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A meta-network-based risk evaluation and control method for industrialized building construction projects

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ABSTRACT

Construction methods in developing countries such as China are gradually industrializing due to rising labor costs, new techniques, tools, procedures and management methods. This makes it essential to develop new risk evaluation and control methods. Previous research seems to ignore the risk management of the application of new construction technologies and procedures. The identification of risk mechanisms is unclear, leading to a lack of clear guidance for risk avoidance and control. This paper describes a network model based on meta-network analysis of project objectives, risk events, risk factors and stakeholders in the construction process of building industrialization. According to ISO 31000, the main processes of risk management in the model has three parts: risk identification, risk analysis and evaluation, and risk treatment and control. Risk factors are identified from previous literature and site investigation, and the indirect impact on project objectives is analyzed and calculated with the networks in the meta-network. The order of importance is evaluated and used as the foundation of risk treatment and control. The analysis of the crucial risk factors makes it possible to identify the stakeholders who influence them, leading to suggestions for relevant control strategies. A residential building construction project in South China that uses the building industrialization construction system serves as a case study to verify the feasibility and applicability of the risk management system. Results show that critical risk factors are construction-related factors and design-related factors. The water and electricity engineers, the project manager, the project secretary, the field engineer, the project supervisor and the main contractor engineer have a significant influence on the risk factors. A stakeholder supervision system with targeted risk control strategies is proposed.

1. Introduction

Building industrialization has had various definitions and concepts in each period along with increasing demands and economic necessities. It is the integration of a wide range of new concepts and techniques, including – but not limited to – automation, robotics, reproduction, preassembly, standardization, mechanization, prefabrication and off-site construction (Zabihi, 2013). Industrialized construction has had a significant influence on improving efficiency, quality and the environmental impact of projects (Aye et al., 2012; Gibb, 1999; Wong and Yeh, 1985). The most significant advantage of prefabrication is that better supervision on improving the quality of prefabricated products can be conducted (Tam et al., 2007). The movement of the construction industry toward industrialization in the fabrication system includes the trend of helping the building industry achieve benefits and share them with the end-user (Martinez et al., 2008). This trend gains considerable attention and support from the government in China (Ji et al., 2017). In the transformation process of building industrialization, new concepts and techniques create greater requirements for project management for several reasons. First, compared to the traditional construction process, construction workers typically need to learn new techniques and become more familiar with the process of prefabricated building components assembly. Second, prefabricated components and new construction equipment (e.g., self-climb form, which is an intelligent wall formwork) greatly increase

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the construction speed and enhance the flexibility of project planning (Jaillon and Poon, 2009). New management modes, such as interspersed construction – a new construction planning technology (Feng and Hu, 2016) –, have been applied to project management and have had significant influences on project duration and cost. Building industrialization brings positive changes in the construction process (Lovell and Smith, 2010) as well as complexity and uncertainty to project implementation. Industrialized construction projects are generally subjected to more risks compared to traditional projects (Karimiazari et al., 2011; Luo et al., 2015).

Risk factors (e.g., the seam material is not securely fastened) increase with the new construction system of building industrialization (Luo et al., 2015), and they are more complex as more relationships exist among project objectives, risk events and risk factors. Some risk events can even lead to the failure of realization of project objectives, and risk factors can lead to risk events, so more strict requirements for risk management are necessary. Thus the relationships among project objectives, risk events and risk factors need to be considered (Bu-Qammaz et al., 2009; Fang and Marle, 2015; Fang et al., 2012; Guan and Guo, 2014; Luo et al., 2015; Tavakolan et al., 2017). However, there are still some limitations that need to be addressed. First, effective risk control methods are necessary for the successful risk management of industrialized building construction projects, while the risk management and control skills of managers of different levels (project managers, field engineers, supervision engineers) may fail to meet the requirements of a new construction management system (Liu, 2017). But very limited studies focus on proposing targeted risk control methods based on how the risk factor lead to the deviation of project objectives and affect each other (Kuo and Lu, 2013; Wang et al., 2016). Second, previous project risk management has analyzed and assessed risks from the perspective of the whole project (e.g. economics risks, market risks, risks from the external environment) (Luo et al., 2015; Xiahou et al., 2018), and there has been little attention focused on the potential risks associated with the implementation of building industrialization, which are listed in the case study of this paper. Third, a substantial proportion of researchers in this field have analyzed only the direct influences of risks (Luo et al., 2015), while overlooking the interaction between one risk event and other risk events (Han et al., 2008) (e.g. the interaction between "design changing" and "unreasonable construction planning"). Assumptions for some research methods of risk management limit certain kinds of associations. For example, the analytic hierarchy process (AHP) assumes that risk factors are isolated, which is the prerequisite of the comparison for the factors' weight judgment (Saaty, 2004). In the Bayesian network analysis process, closed loops among risk factors and events are not considered (Borsuk et al., 2004).

In order to bridge the knowledge gaps of risk management and control of industrialized building construction projects, our research was based on meta-network analysis (MNA); thus, it is included a network analysis model composed of stakeholders, risk events, risk factors and project objectives. The meta-network was a complex network composed of various entities and connections among them (Li et al., 2015). MNA can conceptualize a project as multi-node with multi-link meta-networks composed of different node entities and their interdependencies (Zhu and Mostafavi, 2015). MNA has been applied in many fields, such as the social networks and supply chains in the e-commerce market (Wakolbinger and Nagurney, 2004), the integration of social networks with knowledge networks (Nagurney and Dong, 2005), a social media analysis (Carley et al., 2013a) and an assessment of public health systems (Lenz, 2012). The goal of our research was to systematically study the risk assessment and responding mechanisms for the deviation from project objectives in the application of building industrialization. In this model, the association of risk events and factors that led to the deviation of project objectives was revealed, and targeted risk control strategies – based on the analysis of the relationship between stakeholders and risk factors – are proposed.

The structure of this paper is as follows: In the next section, previous studies of risk management in building industrialization projects are reviewed, and the research gap is analyzed. In section 3, the establishment of the meta-network and our calculation methods are described in detail. To show how the risk evaluation and control model can be applied, a case study of a residential building construction project in South China, which applied a building industrialization construction system, is discussed in section 4. Related results and future work are described in section 5.

2. Literature review

2.1. Building industrialization and its influence on construction projects

Previous research has shown that building industrialization has several notable characteristics. The first is standardization – including in the design phase, component production, actual construction and management. Standardization has a significant influence on the improvement of the quality of construction projects in the existing building system (Roy et al., 2005). Standardization and generalization of building components leads to the second characteristic: prefabrication in factories (Jaillon and Poon, 2009). Prefabrication refers to the mass production of building components in factories; these components are then delivered to a project site to be used in construction. The third characteristic is scientific management (Yan et al., 2004). Overall planning and new technology are the bases of scientific management in industrial construction. Building industrialization has been widely adopted around the world (Pan and Sidwell, 2011). According to Mao et al. (2013), in 1996, the levels of prefabrication in the construction industry in Germany, the Netherlands and Denmark already were 31%, 40% and 43%, and the size of the industrialized construction industry in the U.K. was £6 billion in 2006. Compared to these developed countries, building industrialization in China is still in its infancy (Luo et al., 2015), and developers in China lack the experience of industrialized construction approaches (Zhang and Skitmore, 2012).

Building industrialization brings changes to the construction process and affects the achievement of project objectives. Technology associated with building industrialization – especially the use of prefabricated building components, such as prefabricated slabs, beams, precast concrete (PC) roofs, PC balconies and integrated bathrooms – has been gradually introduced in the residential building construction industry in China (Gan et al., 2017). This has had several effects on the construction process, including compressing construction duration (Goodier and Gibb, 2007), increasing building costs (Chiang et al., 2006; Lihong et al., 2013; Mao et al., 2013) and improving building quality (Gan et al., 2017). Assembled building provides an example to illustrate the changes and effects brought by building industrialization. In traditional construction processes, waste arises from design changes, design error, materials remaining, packaging and non-recyclable consumables, and inclement weather (Faniran and Caban, 1998). Xu and Zhao (2010) proposed that assembled building could significantly reduce the disadvantages of traditional building processes while decreasing construction time, costs and environmental impact yet increasing quality. However, at this time, building industrialization is more costly than the conventional construction approach. By comparing assembled building projects