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A social network system for sharing construction safety and health knowledge

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ABSTRACT

Construction is one of the largest contributors to national economies and also one of the most accident-prone industries worldwide. Construction site accidents often result in serious injuries or death, cause serious project delays and cost overruns. Prior studies focused on cause and effect relationships of construction accidents, design for construction safety, effectiveness of worker safety programs and government policies. The focus in those studies has been on generation and utilization of safety-related data and information, and not on how to share safety data efficiently among all stakeholders in the construction industry. This paper proposes a Social Network System for Sharing Construction Safety & Health Knowledge (SNSS), which utilizes semantic wiki web and ontology approach for better communication and representation for construction safety information. SNSS was developed on the basis of a safety semantic wiki template (SSWT), which consists of three components: 1) Safety information module (SIM) which uploads common accident and hazard information for sharing; 2) Safety knowledge module (SKM) where the safety information is refined, confirmed and transferred to a repository of safety knowledge; 3) Safety dissemination module (SDM) which allows users to monitor, manage and retrieve safety information and knowledge. SNSS has been tested in a fall accident case study. The study confirms the applicability and benefits of a social network system for enhancing safety communications among all stakeholders of construction projects and organizations behind the construction business.

1. Introduction

Construction is a very intricate and complicated environment that consists of more than twenty trades with different skilled workers involved in construction process. This leads to construction being a high risk industry. The accidents occur repeatedly and inevitably during construction project [4]. In spite of the attention given in the construction site injuries, the incidence rate of industry is reported to be twice comparing with the industrial average [18]. This plague causes many problems related with cost overrun and schedule delay in construction project. Therefore, many studies have been performed to reduce the incident rate, such as construction safety and health monitoring system that integrates internet and database systems for a total automated safety and health management [5], the game technology based visualizing safety assessment for safety and health training [11], and so on. However, according to Fang et al., most of current researchers have been focused on safety training and education as a main channel to improve construction safety rather than to solve the communication problems in sharing and retrieving construction safety information and knowledge [8].

This limitation has required a high demand for online interactive multiuser and information exchange to achieve the sharing and retrieving safety knowledge purpose. The social networking platform allowed its users to connect and communicate with the others, and would help to successfully obtain the construction safety & health sharing purpose. Social network sites are web-based services that allow an individual to construct a profile, articulate a list of other users that they share a connection with, view and traverse their list of connections, exchange information, and communicate with other users within the system [1]. In the construction industry, the integrated classical project management concepts and social network science theory [6] or the use of social network as a strategic tool for managing construction project [14] could greatly improve efficiency of construction project management. Social networking is a potential and powerful tool to engage, motivate user to share, update, and manage information [7], and plays an important role in exchanging resources among partners which have been applied in many diversified areas [10].

This paper proposes a social network system for sharing construction safety & health knowledge (SNSS) that integrates state-of-the-art of information technologies such as semantic wiki and ontology in order to overcome the communicative barrier of safety knowledge sharing. For efficient representation and effective communication of construction safety knowledge, this paper develops three modules in the

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system — information module, knowledge module, and dissemination module — based on safety semantic wiki template (SSWT). The SSWT exploits semantic wiki and construction ontology combination as the platform of SNSS, which provides a convenient and easy environment for construction safety and health information sharing and knowledge exchange. In SSWT, semantic wiki application allows users to add, remove, edit, change content of incident and hazard cases in a cooperative manner without their having any computer science background, while ontology technology plays role as a tool in accident information arrangement and knowledge retrieval. The safety information module (SIM) allows users to upload and gather safety data through the SSWT. In the SIM module, the safety data (dangerous occurrence or hazard & risk) will be transferred to a comprehensive information. The safety information will be conveyed and analyzed in the safety knowledge module (SKM). It is noted that the SKM module will mobilize and utilize domain experts to join in knowledge contribution and refinement phases for achieving the best knowledge. And the whole safety information and knowledge will be manipulated in safety dissemination module (SDM) on a website. It supports users to construct, participate, and explore high-level construction safety and health knowledge easily and conveniently. The proposed SNSS system could be utilized as a beneficial tool for construction safety and health management in the industry.

2. Literature review

2.1. Safety data, information, and knowledge

Before entering more deeply into a discussion about this research, several terminologies, which include construction safety data, information and knowledge need to be understood to make the paper more clear. According to Wikipedia, data are values of qualitative or quantitative variables, belonging to a set of items [24]. Information is a message or collection of messages in an ordered sequence that consists of symbols, or it is the meaning that can be interpreted from such a message or collection of messages, while knowledge is a familiarity with someone or something, which can include information, facts, description, or skills acquired through experience or education [26,27]. Data is the lowest level of abstraction, information is the next level, and finally, knowledge is the highest level among all three. From the point of view of three definitions above, construction safety data in this paper are accident and hazard & risk records or reports while safety information is considered as the description of accident process, which consists of hazard phenomenon, accident result, etc. Construction safety knowledge is acquired by domain experts based on safety information analysis through a social network platform.

2.2. Communication in construction safety & health

The construction industry is considered to be a distinctly unique and highly fragmented environment where lack of safety knowledge is a critical reason for high accident rate causing cost and time overruns [22]. The effective safety knowledge and information exchange is becoming more important to reduce dangerous occurrence of accidents as well as hazards and risk in the construction industry [13]. However, it is difficult to solve this problem due to nonstandard knowledge, and vague, ambiguous, and inconsistent safety standard and regulation [8] or the subjective nature and ad-hoc nature of construction knowledge [29]. In other words, the lack of construction safety information exchange and knowledge sharing is a main reason that causes on-site accidents and thus low construction productivity. So, in order to achieve better safety performance, an enhanced safety and health communication system is necessary to identify and analyze safety hazards and risk, incident information, and to develop proactive accident prevention method in construction process.

2.3. Semantic wiki website

Unlike some content management system, semantic wiki websites offer sharable environment that allows visitors to easily add, remove, edit, and change available content in a collaborative manner without using any complex commands or learning programming language [15]. West and West have found in their review that wiki could support the dynamic online communication where wiki customers could write, discuss, comment, edit and evaluate information [23]. Furthermore, the wiki system is used for many different purposes such as database for research and writing, information management, collaborative tool for documents needed to update frequently due to the free expandable collection of interlink web pages or storing and modifying information functions [20]. Buffa et al. proposed a system, called Sweet Wiki that combines general wiki advantages and semantic web technology [3]. The Sweet Wiki not only formalizes and reuses information based on semantic searching and navigation but also supports knowledge relationships between searching keywords and the results through semantic tagging. Obviously, semantic wiki technique would be an excellent tool in information sharing and knowledge exchange.

2.4. Ontology application

An ontology is a representation model which defines concepts, attributes, and relations with explicit specifications that could solve the problems of ambiguity in knowledge sharing and reuse [19]. According to Rezgui, ontology plays a critical role in proposing knowledge environment and providing a semantic reference to ensure relevance, accuracy, and complete information [17]. Lima et al. suggested e-COGNOS that applied ontology as the main feature of the platform providing a formal representation of knowledge domain with an effective means [12]. Reusable ontology is more important for information integration, knowledge-level interoperation, and knowledge base development [9]. Tudorache and Noy developed Protégé system as an open-source platform that provides a growing user community with a suite of tools to construct domain system and knowledge based applications with ontologies [21]. The Protégé system enables users not only to establish and populate hierarchical ontologies but also to build a new ontology class. In summary, ontology is a potential and powerful technology to facilitate knowledge sharing, reusing and also knowledge acquisition.

2.5. Need for an integration semantic wiki and ontology with social network

The social network provides the conduit for users to engagingly share their knowledge and experiences on their term, and communicate with others. However, social network seems chaotic due to no predefined index, no knowledge managers, and no structure. This causes some problems related with data repository and knowledge management. Previous literature review indicates that semantic wiki and ontology can potentially play a key role to facilitate a hierarchical view of information and knowledge management. Therefore, the integration of semantic wiki and ontology with social network would bring a powerful and strong tool in sharing, retrieving and reusing information as well as managing knowledge. To do this, the next section will propose a social network system which utilizes state-of-the-art semantic wiki and ontology for better communication and representation for construction safety information & knowledge.

3. Social network system for sharing construction safety & health knowledge

The main purpose of developing a social network system is to enhance information sharing and knowledge exchange through social communication. The key benefit of social network system does not require the authority expert as an intermediary, so it allows users to

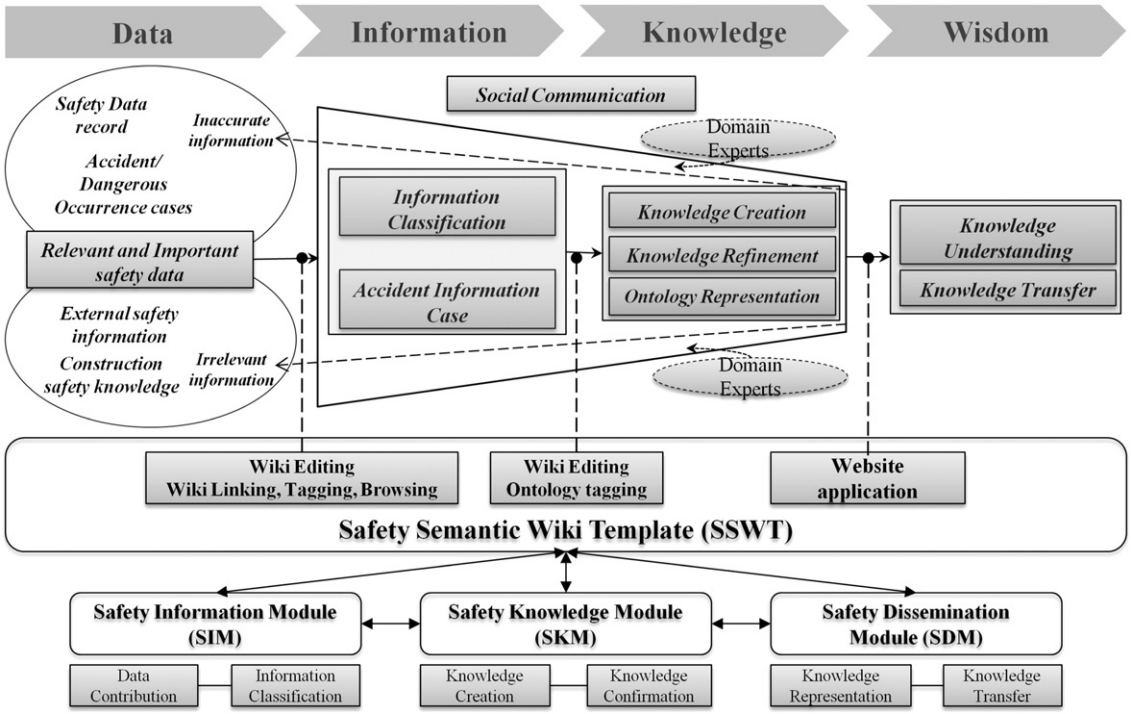

Fig. 1. The disintermediation process of SNSS.

have a more direct access to data and information. As illustrated in Fig. 1, the disintermediation process properties of SNSS mobilize and utilize expert domains to take over the role of the intermediary and to help users attain accurate safety information and knowledge. The SNSS is a broker between user and information, which enables the individual to play an active role in perception rather than just passively receiving impression from surroundings. Through this disintermediation process, the safety data are transferred to information using wiki editing, tagging, browsing, and linking, and the safety information is changed to the safety knowledge using ontology tagging and wiki editing. Then the safety knowledge will be available in the website for the use of specific safety knowledge.

Unlike some knowledge management systems, the SNSS is structured under a semantic wiki system as a bridge to link the following three modules: safety information module (SIM), safety knowledge module (SKM), and safety dissemination module (SDM), as illustrated in Fig. 1. The safety semantic wiki template (SSWT) is a backbone of the SNSS that is designed to support a flexible environment for information collection, knowledge creation and dissemination on construction safety. The SIM would convey relevant and important accident data to safety information by using the wiki techniques of SSWT. By utilizing social experts, the SKM refines the comments on safe information for safety knowledge achievement and ontology representation. The SDM where safety knowledge would present on the web-based as social website shares and disseminates safety information and knowledge. The SSNS system would offer a user-friendly approach to those involved in creating a good sharing and communication environment that help users find the right safety knowledge at the right time.

3.1. SNSS technique definition

Before describing deeply about the SNSS system, some key functions that were incorporated in the SSNS framework would be specified:

1. Tagging–linking–browsing: This is the common technique that has been applied in social network web 2.0 to enhance the annotation of information [2]. In the SNSS, this technique allows users to place tags, link to published information, and browse their own data on the SNSS's database and user profile. Furthermore, users could be able to select tags from safety ontology library of SNSS to classify the safety information and knowledge. Going beyond that, social tagging–linking–browsing is used for information discovery, sharing, and navigation as well as information extraction.
2. Commenting: This approach allows users to share their opinions and experiences about the accident information, hazard causes and prevention method by writing comments on the SNSS without their having any computer science background. The peer review in commenting function would enrich the SNSS contents. It is noted that users could incorporate social tagging–linking–browsing in commenting function to annotate their comments.
3. Editing: Users can add supplementary ideas or correct errors in original safety information by using editing function. The editing process often begins with the author's idea for the work itself, continuing as a collaboration between the author and the editor as the work is created [25]. As such, the editing function would mobilize and utilize social experts to collaboratively work together that can improve SNSS's safety database both of quantity and quality.
4. Voting: This technique allows users to rate the comments on accident cases to refine safety information by using like, dislike, or neutral functions in SNSS. Through the peer rating, users are able to agree or disagree with other users' comments or ontology tagging not only to reject the wrong safety information but also confirm the good safety knowledge. Voting process in SNSS would help to achieve the best safety knowledge to deliver to users.
5. Grouping: Similar to general social network sites, this approach via users' profile can gather users that had same interest, major, job, etc., into groups. It allows users to manage and monitor the safety information and knowledge following their needs easily. Furthermore, users are able to connect with their friends or make new friends conveniently that create the good environment for safety knowledge sharing and exchange.

3.2. Safety semantic wiki template

The safety semantic wiki template (SSWT) is designed under the collaboration between semantic wiki web and construction safety

ontology technologies to allow visitors to share safety information and knowledge as well as to classify them easily and conveniently without their having any computer background. Firstly, the semantic wiki web provides an elegance and flexible form of safety knowledge, which users can add, comment, remove, and edit its content via web browser. The SSWT pages are directly edited by all users, and allow them to create new topic pages as required. Similar to Wikipedia, the SSWT page creates a knowledge network through tagging, linking, and browsing. Secondly, the safety ontology provides the safety classification framework that presents the correlation of safety information and their corresponding significance. The ontology applied in the SSWT constructs conceptual maps of safety information based on Protégé [21] in order to provide an effective safety catalog for reference to users as they perform information search and contribution. Fig. 2 delineates the safety catalog ontology that is connected with a comprehensive SSWT. The functions of sharing and reusing of ontology enable users to search, identify and manage text safety information easily and accurately. With taken advantages of semantic wiki and ontology, the SSWT provides open safety platform for its users to contribute, share, evaluate, and synthesize their safety knowledge. Furthermore, the SSWT supports safety knowledge management in terms of knowledge accessing and extraction.

As noticed in Fig. 3, there are two main sections which are information and knowledge of construction safety in the SSWT. Firstly, in the section of construction safety information, the visitor will contribute to upload cases of accident, unsafe situation or hazard by describing as to what kind of hazard, how the accident happened, and so on. Similar to other social network pages, they can use dynamic editing and semantic resources by tagging in order to create better description of unsafe phenomenon. Secondly, domain experts take part in analyzing the uploaded accident information to suggest accident causes and prevention methods in the construction knowledge section. It is noted that this knowledge section of SSWT would support three main functions of bringing the best result: 1) Discussion forum where experts can easily and collaboratively insert their expertise to analyse accident or dangerous case; 2) safety voting and confirmation for expert evaluation to attain the best knowledge; and 3) ontology representation to categorize construction safety information and knowledge.

3.3. Safety information module

The safety information module (SIM) is the fundamental module of SNSS that is devised for construction engineers/participants to share accident and dangerous occurrence data. The known accident data and its relative information would be input step by step in the SSWT, which include: (1) accident case name and location; (2) specific accident data such as work phase, hazard type and case, spaces, as well as related accident element; (3) file attach to upload visual information such as accident case picture or video for better understanding of accident; (4) description section to depict detailed accident process and also level of damage of accident case; and (5) result section to figure out the real situation after the accident happened (refer to the top portion of Fig. 3). With these collaborative safety data contributions and classification of the SSWT, an active user engaged community can be created. It should be noted that the SSWT, similar to wiki pages, would support functions of editing (B) and semantic tagging–browsing–linking (A) (C) to participants for ambiguous terminology explanation and data supplement without their having any computer science skill (refer to the middle portion of Fig. 3). Through the process of uploading and supplementing data in the SIM, the safety data are transferred into safety information and are ready for information analysis to convert it into safety knowledge.

The top and middle portions of Fig. 3 exemplified the safety information module through a 'Fall off a topping scaffold' real accident case. The general information including (1) accident case: fall to below, (2) work phase: maintenance, (3) work type: roof painting, (4) spaces: third floor, (5) related element: scaffold, and (6) file attach: falling direction and accident scene pictures, would classify not only to help users easily read and organize accident information but also allow the management and storing of information effectively. The falling case sequence was continuously detailed step by step. A worker who was assigned a roof painting task, erected a mobile scaffold along a corridor at fourth storey. During the erection process, he didn't check the quality of the steel bar of the scaffold. Furthermore, the scaffold ladder was not installed for climbing. After finishing scaffold erection, the worker didn't check the stability of the scaffold and directly stood on the handrail to climb to the scaffold. The scaffold collapsed and resulted to death of one worker.

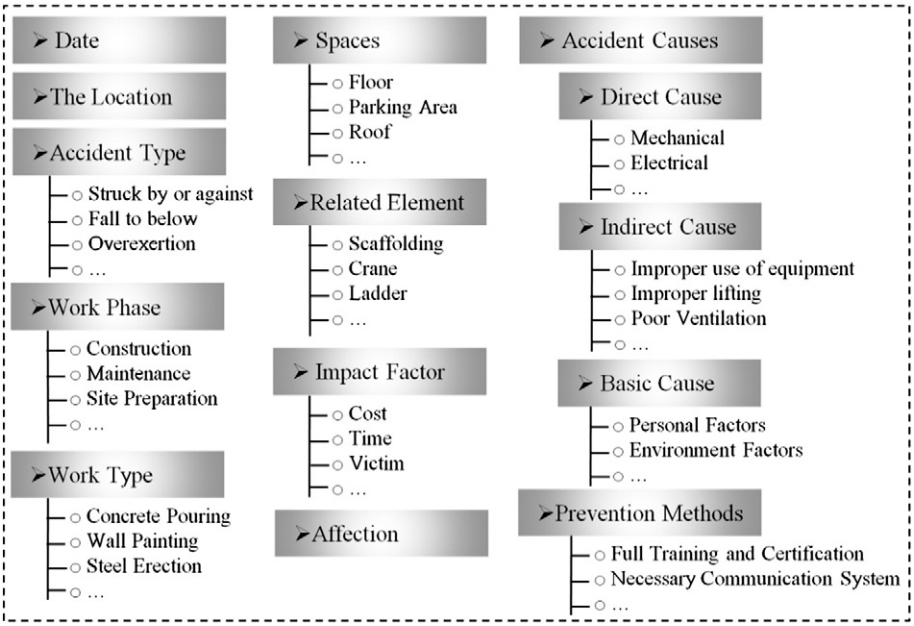

Fig. 2. Safety catalog.

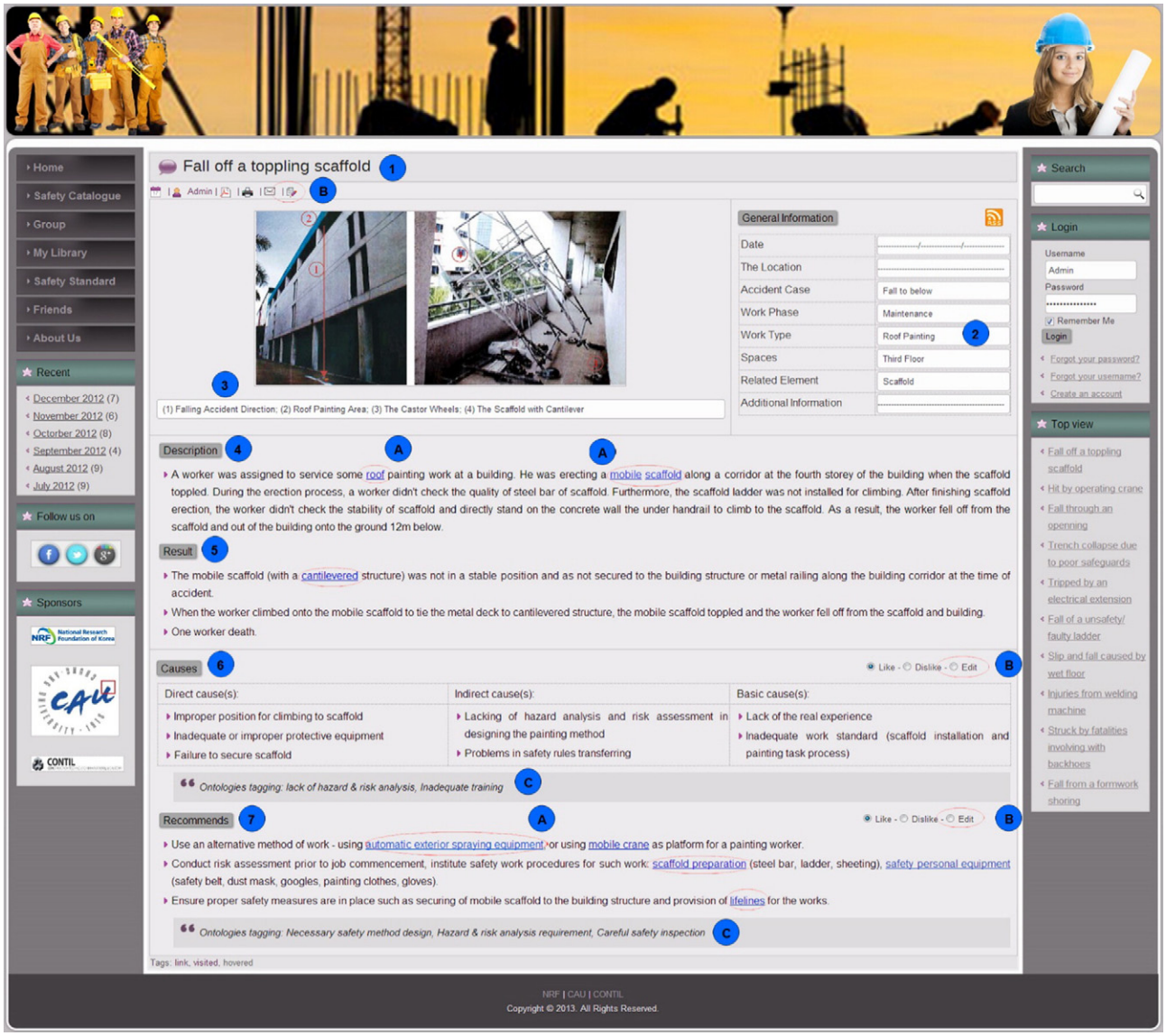

Fig. 3. A sample case of SSWT. (A) wiki tagging; (B) wiki editing; (C) ontologies tagging.
This case study was extracted from "Falls from Height — Case Studies Construction Industry", Workplace Safety and Health Council, Lee Tzu Yang, 2008 [28].

These falling scenarios showed that the safety information module creates a good environment to share and present accident data and also store and manage safety information effectively and efficiently.

3.4. Safety knowledge module

In the safety knowledge module (SKM), the accident information are analyzed and refined through the contribution of domain experts. Fig. 4 illustrates the refining process that is a main core of SKM. The SSWT provides the knowledge contribution forum for experts to add their expertises by clicking the editing button icons (B) in cause (6) and recommendation (7) sections (refer to the bottom portion of Fig. 3). By leveraging on state-of-the-art of social network system, the SNSS supports users with an easy and convenient environment to share their experiences about the causes and prevention method of accident phenomenon by commenting ideas and uploading evident documents. After this expertise contribution activity is finished, all analytical accident causes and recommendation ideas would be refined to achieve best results through a voting process by domain experts. In the voting process, domain experts give rating points by inserting "like" or "dislike" or "neutral" opinions to each idea via the voting tool of SSWT in a pre-defined time. At the end of the pre-defined time, the idea acquires the highest score voting, and it is the credible knowledge.

The information of 'fall off a topping scaffold case study' would be converted to safety knowledge as illustrated in the bottom portion of Fig. 3. Seven users (lecturers) joined in analyzing and refining the falling accident case. From the accident information found on the top and middle portions of Fig. 3, users would comment their ideas on accident causes and prevention methods. Based on the editing and voting functions, this falling accident causes were defined following direct, indirect, and basic causes. The causes in three catalogs were arranged from top to bottom following the voting score (high priority in direct cause is improper position for climbing to the scaffold, in indirect cause it is lack of hazard analysis and risk assessment in designing the painting method, and in basic cause it is lack of real experience). And the prevention method has a best score in this case study, that is to use an alternative painting method — using automatic exterior wall spraying equipment or using mobile crane. There is no doubt that the semantic wiki and ontology technologies provide users with a powerful tool to acquire the good safety knowledge.

After safety knowledge is confirmed, the whole knowledge in the SSWT would be converted into ontology classes, as illustrated in Fig. 5.

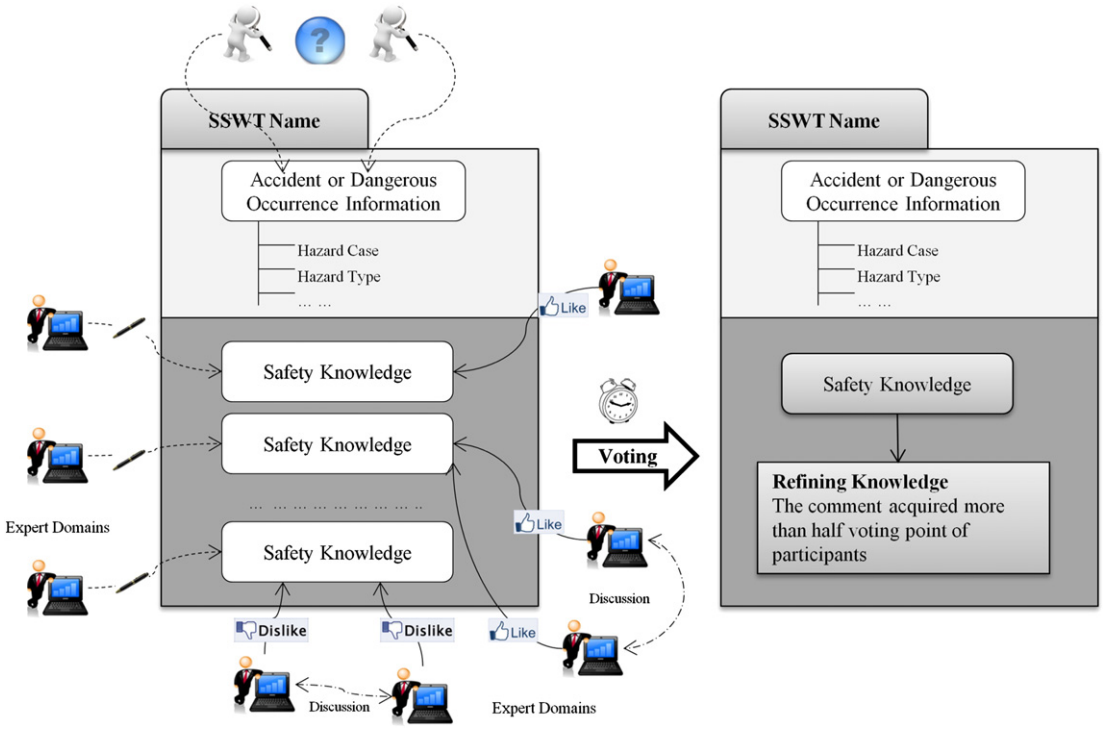

Fig. 4. Construction safety knowledge analyzing and refining.

Via ontology library of SNSS, domain experts would execute ontology tagging and verification for the knowledge sharing and reuse. The ontology library of SNSS has been built based on the theory of Collaborative Protégé [21] that supports collaborative ontology editing and voting to allow expert participants not only to extract ontology class from the library but also to contribute and define new ontology classes onto the ontology library. Particularly, in the case of accident cause and recommendation knowledge, there could be more than one ontology classes to be tagged based on the different theories of the construction industry. In the SNSS, users can play an active role in establishing safety information and knowledge in the form of systematic and automatic procedure.

3.5. Safety dissemination module

The safety dissemination module (SDM) of SNSS consists of the following three layers: Interface Layer to implement, Management Layer to create knowledge from user input, and Data Layer to store the input data from users, as illustrated in Fig. 6. The Interface Layer including searching engine, SSWT pages and social services allows users to interact with a website to create safety knowledge based on the semantic wiki web and ontology applications. The Management Layer includes three parts to support the system management: 1) SSWT Management creates and modifies the safety knowledge in wiki pages as well as supports domain experts to accumulate knowledge and to construct ontology classes; 2) Ontology Management provides ontology class name list and new ontology class creation; and 3) Refining Engine allows users to discuss and score the knowledge. The score of knowledge is stored in the data layer for knowledge refinement. The Data Layer consists of Database Storage and Safety Ontology Library. Ontology Library is encoded based on Protégé [21] that is the cornerstone to support the knowledge classification framework of the Database Storage. The SDM clearly illustrates the interaction between social network with semantic wiki and

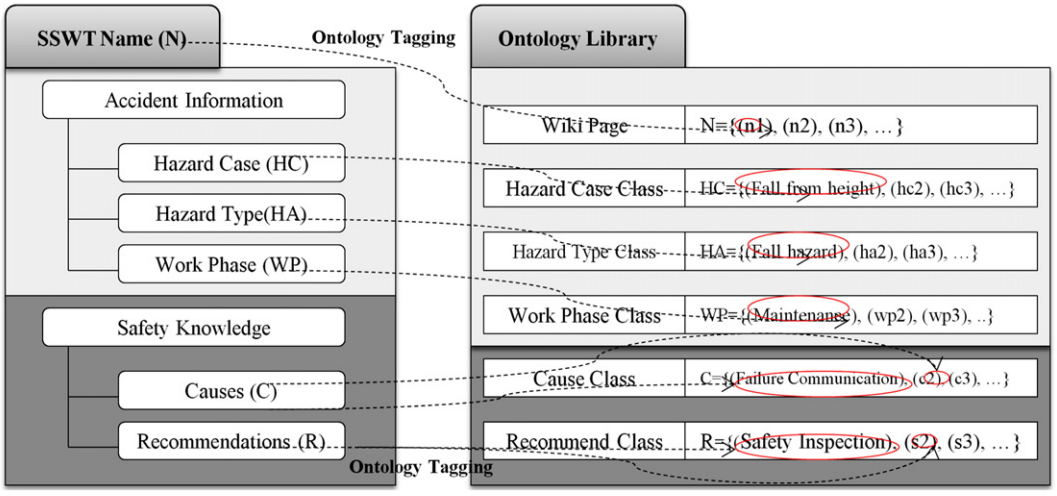

Fig. 5. Ontology converted information and knowledge.

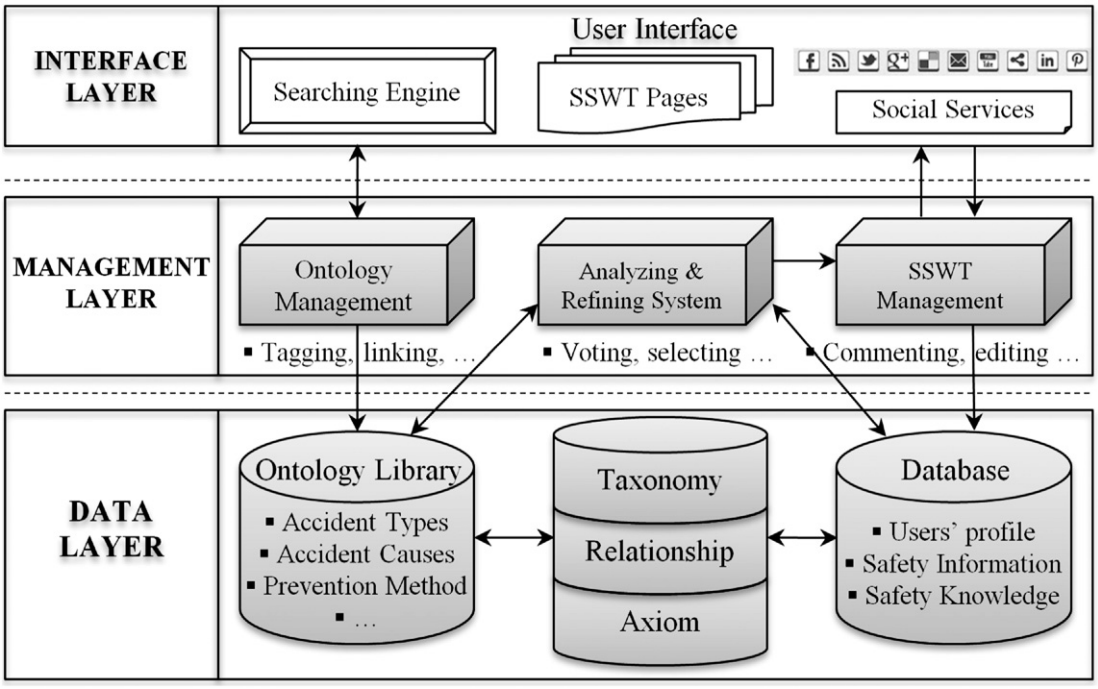

Fig. 6. Dissemination module technical architecture.

ontology. The social network technology provides the platform for users to share, represent accident data and also exchange and evaluate the information with others while semantic wiki and ontology techniques support hierarchical safety catalog to classify and structure the safety information. The social network controls the information accessibility and user interaction, plays an important role in management and interface layer. Ontology and semantic wiki would manage the safety knowledge and the relationship between the information. The integration of social network with ontology and semantic wiki in the proposed system would enhance information retrieval and knowledge management in terms of access and extraction.

In the dissemination module, some key functions has been specified as follow: (1) Profile: This approach allows users to define and maintain their profile including user's name, kind of job, study area, working place, and so on; (2) Safety information and knowledge sharing: SNSS's users can upload accident knowledge & experience and comment or vote to other user's information via SSWT if they are willing to share; (3) Group Tool: Due to the user's profile, the system would automatically match relevant safety information with user's job, major, etc. to provide them valuable safety catalogs; and (4) Navigation tool: it is used for ontology tree as safety categorization and for searching safety knowledge. And also typical website interfaces are provided for managing information share and knowledge exchange. This feature of SDM would attract many people to take part in for the creation of qualitative and quantitative safety knowledge in the SNSS.

4. System evaluation

The system has been tested with a real accident scenario in order to figure out the potential applicability and limitations of the SNSS. And the system practicability and applicability have been appraised and evaluated through interviews. The interviewees were divided into four groups: student, lecturer, safety manager, and site supervisor. The evaluation criteria were identified as the following: ease of use, information sharing, communication and increase knowledge accessibility [16,29]. The summary of the interview result is shown in Table 1.

The results indicate that the interviewees generally agreed that the proposed SNSS has great potential in the creation of a good environment for construction safety knowledge retrieval in the construction industry. The SNSS is applicable in construction academic and commercial area, and could support information sharing, knowledge representation in storing and managing construction safety data. The results can be explained through the effectiveness of semantic wiki and ontology, and integration with social network techniques towards knowledge management. However, the interviewees also expressed that they were unfamiliar with the communication platform and it is difficult to use for chatting and talking. Furthermore, it should be noted that some limitations of the system were found: 1) the pre-defined time for knowledge voting creates some difficulties for users to join in the safety contribution and confirmation process; and 2) the knowledge transfer procedure sometimes encountered problems due to the abuse

Table 1
Summary of interview result.

1 — Useless 2 — Ineffective 3 — Normal 4 — Effective 5 — Highly effective	Average SNSS rating			
	Ease of use	Information sharing	Communication	Increase knowledge accessibility
Lecturers (7)	3.88	3.95	3.23	3.67
Construction students (12)	4.02	3.74	3.44	3.88
Safety managers (5)	3.52	3.98	3.06	3.56
Site supervisors (4)	3.3	3.03	2.98	3.38

of semantic resources tagging, linking and ontology tagging for knowledge sharing and reusing.

The use of SNSS, in contrast with traditional safety information management system, provides a new communication platform for managers, workers, owners, etc. The users cannot only get the right information that they need in a timely manner but also share and store their safety experiences through connecting with SNSS. By utilizing this system, users can improve their safety knowledge and have effective decision making.

5. Conclusion

This paper presents a social network system for coordinating and sharing construction safety and health information and knowledge in the construction industry, which are focused on combining unique features of semantic wiki web and ontology to create a more effective and efficient representation and communication tool. The core of the proposed SNSS is the SSWT that allows users to conveniently and cooperatively contribute, refine, and retrieve knowledge linking three modules — information, knowledge and dissemination. A prototype system was developed and tested with a real accident case scenario. Through the recommendation via interviews with some field safety managers, it is confirmed that the SNSS could greatly enhance the current practices and communication problems of construction safety knowledge. However, there are still some limitations such as the pre-defined time or the abuse of semantic tagging and ontology tagging that will be further examined in the future research. And some research efforts would be directed toward the combination of social network and virtual technique for establishing the good knowledge sharing environment as well as developing the construction safety training or education tool.

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References

[1] D.M. Boyd, N.B. Ellison, Social network sites: definition, history, and scholarship, J. Comput.-Mediat. Commun. 13 (1) (2007).
[2] A. Bruns, Blogs, Wikipedia, Second Life, and Beyond: From Production to Produsage, Peter Lang, New York, 2008.
[3] M. Buffa, F. Gandon, G. Ereteo, P. Sander, C. Faron, SweetWiki: a semantic wiki, Web Semant. Sci. Serv. Agents World Wide Web 6 (1) (2008) 84–97.
[4] A. Carbonari, A. Giretti, B. Naticchia, A proactive system for real-time safety management in construction sites, Autom. Constr. 20 (6) (2011) 686–698.
[5] S.O. Cheung, K.K.W. Cheung, H.C.H. Suen, CSHM: web-based safety and health monitoring system for construction management, J. Saf. Res. 35 (2) (2004) 159–170.
[6] P. Chinowsky, J. Diekmann, V. Galotti, Social network model of construction, J. Constr. Eng. Manag. 134 (10) (2008) 804–812.
[7] G. Eysenbach, Medicine 2.0: social networking, collaboration, participation, apomediation, and openness, J. Med. Internet Res. 10 (3) (2008) e22.
[8] D. Fang, J. Huang, P.S.W. Fong, Sharing construction safety knowledge through social network, CIB W099 — Safety and Health in Construction CIB Publication 357, Salford, United Kingdom, 2010, pp. 215–226.
[9] A. Farquhar, R. Fikes, J. Rice, The Ontolingua Server: a tool for collaborative ontology construction, Int. J. Hum. Comput. Stud. 46 (6) (1997) 707–727.
[10] S. Kim, E. Suh, Y. Jun, Building a knowledge brokering system using social network analysis: a case study of the Korean financial industry, Expert Syst. Appl. 38 (12) (2011) 14633–14649.
[11] H. Li, G. Chan, M. Skitmore, Visualizing safety assessment by integrating the use of game technology, Autom. Constr. 22 (2012) 498–505.
[12] C. Lima, T. El-Diraby, J. Stephens, Ontology-based optimisation of knowledge management in e-construction, J. Inf. Technol. Constr. 10 (2005) 305–327.
[13] K.-Y. Lin, The development of a sustainable e-learning model — using construction safety and health education as an example, Comput. Civ. Eng. 2009 (2009) 593–602.
[14] F.Y.Y. Ling, S. Li, Using social network strategy to manage construction projects in China, Int. J. Proj. Manag. 30 (3) (2012) 398–406.
[15] T. Mills, Wiki-based construction knowledge sharing, The ASC Annual Conference, Associate Schools of Construction Flagstaff, Arizona, US, 2007.
[16] C.-S. Park, H.-J. Kim, A framework for construction safety management and visualization system, Autom. Constr. 33 (2013) 95–103.
[17] Y. Rezgui, Ontology-centered knowledge management using information retrieval techniques, J. Comput. Civ. Eng. 20 (4) (2006) 261–270.
[18] S.M. Rowlinson, Construction Safety Management Systems, Spon Press; Taylor & Francis, London; New York, 2004.
[19] C.-W. Shih, M.-Y. Chen, H.-C. Chu, Y.-M. Chen, Enhancement of domain ontology construction using a crystallizing approach, Expert Syst. Appl. 38 (6) (2011) 7544–7557.
[20] C. Sofia Pereira, A.L. Soares, Improving the quality of collaboration requirements for information management through social networks analysis, Int. J. Inf. Manag. 27 (2) (2007) 86–103.
[21] W099-Special Track 18th CIB World Building Congress May 2010 Salford, W099-Special Track 18th CIB World Building Congress May 2010 Salford, United Kingdom, 2009.
[22] N.M. Ulang, A. Gibb, C.J. Anumba, The communication of health and safety information in construction, CIB W099 - Safety and Health in Construction CIB Publication 357, Salford, United Kingdom, 2010, pp. 265–277.
[23] J.A. West, M.L. West, Using Wikis for Online Collaboration: The Power of the Read–Write Web, Jossey-Bass, San Francisco, CA, 2009.
[24] Wikipedia, Data Definition, http://en.wikipedia.org/wiki/Data.
[25] Wikipedia, Editing Definition, http://en.wikipedia.org/wiki/Editing.
[26] Wikipedia, Information Definition, http://en.wikipedia.org/wsiki/Information.
[27] Wikipedia, Knowledge Definition, http://en.wikipedia.org/wiki/Knowledge.
[28] L.T. Yang, Falls from height — case studies construction industry, Workplace Safety and Health Council, 2008.
[29] J. Zhang, T. El-Diraby, Social semantic approach to support communication in AEC, J. Comput. Civ. Eng. 26 (1) (2012) 90–104.