VÉDELEM TUDOMÁNY
KATASZTRÓFAVÉDELMI ONLINE TUDOMÁNYOS FOLYÓIRAT

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EVALUATION OF BIM-BASED WORKFLOWS IN FIRE SAFETY ENGINEERING

Abstract

Building information modelling and management (BIM) is a process supported by various tools, applications and technologies involving the generation, optimization, and management of digital representations of physical and functional characteristics and information of constructions throughout its entire lifecycle. BIM can be used to provide, or store information related to fire safety. Some of these applications are known and used already, however, many possibilities are nowadays still in the research and development. In our research, we evaluated the possible BIM-based individual applications based on scientific literature and composed a workflow of a construction project that is organizing the use of engineering design and management involving BIM. We discussed the possibilities of BIM applications throughout the analysis of building constructions for fire loads, fire and smoke propagation and evacuation simulation, integrated smart monitoring systems for fire alarm and incident management as well as innovative fire prevention solutions such as AR/VR applications. Our research goal is to facilitate the interconnection of BIM engineering applications and fire protection. We concluded that BIM can be used throughout the whole lifecycle of a building project and all fire safety engineering applications can optimize and generate changes in the building design if these assessments interact to each other and use the same dynamically developing BIM model.

Keywords: building information modelling, innovative engineering methods, fire safety engineering

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BIM-ALAPÚ MUNKAFOLYAMATOK ÉRTÉKELÉSE A TŰZVÉDELMI MÉRNÖKI MUNKÁBAN

Absztrakt

Az épületinformációs modellezés és -menedzsment (BIM) egy különböző eszközökkel, alkalmazásokkal és technológiákkal támogatott folyamat, amely magában foglalja a fizikai és funkcionális jellemzők, valamint az építményekre vonatkozó információk digitális reprezentációinak előállítását, optimalizálását és kezelését annak teljes életciklusa alatt. A BIM felhasználható a tűzbiztonsággal kapcsolatos információk nyújtására vagy tárolására is. Ezen alkalmazások némelyike jelenleg ismert és alkalmazott, azonban még sok lehetőség rejlik az egyes alkalmazások kutatásában és fejlesztésében. Kutatásunk során a rendelkezésünkre álló szakirodalom alapján értékeltük a lehetséges BIM-alapú alkalmazásokat, és egy átfogó munkafolyamatot állítottunk össze, amely rendszerezi a BIM-et magában foglaló mérnöki tervezés és menedzsment használatát. Ennek során kitérünk a BIM alkalmazási lehetőségeire az épületszerkezetek tűzállóságának modellezésére, a tűz és a füst terjedésének, valamint a kiürítés szimulációjára, az integrált intelligens monitoring rendszereknek a tűzjelzés és az események kezelésére, valamint az innovatív tűzmegelőzési megoldásokra, például az AR / VR alkalmazásokra. Kutatási célunk a BIM mérnöki alkalmazásának és a tűzvédelem összekapcsolásának elősegítése. Arra a következtetésre jutottunk, hogy a BIM tűzvédelmi szempontból is alkalmazható az építmények teljes életciklusában, és minden tűzbiztonsági mérnöki alkalmazás optimalizálhatja és változtatásokat generálhat az épület tervezésében, ha ezek az értékelések kölcsönhatásba lépnek egymással, és ugyanazt a dinamikusan fejlődő BIM modellt használjuk.

Kulcsszavak: Épületinformációs modellezés, innovatív mérnöki módszerek, tűzvédelem

1. INTRODUCTION

Nowadays, in addition to traditional fire protection design, we increasingly use so-called engineering methods, but these are mostly computer-aided, software-assisted design processes, which typically do not handle, and in many cases, hinder the development and long-term sustainability of complex fire protection. Based on our professional experience and on our research, a significant part of today's engineering methods does not form part of a comprehensive fire protection concept that provides complex solutions, does not necessarily make a way for design decisions, and does not reflect a use-oriented approach, but prepares the implementation of technical solutions more favourable than the requirements of the National Fire Protection Code (NFPC) [1].

According to our assumption, instead of the so-called engineering methods utilized in the field of architectural fire protection today, with new, scientifically based, complex, use-oriented innovative engineering methods endowed with building information modelling and algorithmic design methodology, a more advanced, safer, sustainable complex fire protection can be created, which can be dynamically changed to meet social needs [2]. To verify our hypothesis, we analysed and evaluated the possibilities of the building information modelling- based fire safety engineering applications in the field of fire prevention.

Building information modelling and management (BIM) is a process supported by various tools, applications and technologies involving the generation, optimization, and management of digital representations of physical and functional characteristics and information of constructions throughout its entire lifecycle. BIM can be used to provide, or store information related to fire safety and also in fire protection net which covers the entire lifecycle of buildings, which enable us to realize a new, high-level long-term sustainable safety within a sustainable smart city [3].

In BIM, level of development (LOD) represents and gives information about both the level of geometry (LOG) of the visible model and the level of information (LOI) content. Therefore, LOG represents the quality of the graphical information, while LOI mostly represents the non-graphical information of a BIM model or object such as performance, execution, or product/material properties. LOG is often used as a synonym to level of detail, which is also often abbreviated as LOD [4]. The following BIM level of developments exist in the practice:

LOD 100 is used mostly for conceptual design in early stages of the project. In this case the building 3D model is developed to represent the information on basic level. Parameters like area, height, volume, location, and orientation are defined only. LOD 200 is used for schematic design purposes, where elements are modelled with approximate quantities, size, shape, location and orientation and non-graphical information are also can be added to the model elements. LOD 300 is used for detailed design processes, it requires accurate modelling and shop drawings, where elements are defined with specific assemblies, precise quantity, size, shape, location, and orientation, while non-graphical information content, such as performance data are added to the model elements as well, improving its LOI. LOD 300 is contains all quantity, size, shape, and location of objects, such as building constructions and it can also contain non-graphical information content such as performance data added to objects. LOD 350 is usually contains the object related elements and their connections and interface with various systems and other building elements and used for construction documentation and space required for installation or operation is also added. LOD 400 is used for fabrication and assembly, the BIM model elements are modelled as specific assemblies, with complete fabrication, assembly, and detailing information in addition to precise quantity, size, shape, location, and orientation including the necessary non-graphical information, respectively. LOD 500 corresponds to the reality as-built and used in the stage of maintenance and operation of the building. It records the as built state and to create such a model, huge amount of work and continuous assessment is required. But if it is available, it can provide almost every information for facility management purposes.

Most of the BIM-based fire safety engineering applications require a certain level of development for the BIM model, usually at least around LOD 300 or LOD 350 up to LOD 500. To provide inter-exchange of a building information model without loss or distortion of data, openBIM software environment supports Industry Foundation Classes (IFC), since it is an open file schema, created to facilitate interoperability between different software and operators. However, IFC files are mostly for referencing, archiving, and exchanging the original content created in different workflows throughout its entire lifecycle of design to maintenance, it contains usually just enough information for simulation software to read and analyse, but should not be edited, neither able to contain or transfer simulation analysis results. Therefore, even if the BIM model with appropriate LOD level is exchanged using IFC files, we have to use mostly separated and closed individual workflows nowadays for the engineering methods during design relevant to fire safety engineering, however the same IFC files can be used for design of structures, simulations and optimization, evaluation of performance, compliance checks, organize virtual trainings, and could provide data during fire alarms and rescue tasks.

2. METHODOLOGY

In our research, we are going to demonstrate and evaluate the possibilities of BIM in fire safety engineering. To be able to collect all the relevant fire safety engineering applications and methodologies regarding design, construction, and management of a building, we scanned three public scientific databases (science direct, google scholar and researchgate) for papers containing fire safety and BIM applications. During the research, we analysed and evaluated 22 selected, relevant papers, and collected the possible workflows using fire safety engineering, design, and management BIM-based tools. Using the results of the data extraction, we composed a schematic workflow for the whole building lifecycle regarding fire safety engineering and rescue management to be able to show that BIM applications can be used throughout the whole lifecycle of a building construction project.

3. RESULTS AND DISCUSSION

In the following chapters, we present the evaluation of four selected fields in BIM-based fire safety applications regarding to our scientific literature review, data extraction and analysis.

3.1. BIM-based analysis of building construction for fire loads

The first analysed process was the use of fire safety engineering in building constructional design and product development. According to the relevant literature [5]–[7], we can create analysis of building constructions for fire loads based on BIM models containing the building construction's geometrical data. The 3D geometrical model could be generated using BIM-based tools. The numerical model can use imported geometry (e.g. Ansys using CADFEM BIM inside Ansys extension [8]) or can be directly live linked from a BIM software that can read IFC or create BIM models to a multiphysical simulation environment called Comsol Multiphysics [9]. If the numerical model is created with care, attention to the physics and professionalism, the simulation results could match to experimental fire test results with good agreement as observable in Figure 1. However, to obtain a performance rating of a building construction, experimental results needed. Therefore, a building construction's response to fire can be modelled in advance, and the numerical results can give additional inputs to reduce the costs and provide a preliminary test, to perform real laboratory experiments on structures that meet the requirements by simulation. Besides the preliminary results, the numerical simulation results can supplement the experimental data showing e.g. the temperature distribution throughout the entire model. These analyses can provide precious additional data even during fire rescue on the building construction.

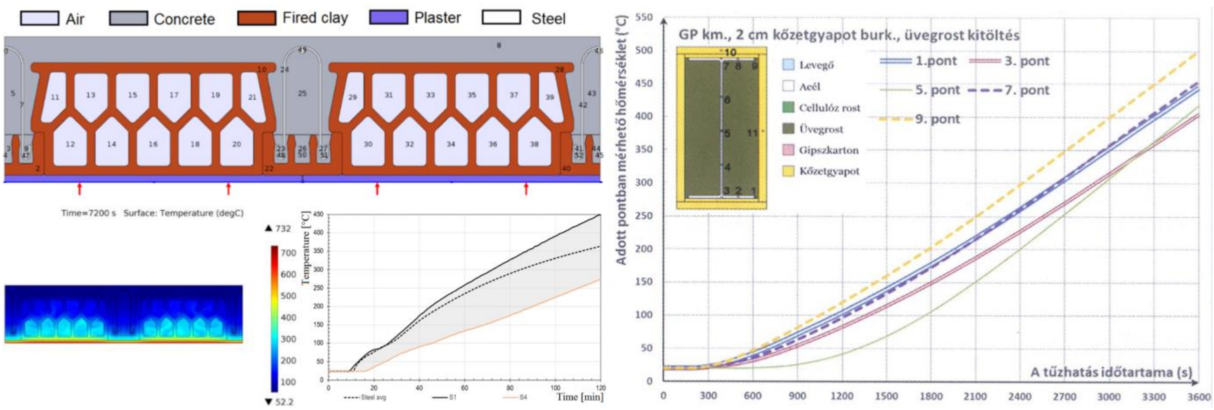

Figure 1: Numerical simulation based on BIM object of a ceramic slab (left) [6] and on a steel section with fire protection cover (right) [7].

The fire resistance performance of building constructions can be stored later in the design stage in the BIM model file besides its geometrical and graphical data as an additional information and it can be checked by authorities by performing either clash detection-based compliance check or automatic code checking [10], [11] for the fulfilment of the required and stored information regarding the NFPC.

3.2. BIM-based fire and smoke propagation and evacuation simulation

In BIM-based workflows in fire safety engineering the authors analysed two software in the field of fire and heat spread, and in the field of evacuation to be able to create the innovative fire safety engineering methodology. In the current Fire Protection Technical Guide of Fire-, smoke propagation and evacuation modelling [12], Fire Dynamics Simulator (FDS) is listed as the applicable fire and smoke propagation simulation tool, perhaps because the code is validated through experiments [13]. It is a large-eddy simulation (LES) code for low-speed flows, with an emphasis on smoke and heat transport from fires [14] that can use third party graphical user interfaces (GUI) to the code, like Pyrosim [15] (see Figure 2), are able to perform dynamic simulations which can provide important information even to structural engineers or building construction specialists. It can also import IFC among other CAD file formats, and able to visualize the simulated smoke, temperatures, velocities, toxicity, and other outputs for the FDS analysis. Using this GUI, we are able to creates videos in real-time by recording while adjusting the camera and data visualization that is useful during performance-based design [16]. Pyrosim is able to easily switch between Smokeview provided by NIST [14]. It also includes tools helping to create and validate multiple meshes for the numerical simulations, that allows the use of parallel processing to speed up the solution, conform meshes to the geometry to reduce the number of cells and solution time, and change the resolution of different meshes to focus of regions of interest. FDS version 6 introduced the integration of Heating, Ventilation, and Air Conditioning (HVAC) systems into the CFD simulation since it can transport contaminants and heat through the building. The HVAC system can model flow independent of any fire analysis. They may also serve as part of the fire protection system for a building when used to exhaust smoke or maintain stairwell pressurization.

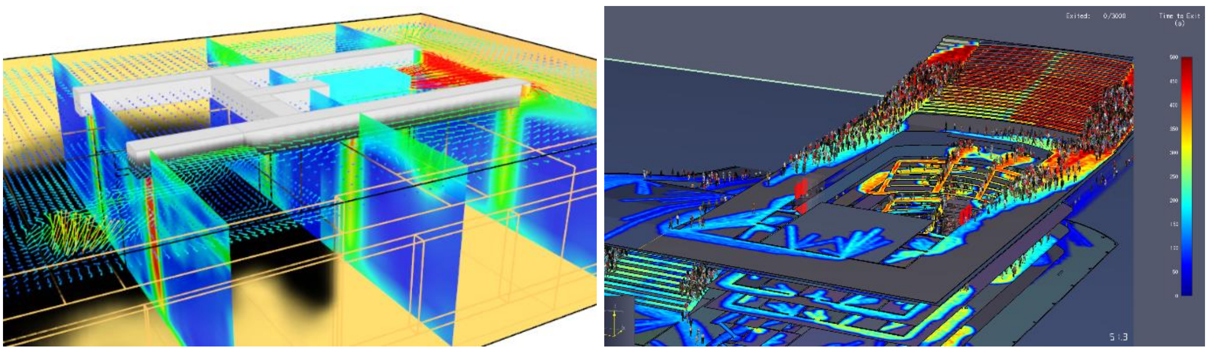

Figure 2: 3D visualisation of fire and smoke propagation (left) and evacuation simulation (right) [15]

There are many different evacuation models [17], however, the applicable evacuation simulation tools are also listed in [12], among others Pathfinder [15] (see Figure 2) is an agent-based simulator able to model the egress of humans from a building and animate 3D results. It also able to import IFC files and creates a triangulated mesh for geometry, therefore, it can represent curved graphical details and facilitates continuous movement of persons throughout the model, compared to other simulators that subdivide the space into cells that can artificially constrain the movement of occupants. Pathfinder supports two simulation modes. In Steering mode, agents proceed independently to their goal, while avoiding other occupants and obstacles. Door flow rates are not specified but result from the interaction of occupants with each other and with boundaries. In SFPE mode, agents use behaviours that follow guidelines of the Society of Fire Protection Engineers, with density-dependent walking speeds and flow limits to doors. SFPE results provides a useful baseline for comparison with other results, but SFPE calculations do not prevent multiple persons occupying the same space. Pyrosim is also able to use Results Viewer with a similar interface, which can also integrate Pathfinder occupant movement results [15], as well as with smoke and fire data imported from FDS results, Pathfinder can demonstrate areas of high danger by tracking occupant Fractional Effective Does (FED) of contaminants. Although, in case of fire, because of the changed visibility or blocked paths, evacuation may differ from the optimum. This can be modelled if the fire dynamics simulation is connected to the evacuation model and performed together [18] to support a BIM-based fire evacuation planning and create walkthroughs of egress routes according to the analysis to improve human evacuation performance [19].

3.3. BIM-based integrated smart monitoring systems for fire alarm

At the birth of fire alarms, the alarm was given by available acoustic signals. Then the invention of the telephone and the fire detector allowed direct detection and signalling of the fire and its transmission to organized fire brigades. Computer was invented in the 20th century, that made it possible to receive and transmit information quickly. GIS appeared in fire protection and firefighting, which was a significant step in the field of fire detection and alarm. The telephone, the fire alarm and the computer were connected [20]. At present, wireless sensor networks within a building can be used as a fire alarm and providing precious information on the properties and location of the fire not only to the firefighters, but for the civilians in the building for fire emergency management [21]. BIM models can be linked to locate firegrounds by using the building model and sensor data [22], [23] to be able to use during incident management and support building fire emergency response operations (see Figure 3).

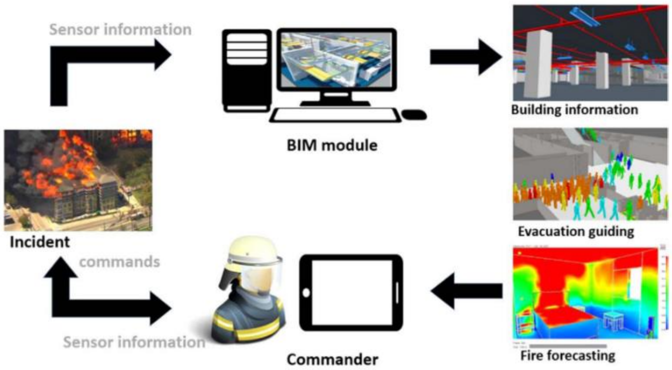

Figure 3: Future use of BIM during incident management [22]

Integrating BIM and the building management and automation system and Internet of Things can provide real time fire monitoring and support the firefighters in fire scenes, who are able to gather as much information as possible to support them during incident management [24], and since time is key in case of an event, to prevent overload of data, multi-decision making algorithms and fire risk assessment systems should support the commander on his decisions in buildings [25]–[27] or even in construction sites [28].

3.4. BIM-based fire prevention solutions

LOD 500 level as-built BIM models can be used for maintenance and management purposes, whereby inspection of the fire safety equipment should happen. Simply using the information stored in the model concerning fire safety equipment [29], or even deploying Augmented Reality (AR) using the BIM model, the employees can check the location of the fire safety equipment increasing effectiveness of the maintenance [30].

Virtual Reality based fire training can increase situational awareness also. The safety education training could include 3D representations of the hazardous areas and escape routes [29] or may takes place in a virtual reality (VR) environment generated from the building information model of the building and the training could be conducted using a virtual reality head mounted device (HMD) [31], therefore residents, building users and even firefighters can use the virtual building to practice evacuation and rescue in case of fire alarm or emergency. Additionally, if we connect this feature to fire dynamic and evacuation simulations, we may can test and validate virtually the building even before construction started.

Besides VR, Augmented Reality can facilitate indoor pathfinding efficiency. Real time information from the building can be obtained dynamically even on a mobile phone, and data, such as information of the fire location and advised evacuation paths can be visualized and firefighters' efficiency can be improved through this framework [32].

3.5. BIM-based workflow for fire safety engineering

The schematic workflow of BIM-based fire safety applications connected to each other is represented in Figure 4 based on the scientific literature review, data extraction and analysis. The key between the applications is the interaction provided by BIM applications, that can optimize and generates changes in building design in the design and construction stages.

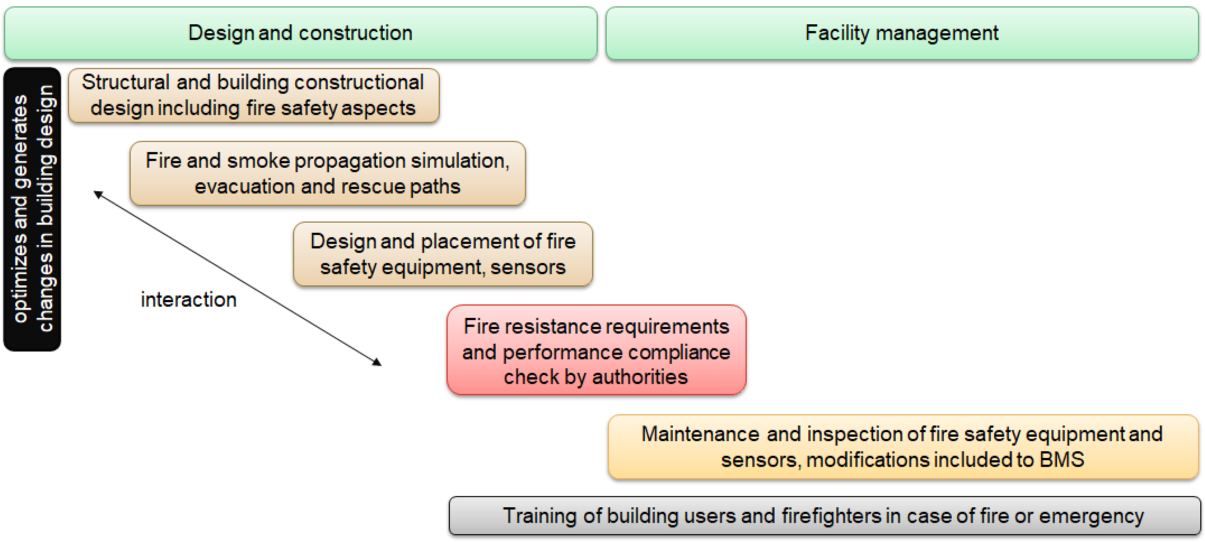

Figure 4: BIM-based workflow of a building related to fire safety engineering

4. CONCLUSION

During our research, it became clear that BIM can be used throughout the whole lifecycle of a building project, although most of the applications nowadays exist individually. There are several fire safety engineering applications supporting BIM and able to use IFC files as their input. If the designers and engineers using these applications, then all fire safety engineering applications can optimize and generate changes in the building design, e.g. the results of a fire and smoke propagation and evacuation simulation can show the optimal path of evacuation within a building where the structure of the building could be reinforced or fire safety equipment could be placed. Therefore, instead of individual assessments, we have to think in a complex system, where each process in the workflow could interact with each other using the same dynamically developing BIM model leading to a valuable contribution to all building projects.

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