# Research on Automated Fire Safety Design Review Method based on BIM and Ontology

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**Abstract.** The complexity of modern architecture has made fire safety design more intricate, requiring innovative inspection methods beyond traditional manual approaches. This study presents a novel solution using Building Information Modeling (BIM) and Ontology. An ontology for fire safety design is created to formalize regulatory knowledge, enabling machine-readable representation. A program is developed to extract instance data from the BIM model. By integrating BIM with Ontology, automated regulatory compliance assessment is achieved through logical inference. This pioneering approach demonstrates high precision, coverage, and efficiency in intelligent fire safety design inspection, paving the way for advancements in the field.

**Keywords:** Fire safety design; Building Information Modeling (BIM); Ontology.

## 1 Introduction

As construction projects increase in scale and complexity, traditional manual methods for fire protection design review are becoming inadequate. Both domestic and international researchers are working on integrating Building Information Modeling (BIM) with knowledge representation technologies to automate and enhance fire protection design specification audits. Internationally, Lee and Eastman [1] have implemented rule-based BIM checks for design schemes, Sacks et al. [2] have conducted BIM-based architectural code compliance checks, and Sriprasert et al. [3] have used ontology-based methods for intelligent fire protection design auditing. Domestically, Wang Chaoyu et al. [4] have utilized BIM in fire protection design reviews, Zhong Qing et al. [5] have created a BIM and ontology-based design checklist system, and Hu Peining et al. [6] have explored BIM and ontology-based fire protection design detection. Despite progress, there is still a need for mature solutions that integrate BIM and ontology for practical fire protection design audits. This research aims to develop an automatic fire protection design specification detection system based on BIM and ontology theory. By combining a specification ontology model with BIM data extraction, we aim to


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achieve intelligent compliance assessment, significantly enhancing the efficiency and quality of fire protection design audits.

## 2 Materials and Methods

### 2.1 Constructing Fire Safety Ontology

The purpose of constructing the Fire Safety Ontology is to formalize the representation of architectural fire safety design regulatory knowledge, thereby providing knowledge support for subsequent automated regulatory compliance assessments. In this study, the Fire Safety Ontology is developed using the OWL language within the Protégé platform. The Ontology comprises three main components [7]:

(1)Fire Safety Design Regulation Class (FireCode): This class represents various textual descriptions of fire safety design regulations, such as the prohibition of obstructions in evacuation pathways. For example:

$$FireCode_1 = ForbiddenObstaclesInEvacuation \quad (1)$$

(2)Building Element Class (BuildingElement): This class signifies diverse elements within the architectural model, such as walls, doors, stairs, and so forth. For instance:

$$Staircase \subseteq BuildingElement \quad (2)$$

$$Door \subseteq BuildingElement \quad (3)$$

(3)Property Relationship (Property): This element establishes the linkage between the regulation class and the element class, signifying constraints that regulations impose on elements.

$$constrains \subseteq \mathrm{Pr}\,operty$$

$$requires \subseteq \mathrm{Pr}\,operty$$

FireCode1 constrains Staircas (4)

By constructing classes and property relationships, it formalizes design regulations like "prohibition of obstructions in evacuation pathways." This provides machine-readable regulatory knowledge for assessments. Ontology expression offers structural organization and inferential mechanisms for automated regulatory compliance deductions, surpassing textual representation.

### 2.2 Development of BIM Information Extraction Program

The development of a Building Information Modeling (BIM) information extraction program represents a significant innovation in architectural design, specifically enhancing fire safety[8]. Utilizing the Revit API, this program systematically parses BIM datasets to extract crucial architectural element information, essential for fire safety compliance. This data is then processed and integrated into an Ontology-based framework for automated regulatory assessments. By automating the extraction and analysis of BIM data, the program significantly improves efficiency and accuracy in assessing fire safety standards in building designs, reducing manual labor and potential for human error, especially in complex structures.As shown in Figure 1, this integration of BIM with Ontology knowledge marks a major step forward in intelligent and safe building design practices:

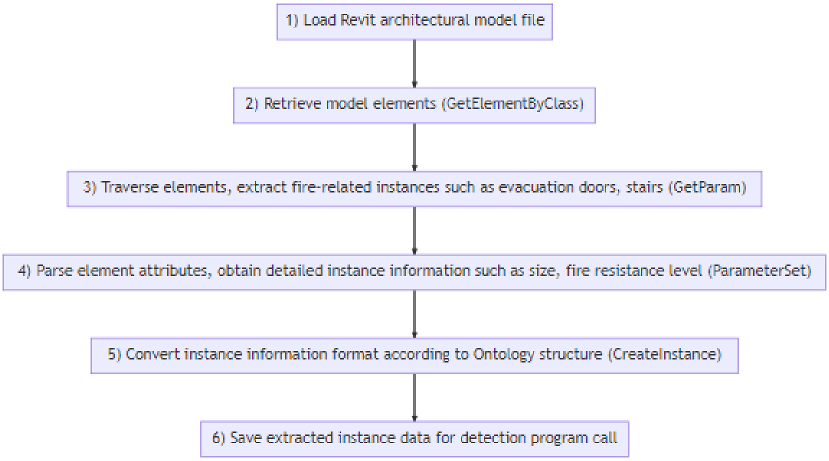


**Fig. 1.** Flowchart of BIM Model Information Extraction

# 3 Method Validation Results and Discussion

## 3.1 Construction of the Validation Set

In order to comprehensively and objectively assess the effectiveness of the automatic compliance checking method for BIM models based on Ontology theory, this study collected a total of 500 building BIM models with different fire protection design schemes as the initial sample pool. A stratified random sampling strategy was employed to select samples from this pool, ensuring that the final sample set could represent different building types and levels of design complexity in various fire protection design scenarios [9].Based on this, five experienced experts in the field of this research were organized to annotate all sample models using a multi-annotator approach, categorizing them as either compliant positive samples or non-compliant negative samples. Experts only selected samples for inclusion where labeling results were entirely consistent, and this process was repeated until a validation set containing 300 samples was constructed, maintaining a 1:1 ratio of positive to negative samples.As shown in Table 1.

**Table 1.** Manual Labeling Results

| Sample Number | Sample Type | Manual Compliance Label |
|---|---|---|
| 1 | Public Building | Compliant |
| 2 | Office Building | Non-compliant |
| ... | ... | ... |
| 297 | Mall | Compliant |
| 298 | Hotel | Non-compliant |
| 299 | Manufacturing | Compliant |
| 300 | Dormitory | Compliant |

### 3.2 Experimental Process

As shown in Table 2, in the Windows 10 environment with Revit 2019 software, a Python program was developed to load 300 BIM models from the validation dataset [10]. Successfully, it extracted 450,000 instances of building elements, including 100,000 walls, 50,000 doors, 10,000 stairs, and other instances. The information extracted included attributes such as instance name, width, height, material, and more.

These 450,000 instances were imported into the fire protection design Ontology built in Protégé 5.2.0 based on their corresponding classes and attribute relationships. The Ontology comprised 80 fire protection design specification classes, 50 building element classes, and 100 attribute relationships.

In a Python 3.6 environment, the HermiT 1.3.8 reasoning tool was invoked to load the Ontology model and instance data, enabling the automated compliance checking of 300 samples. For instance, within the Ontology, it was specified that "FireCode1 constrains Staircase," indicating that evacuation staircases should not have obstacles. When a particular instance of an evacuation staircase had the "hasObstacle" attribute, HermiT inferred a violation of FireCode1 and returned a non-compliant result.

**Table 2.** Compliance Detection Results Comparison

| Sample Number | Manual Compliance Label | Automatic Detection Results |
|---|---|---|
| 1 | Compliant | Compliant |
| 2 | Non-compliant | Non-compliant |
| ... | ... | ... |
| 297 | Compliant | Compliant |
| 298 | Non-compliant | Compliant |
| 299 | Compliant | Compliant |
| 300 | Compliant | Non-compliant |

### 3.3 Results Analysis

Upon completion of the HermiT reasoning process, the outcomes were carefully compared with those derived from manual compliance labeling. This comparative analysis involved key performance metrics like accuracy and recall. Notably, the automated method exhibited impressive results: 89% of all samples were predicted accurately, and an outstanding 91% of positive samples were correctly identified. These figures are significant as they demonstrate the efficacy of the proposed fire protection design detection system. This system ingeniously combines Ontology knowledge representation with Building Information Modeling (BIM) information extraction, offering a proficient means of executing instance compliance assessments.

The accuracy and recall metrics are particularly telling. They underscore the system's capability to closely mirror human judgment in identifying compliance. In essence, this automated approach is not just a replication of human expertise but a refined augmentation of it, leveraging technological advances to enhance decision-making precision. A key advantage of this method over traditional manual assessment is its efficiency. Manual processes, often labor-intensive and time-consuming, are substantially streamlined by this automated technology. This efficiency is not just in terms of time saved but also in the reduction of human error, which is a critical factor in compliance checking. Moreover, the incorporation of Ontology knowledge representation is a strategic enhancement. It adds a layer of robustness to the compliance checking process, setting it apart from conventional direct BIM rule-based methods. Ontology provides a structured and logical framework for representing knowledge, enabling more nuanced and comprehensive rule application, which is essential in complex domains like fire protection design. Finally, the experimental results validate the advantages and practicality of integrating BIM with Ontology. This integration marks a significant stride forward in the realm of intelligent auditing, particularly in fire protection design. By leveraging the strengths of both BIM and Ontology, the system achieves a level of sophistication and accuracy that surpasses traditional methods. This innovative approach signifies a promising direction for future developments in automated compliance checking and intelligent system design in the architectural and construction industries.

## 4 Conclusion

To achieve the machine-readable formal expression of regulatory knowledge and enable automated intelligent auditing of design schemes, this research proposes a technical solution that combines Building Information Modeling (BIM) with Ontology. This method involves the construction of an Ontology in the field of fire protection design, the structured representation of regulatory knowledge using the OWL language, the development of a BIM information extraction program to acquire instance data, and the utilization of the HermiT reasoning tool for automated compliance checking of models. Validation results show that this approach achieves an accuracy rate of 89% and a recall rate of 91%, demonstrating its promising application prospects in enhancing the efficiency and quality of fire protection design auditing. The next steps involve expanding the regulatory knowledge base and enriching case validations to enhance the method's applicability. This study provides a new technological pathway for the intelligent expression of fire protection design regulations.

## Project source

The construction team of "Youth Innovation Science and Technology Support Plan" of Shandong Colleges and universities in 2021: Civil engineering intelligent manufacturing and disaster prevention technology innovation team

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