S5-3

# REQUIREMENTS FOR AUTOMATED CODE CHECKING FOR FIRE RESISTANCE AND EGRESS RULE USING BIM

**Jiyong Jeong[1] and Ghang Lee[2]**

[1]Research assistant, Building Informatics Group, Department of Architectural Engineering, Yonsei University, Seoul, Korea
[2] Assistant Professor, Building Informatics Group, Department of Architectural Engineering, Yonsei University, Seoul, Korea
Correspond to Ghang Lee at glee@yonsei.ac.kr

**ABSTRACT:** The more repetitive, complex and objective the work, the more effective automation is. Code checking is an example of this. Checking building codes through a thick set of drawings is error-prone and time-consuming. In order to overcome this problem, several organizations have initiated efforts to automate building-code checking. Initiated study mainly focused on checking codes for invalidation, required size and crash, and then area of checkable codes have been expanding. But, it has not been considered for codes regarding anti-disaster/egress, which is also issued these days.
This study is about how to automatically check codes for anti-disaster and egress based on Korea building codes. The codes can be categorized as five sections: egress way, material/capability, principals of evacuation, evacuation stairway and fire protection partition. To check automatically, there are problems, such as expression of codes for egress and limitation of extractable information from the BIM model. This paper shows what problems exist and assignments to be resolved. Also, current developing processes are presented, and suggestions are made about the direction for the work that remains.

*Keywords: Automated code checking; Egress rule; Anti-disaster; BIM requirement; Fire-resistance*

## 1. INTRODUCTION

The more repetitive, complex, and objective a task is, the more effective it is when a computer does the work instead of a human, which is basic concept of automation. Automation will not only reduce time and resources but will also minimize errors. For instance, this is true for building code checking. As buildings become larger and more complicated, interest in them and the necessity for them are increasing. According to Jeffrey Wix [9], 85% of architects are interested in automated code checking as they spend, on average, more than 50 hours checking laws per project, and around 11% spend more than 100 hours.

It is now possible to share and manage the information of building life-cycle through the development of BIM, and efforts to utilize automatic law checking are in progress in many places[3,6,8,10].

Most automated code checking to date have been on the invalidation of spaces, fitness of object for standard and size needed in design process. However, there is not study for anti-disaster and egress rules, which is becoming increasingly important. That is because it is not a basic design check, but next step after compliance of that.

This study covers research on the automated code checking for pertaining to anti-disaster /egress rules, based on the Korea building code. The basic objective of these codes is to maintain buildings so that, if necessary, people can evacuate safely in emergencies. Therefore, if the results of this study are successfully implemented, building safety and cost savings should increase.

However, current software for automated code checking do not support specific function to check anti-disaster and egress rules. For instance, the geometrical interpretation of codes and attributes related to materials, etc., are still problematic. This study will show these problems and the current developments to solve them.

## 2. PURPOSE AND RANGE OF STUDY

Automated code checking will not only minimize missed part or errors but will also reduce inefficiencies

the time and effort spent on manual check. It will be more difficult as buildings become larger and more complicated, and requiring additional time for code checking. Thus, If code checking were automated, it would not only reduce errors and necessary resources (such as time, money, and manpower), but also make collaboration between institutions easier. It is one of the reason for necessity that codes must be checked accurately and fairly because building codes affect the profits/losses of owner in many ways and directly affect safety. Considering all of these benefits, automated code checking should be developed and used. As mentioned, buildings are increasingly larger and more complicated, making the automation of code checking is regarded essential instead of optional. It is difficult that covering all kind of codes at once because amount of codes is bulky and complex. So the scope of this study will be limited to automated checking for codes for anti-disaster /egress, which are important in ultra-large scale buildings.

## 3. LIMITATIONS OF THE CURRENT CODE-CHECKING SOFTWARE APPLICATION

The Solibri Model Checker (SMC) of Solibri Co., in Finland, is the most widely known software related to code checking. Although the development of SMC is ongoing, this program remains the only one that can check models[1]. The CORENET project of Singapore and the SMARTcodes of ICC in the U.S.A., both of which actively research code checking, are also using SMC for their development.

The functions and limitations of SMC are as follows. SMC was developed to quickly and easily introduce BIM with a small amount of risk. SMC checks faults in design models and analyzes model integrity, thereby reducing time and resources required for repeated work and enhancing quality at the design stage. Most BIM applications can be accepted due to using a standard IFC(Industry Foundation Classes) format[7].

BIM transforms building information into IFC formats to bring them into the program and then checks their suitability based on pre-defined rules. This program checks basic rules, such as whether necessary spaces keep standard, validation and constraints for specific objects. Through the Constraint Set Manager, users can configure their own check list to designate items using pre-defined rules and adjust associated parameters. In addition, the program displays results of checking by item visually and simply, and this facilitates the immediate preparations of detailed reports. The interfaces can be divided into two parts: code checking [Figure 1] and rule set configurations [Figure 2].

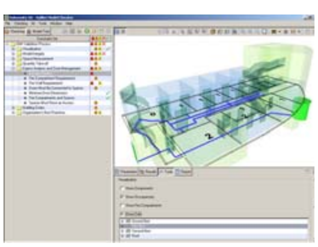


**Fig 1**
**SMC code checking[1]**

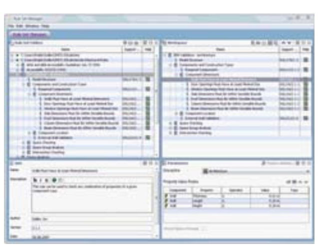


**Fig 2**
**Rule set configurations[1]**

There are several problems, however, in applying the current Korea building code to SMC.

First, criteria for the applications of codes are different. For instance, in measuring evacuation distances, Korea building code require measuring the distance on the basis of the longest straight distance from the reference point to the entrance. In contrast, SMC calculates the distance of movement through corridors from a door to door based on the fire egress rule of Finland.

Second, there are difficulties in adding new code. Adding code not in an existing rule set of items requires accessing the API(Application Programming Interface) for additional programming. The present SMC supports reviews of evacuation routes, fire wall requirements, etc., but does not support fire-protection partitions and requirements for materials for structural performances. In other words, whereas SMC supports work at the level of design reviews, such as checks of errors in designs, requirements for sub-materials and dimensions, etc., anti-disaster/egress rule that this study focus on needs an additional effort because it is following process that should be after basic checking.

Finally, there are technical problems. SMC follows the IFC international standard format, yet there are cases where errors occur in transforming files that make it difficult to do proper checking. However, this problem is not unique to SMC, but one that has to be solved from the technical aspect of BIM.

For the above-mentioned reasons, limitations were acknowledged in applying SMC to Korean anti-disaster/egress rules, and made a decision to process our own study. Because of additional work such as changing criteria for the applications of code and additional development for specific local codes, adopting to previous program takes as much as developing ourselves. Furthermore, it will process that expression of codes not defined for automated checking. Therefore, research for checking related codes are in progress, and they will be described in detail below.

## 4. METHODOLOGY

The purpose of this paper is to enable automated checking for codes regarding anti-disaster and egress. The problems will be elucidated and the current state of work in progress will be introduced.

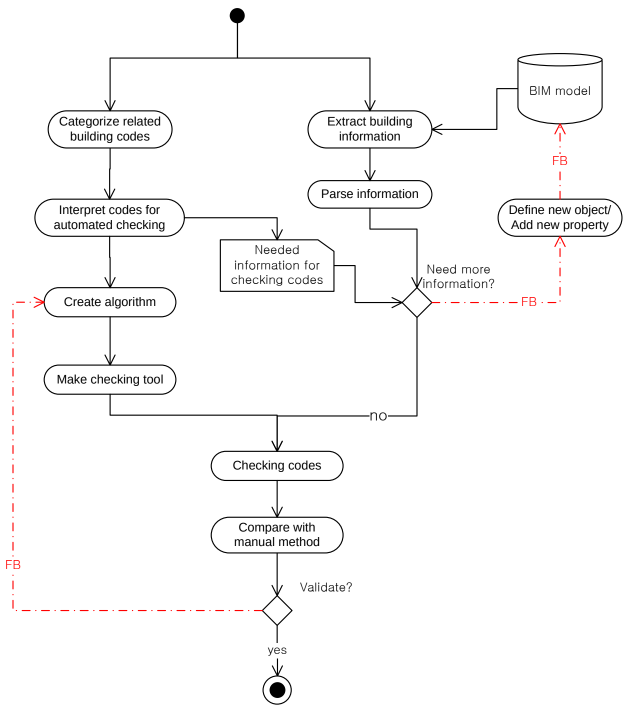



**Fig 3 Process of the study**

The research can be divided into two parts, as shown in Figure 3: re-interpretation of codes for automated checking and attributes that must be contained in a BIM model. These two parts will eventually be combined to facilitate automated checking. The process models were prepared using the Georgia Tech process to product modeling(GTPPM) tool[4].

## 5. CLASSIFY CODES

In order to set up automated code checking, we must re-interpret existing codes into a form that can be automatically checked. We start with the codes regarding anti-disasters and egress that are within the scope of this research.

The related codes extracted from the building codes under the control of the Ministry of Land, Transport and Marine Affairs[5] can be categorized into five groups discussed below [Table 1].

## 6. RE-ANALYZE CODES AND REQUIREMENTS FOR BIM MODEL

For automated code checking regarding anti-disaster and egress rules, the five development groups for implementation are as follows: egress distances, materials/performances, principles of evacuation, evacuation stairways, and fire-protection partitions. Among these five, two have already been developed through existing studies and are in use, egress distances, or can be evaluated on 2D, the principle of evacuation. The requirements for automated code checking and the problems in the remaining three categories are described below.

### 6.1 Material/Capability: Fire-Resistance

The part of materials and performances should be considered first, as there are few studies on automated checking. This section focuses on evaluating fire-resistant structures. The methods to check fire-retardant materials and non-combustible materials are similar and therefore omitted here.

Fire-resistant structures do not collapse quickly while people are evacuating in an emergency. Examples of related codes related are shown in Table 2.

In Table 2, (a) defines fire-resistant structures. This shows the attributes that certain sub-materials of buildings must have. For instance, the table explains walls as an example, and the regulations specify that reinforced concrete structures or steel-reinforced concrete structures with a thickness of 10cm or thicker are required in order to be certified as fire-resistant structures. This information should be prepared as algorithms in advance, so that they can be checked using only the necessary information. To this end, information on the materials and dimensions of sub-materials should be extracted from the attributes of the building to evaluate whether it is a fire-resistant structure.

**Table 8 Categorized code regarding anti-disaster and egress**

| Section | Related codes | Information for checking | Past study |
|---|---|---|---|
| Egress way | Regulation of Walkway distance with location of room, material, basic building information | Walkway distance<br>By floors<br>Connection of floors | ○ |
| Material/Capability | Major structural parts of specified building should be fire-resistant structure<br>Retardant materials and non-combustible materials | Use of building<br>Structure, material, dimension | X |
| principles of evacuation | Two-way principles of evacuation | Use of building<br>Floor area | △ |
| Evacuation stairways | Duty of installation for fire protection partitions / special fire protection partitions | Building stories<br>Structure, material<br>Fire protection door | X |

| | | | |
|---|---|---|---|
| Fire protection partitions | Criteria of installation for fire protection partitions | Information for dividing section<br>Floor area<br>Building stories<br>Material | X |
| Etc | Exception rule | | |

* Legend: O-exist several studies, △-can be applied 2D method, X-no study

**Table 9 Examples of codes related to fire-resistant structures**

| |
|---|
| (a) Reinforced concrete structures or steel-reinforced concrete structures with walls 10cm thick or thicker are fire-resistant structures.<br>(b) “Major structural parts” refers to supporting walls, pillars, floors, beams, ceiling frames, and main stairways. Intermediate pillars, the lowest floor, small beams, awnings, outdoor stairs, and similar parts (i.e., non-structural parts) are excluded.<br>(c) Cultural or meeting facilities (except for exhibition halls and zoos/botanical gardens) are religious facilities and buildings used for bars or funeral halls, with a total area for seating or the floors of meeting rooms of 200 $m^2$ or larger (1,000$m^2$ for outdoor viewing seats). |

Processes to evaluate fire-resistant structures with information extracted from walls are currently being developed [Figure 4].

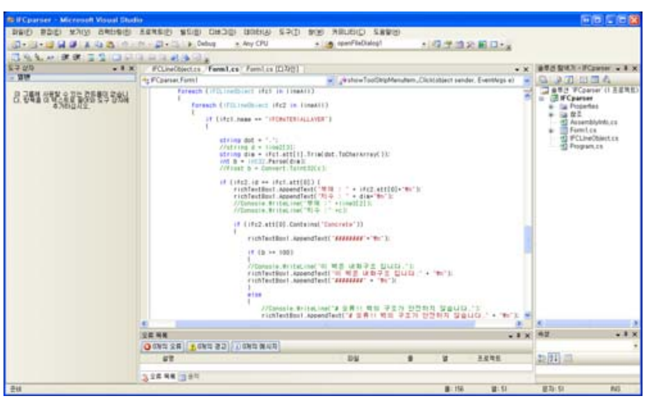


**Fig 4 Programming for code checking**

Most of processes for checking fire-resistant structures are implemented on major structural parts. In Table 2, (b) major structural parts are defined. Major sub-materials in the buildings are also included. However, the fact that exceptional parts are not clearly defined is a problem for automated checking. Exceptions have been evaluated by people based on the structural roles of sub-materials, but clear criteria and bases are necessary for a computer to evaluate them. Therefore, the criteria should be more strictly delineated, and determining how to treat exceptional cases is still a problem.

If it becomes possible to determine whether major structural parts are fire-resistant, then it will be possible to evaluate the codes applied to buildings. Item (c) in Table 2 shows examples of codes regarding the criteria for subjects of consideration. Buildings are evaluated on whether they are subjects for checking, taking into consideration both the buildings and their areas. Buildings are evaluated on whether their major structural parts satisfy criteria as fire-resistant structures. The checking screen applied with the actually developed program is as shown in Figure 5.

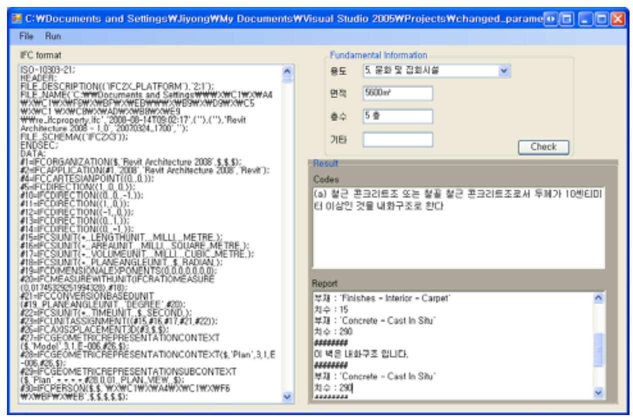



**Fig 5 Program for checking fire-resistance**

### 6. 2 Evacuation stairways

This section discusses evacuations through stairways in an emergency. The codes determine the number of evacuation stairways and the necessity of special evacuation stairways based on the scale and use of a building.

Below are several examples of the major contents [Table 3].

**Table 10 Examples of codes regarding evacuation stairways**

| |
|---|
| (a) The number of evacuation stairways = (Total of the floor area for relevant use -2000㎡)/2000㎡<br>(In addition to direct-access stairways, a stairway should be installed per each 2,000$m^2$ over a floor area of 2,000㎡, for the safe use of the floor, and the direct-access stairway should be installed separately so that it |

cannot be used from the 4th floor or lower floors)

(b) Direct access stairways installed on the 5th floor or higher floors or in the 2nd underground floor or lower floors should be installed as evacuation stairways or special evacuation stairways.

(c) Regulations for exceptions

1. If the total of floor areas of the 5th floor and higher floors is 200m$^2$ or less

2. If fire-protection partitions are installed per the floor area of 200m$^2$ or less on the 5th floor and higher floors

Before checking the above codes, it is necessary to first indentify the definitions of direct-access stairways, evacuation stairways and special evacuation stairways. First, direct-access stairway refers to a stairway connected to the evacuation floor or to the ground floor.

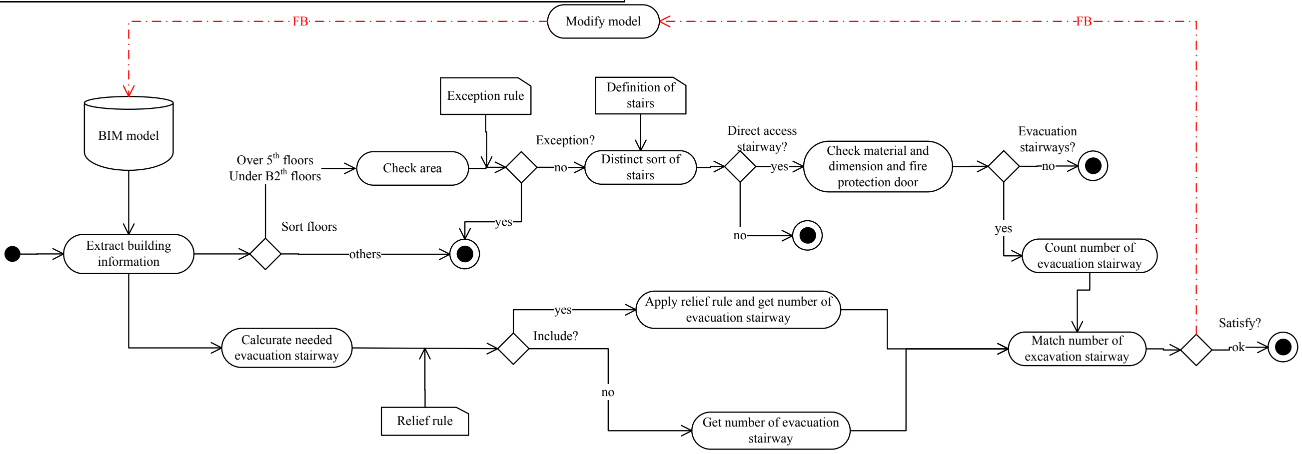



**Fig 6 Checking process for evacuation stairway**

In other words, it refers to the stairways connected to enable evacuation at once instead of requiring people to go down a stairway and move along a corridor connected to another stairway. Of direct access stairways, evacuation stairways are finished with incombustible materials and equipped with spare lighting and fire-protection doors, thus they are safer direct-access stairways. Special evacuation stairways refer to those evacuation stairways equipped with double fire-protection doors.

Therefore, what must be checked first is determining whether stairways have direct access. Direct access is not separately designated as an attribute in IFC and must be separately defined. The simplest way is to define and enter new attributes using 'propertyset' at the time of modeling (propertyset can define attributes not supported by IFC). But this is not automation in a strict sense because it requires additional manual work. If propertyset is abused, another problem will be issued, interoperability. Ideally, stairways must be automatically recognized as direct-access stairways. It must therefore determine whether these stairways are connected to an evacuation floor or to the ground floor or to stairs connected to either or both. Studies on evacuation floors[2] are actively being performed, so the process to reflect them in BIM models should be implemented first.

If direct-access stairways can be identified, evacuation stairways can be identified by checking the materials to determine whether the stairways were built with noncombustible materials and whether extra lighting and fire-protection doors have been installed. Furthermore, in the case of special evacuation stairways, it is necessary to have fire-protection doors and to identify them as double fire-protection doors or as two fire protection doors within a certain distance. The kinds and performance of fire-protection doors will be explained in the section for codes regarding fire-protection partitions below.

Once the kinds of stairways are identified, whether they meet the required standards has to be determined. For instance, suppose that the 7th floor is 5,700$m^2$. Since an evacuation stairways are necessary for the 5th floor and higher, based on the calculation formula in Table 3,

The number of evacuation stairways =

$$(5,700 - 2,000)m^2/2,000\ m^2 = 1.85$$

Consequently, about two evacuation stairways are necessary. Therefore, if there are two or more evacuation stairways in BIM models, they are suitable.

Exceptional provisions can be checked by considering areas, and stairways need not be checked for floors that are not applicable.

The algorithm for reviewing evacuation stairways is illustrated in Figure 6.

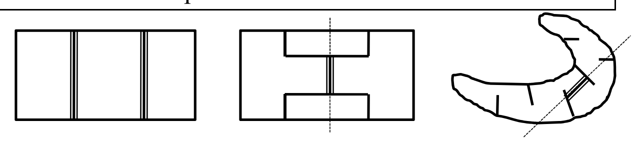
### 6.3 Fire protection partitions

Fire protection partitions are designed to physically block a fire in a large building to prevent the fire from spreading to throughout the building and to minimize fire damage.

How to express the fire protection partitions in the BIM model is an issue. Currently, most of BIM modeling tools can label or name certain spaces (rooms) but cannot partition desired spaces that are not rooms and then give attributes to them

**Table 11 Examples of codes regarding fire protection partitions**

| |
|---|
| (a) Buildings having fire-resistant structures or structures made of incombustible materials with the total area of 1,000$m^2$ should be partitioned with floors, walls and first-class fire protection doors, in accordance with the criteria defined by the decree of the Ministry of Land, Transport and Marine Affairs.<br>(b) Floor unit: Fire protection partitions should be installed on the 3rd floor and higher and underground floors (regardless of areas)<br>(c) Area unit<br>–The 10th floor and lower: Each floor area of 1,000$m^2$ or less should be partitioned<br>– The 11th floor and higher: Each floor area of 200$m^2$ or less should be partitioned |



(a) (b) (c)

Fig 7 Expression for fire protection partition

To express fire protection partitions, first, the definition of the attributes of fire protection doors should be clear. In Table 4, for instance, the first class fire protection doors are equipped with performance features that passed the test criteria of the Ministry of Land, Transport and Marine Affairs. These criteria specify that the doors are always closed or automatically closed by heat during a fire. However, current modeling tools do not separately support objects for fire protection doors so their attributes should be defined by the propertyset for walls or doors. Standardized fire protection doors should be added to the BIM library so that fire protection doors can be regarded as an object within the IFC format.

If attributes of fire protection door is defined clearly, it can be used for criteria that divide fire protection partition. However, the way to automatically represent partitions is not simple. For instance, in Figure 7, (a) is made of a simple structure that can be considered using form that consist of fire protection doors and outer walls. But in the case of (b), the fire protection doors are connected to the inner walls so a different method should be used. Since most buildings are symmetrical and likely to have similar areas for fire protection partitions, a method is needed to divide these into fire protection doors plus an extension and a part used as an outer wall. Since asymmetrical structures like (c) or other exceptional structures may occur, studies on a method to define fire protection partitions automatically should be clarified.

Once it has become possible to define fire protection partitions on BIM models, the area unit and the floor unit should be checked, if they satisfy the requirements for fire protection necessary for that building. As a method for check, if the area of the fire protection partitions on each floor is smaller than the defined criteria, the building can be considered to be in conformance with the code.

Regulations for sprinklers and certain materials have been eased, to implement this loosen rule, it should be studied.

## 8. FURTHER STUDIES AND CONCLUSIONS

By now, methods to check codes regarding anti-disaster and egress and related problems have been examined. Major matters include the issues of how to extract the information needed by codes from BIM models as attributes, the issue of expressing codes and the obscurity of codes. These problems can be solved by making rules to define attributes manually at the times of modeling, such as propertyset. However, removing such rules must be automated. Therefore, studies should be implemented to reduce such rules.

Furthermore, if the sub-materials used in modeling tools could be standardized in their performances or grades through testing or certification systems, more efficient and accurate checking of codes will be possible. Also, going further from documented information to providing visual information using 3D for users to enable not only the identification of outcomes but also the direct corrections will maximize the efficiency of the program.

Expecting that this study will become the first step toward other studies on automated checking for codes related anti-disaster and egress, this author will expand the area of program development.

## ACKNOWLEDGMENTS

This work was supported by the Korean Institute of Construction & Transportation Technology Evaluation and Planning (KICTEP) with the program number of "06-Unified and Advanced Construction Technology Program-E01."

## REFERENCES

[1] AECbytes, Solibri Model Checker, Lachmi Khemlani, (Mar. 31, 2009).

[2] J.-P. Choi, B.-J. Kang, Y.-S. Park, Y.-J. Lee, Schematic development of 'Refuge Floors' and 'Areas of Refuge' for high-rise buildings, Architectural Institute of Korea 21 (11) (2005).

[3] E.A. Delis, A. Delis, Automatic fire-code checking using expert-system technology, Journal of Computing in Civil Engineering 9 (2) (1995) 141-156.

[4] G. Lee, R. Sacks, C. Eastman, Product data modelling using GTPPM - A case study, Autom. Constr. 16 (3) (2007) 392-407.

[5] MLTM, Ministry of Land, Transport and Maritime Affairs (http://www.mltm.go.kr/) (Feb. 15, 2009).

[6] I.A. Santos, F. Farinha, Code checking automation in building design: new trends for cognition, Computing in Civil Engineering 2005, Vol. 179, ASCE, Cancun, Mexico, 2005, pp. 14-14.

[7] Solibri, http://www.solibri.com, (Mar. 9, 2009).

[8] X. Tan, A. Hammad, P. Fazio, Automated code compliance checking of building envelope performance, Computing in Civil Engineering 2007, Vol. 261, ASCE, Pittsburgh, Pennsylvania, USA, 2007, pp. 32-39.

[9] J. Wix, BIM Automated code checking based on SMARTcodes, BuildingSmart Forum (2008).

[10] Q.Z. Yang, X. Xu, Design knowledge modeling and software implementation for building code compliance checking, Building and Environment 39 (6) (2004) 689-698.