Safety Regulation Classification System to support BIM based Safety Management

Rahat Hussain[a] Do Yeop Lee[a], Hai Chien Pham[a] and Chan Sik Park[a]

[a]Department of Architectural Engineering, Chung Ang University, Seoul, South Korea

E-mail: rahat4hussain@gmail.com , cpark@cau.ac.kr

Abstract –

Construction accidents, injuries, and fatalities have not declined significantly, despite continuous efforts from researchers, safety professionals, and strongly-enforced safety laws. In managing safety, construction personnel are required to access a variety of rules, regulations, guidelines, and documents. However, finding the right contents, and communicating them to right person tends to be tedious and time-consuming, because construction safety information is not systematically structured. This study contributes to addressing this issue by introducing a system framework for integrating BIM dataset with classified regulation document. To accomplish the study objective, a general classification system is developed for safety rules using criteria that can reflect safety rules in BIM environments. To demonstrate, the OSHA's safety and health technical guidelines are selected to classify the legal provisions into safety management steps and tasks aiming to integrate with construction work sequence. From classified safety rules, four different cases are presented to show the practical implementation of classification system. The developed approach is expected to reduce oversights, enable to deliver the relevant safety rules at the right time, and reduce the efforts required for searching through safety contents.

Keywords –

Information Modeling; Construction, Safety Management;

1 Background and Introduction:

The Construction industry is characterized by a number of risk factors due to its complexity and diverse tasks. In managing safety, construction personnel are required to access a variety of rules, regulations, guidelines, and documents. With the advancement of building technologies and Building Information Modelling (BIM) has been recognized as a significant tool for architects and other construction safety practitioners. However, due to the overwhelming number of safety rules and the complexities inherent with them, finding the right contents and communicating them to right person tends to be tedious and complicated. Therefore, it is difficult to expect that clients and construction workers will be aware of the current complicated safety regulations and capable of fulfilling their obligations. These challenges require well-defined and structured rule documents that can be identified and applied automatically to building software models with least human interaction.

The emerging trend of BIM adoption in the architecture engineering and construction (AEC) industries proves to be a valuable solution for the aforementioned problems [1]. One of the promising features of BIM technologies is to integrate safety rules with BIM objects, which is useful for verifying regulations using object characteristics of building models. Parametric and information intensive building objects can represent their own properties as well as related regulation information. Automation of rule checking during design and planning phases of a project has been suggested by different researchers with various approaches. Some efforts focus on mapping text intensive rules from human language to machine readable formats i.e. interpretation of safety rules. These methods are based on standard BIM format, introduced by BuildingSMART, Industry Foundation Classes (IFC) [2]. For example, a remarkable approach is CORENET ePlanCheck, which is the most comprehensive effort for automated rule checking [3].

The ongoing problem in checking rules is the interpretation of safety regulations during planning and executing the models. Rule interpretation is a critical stride for the development of an automated rule checking process. One of the key challenges in rule interpretation is to systemize and classify the set of rules. Safety authorities such as OSHA offer text based, HTML web based data for site safety management. However, the deployment of these safety information on actual sites is arduous due to the informal classification of rule sets. Moreover, when attempted for rule interpretation on site, designers and safety managers are not capable to track the exact job related rule within specific task categories or project phases.

In order to overcome these issues, this research envisions to improve construction site safety by introducing a rule classification system for OSHA's rules document that can be integrated later with existing BIM applications. To accomplish the study goals, OSHA's safety and health technical guidelines are selected to classify the legal provisions into safety management steps and tasks. To ensure the rule applicability with BIM object, the development level of BIM required by the legal clause is considered to classify the provisions of the safety and health technical guidelines. Following the classification, four cases are highlighted by considering various OSHA regulations. The proposed classification approach could help safety practitioners reduce oversights, enable the delivery of the relevant safety rules at the right time, and reduce efforts required for searching through safety contents. In addition, by adopting this system, the accuracy of search results can be improved.

The current state of rule document structure, classification and research efforts is addressed in Section 2. The research methodology and proposed system framework for rule classification are described in the Section 3. Moreover, a classified set of rule with the further discussion about practical implementation of proposed system are included in section 3. The paper is concluded with a summary and discussion of the research contribution.

2 Literature Review:

Rule checking with different approaches based on computer model have been discussed by many authors since last few years [4,5]. Some studies developed code checking tools for regulations [6] and other efforts focused on the method of interpretation of rules into machine readable format [5]. Specific domain based studies are also available in literature, like code checking application for high rise buildings [4]. Some efforts are mainly focused on improving the applicability of these computable rules [7]. For instance, Zhang et al. [8], established a connection between job-semantic modelling of safety rules [8]. More specifically, Chi et al used ontology-based text classification (TC) to integrate safe methods recognized in current resources step and hazards associated with activity based on construction solution database, by using ontology based with unsafe conditions for job hazard analysis [9].

A very few of them have focused on classification of safety rule sets and issues related to them. Due to complexity inherent with rule structure, it is no longer a simple deal like the cases of true/false or if/then conditional parameters. Solihin et al. [2] highlighted three different types of issues associated with current safety rules structures. Arity issues, the rule conditions can be fulfilled with multiple approaches at once. Combinational issue, the rule conditions may lead to more than one possible solution path; these combinatorial problems may get hard to manage. The third important factor to determine the rule checking criteria on BIM application is the level of development (LOD) of building model. Higher the LOD, more informative object model can be expected [2] and more efficient to integrate the regulations. Safety rule with programmed action can support decisions to managers and help to automate the search for hazards to construction worker during work and other operations.

Occupational Health and safety Administration (OSHA), the safety regulation agency offer text based, HTML web page based safety regulations data for site safety management. The standard construction rule classification of regulations is based on major work tasks. However, there is a need to analyze the structure of each regulation for the formal deployment in practice by integrating with BIM objects. Zhang et al. [1] classified OSHA regulations for fall protection in three parts, definition part of the rule specifies the unsafe zone, General requirement part describes the prevention method/methods for the specific case scenario. The third part is related to prevention criteria which is the detail of prevention system [1].

Following the discussion, this study focused more on classification system for OSHA rules in depth in order to introduce a framework for better interoperation of rule. Next section focused on the methodology and explains about the proposed framework for its application.

3 Methodology and Framework:

Establishing safety regulation classification criteria and mechanisms for real time provision of rules to safety supervisors is an important part of safety management. To accomplish this task, a series of safety regulations and BIM model with rich object information should be integrated systematically. If any of them is not properly functioning, it is hard to derive the desired outcomes. Therefore, in order to build a rule mapping network, a comprehensive system framework is introduced by linking class of rule with a 4D BIM model (integrating a 3D model with work schedule).

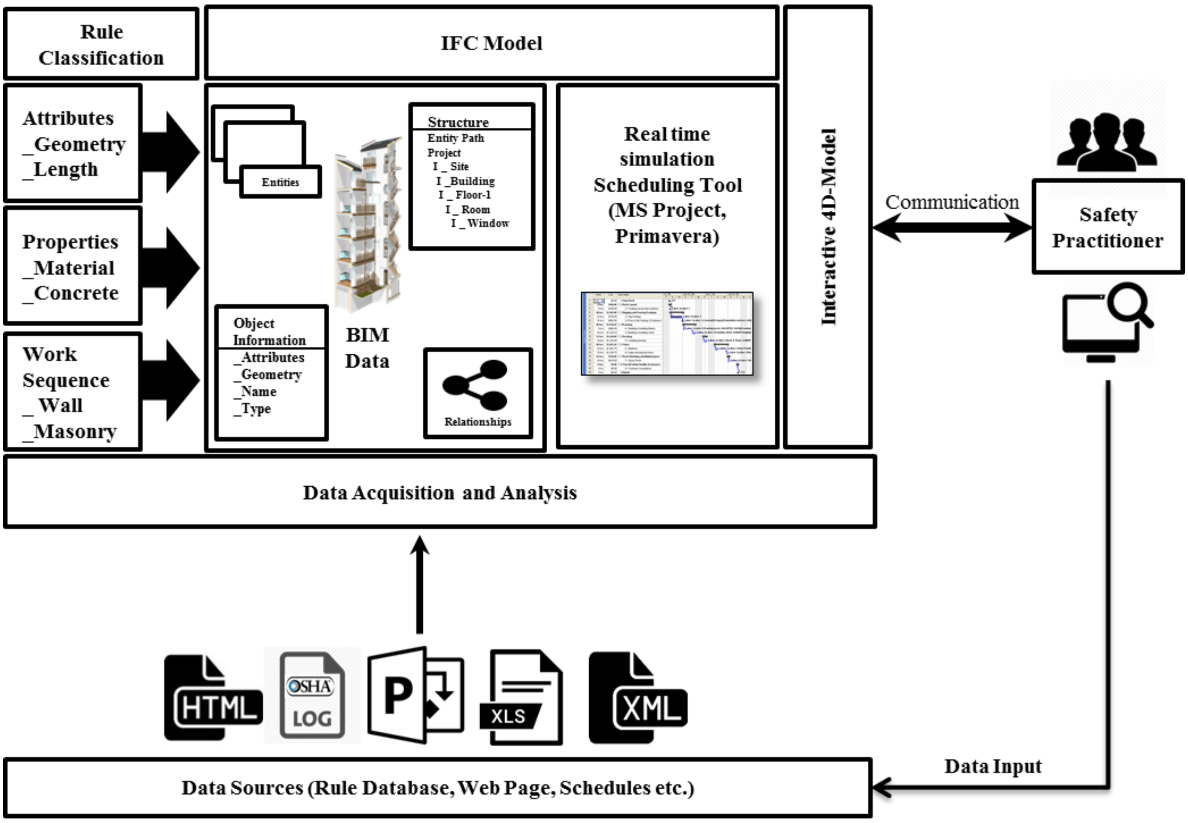

Figure 1. System Framework for applying safety rules with BIM model

While developing a standard classification, the safety document serves as an essential step to facilitate the whole proposed framework. In this paper, general classification criteria are proposed based on analysing OSHA regulation database. Fundamental criteria for rule classification are based on the actual needs of BIM model data. The classification criteria will be discussed in detail in the next section. Figure-1 illustrates the whole process of integrating classified rules with BIM model.

The system effectiveness is based on two fundamental steps. First, developing Rule classification criteria model. This model aims to provide a systematic structure of safety regulations for integration with relevant BIM components. Secondly, creation of 4D BIM model with rich context information of components. Prepare the semantic architecture 2D plan, following the 3D model by adding architecture objects and their properties. BIM data includes object information, work sequences of the building model, entities, properties and their relationships. The process of linking 3D model objects with the schedule information is mandatory for the successful application of the proposed framework. Safety practitioners can collaborate with BIM model by just receiving the respective regulation at each phase of building.

3.1 Development of criteria for rule classification

In order to establish the safety regulation review system, there is a gap to plan out what BIM based IFC models require. The Dataset in IFC model requires object attributes and entity references from rule statement. These may include object geometry, type of work, as well as work sequence which required a proper integration with work schedule. Based on the following discussion, the criteria for classification of rules are developed. However, since there is a limit to analyse all safety regulations and complexities inherent with them, a set of rules is classified according to the four different classes.

The selected set of rules is limited to 119 regulations and best practices which are collected from the OSHA's database for construction regulations. To explain the context in depth, most of the regulations are selected from a specific section of OSHA guidelines i.e. Concrete and Masonry Construction. The proposed classification criteria include following types of classes; Rule Characteristics, Work phase, Work Stage, Prevention Method. Each rule under consideration was analysed in such a way that it may be trackable easily by just mapping the respective class as shown in Figure 2. The ratios of analysed rules are given in Table 1,

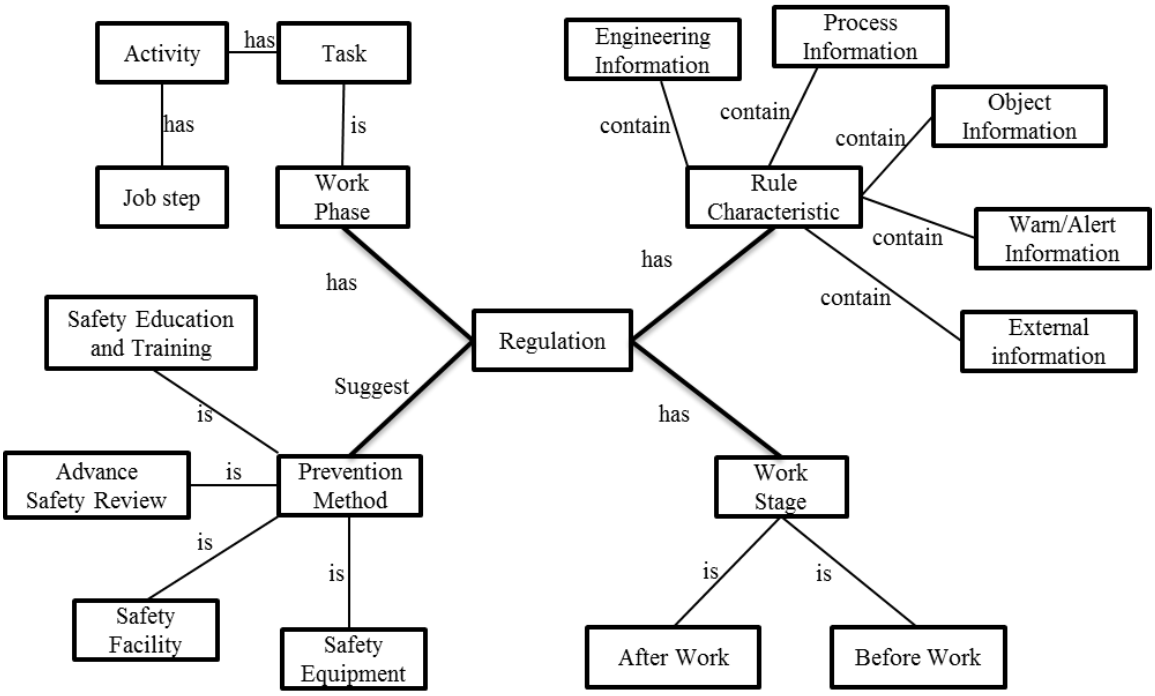

Figure 2. Criteria for mapping Rule Classification

which shows the proposition of rules considered with respect to their class and category.

Rule Characteristics: The analysis of regulation statement in terms of information is covered in category of rule characteristics. These characteristics may include information about engineering knowledge, warnings, detailed safe work process descriptions, object properties (numeric and non-numeric) and external information that can impact on site safety. Engineering information may consider the definition and explanation of specific safety terminologies. Therefore, it is necessary to review the construction safety regulations by considering the process information, which can be assigned to the BIM object.

Object properties in rule statement are considered important for rule analysis because numeric information in rule is one of the basic types of information required in BIM object modelling, including height, slope, width, heat flow rate, and strength. Studies in safety regulation state that numeric value is a prerequisite for reviewing the rule because one can logically review the text only by maintaining an algorithmic equation/table (example is given in Section 3.2.3).

Some regulations provide external information that is not supported by the BIM program or should be reviewed in conjunction with other safety guidelines. Unsupported information mainly includes weather information, country-specific standard material

Table 1 Data for Ratio of Classified Regulations

Category	Class	Percentage	Category	Class	Percentage
Work Phase	Before Work	61%	Work Stage	Task	5%
	During Work	19%		Activity	24%
	others	20%		Job Step	39%
Rule Characteristics	Engineering Information	39%		Others	33%
	Process Information	28%	Prevention Method	Safety Education	8%
	Object Information	15%		Safety Facility	20%
	External Information	8%		Safety Equipment	5%
	Warn/Alert Information	11%		Advance Safety Review	29%
				Others	39%

information and it should be reviewed by reading data constructed in a database format such as TXT or XML file. Therefore, it is necessary to develop the add-on program which can be run on the BIM platform by using the Open-API. Rule statement sometime contains warning/alerts for construction labour/practitioner, which can be deal in BIM model same like external information.

Work Phase: The analysis of regulation statement in terms of work phase. Rule information may be useful before the start of work or during the execution of work. Therefore, each rule is classified according to respective work phase, so that it can be helpful to determine the rule application time. To process this information in BIM model, it is necessary to integrate with time by simulating work phase information of the rule with the work schedule.

Work Stage: The analysis of regulation statement in terms of work stage i.e. task, activity or job step. The purpose of this class is to nominate that either a regulation is applicable for whole tasks or to its sub-activity or simply on a specific job step. This class will help to point out the specific and targeted stage of particular task. Single regulation may be applicable for whole task or for its one sub-stage. Construction of slab is a task and cutting of steel is the job step to accomplish this task.

Prevention method: The analysis of regulation statement in terms of suggested prevention method. Most of the regulations suggest a prevention system for unsafe tasks, which include safety education, safety equipment, advance safety review or additional safety facility. The selected set of rules is classified for each prevention system to easily access the solution of safety issue. Safety net is the one prevention system for fall from heights.

After the classification of rule sets, each rule can be integrated with respective object in BIM model and allowed to check the rule applicability. Checking of rule within the BIM model will suggest the prevention method or technique, according to the specific phase of project. This automated information acquired by BIM manager can be reported back to interested parties before execution of activity.

Some of the practical example cases are discussed in detail to elaborate more the research concept.

3.2 Practical implantation of Classification System:

3.2.1 Case-1:

OSHA Regulation:

"Load transfer from jacks/lifting units to building columns shall not be executed until the welds on the column shear plates (weld blocks) are cooled to air temperature". OSHA 1926.705(n)

Generally, the application of these types of rules include warn/alert information for advance safety review before the work starts. According to the statement, before removal of lifting units or transferring load to structural columns, one should ensure the mentioned conditions. This class of rules does not require any geometrical information or material properties of the object. However, this type of class is the set of rules that requires strict compliance. Moreover, this information can be involved further with BIM information model that can be transferred to the concerned manager while updating the project.

3.2.2 Case-2:

OSHA Regulation:

"All vertical slip forms shall be provided with scaffolds or work platforms where employees are required to work or pass" (OSHA 1926.703(c) (3)).

After analysing the regulation statement, the following categories with classes can be derived: vertical slip forms are additional safety facility for the scaffolding activity of concrete casting. This engineering information should be provided to the relevant safety supervisor before the start of concrete work on site. Therefore, the classification for this rule will be; engineering information as rule characteristic, before work as a work phase, job step as a work state and safety facility as a suggested precaution method in the regulation.

Similar to case-1, this type of class is the set of rules that require a strict compliance for practical implementation. To do so, Solihin et al. (2015) suggested a separate knowledge base to consider this type of rule during BIM design as well as execution phase [2].

3.2.3 Case-3:

OSHA Regulation:

"All masonry walls over eight feet in height shall be adequately braced to prevent overturning and to prevent collapse unless the wall is adequately supported so that it will not overturn or collapse. The bracing shall remain in place until permanent supporting elements of the structure are in place" OSHA Regulation 1926.706(b).

This rule has a conditional statement about the attributes of the BIM object related to its geometry i.e. condition to check whether the wall height is more than 8 feet (2.44 meter). If the condition satisfies, the preventative measure which is additional facility in terms of bracing will be applicable. The default tabular format of rule interpretation is also shown in Table-2.

Irrespective of other cases, this type of class requires more details in the form of geometric attributes and properties of BIM objects. This type of rules can be

Table 2 Example of OSHA rule interpretation

Dimension criteria for wall	Hazard	Prevention Method
Height <= 8 feet (2.44 metre)	-	Not considered
Height > 8 feet (2.44 metre)	Overture/Collapse	Bracing

interpreted for BIM dataset easily by using SWRL rule. To maintain the geometrical consideration, the measuring units should be converted from U.S standard to metric during interpretation [8].

3.2.4 Case-4:

OSHA Regulation:

"Reinforcing steel: Reinforcing steel for walls, piers, columns, and similar vertical structures shall be adequately supported to prevent overturning and to prevent collapse." (OSHA 1926.703(d) and 1926.703(d)(1))

By reviewing the rule statement, the categories and respective classes can be derived as follows: Engineering information as well as warn alert information is provided in this rule. In other words, reinforcing steel needs safety facilities in terms of additional supports during construction. The work phase is during construction and the work stage is sub activity of major task. This class of rules needs well defined entities (walls, piers, columns) for processing in BIM model. Moreover, to process this class of rules, well-structured relationships among entities are also required. Hazard alert information is also included sometimes i.e. overturning and collapse.

4 Discussion

In order to classify the safety regulations effectively, it is necessary to switch from referencing document-based rule information and use digital information for review. Inaccuracy in searching for rules can be minimized by improving the rule classification system and combining rule information with the BIM model object information. In addition, through the incorporation of work schedules with BIM objects, safety information can be delivered at the specified time. The proposed regulation classification system can reduce the rule searching time, human input and finally affect the whole safety management process. This work also showed the example cases of four different OSHA regulations to demonstrate the objective in depth.

However, various limitations were revealed in the course of the research, and the following should be solved for the successful implementation of the regulation classification system with BIM. There is a limit to analyse all safety regulations and complexities inherent with them. Hence, a set of rules containing 119 safety provisions only are classified in the four different classes. The inefficiency in mapping rule information with object information may necessitate manual work during rule processing in BIM models. In order to overcome this issue, an ontology based algorithm of rule documents can be developed to integrate the safety regulations with the object information of the BIM. However, there are still some clauses that cannot be reviewed solely based on BIM object information. These rules are designed for the general activities during construction. Therefore, it is necessary to define such rules in planning phase with each general work tasks in BIM based object model. Furthermore, a practical case study with an evaluation of the proposed system will be presented in future research.

5 Conclusion

Safety in the construction industry is directly connected to the lives of the workers and should be considered as a critical need of construction sites to avoid accidents and risks. With the increasing trend of technology in the construction industry, technology development and diversified nature of risks and hazards, current safety regulations have been revised in a complicated way. The regulations that are applied during different phases of project should be assessed and analysed to enable easier access and to reduce oversights. This research envisions to improve construction site safety by introducing a rule classification system for OSHA's rules document that can be integrated with BIM applications at a later stage. OSHA's safety and health technical guidelines for Concrete and Masonry Construction are selected to classify the legal provisions into safety management steps and tasks. In order to understand the rule processing, the information level of BIM required by the legal clause was mapped with the classified network. To this end, four different cases were selected to discuss the practical applicability of OSHA regulations. The proposed regulation classification system can reduce oversights, rule searching time and finally affect the whole safety management process. The next step of research will focus on the methods to improve the applicability and performance of the system more thoroughly through a real-world case study.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2016R1A2B3016694).

References

[1] Zhang, Sijie, Jochen Teizer, Jin-Kook Lee, Charles M. Eastman, and Manu Venugopal. 2013. “Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules.” Automation in Construction 29:183–95.

[2] Solihin, W. and C. Eastman. 2015. “Classification of Rules for Automated BIM Rule Checking Development.” Automation in Construction 53:69–82.

[3] CORENET e-PlanCheck: Singapore's Automated Code Checking System. http://www.aecbytes.com/archives/categories/feature.html

[4] Choi, Jungsik, Junho Choi, and Inhan Kim. 2014. “Development of BIM-Based Evacuation Regulation Checking System for High-Rise and Complex Buildings.” Automation in Construction 46:38–49. Retrieved (http://dx.doi.org/10.1016/j.autcon.2013.12.005).

[5] Pauwels, P. et al. 2011. “A Semantic Rule Checking Environment for Building Performance Checking.” Automation in Construction 20(5):506–18. Retrieved (http://dx.doi.org/10.1016/j.autcon.2010.11.017).

[6] Poças Martins, J. P. and V. Abrantes. 2010. “Automated Code-Checking as a Driver of BIM Adoption.” International Journal for Housing Science and Its Applications 34(4):287–95.

[7] Beach, Thomas H., Tala Kasim, Haijiang Li, Nicholas Nisbet, and Yacine Rezgui. 2013. “Towards Automated Compliance Checking in the Construction Industry.” Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 8055 LNCS(PART 1):366–80.

[8] Zhang, Sijie, Frank Boukamp, and Jochen Teizer. 2015. “Ontology-Based Semantic Modeling of Construction Safety Knowledge: Towards Automated Safety Planning for Job Hazard Analysis (JHA).” Automation in Construction 52:29–41.

[9] Chi, Nai Wen, Ken Yu Lin, and Shang Hsien Hsieh. 2014. “Using Ontology-Based Text Classification to Assist Job Hazard Analysis.” Advanced Engineering Informatics 28(4):381–94. Retrieved (http://dx.doi.org/10.1016/j.aei.2014.05.001).