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BIM and safety rules based automated identification of unsafe design factors in construction

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Abstract

Design for Safety (DfS) has been considered as an effective approach to improving construction safety performance via taking into account safety problems during design. The approach, however, is not yet implemented effectively and efficiently in practice. This research tries to develop a practical DfS approach, which can automatically identify potential safety problems resulted from design by integrating BIM (Building Information Modeling) with design safety rules. Design safety rules related to construction safety is defined and built based on design regulations or codes, and a BIM and safety rules integrated approach developed to implement the automated identification of safety problems. Furthermore, a test-bed project is presented to test the validity of this approach. As a result, the unsafe factors in design can be detected during construction to aid in construction safety management on site. Compared with traditional safety management methods, the BIM-based DfS approach is automated, thus reducing the time and labor cost spent on safety checking and improving the performance of construction safety management.

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Keywords: Building Information Modelling(BIM); construction safety; design for safety(DfS); safety rules

1. Introduction

Construction safety is a serious issue in the construction industry, which has been one of the most dangerous industries. Design for Safety (DfS) is regarded as an efficient approach to reducing safety problems in construction. That is, safety problems could be identified during design. According to Reason[1], some factors that have negative effects on construction safety may be arisen in the conceptual design stage, and then may deteriorate to accidents in construction processes. Gambates also found that 40% of construction accidents were related to design through the

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analysis of 224 construction accidents and confirmed that there exists the causal relationship between design and accident [2, 3]. Thus design has an serious influence on construction safety, and construction accidents can be prevented through considering unsafe factors in design.

From the perspective of Design for Construction Safety(DFCS), safety issue should be considered during the course of design, so as to eliminate design-related safety problems. Behm found that DFCS can eliminate nearly one third of potential safety hazards, 50% of which are directly related to unsafe design[4-6]. The key point of implementing DFCS is to make it timely and confident for architects and engineers to identify potential safety problems in design. In order to achieve this, some research has been conducted. For example, Yuan applied DFCS in subway design, but lacking detailed research on the content of safety knowledge base[7]; Kim structuralized the workers-oriented design proposal to check the design proposal with safety-hazard-identifying software[8]; Choi developed a rule-based automatically checking system to share drawings and documents information by integrating standard for the exchange of product.

2. Safety rule of design

Safety regulations and codes are the foundation of construction risk identification. To realize automatic risk identification, it is significant to match BIM components or activities with relevant safety regulations and codes. A safety rule system is thus built by 1) classifying construction safety information, 2) building a safety rule system and 3) translating safety rule system to machine readable language.

Different kinds of regulations may categorize unsafe design factors from different perspectives and may describe the same rule in different format. To facilitate rule searching, it is essential to reorganize these rules in the same format and same system. But all of these regulations can be classified into safety protection, design calculation and design checking. As the rules are used to prevent safety accidents, the design safety related information is reorganized according to accident-related attributes. A framework of safety rule system can be developed based on the organized items. Table 1 shows the framework of safety rule system.

Table 1. Framework of design safety rules.

Safety rules	Example
Accident type	Fall
Accident subject	Hole
Attributes	Vertical
Parameter	H=0cm
Safety rules	Safety Guards
Regulations	Unified Code for Safety Technology in construction 5.3.2
Prevention measures	Handrails

To facilitate information retrieval, safety rules are coded according to accident type, accident subject and other properties. Each safety rule is given a unique number ID, which can be understood by computers. Each safety rule code contains five parts: rule types, accident types, accident subjects, attributes, rule number and item number, as shown in Figure 1[10].

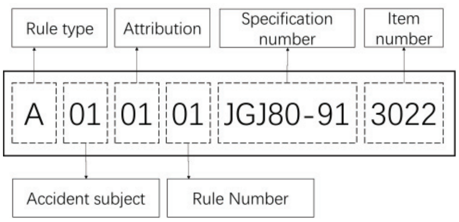

Fig. 1. Coding method for design safety rules

3. Coding of design components

To realize automatic comparison of design information and safety rules, design components should also be coded. To ensure the uniqueness of component ID, an ID consists of two parts: name ID and data ID. Name ID contains information about accident types. For example, the doors of a BIM model have a same name ID. Data ID contains information related to component parameters, including accident type, accident subject, key words and other information. The system will first determine the type of accidents according to name ID, and find out of the related rules. Then the data ID will offer the component's properties, which are in turn used to be compared with safety rules.

By matching component ID and safety rules, unsafe design factors can thus be identified, and the locations and time of these factors will also be recorded. Finally, designers can improve their designs according to the record.

4. Integration of safety rule and BIM

To realize the integration of safety rules and construction information, a tool is needed to store and manage the information related to building and construction process. BIM, a visualized and digital construction information database is applied due to the following reasons:

- Digital construction information. BIM contains the design information of each components, and the information is digitalized, which can be extracted easily by programs.
- Well-organized construction information. The information stored in BIM is categorized by components. It is an important characteristic, as the design information in the proposed system is also sorted by components. Thus the information stored in a BIM model can be directly combined with the system without reorganization.
- Parameterized construction information. BIM is a parameterized model, which means if you modify one parameter of one component, all the relevant parameters will be changed automatically. This character will facilitate the modification of unsafe design factors a lot. For example, if you reduced a window opening, then the size of the window will change as well.
- Visualized construction information. BIM is a visualized model, which helps designers and safety managers to find and rectify unsafe factors more easily.

By comparing safety rules and the building information stored in BIM, unsafe design factors can be identified and visualized in building information model. Based on the visualized identification results, designers are able to improve design proposal directly or share the results with contractors to improve construction planning. Besides, the identification reports can be used continually in construction safety management on site.

Figure 2 presents the process of integrating safety rule system and BIM. First, safety rule database is integrated with building information model. Then component ID is matched with safety rules ID to identify accident subjects in the model. Then the system will compare component parameters against safety rules. If dangerous area is found in design, relevant design information will be recorded and a prevention will be given. Table 2 shows an example for possible checking results.

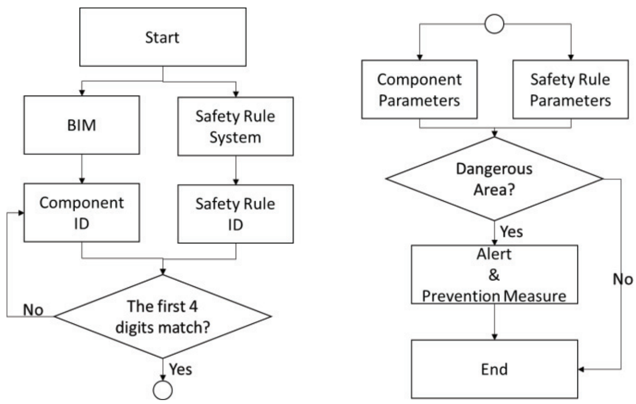

Fig. 2. Automated identification of unsafe design factor based on safety rules and BIM

Table 2. Automated record of unsafe design factors identified (example).

Component ID	Parameter	Rule code	Position	Prevention measure
01010001	R<=2.5cm	A01-0101JGJ80-91-3022	(x,y,z)	Null
01010002	R<=25cm	A01-0102JGJ80-91-3022	(x,y,z)	Cover
01010003	R<=50cm	A01-0103JGJ80-91-3022	(x,y,z)	Cover
01010004	R<=150cm	A01-0104JGJ80-91-3022	(x,y,z)	Steel bar protection net
01010005	R>=150cm	A01-0105JGJ80-91-3022	(x,y,z)	Handrail and protection net

5. Experiment and demonstration

In order to demonstrate the feasibility and validity of the BIM-safety rule-integrated approach to automatically identifying unsafe design factors, a test platform is customized by combining Autodesk Revit and Unity 3D. IFC (Industry Foundation Classes) is applied as the basic standard for BIM modeling.

As an experiment, the windows of a four-story building was used to test the above approach. At first, the BIM model of the building was built with Autodesk Revit. During the modeling process, component ID was configured for each of components (windows). Other parameters, e.g. position and size, can also be easily extracted from BIM model, as shown in Figure 3.

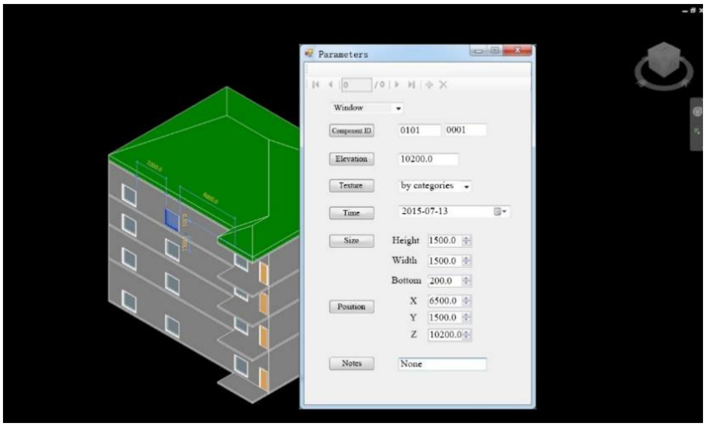

Fig. 3. Properties of windows extracted from BIM model.

Then the building information model was imported into Unity 3D, which has been linked with design safety rules. With the aid of a script, the Unity platform extracted the window's component ID - "0101", and searched for the safety rules with the ID like "A01-01XXXXXXX-XXXX". As a result, the attribute parameters of this window was compared with the safety rule. In this case, as the window's elevation is higher than 1.2m and its height and width are all larger than 1.5m. According to safety rule A01-0104JGJ80-91-3022, a 1.2m-high guardrail is needed, thus being recommended as shown in Figure 4.

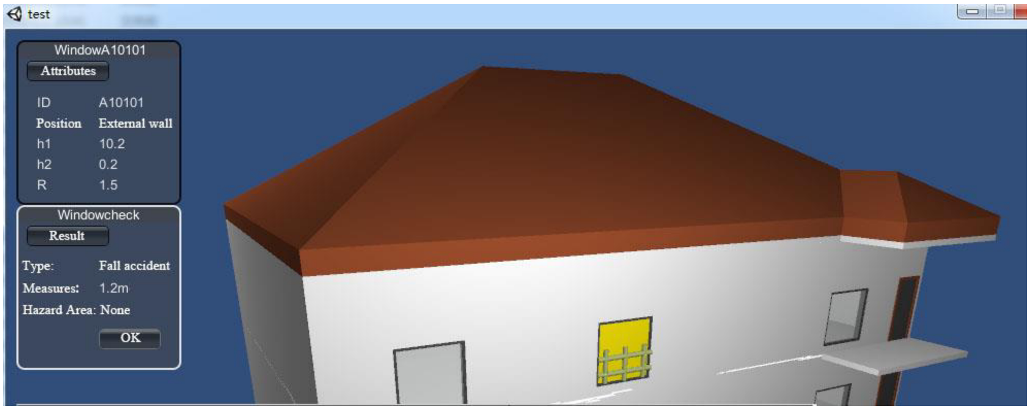

Fig. 4. Identification results of the unsafe design factors of windows

6. Conclusion

As shown in this paper, construction safety is a serious issue in construction industry. Design for safety, which means take safety into consideration during design period, is considered as an efficient method to solve this problem. However, due to the dynamics and complexity of construction projects and the diversity of safety-related rules, it is difficult to identify unsafe design manually. To solve this problem, a safety rule and BIM based platform is developed to identify and rectify unsafe design automatically.

The proposed platform is realized by the following procedures:

- A safety rule system is built by categorizing safety rules and then extracting basic and necessary information from them. Besides, each rule is attached to a unique code.
- Each component is matched with a unique component code, which represents its properties and parameters.
- Components information is extracted from BIM and each component is paired with safety rules by matching component ID and safety rule ID.
- By comparing component parameters and related information in safety rules, unsafe design factors are identified and rectified.

Based on the above framework, an experiment is executed and prove the feasibility of the framework. However, a fully developed platform is expected to be developed by enrich the safety rule system and allow the safety identification of a dynamic construction process.

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