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# Applying building information modeling to support fire safety management

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ABSTRACT

Building information modeling (BIM) is useful in three-dimensional (3D) visualization and data/information storage for planning and maintaining building projects. Recently, researchers globally have been exploring the applications of BIM. In this work, a BIM-based model is designed to support fire safety management of buildings. The model comprises four modules — evacuation assessment, escape route planning, safety education, and equipment maintenance. The evacuation assessment module integrates BIM with a Fire Dynamics Simulator to calculate the required safety egress time and the available safety egress time to evaluate the ability to evacuate in case of fire. The escape route planning module utilizes BIM to determine whether the distance of an escape route is acceptable. The safety education module presents hazardous areas, videos of escape routes and directional maps, all in three dimensions, to educate the occupants of the building about fire safety. The equipment maintenance module is implemented in a web-based prototype to support maintenance tasks in a remote management manner. The results of applying BIM have demonstrated that BIM can effectively provide 3D geometric data to support the assessment and planning of fire safety (using the first three modules), and it can store information in support of safety management and property management in a web-based environment (using the equipment maintenance module).



## 1. Introduction

Building information modeling (BIM) is effective in three-dimensional (3D) visualization and data/information storage for planning, constructing and operating/maintaining building construction projects [1]. Currently, researchers worldwide are considering potential applications of BIM. Some BIM-based applications are mature and have been widely used in practice, such as for construction interference detection [2], four-dimensional (4D) schedule visualizations [3], and quantity take-offs [4]. However, many possible applications require further investigation to examine the relevant benefits/challenges of using BIM, including integration with simulations of operations for scheduling purposes [5], structural safety analysis [6], and fire safety management [7,8]. The present study explores how BIM (with its 3D visualization and data storage capabilities) can facilitate fire safety management, which is frequently carried out in a two-dimensional (2D) environment.

Effective fire safety management is a critical task in planning, designing, and operating a building [9]. During the planning and design phases of a new building construction project, the architect must assess whether the planned fire compartment, escape route and fire safety equipment meet regulations [10]. In the operation phase, the occupants/users of a building should be familiar with the escape routes in case of fire and maintenance staff must have the relevant information (such as responsible staff and location) about fire safety equipment and ensure that the equipment is in good working order [11].

This work extends an earlier investigation [12] to develop a more comprehensive BIM-based model to support fire safety management in the design and operation of a building. The proposed model is composed of four modules, which are evacuation assessment, escape route planning, safety education, and equipment maintenance modules. The first three modules use the 3D geometric data in BIM to assess fire safety requirements, while the equipment maintenance module combines safety management with property management in a web-based environment.

The rest of this paper is organized as follows. Section 2 reviews current applications of BIM to fire safety management and the fire safety features of a typical building. Section 3 elucidates the proposed model. Section 4 presents the results of a case study in which BIM is utilized.

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Section 5 draws conclusions and provides recommendations for future research.

## 2. Literature review

### 2.1. Current applications of BIM in fire safety management

Most studies of the application of BIM to fire safety management have focused on providing 3D geometric data concerning building elements to support real-time information inquiries or evacuation simulations. For instance, Rüppel et al. [13] designed a system that can help emergency rescuers to find the shortest way to a location within a complex building. The system combines ultra-wide band, wireless local area network and radio frequency identification to establish a real-time information query system. The 3D objects in a BIM model represent the building components (such as walls, doors, and rooms), which support the routing function of the system. The system is integrated with BIM to provide rescuers with information about their immediate surroundings when they are inside the building.

Li et al. [8] introduced an algorithm called EASBL to locate first responders and trapped occupants in buildings in fire emergency response operations. The EASBL algorithm is based on BIM, as it relies on BIM to improve the accuracy of room-level localization. The geometric information that is generated by a BIM model is used to identify possible locations of people, such as rooms, corridors and staircases. The building information is also utilized to evaluate the accessibility of indoor spaces, based on the layout and usage of the spaces that are retrieved from the BIM model. The use of annotations in BIM, such as room numbers, facilitates communication between an incident coordinator and deployed first responders, so that the latter can rapidly follow commands to find specific locations to rescue an occupant.

With respect to research that involves the simulation of evacuation, Rüppel and Schatz [7] developed a prototype of an interactive game to examine human behavior during the evacuation process in various emergency scenarios. BIM-based models serve as a basis of game scenarios, allowing such scenarios to be quickly established. The advantage of this scheme is that designers, creators, operators, and users of a building, as well as rescue forces, can simulate various scenarios in the shortest possible time.

Abolghasemzadeh [14] proposed a method of simulating building egress, which takes into account the behavioral response of occupants to changeable environmental conditions in case of a fire. His method was implemented in the BIM environment, where all building elements are directly accessible in the egress analysis. An occupant of a building can be modeled in a BIM environment as an “agent” with appropriate characteristics. The agent's motion can then be analyzed and visualized in the building model.

### 2.2. Fire safety features of a building

#### 2.2.1. Evacuation capability of building

Fire safety can be defined as incorporating fire prevention, limiting the spread of fire and smoke, extinguishing a fire and the probability of making a quick and safe exit [11]. The probability of a safe escape is a major determinant of the fire safety features of building [15,16]. The escape time depends on characteristics of the fire (such as growth, smoke yield, toxicity and heat generated), human characteristics (such as personality, observational abilities, responsibility for other evacuees, and familiarity with the layout of the building), and characteristics of the building (such as its layout, constituent materials, compartments, density of occupants, ease of finding a way through the building, and maintenance) [11].

Of the above three characteristics, building characteristics decisively affect the other two types of characteristics [11]. For example, building configuration and the use of materials can influence the characteristics of fires, including ignition sources, fuels, and fire development [17]. Raubal and Egenhofer [18] found that the degree of architectural differentiation, which refers to unique building characteristics that people can use to orientate themselves, markedly affects the ease with which personnel can find their way through the building (a human characteristic). Consequently, building characteristics are the most important consideration in fire safety design.

#### 2.2.2. Safety egress time

Safety egress time can refer to both required safety egress time (RSET or $t_{required}$) and available safety egress time (ASET or $t_{available}$). The RSET is the period between the outbreak of a fire and the time when an occupant can reach a safe place, while the ASET is the period between the outbreak of a fire and the time when fatal environmental conditions pertain [11,14,19].

According to safety regulations in Taiwan [20], the RSET ($t_{required}$) is defined as,

$$t_{required} = t_{start} + t_{travel} + t_{queue} \tag{1}$$

$$t_{start} = \frac{\sqrt{\Sigma A}}{30} + 3 \tag{2}$$

$$t_{travel} = \max \frac{l_i}{v} \tag{3}$$

$$t_{queue} = \frac{\Sigma \rho A}{\Sigma N_{eff} B_{st}} \tag{4}$$

where, $t_{start}$ = evacuation starting time, $t_{travel}$ = walking time, and $t_{queue}$ = time spent queuing to go through an exit. $\Sigma A$ is the total floor area ($m^2$) of a particular area (room or zone) to be evaluated. $l_i$ denotes the distance from any point in this area to the closest exit. $v$ ($m/s$) is the walking speed. $\rho$ is the density of people within the area. $N_{eff}$ is the effective flow coefficient. $B_{st}$ is the width of the exit.

Notably, Eqs. (1)–(4) are derived from the following assumptions [21]. (1) The occupants are uniformly distributed in the evacuation area; (2) occupants are evacuated by following escape routes to which they are directed; (3) evacuated occupants walk at the same speed; (4) if multiple escape routes are available, then the closest one will be selected for evacuation.

The ASET ($t_{available}$) is calculated as the time between fire ignition and the establishment of extreme conditions that a person cannot tolerate heat, toxicity, or smoke. Table 1 lists the personnel's tolerance limits of various hazards, defined by the SFPE (Safe Fire Protective Engineering) manual [19]. For each hazard, the duration to reach the tolerance limit can be calculated. Then, $t_{available}$ is the shortest of the three calculated durations, because exceeding this shortest duration will likely be fatal or at least cause serious casualties.

Calculations of the ASET and the RSET are crucial to ensuring safe escape in the case of fire [11]. The evacuation must be completed (RSET) before fatal conditions are reached (ASET).

#### 2.2.3. Evacuation simulation models

Computer simulation modeling allows for testing of numerous environment-specific safety evacuation scenarios at low cost [22]. The evacuation simulation model is based on the fire scenario, the distance to exits, the walking velocity and the flow rate capacity [23]. Simulation studies typically fall into one of the following three categories [22];

**Table 1**
Personnel tolerance limits for various hazards, as defined by the SFPE manual.

| Hazard | Tolerance limit |
|---|---|
| Heat convection | Temperature > 60 °C. |
| Toxicity | Concentration of carbon monoxide (CO) > 1400 ppm. |
| Smoke coverage | Visibility < 2 m. |