Development of BIM-based Real-time Evacuation and Rescue System for Complex Buildings

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Abstract –

With the architectural environment is constantly changing such as high-rise buildings, high-ceilinged space, and special space constantly constructed, thus the fire disasters are becoming diverse and difficult to predict. Therefore, the development and application of building's fire disaster prevention integration system become an urgent requirement for prevention the disaster and reach all protection of life and property.

The response system and organization of fire prevention and disaster relief currently in Taiwan, the planning of evacuation and rescue guidance main depends on human judgment to obtain disaster information. This method may easily either cause error conduction associated with information transfer or can't rescue immediately due to the human negligence or human limitations. Furthermore, wireless sensor networks have been widely discussed in many domains of building disaster-prevention management. This study will focus on fire disaster and combine the application of Building Information Modeling (BIM) to construct a BIM-based building fire prevention and disaster relief system, with integration of fire prevention equipment information, bluetooth sensor technology, and route optimization information of evacuation and rescue. In order to create intelligent fire disaster prevention system frame, which applied the BIM model shows the research results of three-dimension (3D) visualization. Under the fire incidents created by information integration platform, it can provide early detection and accurate alarm ability, endangered people can have correct and rapid guide the evacuation, fire-fighters can obtain the correct information and assist the right guidance of the rescue routes, as a result, reached the purposes of safety and disaster reduction.

Keywords –

Wireless Sensor Networks; Building Information Modeling; Bluetooth Sensor; Route Optimization, 3D Visualization

1 Introduction

In recent years, the rapid development in Taiwan's economy, the enhancement of the construction techniques, and the urbanization of population that have led to the intensive and highly land uses of urban. These phenomena will cause the buildings to develop gradually the high-rise and particular types, such as Taipei 101 building, congregate housing, shopping mall, public buildings, Taipei main station, and MRT station in Taiwan. For this reason, the use of inner spaces for high-rise buildings will be more complex than general ones. Besides, due to the highly capacity and centralized goods for these high-rise and complex buildings, there are the difficulties to escape and rescue as a result of the high-rise and the complex routes when the fire disaster is occurred. Hence, in order to ensure the safety of personnel, the users just use the escape facilities or fire extinguishers to save oneself. This condition will cause the higher fire hazards in high-rise and complex buildings then in the general buildings [1]. Thus, building's fire and disaster prevention integration system and application development has not only become an urgent requirement for prevention the disaster, but also to enhance disaster prevention trend.

Furthermore, with the building's environment are constantly changing, the disasters are becoming diverse and difficult to predict. The fire disaster prevention management for buildings has been highly concentrated on. The tasks includes alarm notification [2, 3, 4], the design of fire evacuation guidance in the building [5, 6], and evacuation routes simulation [7, 8, 9], etc. However, the common evacuation routes were usually guided in 2D views, but are not able to advise the exact location within the building in the immediate condition, then to select the proper evacuation exit. In recent years, some applications of Building Information Modeling (BIM) have been addressed to develop on building disaster-prevention management [10, 11, 12, 13]. The use of BIM can help us to display the distinct site-layout in 3D visualization and immediately grasp the status of the fire and disease in the building. BIM is a kind of new concept and has the ability to improve the traditional 2D plane for disaster prevention management. On the other hand, the fire disaster prevention must integrate sensing technology, analysis, judgment, decision, and action ability. Thus, the key aspects for the study will be : (1) "Effective Detection" to provide earlier detection and accurate alarm abilities, and the immediate mechanisms of extinguishing ; (2) with "Correct Refuge" view , endangered people can have correct and rapid guide the refuge ; (3) with "Fire Relief" view provides fire-fighters the correct information and assist the right guidance of the relief route; (4) with "Integration System" to perspective information integration and sharing mechanism , with a BIM information integration platform to integrate the various fire and rescue information. Then, this effectively exert the linkage mechanism to solve the information transmission problems between endangered people and fire-fighters.

This study proposes the application of BIM to construct buildings in 3D massing models, with integration of fire prevention equipment information, bluetooth sensor information, and route optimization information of evacuation and disaster prevention. In order to create intelligent fire and disease prevention system frame, which applied the BIM model shows the research results of visualization. When the bluetooth sensors detect the information of smoke and high temperature earlier, the system can determine the authenticity and sound the alarm to monitor locations and the evacuation/rescue routes which planned by the back-end operation in BIM's 3D model. Furthermore, the system can instantly show which floor occurs the fire disaster and the space plan of the suspected fire area in the 3D model, then connect the users' APP trapped in the fire scene to active a real-time and dynamic evacuation guidance. The proposed integration system will enhance the time effectiveness and safety of evacuation / rescue.

2 Proposed BIM-based fire reduction system

In order to achieve the message passing among the upstream, middlestream and downstream, and integrate all of the on-site fire information so that can share and analyze the real-time data to the users. This study writes an Application Programming Interface (API) through Revit 2015 to integrate the FireSense system which combines the application of smoke detectors with bluetooth wireless sensor networks, evacuation / rescue guiding device for mobiles (see Fig. 1), and the evacuation / rescue routes planning through Dijkstra's algorithm [28] searching the shortest path for BIM-based system. The BIM platform can provide the data storage of fire agency to update, query and share data, furthermore, apply capabilities of 3D visualization to support fire safety management. The BIM-based system consists of four modules: (a) FireSense module, (b) Enviro-Sense/Location module, (c) Evacuation Planning module, (d) Fire Rescue Planning module, and (e) Global Information module. Fig. 2 shows the integrated system framework. The figure presents the inputs, information transmissions, and outputs of each module. Follow subsections will introduce the modules of the BIM-based intelligent fire reduction integrated system.

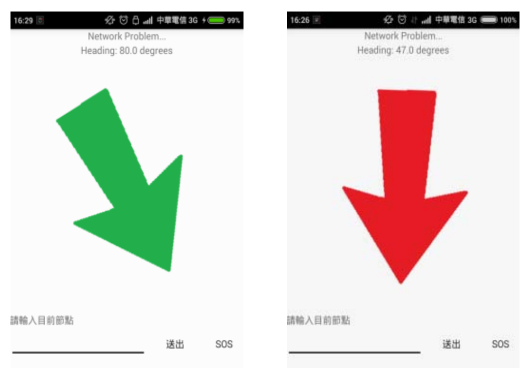


Figure 1. Mobile guiding device

2.1 FireSense module

The FireSense module mainly provides users to monitor the on fire stories of a building. The module combines the multi-functional smoke detector of bluetooth which integrates with temperature sensor, smoke sensor, LED illuminant, power management, System on a Chip (SoC), and power supply (see Fig. 3) to detect the temperature/smoke conditions nearby fire

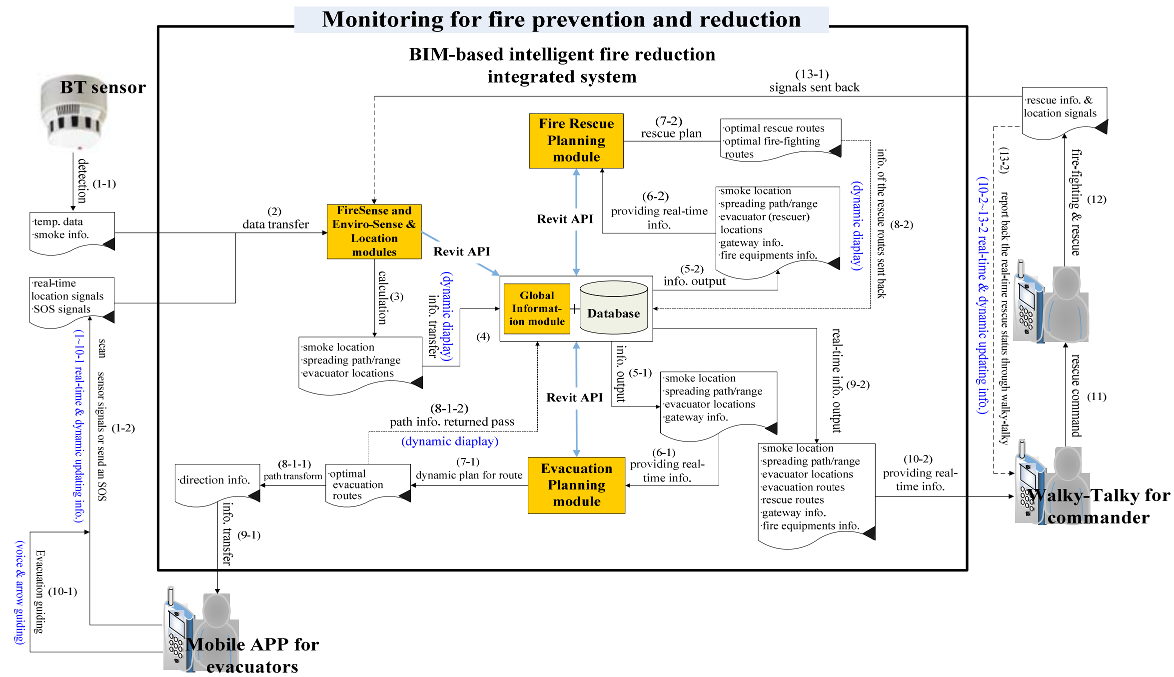


Figure 2. Framework of proposed system

scene and provide the direction guiding of emergency evacuation. Besides, the real-time detected data will be stored in SQL server of the proposed system. When the temperature/smoke are higher than the alert values, the system will highlight the on fire stories of a building and notify the proper fire locations by displaying tips through the FireSense module.

Figure 3. Main components of the FireSense device

2.2 Enviro-Sense/Location module

The FireSense module also combines the multi-functional smoke detector of bluetooth 4.0 to broadcast sensor ID through a radio mechanism of BLE (Bluetooth Low Energy). The broadcast information will be received by smart phones or tablets which support the BLE, and furthers, the smart phone on one's hand can capture the Receiver Signal Strength Indicator (RSSI) through matching up the use of mobile APP to proceed a one's location. Fig. 4 shows the process of personal location. First, the bluetooth MAC of smart phone will be captured by user's APP and provided to the server to track each user's location. Second, the MAC will be stored in a new object of HttpThread to upload the location information. Third, starting the smart phone's bluetooth to scan the multi-functional smoke detectors around the user. The action will last one second to obtain the device ID of the multi-functional smoke detectors around the user and each RSSI. Fourth, the all received device ID and RSSI will be upload to the server and calculated the user's location by the server. Fifth, when completing the uploading process, the all data will be cleared and repeat step3 and step 4 to continue the locating process. Furthermore, the commander can find out the evacuators are in which smoke detector's ID on BIM model through the locating information.

Thus, the module will provide users to query the current real-time information of the fire scene which consists of the temperature/smoke information, quantity of bluetooth sensor charge, and fire/evacuators/rescuers locations. When users click on the sensor components of BIM model from this module, the users can not only query the above mentioned environmental data but also get the detected time and alarm status. On the other hand, if the users click the human shape components on BIM mode, the information of sensor ID which the evacuators/rescuers stay in, number of people, and people's identity can be provided to grasp the latest current situation of fire scene.

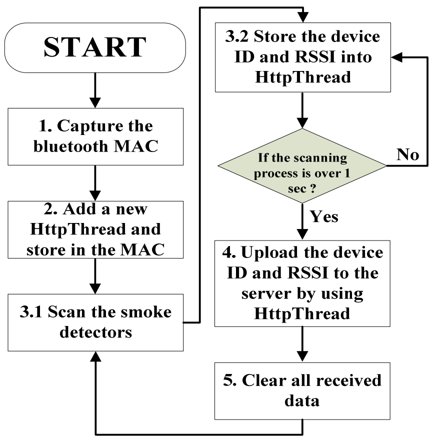


Figure 4. Locating process in back service through integrating smoke detectors and user's APP

2.3 Evacuation Planning module

The evacuation planning module not only provides users to look over the location information of fires, evacuators and rescuers at the same time but also uses the BIM 3D visualization to help preliminarily allocate the evacuation areas of the building to each exit according to the latest locations of fires and evacuators. Besides, the module can real-time calculate the shortest safe path from the start node (evacuator locations) to the end node (exit) on the basis of Dijkstra’s algorithm and dynamic display the evacuation routes on the target BIM modeland so that provide the fire commander to grasp the evacuation status of evacuators rapidly. However, the shortest safe path is determined by multiplying penalty factor from the relative paths of on fire nodes to evade the fire areas. Thus, the Dijkstra’s algorithm can be defined through the following function [14] :

$$\mathrm{dist}[j] = \min[\mathrm{dist}[j], \mathrm{dist}[k] + \mathrm{c}(k, j)] \quad (1)$$

where dist[i] is the shortest path from starting point to i, c(i ,j) presents the distance from i to j. Owing to penalty factor must be a comparatively large value, The study raises a suggestion that takes the penalty factor equation to be set as the longest path from all proper paths, and further times 100 to ensure the relative path of on fire longer than other safe path. This method will be avoided effectively to pass through the fire areas.

On the other hand, an evacuation guiding APP device for mobile (hereafter, mobile APP) is applied by this study owing to its popularity, well performance and easy to carry. After the dynamic evacuation routes are calculated by the proposed module, the results of routes and next target node will be uploaded to database through internet and connect the direction angle on PHP web server at the same time to provide for the use of mobile APP of voice and arrow (shown as Fig. 5). The mobile APP is in combination with the application of gyroscope [15] and orientation sensor [16] which built-in the smart phone to calculate the horizontal azimuth of mobile device and guide direction through an arrow. When the evacuators move to next nodes, the module will recalculate new paths in accordance with the latest location data on BIM model and re-guide through mobile APP to achieve the target of dynamic real-time evacuation guiding and helping evacuators escape to exit rapidly and safely.

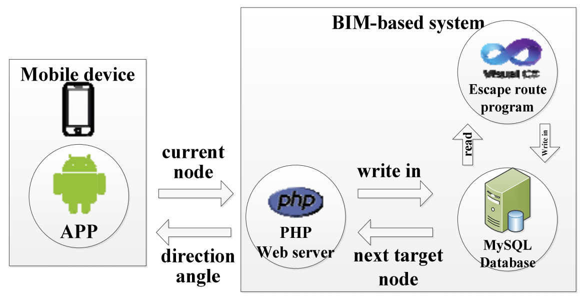


Figure 5. Communications between module and mobile device for evacuation

2.4 Fire Rescue Planning module

The functions of fire rescue planning module are similar to some parts of the evacuation planning module. It also can not only provide commander to look over the location information of fires, evacuators and rescuers, but also display the dynamic real-time fire rescue routes on the BIM 3D visual model. The planned routes are divided into two parts: (a) fire-fighting routes, and (b) rescue routes. In the phase of planning fire-fighting routes, the calculation method is the same as optimal evacuation routes by using of Dijkstra’s algorithm. But we won't take the penalty factor into consideration in planning fire-fighting routes and avoid the clash with evacuation routes, owing to fire-fighters must find the shortest path to arrive the fire point and act a fire-fighting. In the phase of planning recue routes, we further import the concept of many (gateways)-to-many (evacuators) into Dijkstra’s algorithm and consider the penalty factor equation to calculate the shortest recue routes. The planning results will be uploaded to database through internet to provide for the use of mobile rescue device of voice and arrow (shown as Fig. 5). This model can assist to grasp fire conditions quickly and correctly for on-site commander, help reaching the fire point and the location of victims through the fastest and safest ways for the indoor fire-fighters, and optimize the abilities of fire reduction to enhance the rescue efficiency.

2.5 Global Information module

The global information model not only shows the look of building and fire equipments and locations, etc. on BIM 3D visualization, but also integrates all of fire and disaster reduction information of the first four modules. This function can provide fire commanders to proceed an overall grasp of all real-time information of the fire scene and make quick and correct disaster relief decisions.

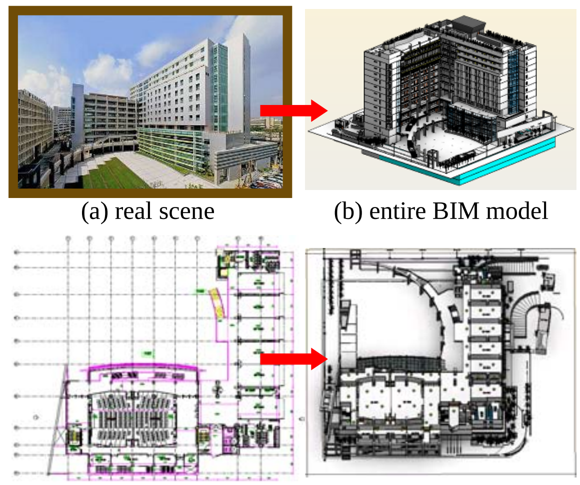
3 Case study and system operations

Autodesk Revit Architecture 2015 which opens a full-fledged API called Revit Platform API [17] is utilized herein to develop the proposed BIM model as a result of its popularity and practical utility in Taiwan. Implementing the five modules requires a BIM model with a level of detail (LOD) of 300. An LOD 300 BIM model should contain columns, beams, walls, floorslabs in structure phase, and windows, decoration walls, stairs, doors in architectural phase as objects, along with their size, shape, location, orientation and geometric data (such as length, area, and volume) [18]. The five modules of this BIM-based system are developed on a Windows operation environment and the .NET Framework 4.5, and compiled by using the C# programming, with a Windows 7 computer operating system. Besides, using the SQL SERVER 2010 to manage database and communicate with Revit.

The following subsections describe the results of applying the proposed BIM-based system in a case study.

3.1 Building description

This study concentrates on the high-rise and complex building "International Building (hereafter, IB) of Taiwan Tech" located in northern Taiwan as a case study. The IB building is a building of twelve-storey on the floor with a cockloft designed to act as the uses of office, classroom, performance space, and meeting room, and three-storey below ground as parking lots. The total floor area of this building is about 36535.24 square meters, and the building height is 49.6 meters (see Fig. 6 (a), (b)). Based on the experience of the architect and the fire safety staff, occupants who use gateways of each storey exits will face the most danger because they are in the higher and complex area. On the other hand, since most of the student are mainly gathered up to conduct a class on the third or fourth floors with the more exits, the actions of evacuation and rescue are relative difficult if a fire occurs. Accordingly, in the following sections, where applicable, the area in which occupants use the third floor of IB building as exiting floor will be used to illustrate the simulations and experimental verifications of the proposed modules. The case floor (the third floor) looks like a "L-shape" with six gateways, as displayed in Fig. 7.



(a) real scene (b) entire BIM model

(c) 2D plane for the 3rd floor (d) 3D model for the 3rd floor

Figure 6. Case building (IB) in NTUST

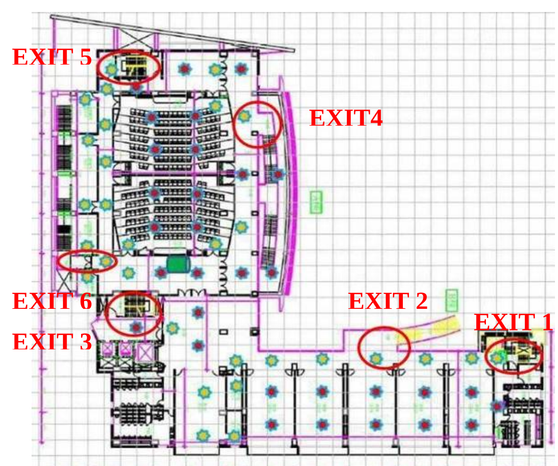


Figure 7. Exits layout of the third floor plane in case building

Besides, this study aims to guide information system into BIM model and be good at using each fire equipment /space data of BIM model to let fire safety staff making a correct decision though the display of

BIM 3D visualization. But before operating the BIM-based system, there must be a constructed BIM model. Therefore, we need to establish the complete BIM model before guiding into integrated system. For this reason, a BIM model of the case building (IB) during operation phase was made available using Autodesk Revit Architecture 2015 (see Fig. 6 (b), (d)).

3.2 Bluetooth sensor layouts and encoding principle

The BIM-based intelligent fire reduction integrated system combines the application of multi-functional smoke detector of bluetooth to detect environmental conditions. In this study, there are 61 bluetooth sensors embedded in the third floor of the IB building as nodes (e.g., located on classrooms, sidewalk, corners, and exits), and the distance of each node equals 5m. We also construct all of the sensor components on the BIM model shown as Fig. 8 (green balls). The follows will describe the principle of bluetooth sensor encoding. The sensors which embedded in interior spaces (including the large meeting rooms and classroom) are numbered by original spatial code (initial number as 301). Thus, the principle of the interior spaces is through the clockwise from the first sensor of upper right to number. For example, Fig. 8 shows that there are four bluetooth sensors embedded in meeting room 301, so the codes are numbered by 3011, 3012, 3013, and 3014 in turns according the principles of top-down and right-left. The similar same as the external sidewalk, the initial value is 300 and the codes are numbered as 3001, 3002, and so on from the first sensor of upper right in Fig. 8 according to right-left and top-down (see Table 1). The codes in this system provide the unique id for bluetooth sensors. The system combines the technique of blutooth wireless sensor networks and writes in/ reads the sensor id and spatial data to real-time locate people/fire in buildings through the display of BIM 3D visual model.

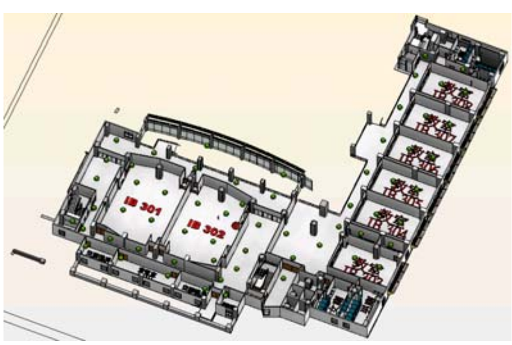


Figure 8. Bluetooth sensor embedded in the 3rd floor of IB building

Table 1. The bluetooth sensor id on the 3rd floor of the IB building

Category	Space No.	Floor	Sensor ID
Meeting room	IB 301	3	**3011**
	IB 301	3	**3012**
	IB 301	3	**3013**
	IB 301	3	**3014**
Meeting room	IB 302	3	**3021**
	IB 302	3	**3022**
	IB 302	3	**3023**
	IB 302	3	**3024**
Classroom	IB 303	3	**3031**
	IB 303	3	**3032**
		⋮	
Classroom	IB 308	3	**3081**
	IB 308	3	**3082**
Sidewalk	-	3	**3001**
		⋮	
Sidewalk	-	3	**30061**

3.3 Operating process of the proposed system

The use of the BIM-based system which established by the communications of BIM model and API, has four operating phases as follows: (a) implementation phase, (b) start phase, (c) update phase, and (d) storage phase. The subsection will introduce the four operating frameworks.

(a) Implementation ： When carrying out Autodesk Revit Architecture 2015 to open the target building of BIM model and operate the system, the five modules will be added in the two ribbon panels: "Fire Monitoring" and the "Fire 3D Visualization" of the "Building Fire Prevention and Disaster Relief " tab (see Fig. 9), then pushing each module's button can prepare to start this system.

(b) Start：After implementing, the system will spend a few seconds to capture BIM model and the data from SQL database, and then the dynamic 3D visual data of fire scene will be displayed on BIM model. This current data of visualization model and relative components can be provided to the fire rescuers as references.

(c) Update：When the fire occurs, most of the fire information can be displayed on BIM model of this "BIM-based intelligent fire reduction integrated system" clearly, and "real-time" update the dynamic fire information under a steady interval through compiling the API. The latest dynamic fire data on BIM model can be provided to the relative rescuers.

(d) Storage：In this phase, all of the information which ever displayed on the BIM-based system will be stored and feedback into the SQL database automatically. Furthermore, these past data can be queried or analyzed someday.

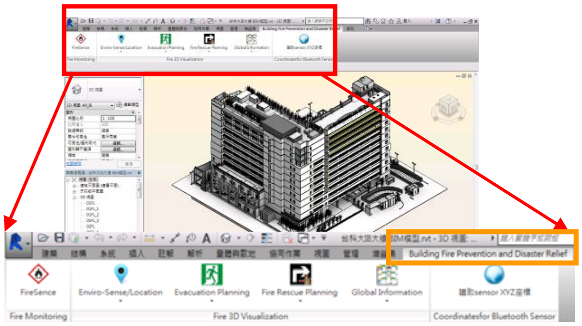
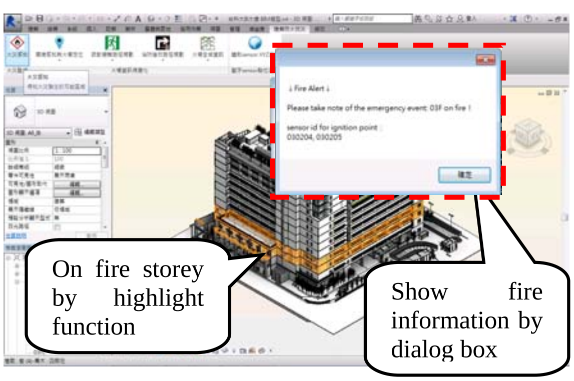


Figure 9. The panels of five modules

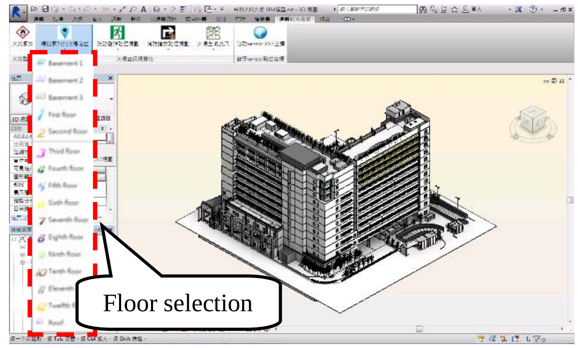
3.4 Case simulations

3.4.1 FireSence

First, we start Revit 2015 to open the 3D model of the case building, then click the "FireSense" button within the "Fire Monitoring" tab to prepare monitoring the fire event. In this case study, we assume the fire initial ignites on third floor of IB building. When a fire occurs, the walls of on fire storey will be all highlighted by orange color and moreover shows the dialog box to notice the information of the proper on fire floor and fire locations shown as Fig. 10 (a). When the available fire information obtained in this system, follows users can click the last four module embedded in the tab of "Fire 3D Visualization" to look for another real-time fire disaster information, such as evacuation routes, personnel status,...etc. Fig. 10 (b) shows the user selects the needed 3D sectional drawing of floor to look for relative fire information.



(a) on fire storey alert

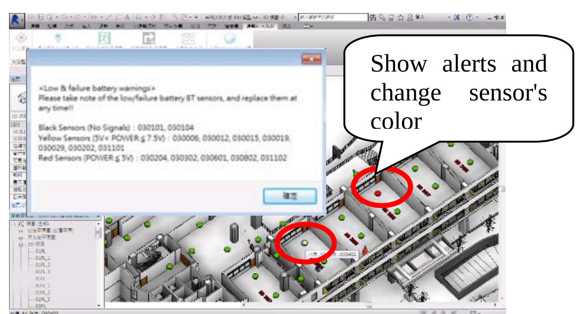


(b) Select floor to open 3D sectional drawing

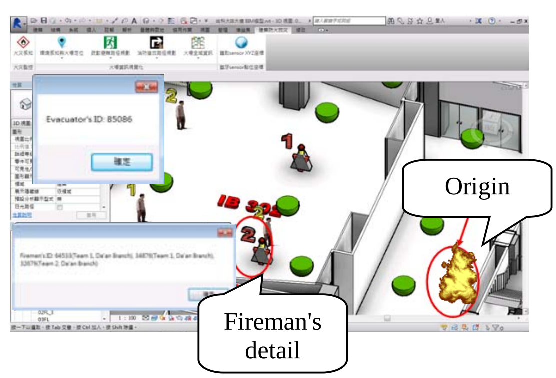
Figure 10. Functions of FireSense module

3.4.2 Environmental detection and personnel localization

The Enviro-Sense/Location module provides a 3D representation of hazardous/personnel locations, environmental conditions, and the alert for low battery bluetooth sensors. When users carry out this module to look for the fire information, the system will show a alert window to advice users needing to replace battery, and change the sensor component color into red if there is a low battery bluetooth sensor (see Fig. 11 (a)). In addition, users can also click the sensor component button to query its id, detecting time, smoke value, and current temperature.



(a) visualization for low battery sensor



(b) Visualization of personnel locating

Figure 11. Functions of Enviro-Sense/Location module

The second deliverable of this module - fire/personnel locating - is very useful in fire disaster management. Because most high-rise buildings own the more complex indoor spaces and structure designation, so the difficulty of disaster reduction will be increased from fireman's opinions. Based on the results of the assessment using the previously described Enviro-Sense/Location module, Fig. 11 (b) presents a real-time dynamic 3D locating map using the 3rd floor of IB building, as an example. Moreover, this module's query function is used to provide the personnel's identity (device id of smart phone) and organization. And the personnel amounts under each bluetooth will be calculated and displayed on the 3D model of the human shape components. In Fig. 11 (b), the fire symbol presents on fire location, the real human shape component is trapped evacuator, and the component of red head with triangular body presents fire-fighter.

3.4.3 Evacuation/Rescue Planning and Guiding

When a fire first ignites, it may be small enough that you can have an even better chance to escape from the fire scene without risking injury by use of the mobile APP provided evacuation data by our proposed BIM-based system on hand. Initially, the architect of the case building used 2D drawings to make an guiding map. The proposed evacuation planning module uses the 3D BIM model to display the real-time evacuation routes from each personnel location. This study further added an additional rescue guiding map based on BIM model.

In this simulation, we will prior discuss the results of evacuation planning and guiding, owing to the methods of planning rescue routes and guiding are similar to each other. Therefore, in this part, a evacuation planning case study is simulated. We assume the on fire location is No. 030019 and the initial location of two evacuators are No. 030204. The shortest path where these two evacuators can originally escape is from No. 030204, No. 030019, No. 030020 to No. 030029 (see Fig. 12). But in order to avoid the origin fire, the evacuation route is planned from No. 030204, No. 030203, No. 030022 to No. 030013 (Exit) according to the proposed method of planning evacuation presented in Subsection 3.3. Fig. 12 resents the guiding processes between for the interactive relationship between 3D visualization guiding on BIM model and the arrow guiding of the use of mobile APP.

Figure 12 Process of the real-time evacuation guiding

4 Conclusions

Currently, many structures of buildings are most constructed by the fireproofing. When the fire occurs, the people in this kind of buildings still have a heavy casualties and property damages. It can be seen that it is insufficient to be just provided with fire resistance for structure itself. In response stage of the fire, the real-time fire location, the spreading status of smoke, and the occupants' locations must be overall taken into considerations. Furthermore, it is needed for helping evacuators to evacuate from a dangerous area quickly and safely while a emergency event occurs. Besides, saving lives in building fires depends on locating fires quickly and accurately, attacking them aggressively and reaching occupants who may be trapped in the interior of a building to act a disaster relief through fire-fighters.

For those reasons, This study promotes the usages of BIM spatial and visual information in combinations with "fire alarm sensing system", "location-aided design", "planning of the optimal evacuation and rescue route", and "real-time guiding system of mobile APP" in an BIM-based integrated system for evacuators, fire-fighters, and commanders in the preparedness and the response stages. The proposed integrated system hopes to solve the problems of the error information or without evacuating quickly and rescuing immediately which resulting of the human errors and the human limitations when the fire occurs in buildings. In this study, the numbers of the fire and personnel locations are transmitted by bluetooth sensors which constructed within a building then send back them to the BIM-based integrated system, and combine the database's searching and integrate the relative information of the disaster prevention / reduction (e.g., fire facilities information, etc.) to provide the consultations for planning routes, dynamic guiding, and rescue decision-making.

Applying the "BIM-based intelligent fire reduction integrated system" developed by this study can greatly enhance the accuracy of the fire alarm and real-time monitor the status of disaster areas to plan and show the optimal evacuation / rescue routes by the use of BIM 3D visual model with mobile guiding system. Fortunately, this can not only be used by fire-fighters to quickly locate destinations (e.g., the location of a fire and potential victims) but also reduce response times to accidents and minimize the search times required to find potential trapped evacuators.

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References

[1] Gang Zhao, "Taiwan Super High-rise Building Fire Disaster Prevention", *China Fire Association Scientific Technology Annual Meeting & Guangdong High-rise Building Fire Safety Management Summit*, Chinese Association of Fire Protection, 2012.

[2] S. Matthews et al., "Field evaluation of two image-based wildland fire detection systems", *Fire Safety Journal*, Vol. 47, pages 54–61, 2012.

[3] F. Yuan, "Video-based smoke detection with histogram sequence of LBP and LBPV pyramids", *Fire Safety Journal*, Vol. 46(3), pages 132–139, 2011.

[4] B.U. T¨oreyin, Y.Dedeoglu, U.G¨ud¨ukbay, A.E. Cetin, "Computer vision based method for real-time fire and flame detection", *Pattern Recognition Lett*, Vol. 27(1), pages 49–58, 2006.

[5] S. Cao et al., "Modeling pedestrian evacuation with guiders based on a multi-grid model", *Physics Letters A*, Vol. 380, pages 540–547, 2016.

[6] H. Ran et al., "Influences of intelligent evacuation guidance system on crowd evacuation in building fire", *Automation in Construction*, Vol. 41, pages 78–82, 2014.

[7] Tanaporn Tanachawengsakul et al., "A simulation study on fire evacuation routes in primary stage for a historic canal residential area" *Procedia -Social and Behavioral Sciences*, Vol. 216, pages 492–502, 2016.

[8] Yu Cai et al., "Study on law of personnel evacuation in deep buried metro station based on the characteristics of fire smoke spreading", *Procedia Engineering*, Vol. 135, pages 543–549, 2016.

[9] Vancho Adjiski et al., "Simulation and optimization of evacuation routes in case of fire in underground mines", *Journal of Sustainable Mining*, Vol. 14(3), pages 133–143, 2015.

[10] Y. Zou et al., "A review of risk management through BIM and BIM-related technologies", *Safety Science*, ***In Press***, 2016.

[11] S.-H. Wang et al., "Applying building information modeling to support fire safety management", *Automation in Construction*, Vol. 59, pages 158–167, 2015.

[12] J. Choi et al., "Development of BIM-based evacuation regulation checking system for high-rise and complex buildings", *Automation in Construction*, Vol. 46, pages 38–49, 2014.

[13] Kun-Chi Wang et al., "Application of Building Information Modeling in Designing Fire Evacuation-a Case Study", *The 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014)*, July 9-July 11, 2014, Sydney, Australia, 2014.

[14] E. W. Dijkstra, "A note on two problems in connexion with graphs", *Numerische Mathematik*, 1959.

[15] Wikipedia, "Gyroscope", 2015.04, <http://tinyurl.com/o7ggnk7>.

[16] Bin-Hua Huang, "Android 4.X App", *GOTOP Information*，pages 10-2 - 10-19, 2013.

[17] Autodesk, Inc., "Revit 2015 API Developer’s Guide", Jul.16.2015.

[18] Robert S. Weygent, "BIM Concept Development: Standards, Strategies, and Best Practices", New Jersey: John Wiley & Sons Inc, 2011, pages 79-85.