Safety Science 87 (2016) 202–213

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Construction risk knowledge management in BIM using ontology and semantic web technology

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ARTICLE INFO

Article history:
Received 17 June 2014
Received in revised form 3 April 2016
Accepted 9 April 2016
Available online 22 April 2016

Keywords:
Construction risk
BIM
Ontology
Semantic web technology

ABSTRACT

The development of Building Information Modelling provides a visual and information-rich environment to incorporate the construction risk knowledge in the domain of safety management. Ontology and semantic web technology offer an opportunity to enable such domain knowledge to be represented semantically. This paper attempts to take advantage of the strength of BIM, ontology and semantic web technology to establish an ontology-based methodology/framework for construction risk knowledge management in BIM environment. The risk knowledge is modelled into an ontology-based semantic network to produce a risk map, from which the interdependences between risks, risk paths can be inferred semantically. Based on the semantic retrieval mechanism, the applicable knowledge is dynamically linked to the specific objects in the BIM environment. Based on the methodology, a prototype system is developed as a tool to facilitate the construction risk knowledge management and reuse in hope of indirectly improving the construction risk analysis process. A case application is implemented to demonstrate the risk prevention through construction process/method selection, including the risk factors identification, risk paths reasoning and risk prevention plan recommendation. Finally, a questionnaire survey highlights the potential benefits and limitations on the deployment of such system.

1. Introduction

In any construction project, risk management is a very knowledge intensive process. The probable risks are identified by experts through the risk evaluation exercises based on their individual expertise and available design information (i.e. 2D construction drawings). Having identified the possible risks, relevant preventive measures can be put in place. However, it is recognised that 2D information does not effectively support risk identification because limited information is provided by 2D drawings (Li and Hua, 2012). Also, the provided information is not dynamic and only represents the project at certain stage. By comparison, Building Information Modelling (BIM) has been evidenced to substantially improve the information environment for the construction risk identification and prevention (Smith and Tardif, 2009; Kiviniemi et al., 2011). In a BIM environment, more effective and proactive construction risk and safety management can be accomplished (Ku and Mills, 2008).

Ontology is the formal conceptualization of knowledge in a certain domain (Zhang and El-Diraby, 2012). There is plenty of research discussing the use of ontologies to support semantics in the construction industry (Mutis and Raja, 2009; Svetel and Pejanovic, 2010). Ontology and semantic web technology has offered a way to semantically represent and reuse domain knowledge (Anumba et al., 2008; Elghamrawy et al., 2009). The literature review also demonstrates the advantages of BIM, ontology and semantic web technology in their own respective applications; however, there is little research in combining BIM, ontology and semantic technology for the construction risk management. Meanwhile, with the development of BIM, people come to realise that only rich information is associated with the building object models, can the value of BIM be fully reached. Even though BIM provides potential for many analysis and simulation processes which is impossible using traditional 2D design approaches, the static links of the information to the building objects models mean that once the project models or information change, the links have to be re-established again. This contributes to the dilemma between integrating more information into the building object models and the proper model size (Zhang and Xing, 2013). In fact, the information should be integrated with (linked to) the building object model in a dynamic and flexible way.

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http://dx.doi.org/10.1016/j.ssci.2016.04.008
0925-7535/

In this context, this paper attempts to take advantage of the strength of BIM, ontology and semantic web technology to establish an ontology-based methodology for construction risk knowledge management in BIM environment, to organise, store and reuse construction risk knowledge.

The construction risk knowledge is modelled into an ontology-based semantic network to produce a risk map, from which the interactions and interdependences between risks, risk paths can be captured and inferred semantically. Based on semantic reasoning and retrieval mechanism, the applicable knowledge is dynamically linked with or recommended to the specific objects in a BIM environment. Based on the methodology, a prototype system is developed as a construction risk knowledge management tool to facilitate the knowledge reuse during the risk analysis process. A case application and a questionnaire survey are done to further show the applicability and benefits.

2. Related work

2.1. Risk knowledge model and representation

Research investigations suggested that practical risk management was often based on previous experience and knowledge (Han et al., 2008; Tserng et al., 2009) and knowledge reuse is one of the key areas in construction risk management research (Zoysa and Russell, 2003; Tah and Carr, 2001). Several risk analysis and modelling techniques, such as the Check List, Failure Mode and Effects Analysis (FMEA) tables, Hazard and Operability study (HAZOP), What–If rule, and Fault Tree Analysis (FTA) diagrams, have been developed to facilitate the risk management. A number of knowledge-based risk and safety management applications have also been developed to improve the safety performance, for example, Kamardeen (2009) developed a conceptual framework of web-based safety knowledge management system for builders; Goh and Chua (2010) proposed a case-based reasoning approach of construction hazard identification. In these applications, the risk knowledge models/schemas were developed and represented in Object-Oriented approach.

In practice, the risk checklist is mostly used as a tool to help the engineers identify potential risk factors. Some researchers classified risks into groups to manage the lists of risks via risk breakdown structure (Hillson, 2003). However, these tools exclude the causal relationships of risks. Tah and Carr (2001) demonstrated the associations between risk factors and risks using "cause-and-effect" diagrams. Dikmen et al. (2007) also pointed out the importance of independencies among risk-related factors. In many risk management system, the interdependencies are modelled in relational database system. However, in a traditional relational database, semantics relations are not explicitly expressed. It is time-consuming to represent and find the semantic of the field dependencies between the complex table structures. Any changes of the interdependence may imply recreating the interdependence network from the beginning, because of their very complex interaction structure. Therefore, it is necessary to explicitly represent interdependences among risks and risk factors semantically in a model.

2.2. Ontology and risk knowledge management

In the AEC industry, the applications and studies of ontology and semantic technology have been undertaken in risk-relevant management domain. Tserng et al. (2009) proposed the ontology-based risk management framework to enhance risk management performance. Fidan et al. (2011) proposed an ontology model to associate risk-related concepts to cost overruns, and the ontology model was then used for developing a database system. Wang and Boukamp (2011) used ontology to structure the knowledge about activities, job steps and hazards to improve access to a company's JHA (Job Hazard Analysis) knowledge, and discussed an ontological reasoning mechanism for identifying safety rules applicable to given activities. Forcada et al. (2007) applied ontology to interrelate environmental, health and safety risks. Furthermore, the ontology serves as the basis for analysing Environmental, Health and Safety risks and defining technical solutions and preventive measures. All those studies had demonstrated the potential benefits of ontology in risk management and provided the basis for this paper.

2.3. BIM for construction risk and safety issue

In last few years, a lot of work has been done on the BIM-based construction risk management and application. The research from VTT Technical Research Centre of Finland shows that BIM model can support the safety planning by adding the planned temporary site and safety arrangements to the model (Kiviniemi et al., 2011). Zhang et al. (2013), from Georgia Institute of Technology, proposed an approach to extend BIM to integrate automated hazard identification and developed an automated safety checking platform for preventing fall-related accidents. Li and Hua (2012) proposed an object library approach for managing construction safety components based on BIM, in which the knowledge related to the construction safety components, such as the safety equipment, is collected and represented for design decision in design-for-safety. These studies have proven the capability of a BIM technology on improving the safety analysis and decision making. However, the studies so far are only focused on taking advantage of the rich visualisation and information environment BIM provided for the safety management.

2.4. Integrating knowledge with BIM

There are some efforts in integrating the relevant knowledge with BIM, even though they are not focus on the construction risk domain. Fruchter et al. (2009) attempted to transform the BIM into the building knowledge model by linking the knowledge tool with BIM. Meadati and Irizarry (2010) discussed the feasibility of developing BIM as a knowledge repository by adding new parameters for knowledge resource as project parameters or shared parameters. Goedert and Meadati (2008) integrated construction process documentation into BIM. Pishdad and Beliveau (2010) integrated multi-party contracting risk management model in BIM. Calos and Soibelman (2003) described an approach to automate integration of text documents into IFC compliant model-based systems. However, they integrated the relevant information/documents via static links between the information/knowledge and the parameters of the project model. This way of coupling tightly knowledge with specific project models requires creating static links between each product and its applicable knowledge. This issue together with the advantage of ontology and semantic web technique constitutes the starting points of this research.

3. Methodology and framework

3.1. Framework

This methodology proposes a framework for managing and reusing the construction risk knowledge in the BIM environment to facilitate the construction risk analysis process, as shown in Fig. 1, which includes BIM model, ontologies, information