apply KM to new or other construction projects, the process and content of project knowledge must be collected, recorded and stored effectively in the CWTKM system. To assist the participating engineers in illustrating and managing their own project experience, Topic-based mapping is presented to help them explore their acquired experience. . The main objectives of this study are as follows: (1) enhance the illustration capabilities using the TBM approach and mind mapping techniques of captured experience of engineers and experts related to construction projects; (2) optimize the communication of tacit experience among participating engineers in the exchanging environment; and (3) design an efficient topic-based mapping for users to effectively locate parallel experience from relative engineers. The CWTKM system is then applied in selected case studies of a Taiwan construction building project to verify the proposed approach and demonstrate the value of sharing experience in the construction phase.

## 4. Background research

### 4.1 Previous research in knowledge management in the construction industry

In the construction industry, KM is a discipline that promotes an integrated approach to the creation, capture, sharing and reuse of the domain knowledge of a profession obtained from projects that have been previously undertaken. Most project-related problems, solutions, experience and know-how are in the minds of individual engineers and experts during the construction phase of a project. Implicit knowledge is generally undocumented or stored in a system database. To preserve implicit knowledge as corporate property, capturing the implicit knowledge and making it in the form of explicit experience is a vital aspect of KM. Two broad categories of knowledge are tacit knowledge and explicit knowledge. Tacit knowledge is personal, context-specific experience that is difficult to formalize, record or articulate; it is stored in the minds of people (Malhotra, 2000). Tacit knowledge is personal knowledge acquired through individual experience, which is shared and exchanged through direct, face-to-face contact (Malhotra, 2001; Malhotra, 2000; Tiwana, 2000).

Numerous research efforts have focused on applications of knowledge management in construction. A Hong Kong study examined the main barriers to effective knowledge sharing, as well as critical factors and benefits in the construction companies in Hong Kong and the United Kingdom (Fong and Chu, 2006). Intelligent representation structures store and access construction domain knowledge and couple it with advanced planning tools to facilitate rapid formulation and assessment of initial construction project plans (Udaipurwala and Russell, 2002). Fong et al. (2007) pointed out that the knowledge-creating capability of value management teams not only enhances the reputation of value management, but also, helps to dispel the perception of value management as an outdated problem-solving tool.

### 4.2 Previous research on knowledge maps in construction

A knowledge map includes the sources, flows, and points of knowledge within an organization (Liebowitz, 2005). All captured knowledge can be summarized and abstracted through the knowledge map. The knowledge map, also, provides a blueprint for implementing a knowledge management system. Well-developed knowledge maps help users identify intellectual capital, socialize new members and enhance organizational learning (Wexler, 2001). A knowledge map is a consciously designed medium for communication between makers and users of knowledge by a graphical presentation of text, model numbers or symbols (Wexler, 2001). Knowledge mapping helps users understand the relationship between stored knowledge and dynamics. Knowledge maps have been applied in various applications, including development of knowledge maps for knowledge management software tools (Noll et al., 2002). Numerous research efforts have focused on the use of knowledge maps to support various knowledge management tasks (McAleese, 1998). Davenport and Prusak (1998) observed that developing a knowledge map involves locating significant knowledge in an organization and publishing a list or image that indicates a roadmap to locate it. Mind maps (Buzan and Buzan, 1993) illustrate the structure of ideas in an associative manner which attempts to represent how ideas are stored in the brain. A concept map provides a structure for conceptualization by groups developing a concept framework that can be evaluated by others (Trochim, 1989). Dynamic knowledge mapping can assist in the reuse of experts' tacit knowledge (Woo et al., 2004).



## 5. Methodology

Although maps of knowledge representation have been developed for knowledge-based applications, no knowledge map has been developed for knowledge management (KM) in construction. To assist engineers in extracting the knowledge gained from their own experience in projects with which they have been involved, this study proposes a novel topic-based maps (TBM) approach for the application of KM in construction. The TBM help to efficiently illustrate the experiences in the minds of engineers to generate and organize experience within a core topic. The TBM are based on associations flowing outward from a central image in a free-flowing, yet organized, and coherent way. The above content also functions as the experience acquisition tool in the CWTKM system. Furthermore, engineers may access and edit many resources, as attachments, in the system. Hence, the CWTKM system can provide engineers with an experience exchanging environment, as well as a web-based platform for acquiring experience from more experienced engineers.

### 5.1 Concept of topic-based maps

The proposed TBM are specific approaches to KM in the construction field. Although knowledge and concept maps are easily recognized in knowledge management, the proposed TBM approach is a novel concept and is specific to construction KM. TBM can be defined as a diagrammatic and graphic representation of experience linking relationships between knowledge and attributes of MAP. The TBM mainly provide assistance for easily and effectively obtaining the necessary experience of users. The primary advantages of TBM are as follows: (1) TBM are simply, clearly and dynamically represented in the CWTKM system; (2) users can easily navigate the CWTKM in order to: a) understand and determine which engineers and experts own special experience related to a problem as it arises, and b) edit their experience based on what the situation may require; (3) TBM enable users' ability to expand flexible knowledge illustration and linkage; and (4) TBM enhance the available visual knowledge illustration in the maps.

TBM are designed to be easily integrated with mind mapping and their construction experience. The key reason for using TBM is the ease with which the combined experience can be understood and reapplied. Figure 2 illustrates an overview and conceptual framework of TBM utilized in construction KM. Like construction project management, KM is based on the concept of undertaking project planning and control activities. Knowledge and experience gained from activities in previous projects can be collected, managed and applied in future projects. Acquired experience from participating engineers can be accessed and saved as map units in categories for efficient collection, management and finally, retrieval for use in the current projects.

### 5.2 Framework of topic-based maps

Topic-based Maps (TBM) are defined in multiple levels, and constructed from variables which can be broken down by decomposing the knowledge units into smaller map units into which the acquired knowledge is stored. TBM may be comprised of several layers. The project unit is modelled in the first layer. The second-level layers model Map units (drawing illustration). The lower-level layers model knowledge units. Similarly, any map unit in this lower layer can be broken down further to incorporate other components in lower layers. The map contents can be viewed as either a single point or as ranges. The structure of TBM enables users to access stored knowledge through layers based on the

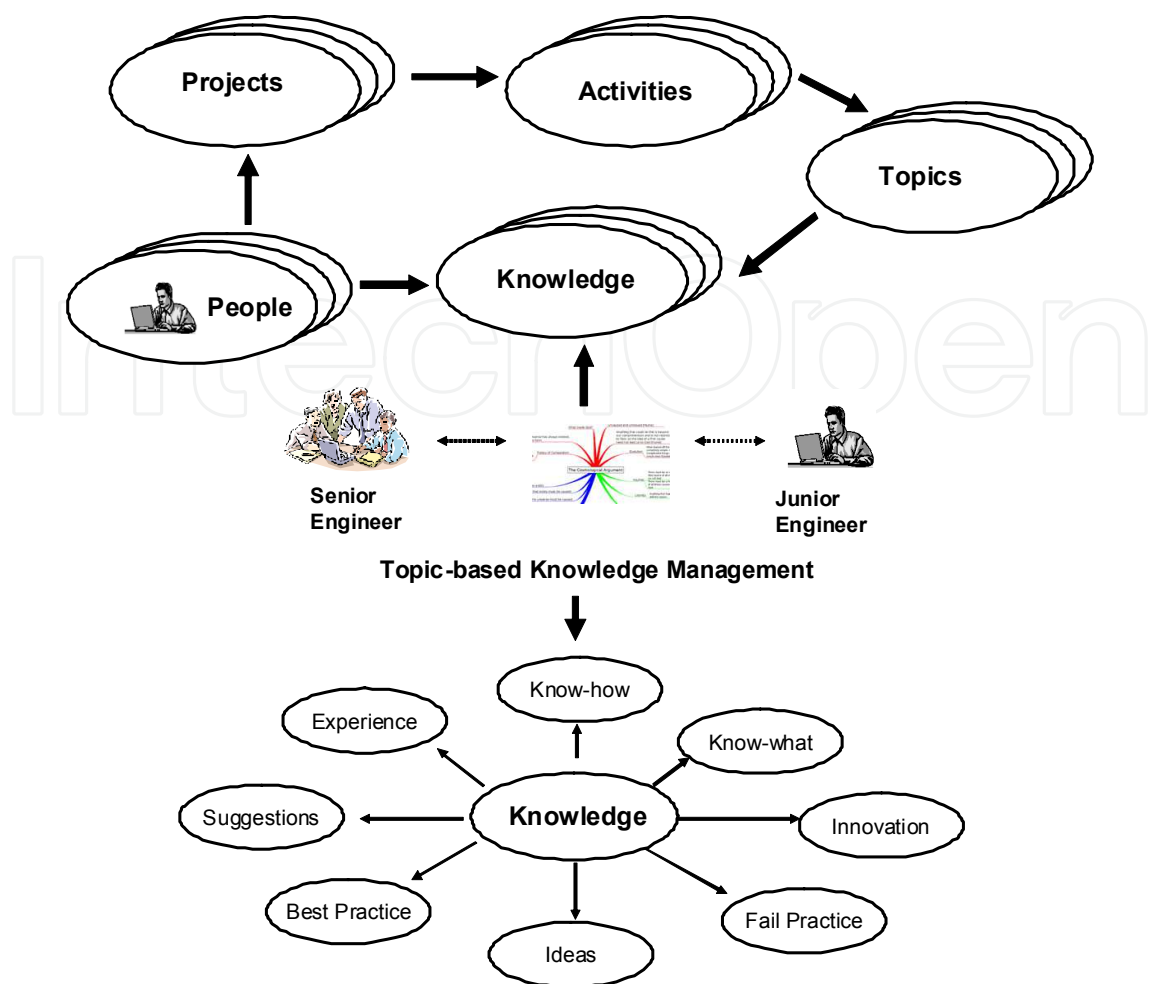


Fig. 2. The application of TBM integrated with mind mapping in knowledge management

attributes and types of acquired knowledge. Knowledge stored in map units of a project map includes both tacit and explicit knowledge. Explicit knowledge may be comprised of an knowledge topic, knowledge description and knowledge attachments (documents, reports, drawing and other explicit sources). Tacit knowledge may include problems-faced descriptions, problems-solved explanations, solution suggestions, and know-how explanations. Additionally, TBM give users an overview of available and unavailable knowledge in core project areas, enabling effective management of tacit and explicit knowledge. Identifying the relationship between main topic and subtopic map units is significant for users to link related knowledge together. The system is naturally designed to automatically or manually link activities which are highly similar. For example, the knowledge of a current project can be utilized, and the same or similar map units contributed by past projects can be accessed while the knowledge of current users is being recorded.

Fig. 3 shows the flowchart of TBM in knowledge management. TBM have components and procedures based on construction project management and, thus, differ from existing knowledge maps. The proposed TBM consist of seven components. These seven components are number of knowledge, knowledge topics, knowledge relationships, knowledge owners, knowledge diagrams, knowledge packages, and knowledge attributes. Procedures are presented for constructing TBM based on a knowledge management

framework. The procedure consists of the following five primary phases: knowledge determination; knowledge extraction; knowledge attribute; knowledge validation; and, knowledge sharing.

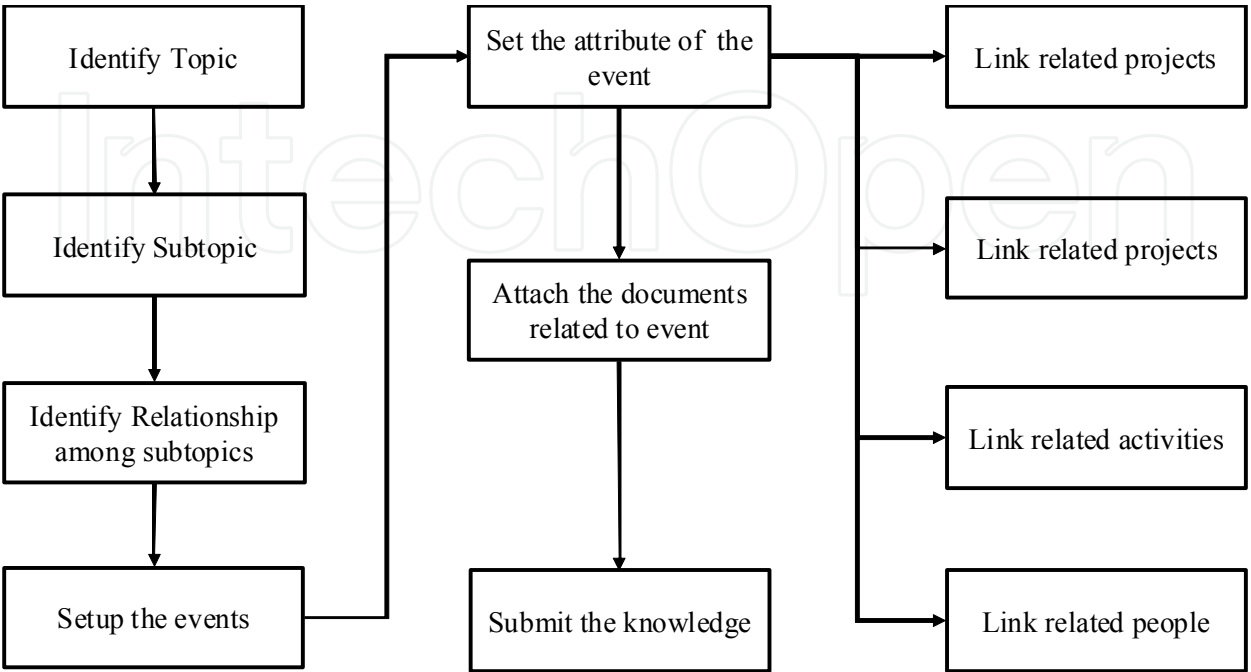


Fig. 3. The Flowchart of TBM in knowledge management

6. System implementation

This section describes the details of the Construction Web Topic-based Maps Knowledge Management (CWTKM) system. The CWTKM system is based on the Microsoft Windows 2003 operating system with Internet Information Server (IIS) as the web server. The prototype is developed using Java Server Pages (JSP), which are easily incorporated with HTML and JavaScript technologies to transform an Internet browser into a user-friendly interface. Software MindManager is used as mind mapping in the study.

Three search functions are supported in the system. The server of the CWTKM system supports four distinct layers: interface, access, application and database layers; each has its own responsibilities. The interface layer defines administrative and end-user interfaces. Users can access information through web browsers such as Microsoft Internet Explorer or FireFox. Administrators can control and manage information via the web browser or by using a separate server interface. The access layer provides system security and restricted access, firewall services and system administration functions. The application layer defines various applications for collecting and managing information. These applications offer indexing, knowledge map edition, digital photo/video management functions, full text search, collaborative work and document management functions. The database layer consists of a primary SQL Server 2003 database and a backup database (also based on SQL Server 2003).

All knowledge information in the CWTKM system is centralized in a system database. Project participants may access some or all of these documents through the Internet according to their levels of access authorization. Any information/experience about the



project can be obtained from and deposited into the system database only through a secure interface. The web and database servers are distributed on different computers, between which a firewall and virus scans can be built to protect the system database against intrusion.

The CWTKM system provides project category search, keyword search and expert category search. The project category and keyword search functions enable users to find the knowledge they need directly from the activities of selected projects. The system, also, provides another function in the expert category for users to find related knowledge according to domain experts. The information held by each domain expert is provided to the users seeking the domain knowledge-related experts. One of the main features of the CWTKM system is enabling users to request assistance in knowledge support and exchange from specific selected engineers or all engineers in the enterprise through the TBM.

## 7. Case study

The following case study involves a contractor with seven years of specific experience in Taiwan high-tech construction projects. The contractor hoped to take full advantage of knowledge management (KM) to obtain the valued experience from participating engineers and effectively manage it for exchange and reuse in other comparable projects. The contractor, therefore, announced that all engineers would be encouraged to use the CWTKM system to apply KM to effectively manage acquired knowledge from participating engineers. The CWTKM system was utilized in the Taiwan construction building project to verify the proposed methodology and demonstrate the effectiveness of sharing previous knowledge in the construction phase. The case study was undertaken in a 11-month construction project with a schedule including approximately 1,450 activities. Moreover, all engineers were encouraged to explore and edit their own experience in the CWTKM system. In the knowledge acquisition phase, senior engineers and knowledge workers undertook most work knowledge acquisition, since tacit knowledge must be acquired directly from the minds of engineers. Further, the tacit knowledge may be transferred into explicit knowledge by senior engineers and knowledge workers themselves. Most tacit knowledge extracted for reuse and storage may be available from the memories of experts and engineers. In a broader view, knowledge extraction may also include capturing knowledge from other sources such as from problem-solution descriptions, suggestions, innovation and collaboration.

In the case study, the senior engineer attempted to edit domain knowledge and experience in the "Contract management among subcontractors" learning lesson. The learning lesson experience in contract problem-facing description among subcontractors, detailed situation description and problem-solution explanations. The knowledge workers and senior engineer initially sketched the main knowledge map based on the original project network-based schedule plan. After the main map was identified, the five experienced senior engineers were invited to edit their experience in the TBM regarding contract problem-facing. Related information/documentation was then collected and converted into a digital format. The attached files included digital documents, video and photo files. After the related attached files were digitized, the senior engineer packaged them as an experience set for submission. The knowledge workers, also, assisted the senior engineers in completing the above digitization work and conferred with them weekly to accelerate the problem solving process. The project activities continued for ten months. All engineers were required

to provide their own knowledge regarding the tasks for which they were responsible. Each engineer created a knowledge map and summarized his experience and domain knowledge in the map to enable the reuse of the solution process for future projects. The knowledge map included: the knowledge topic, knowledge descriptions, knowledge diagram, knowledge attribute, knowledge packages and linkage, the solution to the problem, including related documents, photographs and videos of processes, and expert suggestions, including notes, discussions and meeting records. Knowledge was extracted based on every process defined as it related to the map units of a project. Domain knowledge and knowledge were organized according to the attributes of the map units concerned. When the submitted knowledge set was approved, the system illustrated the process automatically, and an assistant in the KM team attributed the knowledge and classified the knowledge by placing it in an appropriate position (map units in the TBM) in the system. Restated, users can locate and directly access related knowledge simply by clicking on these map units located on the multilevel knowledge maps. In the knowledge storage phase, all knowledge was centralized and stored in the central database to avoid duplicating data. All knowledge can be stored in the system by ensuring that data are all electronic and in a standard format for each file type such as a specific document or drawing format. All knowledge maps must be validated to perform well before the knowledge maps are published. All validation is performed in enterprise KM terms by domain experts, knowledge workers and knowledge map makers. Finally, the knowledge set is automatically backed up from the knowledge database to another database. The system automatically sends a message confirming the update to the appropriate users after approving and storing the experience.

A new project is started after completion of the construction project ten months earlier. A senior engineer encounters two different problems in a new project whose information is unavailable in the CWTKM System. After referring suggestions and assistance from senior engineers, the senior engineer solves the problem and shares the new solution with senior engineers. Finally, the senior engineer creates a new map unit and knowledge package, and submits the obtained suggestion and experience to the map unit of the knowledge map, linked with the related knowledge topics. Moreover, the knowledge is later updated when further feedback and another solution to the same problem are added. The updated knowledge set is republished in the map units of the knowledge map after completing the approval process, and a notice is transmitted to the authorized members.

## 8. Field tests and results

During the field trials, verification and validation tests were performed to evaluate the system. The verification process was proposed to determine whether the system operated as intended while validation was performed to evaluate the system's usefulness. The verification test was conducted by checking whether the CWTKM system could perform tasks specified in the system analysis and design. The validation test involved asking selected case participants to use the system, who then provided feedback via questionnaire. The seventeen respondents included two project managers with 5 years of experience; five senior engineers with 20 years of experience; four engineers with 10 years of experience; four junior engineers with 1 year of test experience; two knowledge workers with 5 years of experience; and one Chief Knowledge Officer (CKO) with 3 years of experience. The CWTKM System was demonstrated to the respondents, who were then requested to express

their opinions of the system via the questionnaire. To evaluate system function and satisfaction with system capabilities, questionnaires were distributed, and the system users were asked to separately rate the conditions of system, system function and system capability, in comparison with the previous system using a five-point Likert scale. A 1, 3 and 5 on the Likert scale corresponded with “not useful”, “moderately useful” and “very useful,” respectively. Table 1 shows system evaluation result. Some comments for future improvements in the CWTKM system were also obtained from the project participants.

| The functionality of system         | Mean Score |
|-------------------------------------|------------|
| Ease of knowledge sharing           | 4.6        |
| Reliability                         | 4.2        |
| Applicable to Construction Industry | 4.1        |

| The use of system      | Mean Score |
|------------------------|------------|
| Ease of Use            | 4.5        |
| User Interface         | 3.9        |
| Over System Usefulness | 4.5        |

| The capability of system                         | Mean Score |
|--|------------|
| Reduce Rework Problems                           | 4.3        |
| Reduce Unnecessary Costs                         | 4.2        |
| Reduce Happening Mistake Percentage              | 4.1        |
| Ease of finding previous experience              | 4.2        |
| Improve Problems Solutions                       | 4.1        |
| Enhance the relationship of knowledge and people | 3.9        |
| Improve Experience Sharing Problems              | 4.5        |

Note: the mean score is calculated from respondents' feedback on fivescale questionnaire: 1(Strongly Disagree), 2, 3, 4 and 5 (Strongly Agree)

Table 1. System Evaluation Result

The integration of mind mapping and TBM technique to share and illustrate available experience significantly enhanced the efficiency of KM processes. Based on the user satisfaction survey, most users agreed that the CWTKM system enables engineers to exchange and share previous experience and knowledge using TBM to express their ideas and thoughts. Furthermore, the TBM provided clear and dynamic representations of experience and effectively identified Map units with experience and knowledge related to the project. The survey revealed a user satisfaction rate of 87 %, indicating that the CWTKM system is useful for assisting engineers in editing their previous knowledge through the

mind mapping and TBM approach to enhance knowledge acquisition and management. The experimental results showed that the CWTKM system significantly enhanced progress in the construction knowledge exchange progress and management. Overall, the use of CWTKM system minimized ineffective experience communication and exchange among engineers.

The significant findings of the case study are summarized as follows: (1) the total number of knowledge units in the system was 317 with 97 knowledge packages during execution of the project; (2) most senior engineers and experts considered recording and editing their experience to be too time consuming; (3) assisting more senior engineers in transferring tacit knowledge can be problematic, because most senior engineers cannot type their knowledge by themselves, and (4) most engineers agreed that the TBM approach and mind mapping are helpful to enabling knowledge sharing and management in construction projects.

## 9. Conclusions

This study proposed a novel and practical methodology for capturing and representing the experience and project knowledge of engineers by utilizing mind mapping and TBM approach. Furthermore, this study developed a Construction Topic-based Map Knowledge Management (CWTKM) system for engineers that provides a concept experience exchange and management service for the reuse of domain knowledge and experience. TBM divide knowledge into map units, thus forming an effective knowledge management tool in construction projects. Effective integration of web technology in CWTKM system has been demonstrated in the case study in the Taiwan construction building project. The CWTKM system enables engineers to exchange and share previous knowledge using TBM to express their ideas and knowledge. Furthermore, the CWTKM system enables users to request knowledge support and to exchange knowledge with selected engineers or all enterprise engineers by submitting problem descriptions through TBM. Novice engineers directly accessing the system can effectively share and exchange knowledge. The integration of the TBM and mind mapping appears to be a promising means of enhancing construction KM during the construction phase of a project. In summary, the CWTKM system can assist engineers in illustrating their ideas clearly and sharing their knowledge. Furthermore, CWTKM system and TBM approach enable users to survey and access effectively the tacit and explicit knowledge of previous engineers and experts in similar projects.

Although further effort is needed to update the explicit/tacit knowledge related to various projects, the proposed system benefits construction knowledge management by (1) providing an effective and efficient web-based environment for exchanging knowledge specifically regarding construction projects; and (2) providing users options by requesting assistance from selected engineers or all engineers in the enterprise who have relevant knowledge by submitting a problem description.

The use of the TBM approach integrated with mind mapping in the study mainly provides assistance to help engineers illustrate their own knowledge easily and effectively. The questionnaire results indicate that the primary advantages of TBM in the system are as follows: (1) the TBM provide clear and dynamic representations, thus identifying the experience and knowledge of engineers relevant to the project, (2) the TBM clearly identify the available engineers or experience to request for experience exchange regarding the special knowledge in the current project and (3) users can locate needed knowledge easily and effectively based on TBM illustration.

During field tests phase, most engineers need to handle the knowledge management progress directly in the jobsite. Therefore, the CWTKM system will be developed for smart phones or Tablet PCs use to enable jobsite engineers edit knowledge and experience directly in the jobsite in the future.

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## **New Research on Knowledge Management Technology**

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Due to the development of mobile and Web 2.0 technology, knowledge transfer, storage and retrieval have become much more rapid. In recent years, there have been more and more new and interesting findings in the research field of knowledge management. This book aims to introduce readers to the recent research topics, it is titled "New Research on Knowledge Management Technology" and includes 13 chapters. In this book, new KM technologies and systems are proposed, the applications and potential of all KM technologies are explored and discussed. It is expected that this book provides relevant information about new research trends in comprehensive and novel knowledge management studies, and that it serves as an important resource for researchers, teachers and students, and for the development of practices in the knowledge management field.

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