An automated safety risk recognition mechanism for underground construction at the pre-construction stage based on BIM

Meng Li,⁎, Hongliang Yu,⁎, Ping Liu

⁎ Corresponding author.
E-mail address: limengwd@126.com (M. Li).

1. Introduction

Underground construction has a large number of uncertainties, which involves numerous safety risks during the construction stage. Over the past decade, underground construction accidents worldwide have caused poor social impacts. For instance, on July 6, 2010, a collapse accident happened at the Prague Ring Road forming a 15-meter deep pit in Prague resulting in public crisis on underground construction [1]. On August 23, 2012, in Warsaw, Poland, the planned underground station was flooded because of the leaks causing a social panic [2]. The latest accident killed 22 workers [3] at a railway tunnel on May 23, 2017 in China. The issue of safety risk for underground construction has been paid great attentions to scholars all over the world [4–6].

Most literatures and guidelines regard risk recognition as the first step and important stage to risk management [7]. In terms of underground construction, safety risk recognition at the pre-construction stage is essential to identify potential hazards and develop preventive measures. Successful safety risk recognition depends on global experiences of similar underground construction projects [8]. However, a highly challenging problem that has been plaguing regulators is the inaccurate collection and sharing of safety risks for underground construction. In order to establish a mechanism that could achieve timely and accurate recognition at the pre-construction stage, Building information model (BIM) is adopted as the risk recognition platform. This paper provides the automated safety risk recognition process based on BIM which is generally composed of three parts. The first part is to build the risk database. By means of knowledge structuralizing, questionnaires, depth interviews and group decision-making, explicit and tacit knowledge source are acquired. The safety risk knowledge source is divided into three categories. SQL database is used to express the safety risk knowledge, and all safety risks are stored in the BIM-cloud. The second part is to analyse the relation between engineering information and safety risks. Risk-related engineering information is extracted from BIM models. Backus–Naur form is used to describe the syntax of languages used in computing. A mapping table of engineering information and safety risks is established. The third part concerns the automated safety risk recognition mechanism in the BIM platform. The safety risk recognition mechanism is expressed as “If e, then h (CF (h, e), λ)” (Bayesian inference). The confidence level as the link is adopted to reveal the mechanism. Finally, a case about flowing sand risk at the foundation pit bottom is conducted. The reasoning process and recognition results are demonstrated. The paper concludes by summarizing the main scientific contribution and giving direction to future research in this field.

A highly challenging problem that has been plaguing regulators is the inaccurate collection and sharing of safety risks. In general, the traditional practice requires a large number of human resources. A primary method to complete safety risk recognition is to examine construction specifications and CAD drawings by engineers with rich construction experiences. Drawbacks of this pattern include the subjective judgment and low efficiency which are easy to produce false arguments or omissions [9]. Besides, a shortage of experienced engineers can adversely affect safety risk recognition for underground construction. In addition, constrained by time and space, prompt sharing of safety risks becomes unrealistic.

In recent years, “Building Information Modeling” (BIM) has become the primary construction management platform in the construction industry because of its convenient multi-dimensional visualization, interactivity and good sharing function. At the design stage, BIM has gradually replaced traditional two-dimensional CAD. By using the BIM-cloud, engineering information can be stored and shared. Besides, it provides the interface function, the platform can extract internal and

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ABSTRACT

A highly challenging problem that has been plaguing regulators is the inaccurate collection and sharing of safety risks for underground construction. In order to establish a mechanism that could achieve timely and accurate recognition at the pre-construction stage, Building information model (BIM) is adopted as the risk recognition platform. This paper provides the automated safety risk recognition process based on BIM which is generally composed of three parts. The first part is to build the risk database. By means of knowledge structuralizing, questionnaires, depth interviews and group decision-making, explicit and tacit knowledge source are acquired. The safety risk knowledge source is divided into three categories. SQL database is used to express the safety risk knowledge, and all safety risks are stored in the BIM-cloud. The second part is to analyse the relation between engineering information and safety risks. Risk-related engineering information is extracted from BIM models. Backus–Naur form is used to describe the syntax of languages used in computing. A mapping table of engineering information and safety risks is established. The third part concerns the automated safety risk recognition mechanism in the BIM platform. The safety risk recognition mechanism is expressed as “If e, then h (CF (h, e), λ)”. The confidence level as the link is adopted to reveal the mechanism. Finally, a case about flowing sand risk at the foundation pit bottom is conducted. The reasoning process and recognition results are demonstrated. The paper concludes by summarizing the main scientific contribution and giving direction to future research in this field.
external engineering information automatically. For example, BIM models could not only provide information of internal static structural components or equipment but also information of external dynamic environment. Then, the BIM platform can extract the useful information by programming. Eventually, a mechanism, which could automatically extract and share engineering information from BIM models, is able to be established [10].

At the project preparation stage, recognizing different kinds of safety risks is critical to reduce casualties in construction. Combining current demand for effective safety risk recognition and developing trend of BIM in the future, a fundamental scientific question condensed is: How to establish the BIM-based risk recognition methodology which could achieve timely and accurate recognition of safety risks for underground construction at the pre-construction stage. The remaining parts of this paper are organized as follows: Section 2 reviews risk recognition and BIM development for underground construction. Section 3 describes an overall framework of safety risk recognition. In Section 4, we elaborate on a methodology for automated safety risk recognition. In Section 5, the mechanism is applied to a real metro construction case; the results demonstrate its feasibility and effectiveness. Finally, conclusions are drawn in the last section.

2. Previous studies

2.1. Risk recognition for underground construction

In the year 2004, the International Tunnel Association issued the first edition of “Guidelines for tunneling risk management”, which indicated that risk identification was seriously considered [11]. Later, in 2009, European Parliament’s “Assessment of the Safety of Tunnels” was issued with the aim to improve tunnel construction management [12]. Engineers were given guidance on risk identification and how to carry out risk management in tunnel construction. Fattahi and Moradi [13] estimated the magnitude and frequency of risk propensity in tunnel projects [14], it merely focused on geotechnical hazards. Park and Kim [15] evaluated risk factors at different stages qualitatively and developed Risk Management Software (TRM1.0) for shelter tunneling using risk databases. Sagong et al. [17] introduced a digitalized tunnel face mapping system (DiTFAMS) based on PDA and WLAN technology which could transfer geological information such as images of the tunnel face to decision makers very quickly. Yoo et al. [18] developed an IT-based tunneling risk management system (TURISK) on the basis of geographic information system software ArcGIS to assess risks caused by the impact of tunnel construction on the surrounding environment and to give guidance on tunnel design [7] and Zhang, et al. [19] listed common risk recognition methods: Check List method, Brainstorming method, Delphi method, What-if analysis, Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Hazard and Operability study (HAZOP), Failure Mode Effect Analysis (FMEA), etc. Besides, Zhang, et al. [20] proposed a novel hybrid approach that merges fuzzy matter element (FME), Monte Carlo (MC) simulation technique, and Dempster–Shafer (D–S) evidence theory to perceive the risk magnitude of tunnel-induced building damage at an early construction stage. In general, there are only a small amount of literatures on how to identify risk events for underground projects. Existing methods or software packages are mainly applied to solve geological risks. Thus, this paper focuses on developing a set of algorithms to recognize all kinds of safety risks for underground construction.

2.2. Application of BIM for underground construction

BIM technology was known as the second revolution in construction industry, which was based on three-dimensional models and was an inevitable choice in the future [21]. According to the statistics from US General Service Administration, nearly half of the construction enterprises in the North American used BIM or related tools. In 2011, the state of Wisconsin and the state of Taxes were required to adopt BIM technology in state-owned investment projects [22]. In some Nordic countries, such as Norway, Finland and Germany, BIM tools were widely used in almost 70% of their construction projects [23]. In China, in terms of applications of BIM technology in underground construction, Hong Kong was in a leading position, twenty of eighty-two metro stations in Hong Kong were modelled by BIM technology [24]. China Railway Design Institute integrated pipeline and infrastructure based on BIM platform in the project of Xi’an underground construction, more than 500 collision points were found through collision detection [25]. Shanghai underground projects also used BIM to carry on pipeline collision inspection and install large-scale equipment, which effectively enhanced the quality of construction [26]. However, it was pointed out that BIM technology was mainly applied to large-scale buildings, and was strictly confined to a particular stage. Min and Miya [27] argued that applications of BIM in underground construction were inadequate except for building simulation and pipeline collision analysis. Obviously, functions of BIM were not fully used for underground construction. In the field of construction risk management, J Fernandes [28] used BIM for risk management on a construction site. M M Mering [29] explained the adoption of Building Information Modelling (BIM) in project planning risk management. In summary, BIM technology is an inevitable choice in the future. Simultaneously, underground construction cases based on BIM are continuously increasing. By using the advantages of BIM technology, it is feasible to carry out effective safety risk recognition for underground construction.

3. The framework of safety risk recognition based on BIM

Safety risk recognition is defined as recognizing safety risks which may cause casualties, environmental damage, economic loss or project schedule delay. In this paper, firstly, we try to establish a safety risk knowledge database to sort out all kinds of safety risk knowledge based on BIM-cloud. BIM models are engineering information carriers which include structural attributes, constraint relations, construction techniques, interactions between structures and surrounding environments, etc. Most safety risks are related to this engineering information, and experienced experts or engineers can recognize them through reading BIM models because relations exist between engineering information and safety risk knowledge. So, recognizing those relations is the key to identify safety risks for underground construction. Finally, an automated risk recognition mechanism for underground construction is proposed based on BIM. The overall research framework is shown in Fig. 1.

4. An automated safety risk recognition methodology

4.1. Building safety risk database based on BIM-cloud

Apparently, the accuracy and effectiveness of safety risk database are influenced by the acquired safety risks. Safety risks for underground construction are related to many influential factors, such as underground architectural forms, construction techniques, geological & hydro-geological conditions and surrounding environments. This part firstly discusses how to recognize underground construction safety risks based on BIM-cloud at the preparation stage excluding equipment risk, behavior risk and management risk due to mechanical equipment failure, mishandling and disorganized construction at the construction stage.
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