Advanced Engineering Informatics 37 (2018) 42–53

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Full length article

A BIM-based visualization and warning system for fire rescue

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ARTICLE INFO

Keywords:
BIM
FDS
IoT
Visualization
Fire rescue

ABSTRACT

Structural fires are common disasters. In Taiwan, about 100 firefighters die during fire rescues each year, primarily because they are unaware of the causes of the fire and unfamiliar with the location's environment. Meanwhile, evacuees often die in the panic of evacuation. To solve these problems, this research proposes a Building Information Modeling (BIM)-based visualization and warning system for fire rescue. A fire dynamics simulator (FDS) simulates various conditions of structural fires in conjunction with the visualization and integration properties of BIM, and the simulation results for temperature, carbon monoxide, and visibility can be integrated and presented in the BIM model for briefing purposes before rescue operations begin. In addition, this research integrates Internet of Things (IoT) technology, which allows real-time situation monitoring. In the event of a fire, the BIM model will immediately display the situation of the fire scene and control LED escape route pointers according to the actual situation. The primary objective of this system is to provide useful information to firefighters such that they can be aware of the fire's environment and create an effective rescue plan. Moreover, the automated LED escape route pointer may assist the building's occupants to escape, provide the firefighters with valuable information, and allow them quickly to discover hazards so that the number of casualties can be minimized.

1. Introduction

Structural fires are common urban disasters. According to the statistics of Taiwan's National Fire Agency, Ministry of the Interior, the incidence of fire accidents has increased annually over the last 5 years. Each year, about 1153 accidents take place. Generally, the people involved in a structural fire can be classified into two groups: the evacuees and the firefighters. These two groups of people each have a distinct motive and goal. The goal of the former is to escape and save their own lives, while that of the latter is to assist the trapped occupants and execute rescue operations. The main reason why most evacuees die at a fire scene is that they have a poor sense of escape, encounter obstacles during evacuation (vigorous flames or blockage in the evacuation route), or lack sufficient time to escape [1]. On the other hand, firefighters often enter the fire scene merely based on their past experience, without full knowledge of the location or spatial configuration. This lack of information is one of the primary causes of death in firefighters [2]. Summarizing the above, the most dangerous conditions in a fire scene for both groups of people are:

- Lack of information about the fire scene and spatial configuration, causing incorrect decision making when choosing the escape route [3,4], and
- The ambiguity of changes in the fire scene, which can cause the occupants to spend too much time trying to escape [5,6].

Based on the aforementioned reasons, this research developed a visualization and warning system based on Building Information Modeling (BIM). This research utilizes the BIM model's capability to visualize and integrate information to provide the results of fire simulations and feedback from real-time information. This system will help the related personnel to escape or perform rescue operations. Hsu et al. reported that BIM can correct the deviations between 3D and 2D diagrams, visualize the building's surroundings and the positions of facilities in 3D, and improve discrepancies when using traditional 2D firefighting management tools [7]. Not only does BIM allow 3D visualization, but its model also contains building information such as the building materials and quantities. Fire trends are highly related to the building materials, and these parameters are crucial to the simulation. Different materials have different densities and physical attributes, so their burning rates also vary. The elemental properties of the material could be said to be one of the major factors governing the intensity of the fire [8]. Hence, information from a BIM model could be inputted to a Fire Dynamics Simulator (FDS) for a more accurate prediction of the fire situation. An FDS primarily uses Computational Fluid Dynamics (CFD) to calculate and solve the fluid mechanics control

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https://doi.org/10.1016/j.aei.2018.04.015
Received 31 October 2017; Received in revised form 11 April 2018; Accepted 30 April 2018

equations created by fire scenes. Researchers who utilized FDS to reenact a fire scene and compared the results with the actual investigative results of the fire scene reported that the heat dissipation rate and the smoke diffusion time were 80% similar to the real data [9]. However, FDS software focuses on calculation, and the model is inadequate for the representation of the building information and 3D visualization. Hence, this study translates the simulation results into the BIM model so that users can obtain important information from a more user-friendly operating interface. The proposed system can create a time progression simulation according to the arrival time of firefighters at the fire scene. After the firefighters have retrieved the rescue information, they can assign teams and determine the flashover time based on the simulation result from FDS and the fire prediction from the BIM 3D model. The proposed system could replace the traditional rescue methodology and reduce casualties among firefighters.

The best time to escape is in the period from the beginning stage of the fire to the flashover. The earlier the detection of the fire, the more time the occupants have to escape. Therefore, the conditions of the fire scene and real-time feedback are crucial to emergency evacuation. This research integrates Internet of Things (IoT) technology, which enables monitoring at the scene. In the event of the source of a fire being detected and also the environment reaching a certain temperature and CO concentration level, the BIM model will immediately display the situation and sound an alert that the building occupants should evacuate. Then the fire simulation results and the real-time situation can be used to control the escape pointers to guide evacuees along a safe escape route, increasing their chance of survival.

2. System framework

This research has developed a structural fire visualization and warning system. The system framework is shown in Fig. 1. A BIM model is the main platform for information resources, integration and visualization. The framework can be divided into two parts. The first part is FDS and BIM Integration. This research uses a BIM model as its foundation, uses FDS to simulate structural fires, and sets the position of the fire source and simulation parameters according to different scenarios. The simulation results and the time are retained in a case database, from which the firefighters can retrieve a case similar to the current situation. The results of a case obtained from the simulation are translated into the BIM model and can be visualized in various ways (e.g., 1D text, 2D diagrams, 3D models) as the rescue basis for the firefighters. The second part is IoT and BIM Integration. This research also integrates an IoT framework to propose a smart escape alert function. Environment sensors gather the building's physical factors, and then these physical factors are used to control the LED guide pointers to present danger alerts and evacuation guidance. The sensory data are stored in a cloud database, from which information is extracted for the BIM model. When the sensor value is anomalous, the BIM model

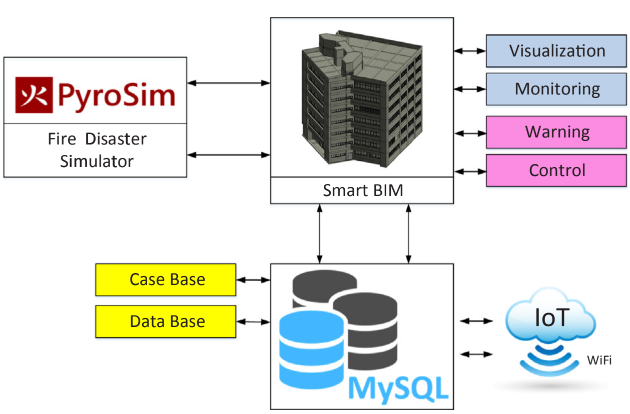

Fig. 1. System framework for the BIM-based visualization and warning system.

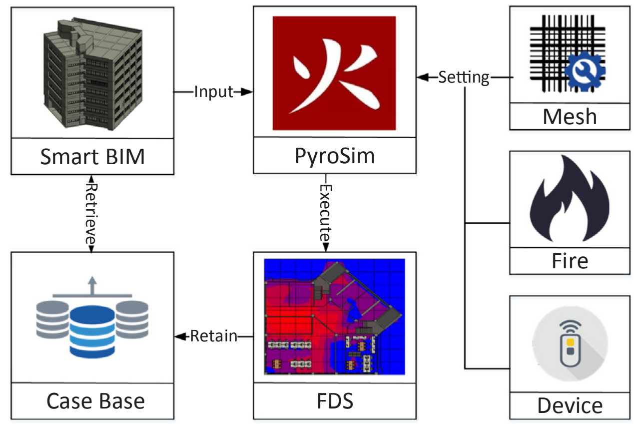

Fig. 2. The concept of FDS and BIM integration.

will respond by visualizing the location of the detected abnormality and subsequently send out warning signals. This system, which both utilizes IoT technology to control the LED pointer to guide evacuees to escape and visualizes the result from the fire simulation, will inform fire rescuers about the fire scene prior to the commencement of rescue operations. This added information should reduce injury and death counts among firefighters while increasing the rescue rate of the evacuees. Fuller discussion will be presented in the next section.

2.1. FDS and BIM integration

Fig. 2 shows the concept of FDS and BIM Integration. In this research, a BIM model is used as the main platform for information sources, integration and visualization, and PyroSim software to perform the structural fire simulation. A basic and essential requirement for any fire simulation model is to obtain accurate information on building geometry. For this reason, this research reuses the information used in the BIM model to reduce the rendering time. Autodesk Revit is first used to draw the BIM model in DXF file format, a standard CAD data-exchange file format. It contains the geometric and drawing data of the model [10]. Then the DXF file is imported into PyroSim, which identifies the material data in the DXF files to construct the model. For this reason, it is necessary to input the correct material properties during the construction of the BIM model. The object properties in the BIM model are characterized into 2 types. The first type consists of the basic properties, such as property definition, object categorization, geometric diagrams, and quantities. The second type consists of the item's visualization property, such as line formation and materials. As this BIM model is primarily used in structural fire simulation, deviations in materials will directly affect the simulation results; therefore, the object properties need to be succinctly defined for the structural fire simulation software. In addition, the positions of openings, functional regions such as air vents, and the burning zone are defined by Surface, as shown in Fig. 3. PyroSim provides a database of material parameters. It can match objects and materials and define the properties of the group in terms of a type of material. Each material has its own heat insulation and conduction properties, which increase the accuracy of the simulation.

Hence, when BIM is used as the input source, reobtaining and reconstructing the data do not consume huge amounts of time and labor. Many previous examples support this. For example, Wang et al. proposed a BIM-based model designed to support fire safety management of buildings [11]. Wu et al. used BIM to facilitate smoke propagation simulation because BIM stores the properties of each building component as well as the relationships between components [12].

Once the material and space have been generated and imported from the BIM model, the next step is to set the parameters for FDS before executing FDS.