BIM as a Structural Safety Study Tool in Case of Fire - BIMSCIP

Marcelo Franco Porto
School of Engineering, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil
marcelo@etg.ufmg.br

and

José Ricardo Queiroz Franco
School of Engineering, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil

and

Luiza Giori Barcellos Correa
School of Engineering, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil

and

Lucas Vinicius Ribeiro Alves
Coltec, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil

and

Renata Maria Abrantes Baracho
School of Information Science, Federal University of Minas Gerais
Belo Horizonte, Minas Gerais, Brazil

ABSTRACT

In making a brief recapitulation, one can see that the invention of technological instruments was present throughout the history of mankind. This is because one of the major functions of technology and the reason why many researchers are committed to its improvement is the development of new tools that allow human life to improve, whether it is in order to overcome difficulties, optimize time, safety or others. In this article we will discuss how technology can be used to contribute to the safety of humans with regard to fighting fire and panic. The goal is to provide a faster and less error-prone standard checking process than the manual method currently in use. The process of creating a plug-in for a BIM environment, to verify compliance of the standards of the Fire Department of Minas Gerais will be described. Emphasis will be given to the development of a code to implement the automatic checking of a group of technical instructions for the structural safety of buildings in cases of fire. The project was developed inside the Federal University of Minas Gerais, sponsored by the Federal Government, and will be given to the Fire Department as a donation, in order to contribute for society. The plug-in is already able to read the project and return consistent results.
Keywords: BIM, Structural Safety, Code Checking, Spatial Analysis, Revit.

1. INTRODUCTION

One of the important safety aspects of a building in case of fire is the possibility of a safe evacuation, which depends essentially on the human behavior and the necessary time [1]. When considering the necessary timing, the study of Chu Guaquan, Wang Jinhui and Wang Qingsong [2] concludes that the fire risk is divided into two parts: probability and consequence. The probability is associated with the number of possible foci of fire, while the consequence is related to the speed with which the fire can be propagated in a certain place.

BIM - Building Information Modeling is today an important tool available for the development of Fire and Panic Systems - FPS. The term BIM, in this context, refers to concepts for the development of a software category, which gathers information from an enterprise from its inception, encompassing the design, construction and maintenance phases of facilities (post-construction) to the end of the demolition life cycle [3]. These characteristics give BIM technology great potential for development. This potential is recognized and cited in studies such as "BIM and fire protection engineering" [4], where it is demonstrated that the project constructed from BIM directives only depends on the amount of information it contains so that the analysis is as close as possible of the actual situation of a fire. Thus, projects developed using methodologies to apply BIM concepts allow complex analysis of the data generated through an intelligent processing of this information [5]. For example, the construction of software based on specific rules, to comply with recommendations in case of fire.

In the case of fire and panic prevention and combat, the technical instructions of the Fire Department must be taken into account, which detail a series of requirements that, when performed efficiently, are of fundamental importance for prevention and combat.

In this article we will discuss the process of creating a plug-in, called BIMSCIP, which is compatible with Revit software, whose purpose is to verify the technical instructions of the Fire Department of Minas Gerais [6]. Emphasis will be given to Technical Instruction No. 06: Structural Safety of Buildings. To verify compliance with a Technical Instruction in a project, it is necessary to use a code checking tool (plug-in) developed for automatic checking of the model. An automatic check consists of the validation and verification procedure, which aims to determine if a given content conforms to a particular standard, code, regulation and others. This validation is then performed by predefined criteria and look for results in the form of Yes / No [7].

Although the system (plug-in) is still in the initial stages of testing, it has already achieved satisfactory results, returning consistent outputs, and may soon be implemented in practice by the Fire Department of Minas Gerais.

2. DEVELOPMENT

2.1. State of the art

With the advent of BIM technology, various analytical software and automatic checks have been created to serve diverse areas such as hydraulics [8], renewable energies [9], foundations [10], among others. For all these demands, what is observed in common is the goal of automation and greater agility in the execution of different processes.

It is worth mentioning that, even in CAD platforms, it is possible to perform automatic checking, despite greater difficulties and lower efficiency. Similar to BIMSCIP, the system PROSCIP, was developed for the same purpose of automatically checking compliance of the Fire Brigade of Minas Gerais standards. The software PROSCIP uses 2D models in a CAD environment, which provides less information and presents more difficulties to perform changes in the project. BIMSCIP, on the other hand, is a system developed for a BIM platform, based upon parameterized 3D models, which encompass much more incorporated information..

Correlated Work

Regarding the evaluation of fire situations in a BIM environment, we highlight the works that aim to determine the fire resistance of structural elements, using finite element modeling and the exchange of information between studies of thermal behavior of materials and structural analysis software [11,12,13]. Such work shows great importance in the resistance of masonry to fire and can be taken as a basis, for example, in the creation of standards such as IT06, which defines the fire resistance to be considered for each type of masonry.

Also noteworthy are works related to the evacuation process of a place in case of fire. An example is the study that shows that the integration of fire monitoring systems between nearby buildings can reduce fire response time by more than 50% [14]. Another example is the study that suggests that fire alarms could also inform safe escape routes and in how many minutes the building should be evacuated [4]. One can also cite the work of Uwe Ruppel and Kristian Schatz, which demonstrate how to create an algorithm to simulate decisions of a human being in case of a fire, since it is impossible in practice to create rescue tests on burned buildings [15]. The proposed simulation is based on games in three dimensions (3D) and takes into account the five senses of the human being in decision-making. For example, in very hot places, the algorithm gives the option of avoiding that route, since somebody could suffer burns.

Nevertheless, these works aim to show aspects of the analysis of resistance of the structural elements or human behaviors generated in case of fire, not including fire prevention through automatic checks using resources of a BIM environment, as is the proposal of the present work.

BIMSCIP

The BIMSCIP system was started with the objective of creating an application capable of simple and automated verification of the requirements of each Fire Department Technical Instruction – IT - each section of the project analyzes a set of rules, such as the provision of fire doors and spacing between fire extinguishers and others.

The project was based on the CAD system, PROSCIP, which essentially has the same functions as BIMSCIP, to analyze 2D CAD projects, but without the resources of BIM The construction of a fire and panic system for a BIM platform is a result of an urgent demand for better and more reliable technologies. The BIMSCIP system was created, based on the concepts and standards of BIM technology, seeking more practicality in the development dynamics and more time saving in the development of projects.

Because Brazil adopts a prescriptive approach with regard to fire safety, unlike countries such as the United States, England and Australia, which are shifting to a performance-based approach [16], a system for automatic verification of prescribed standards by the Fire Department of Minas Gerais was developed. In addition to using a BIM platform for user interaction and project reading, the aim of the system is to automate the task of checking standards for designing firefighting and fire prevention projects. Remembering that currently, this check is done manually, which can generate many errors and require a lot of time.

This article will deal specifically with Technical Instruction number 06 of the General Fire Department, called "IT06 - Structural Safety of Buildings". In order to fulfill its objective, the work will include the analysis, in BIM environment, of structural safety in case of fire of the buildings, modeled in BIM platform. Similar studies were not found in the literature review, which highlights the importance of this study.

2.2. Methodology

To achieve the expected objectives for the BIMSCIP system the following steps were met:

I. Analysis of the technical instructions and the respective ABNT[1] standards involved in the process.

II. Definition of the interaction model with the user. Interface that allows the presentation of technical standards, obtaining information to be added by the user and displaying the results.

III. Definition of the computational environment for development.

The development of BIMSCIP relied on two main programming environments, Microsoft Visual Studio Ultimate © 2012 and Autodesk Revit.

The Visual Studio environment was used to create code in C # language. The choice of this language allowed the interaction and interoperability between the team members.

[1] ABNT: Brazilian Technical Standards Association. Similar to ISO in the international scenario.

The Autodesk Revit .NET application programming environment (API) enabled the custom development of BIMSCIP with the creation of directly executable tools on the Revit platform.
IV. Implementation.
V. Tests.
The design of the building of the School of Engineering of UFMG was defined as a test model, with the appropriate adaptation of the parameters necessary for the operation of BIMSCIP.
VI. Analysis of Results.

2.3. Development

An important concept of structural safety of buildings is the evacuation time in a fire situation, which should be sufficient to enable a safe evacuation before the collapse of the building. To that end, Technical Instruction 06 (IT06) establishes that the structure must present equivalent time of fire resistance and fire resistance time of masonry suitable to the corresponding standard parameter called Required Fire Resistance Time – TRRF.
Therefore, for programming purposes, IT06 should be modulated according to two annexes:
• Annex A: Approval for Fire Resistance Equivalent Time
• Annex B: Approval for fire resistance time of masonry

In order for the BIMSCIP system to be able to identify which part of the model is to be analyzed, the "Isolated Areas" function, which uses information from the Revit platform command, is used to discriminate different regions in the BIM model (Figure 1). In this way, when using the platform, the user must first define this delimitation around the BIM model regions, which are relevant and require the approval of the Fire Department.

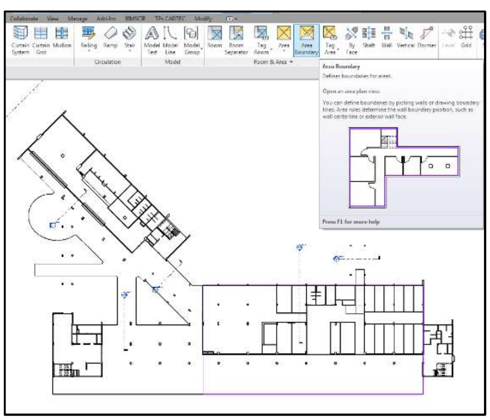

Figure 1 – Isolated Areas delimitation in Revit

A situation that demonstrates the importance of well-defined compartmentalization is the mixed use that some buildings may present. An example would be when a building exclusively for residential use needs to undergo transformations to accommodate a party hall for rent in a particular area and for this requires approval from the Fire Department, only for the modifications of use of that specific area.
Another example is the situation of a building, which presents multiple compartmentalization relevant for analysis, since these divisions aid in the distinction of what is in fact out of standards, enabling approvals independently.
It will also be up to the user to appoint each isolated area, following the standard defined in the instructions so that the BIMSCIP system can identify the type of use and occupation that is desired for the place. The identification of the use and occupation of the compartment directly influences the choice of the parameters necessary for the automatic check, such as the Required Times of Resistance to Fire (TRRF) factor.

Annex A

For a project to be approved in accordance with the calculated evacuation time parameter, Fire Resistance Equivalent Time - TERF, it is necessary for this parameter to be greater than the standard reference parameter, Required Fire Resistance Time - TRRF, which is tabulated for each type of occupation. That is, the evacuation time, calculated from the characteristics contained in the project, must be greater than the time established by the standard.
For the calculation of the Equivalent Time of Fire Resistance, the following formula was adopted by the Fire Department of Minas Gerais:

$$teq = qfi\ \gamma n\ \gamma s\ K\ W \quad (1)$$

where:
teq - equivalent time (minutes).
qfi - fire load (MJ / m²).
$\gamma n = \gamma n1\ \gamma n2\ \gamma n3$ - dimensionless coefficient that takes into account the presence of measures of active protection of the building, determined with the aid of tables of the standard.
$\gamma s = \gamma s1\ \gamma s2$ - safety coefficient that depends on the risk of fire and the consequences of the collapse of the building, determined with the help of tables of the standard.
K - factor determined according to the table of figure 2.
W - factor associated with the ventilation of the environment considered.
E - Correction factor that depends on the material of the structure, determined with the aid of tables of the standard.

Each of the factors specified above was implemented having as input parameters, data and design specifications and as output parameters the desired results.
The determination of the factor K is an example of how the BIM environment was fundamental for the implementation of this formula. The K factor is influenced by the physical properties of the enclosure sealing elements. In this way, families of sealing elements were created to obtain K, such as a fire door, whose parameters; specific mass, specific heat and thermal conductivity must be provided by the user through BIMSCIP interface according to the characteristics of the existing elements of the design. The creation of interfaces with the BIM platform allows the insertion of crucial information to the project by the user during the modeling. Based on the formulas shown in the following table the system can receive the parameters supplied by the user and return the value of K.

$b = \sqrt{\rho c \lambda}$ ($J/m^2\ s^{1/2}\ °C$)	K ($min\ .\ m^2 / MJ$)
$\sqrt{\rho c \lambda} > 2500$	0,040
$720 \le \sqrt{\rho c \lambda} \le 2500$	0,055
$\sqrt{\rho c \lambda} < 720$	0,070

Figure 2 – Factor K Schedule. Source: Minas Gerais, 2005.

The W factor does not require the creation of specific families for its determination, as long as the system extracts information from the model by the access of parameters of the native families of the Revit platform. This factor is influenced by the ventilation of

the compartment and, to obtain it, the code was developed to filter elements such as windows, floors and floor openings, from where it extracts the area parameters to determine W. In addition, the code accesses the height H of the compartment from the height of its walls or its level.
The equation for obtaining W is shown below.

$$W = \left(\frac{6}{H}\right)^{0,3}\left[0,62 + \frac{90\left(0,4 - \frac{A_v}{A_f}\right)^4}{1+12,5\left(1+10\frac{A_v}{A_f}\right)\frac{A_h}{A_f}}\right] \geq 0,5 \qquad (2)$$

Where:
H - compartment height (m2)
AV - vertical ventilation area - windows (m2)
Ah - horizontal ventilation area - floor (m2)
Af - floor area (m2)

Annex B

In order for a project to be approved for the Fire Resistance Time of Masonry, it is necessary that the masonry have a resistance time higher than the Required Fire Resistance Time (TRRF), which is the benchmark standard for each type of occupation, thus guaranteeing sufficient masonry strength for a sufficient time in a fire situation.
The fire resistance time of the masonry varies according to the constituent material of the same, its thickness and existence of thermal coating or not, as tabulated, in Technical Instruction 06 of the Fire Department of Minas Gerais.
Thus, for implementation in the code to verify compliance with this standard, the following logic was followed:
I. Filtering of all existing walls in a particular compartment;
II. Verification of the information aggregated to the walls, such as material, thickness and existence of coating;
III. Cross-reference the information obtained in the modeling with the information in the table;
IV. Return of Fire Resistance Time from Masonry;
V. Comparison with the previously provided TRRF.

It is important to note that, for better code operation, standard materials are provided for users to use in the layers of walls. In addition, in case of masonry with different Fire Resistance values in the same compartment, the system adopts the lowest value among them.

Organization of the code

Although the programming environment used facilitated the construction of the code, its development was done within an organization to avoid slow execution, repetitiveness and difficulty in updating. For this, the paradigm of the object oriented programming was used, aiming to create standards of optimization of the code operation, such as the mentioned pattern of division of the model in isolated areas.
The system environment was built in the MVC-Model-Visualization and Control type, divided into three layers: interface, control and persistence, as represented in Figure 3. In this division, the interface represents the interaction layer between the user and the system and it is where the communication of the content takes place; the persistence layer is the one where the model information necessary for the analyzes to be made is stored; and the control layer is the link between the other two layers, using the information taken from the model to generate a presentation to the user. It is noteworthy that this division is very relevant for the reduction of errors and inconsistencies.

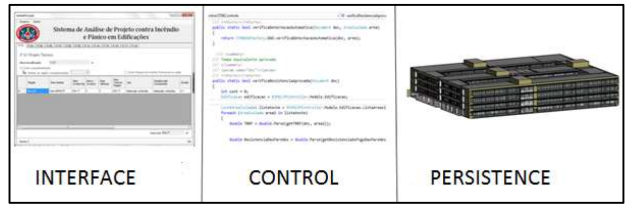

Figure 3 – MVC division.

The Code

For a better understanding of the functionality of the code created to verify compliance with Technical Instruction IT06, the function whose purpose is to determine the fire resistance time for masonry is described in detail below. This description uses Figure 4 as reference:
In section "A" of the code, the function is declared as a public text, which is configured by its input parameters doc (document), and by an isolated area previously extracted by the system command to determine isolated areas of the project.
In section "B" a check is made to avoid unnecessary repetition of the command. If the command already presents compiled result, this result is returned without the need to execute the other commands. This helps in the agility of the project processing in cases where it is not necessary to recalculate the resistances of the walls and so it is enough that a new function only recovers the value already calculated.

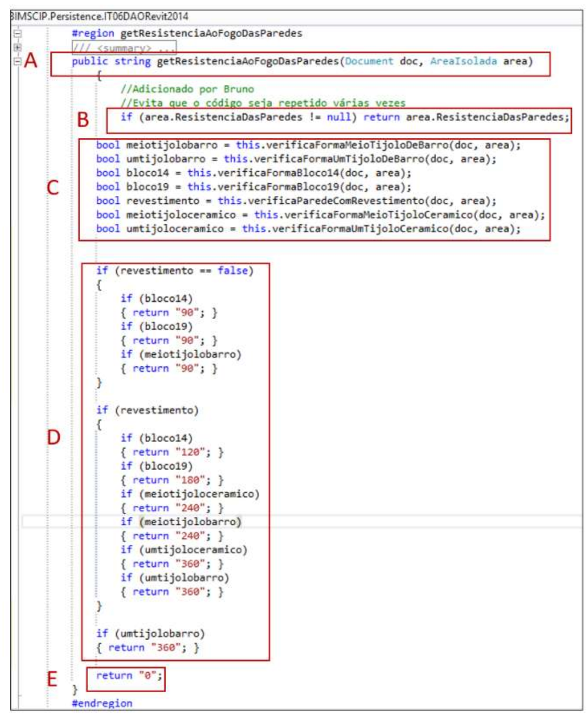

Figure 4 – Code Example.

In "C" several commands that return true or false are triggered. Each one is responsible for identifying the wall material, based on names and thicknesses of the layers configured with structural function in the structure profile of the masonry. The presence of coating in the masonry is also verified to take into account the existence or not of layers with a coating function.

At "D" each type of wall is checked in increasing order of fire resistance. This allows the system to quickly find a wall in the defined patterns, which represents the shortest fire resistance time of the compartment, without having to consider the characteristics of the other walls.

In the "E" section of the code, if none of the wall types mentioned in the standard are identified in the project, the command returns a "0" (null). This result indicates that the strength of the walls in the design will never be greater than or equal to the resistance required by the standard, resulting in the disapproval of Annex B of the project and thus the system requests the user to correct this requirement.

Interface

The system interface for application of the IT06 instruction in the project was divided between the requirements of annexes A and B. The first screen of each of the annexes allows to distinguish isolated areas within the BIM model and perform the analysis for each area and thus to produce the result of its approval or disapproval, as shown in the results window (Fig. 5).

Figure 5 – Main Window, Annex B – IT06.

Fig. 5 shows that the evaluation process of each compartment is executed independently, which can result in approved and unapproved compartments. In addition, the "Details Annex B" field of the results window can be triggered to open a new window, shown in Fig. 8, containing specific details of the approval or disapproval of the analyzed compartment.

Tests and Results

In order to corroborate the consistency of the system's functionality, the BIM model of the Engineering School of the Federal University of Minas Gerais (EEUFMG) (Figure 6) was used, which was built to be the object of study of this work, through the performance of several tests in their compartments.

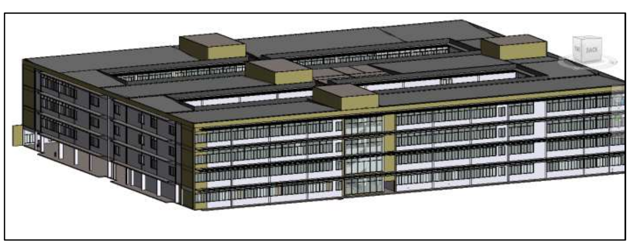

Figure 6- Model of Building 01 of EEUFMG in Rvt.

The BIM model of EEUFMG encompasses entities containing attributes, new materials and specific families of the BIMSCIP system, as shown in Figure 7.

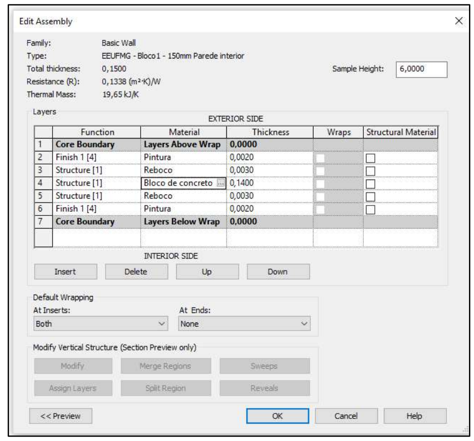

Figure 7- Detail of an internal wall of EEUFMG.

Figure 7 shows information on layers of an enclosed inner wall delimited in the EEUFMG Block 01 project. In this figure it is possible to identify the material of a structural wall, called "Concrete Block", with a thickness equal to 0.14 m. In addition, information is also provided on layers with finishing function, which is interpreted by the system as the wall covering. These data are then filtered and together with others, they are used to calculate several factors, such as the masonry resistance time, which is one of the criteria for approval (or not) of IT06 Annexes A and B for each project.

The results shown in Figure 8, referring to the tests for the structural wall model shows its approval according to the criteria of both annexes A and B, as can be observed.

Figure 8 - IT06 Main Interface.

In addition, Figure 9 shows details of the approval of this wall according to the criteria of Annex B.

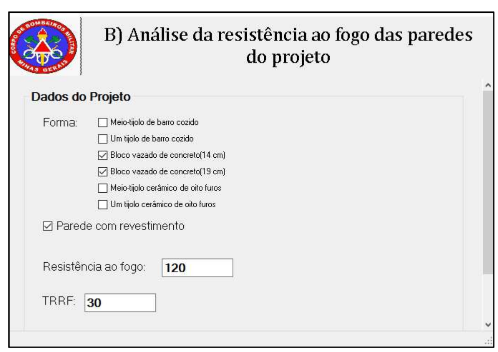

Figure 9 - Detail interface of Annex B.

3. CONCLUSION

The development of the BIMSCIP system was based on modern concepts of software engineering, object oriented programming and Building Information Modeling (BIM) to automate the code verification procedure in Fire and Panic Systems (SCIP) projects. The purpose of the application (plugin) developed is to meet the demands of two types of agents, namely, the professional who develops fire prevention and fire and panic projects and the regulatory bodies for compliance with fire regulations. Technical Instructions (ITs) of various natures to guarantee the safety of persons and properties in fire situations govern these standards.

In the specific case of this work, only the implementation in the BIMSCIP system of the IT06 criteria was presented, which deal with the fire resistance of structures and masonry. The BIMSCIP system automates the compliance checking process required for fire and panic (CIP) projects for buildings by applying a code checking to IT06. The application represents a major contribution of BIM technology to the improvement of efficiency and productivity by allowing the reduction in the development time of these projects and of their respective evaluation / approval by the regulatory governmental bodies. In addition, a project developed and approved with the application of BIMSCIP will have a minimized error index, which translates into a significant improvement in the safety index of the building in a fire situation.

4. REFERENCES

[1] KOBES, Margrethe; HELSLOOT, Ira; VRIES, Bauke de; POST, Jos G. Building safety and human behavior in fire: A literature review. Fire Safety Journal, 2010, 45, 1-11.

[2] GUANQUAN, Chu; JINHUI, Wang; QINGSONG, Wang. Time-dependent fire risk assessment for occupant evacuation in public assembly buildings. Structural Safety Journal, 2012, 38, 22-31.

[3] BRYDE, David; BROQUETAS, Martí; VOLM, Jürgen Marc. The projects benefits of Building Information Modeling. International Journal of Project Management, 2013, 31, 971-980.

[4] SHINO, Gregory K.. BIM and fire protection engineering. ConsultingSpecifying Engineer, Apr 2013, 34-41.

[5] WATSON, Alastair. Digital buildings – Challenges and opportunities. Advanced Engineering Informatics, 2011, 25, 573-581.

[6] MINAS GERAIS. Corpo de Bombeiros Militar. Instrução Técnica n. 06, Julho de 2015. Disponível em: <http://www.bombeiros.mg.gov.br/images/stories/dat/it/it_06_seguranca_estrutural_em_edificacoes.pdf>. Acesso em 10/14/2016.

[7] HJELSETH, E.; NISBET, N.. Overview of concepts for model checking. In: CIB-W78 Conference, 27., 2010, Cairo.

[8] MARTINS, J. P.; MONTEIRO, A.. LicA: A BIM based automated code-checking application for water distribution systems. Automation in Construction, 29, 2013,12-23.

[9] CHENG, J. C. P.; DAS, M.. A BIM-based web service framework for green building energy simulation and code checking. Journal of Information Technology in Construction, 2014, 19, 150-168.

[10] LUO, H.; GONG, P. J.. A BIM-based Code Compliance Checking Process of Deep Foundation Construction Plans. Journal of Intelligent & Robotic Systems, 2015, 79, 549-576.

[11] BALOGH, Tamás; VIGH, László Gergely. Complex and comprehensive method for reliability calculation of structures under fire exposure. Fire Safety Journal, 2016, 86, 41-52.

[12] LAW, Angus. The role of modelling in structural fire engineering design. Fire Safety Journal, 2016, 80, 89-94.

[13] BANERJEE, Dilip K.. A software independent tool for mapping thermal results to structural model. Fire Safety Journal, 2014, 68, 1-15.

[14] LEE, Wonju; CHEON, Minkyu; HYUN, Chang-Ho; PARK, Mignon. Development of building fire safety system with automatic security firm monitoring capability. Fire Safety Journal. 2013, 58, 65-73.

[15] RÜPPEL, Uwe; SCHATZ, Kristian. Designing a BIM-based serious game for fire safety evacuation simulations. Advanced Engeneering Informatics, 2011, 25, 600-611.

[16] TAVARES, Rodrigo Machado. An analysis of the fire safety codes in Brazil: Is the performance-based approach the best practice?. Fire Safety Journal, 2009, 44, 749-755

MARTINS, João Poças; MONTEIRO, André. LicA: A BIM based automated code-checking application for water distribution systems. Automation in Construction: Elsevier. 29: 12-23 p. 2013.