# An Agent-Based Evacuation Model to Support Fire Safety Design Based on an Integrated 3D GIS and BIM Platform

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## ABSTRACT

In this paper, a basic Agent-based evacuation model is constructed firstly. On the basis of the integration of evacuation simulation model and CFD (Computational Fluid Dynamics) fire simulation model, a simulation model for occupant evacuation in fire environment, is proposed. Then, a powerful platform which can be adopted to incorporate BIM into 3D GIS is presented and the simulation scenario of occupant evacuation in fire environment can be implemented effectively on it. The research demonstrated that it is possible to transfer (high level of geometric and semantic) information acquired from IFC-based BIM models into the 3D GIS environment. The results also demonstrated that the 3DGIS-BIMs integration platform provide a sufficient multi-level and amount of geospatial and indoor information for the seamless data fusion and management tasks to support the fire response management processes considering both indoor and outdoor situations.

## INTRODUCTION

With the rapid growth of cities, the number of public buildings needed for urban life has increased, and the functions and structures of these building have also become more complex. In addition, disasters such as fire and explosion (i.e. the 911 Terror Attack), earthquake and tsunami have led to many deaths following the destruction of urban facilities, causing astronomical financial losses and massive casualties. For these reasons, there is a growing demand for building safety design that can not only provide comfortable and effective facilities, but also enable a safety evacuation in the event of an emergency.

Especially, fire occurs frequently in urban life. Once fire occurs in building, fire and fumes will spread rapidly which will result in a difficult evacuation and potentially cause serious injury to human. With the advancement of information and communication technology (ICT) in recent years, a variety of attempts (such as Wing 2006, Madritsch 2009, Kim 2010, Shen 2010, etc.) to better design safe urban facilities have been made by incorporating ICT into the design process. Some evacuation models, such as EGRESS, EXODUS, SIMULEX, EXITT, WAYOUT

(Gwynne 1997), have been successfully established and applied. These models can be used to simulate occupant evacuation and evaluate the evacuation efficiency for buildings. However, the little consideration was taken into about the interaction between occupants and fire/fumes in these models since the situation will become more sophisticated. Moreover, many designers of the indoor evacuation process use conventional approaches, such as 2D access maps to determine the location of entrances in public buildings. However, existing indoor evacuation simulation approaches based on 2D geometries and pre-defined routing remain insufficient for many applications such as emergency response, delivery, utility maintenance and facility management. current studies on user requirements points towards an increased interest in 3D indoor information for evacuation. In fact, as far as large-scale public buildings are concerned, the effective evacuation is influenced not only by indoor configuration but also by outdoor situations. Some researchers state that the ability to understand complex spatial and functional relationship in the contemporary 3D city is enhanced by a 3D representation of the indoor and outdoor infrastructure on which people plan and realize their travel activities (Thill, Dao, and Zhou 2011). In recent years, research has been reported on the development of 3D models that can represent details of building (including roofs, floors, doors and windows) and the integration of GIS and 3D models applied in analysis related to disasters and evacuation (Kwan 2005, OGC 2008, Isikdag et al. 2008, Lee 2009 and Zlatanova 2008, Kim et al. 2009). However, the main barrier preventing the application of these models in practice has been the lack of models providing appropriate semantic representations of indoor geometry and merging effectively with outdoor environments. Recently, a key element of this integrated geospatial information to emerge is detailed geometrical and semantic information about buildings. In parallel, Building Information Models (BIMs) of today have the capacity for storing and representing such detailed geometrical and semantic information. In this context, the research aimed to investigate the methodology and applicability of BIMs incorporated into Geographical Information System (GIS) environment by focusing specifically on this domain; evacuation under fire response management.

In this paper, a basic Agent-based evacuation model is constructed firstly. The intelligent technology is induced in this model to represent self-motivation, response and decision-making ability of human in the escape progress. On the basis of the integration of evacuation simulation model and fire simulation model, a simulation model for occupant evacuation in fire environment, is proposed. Then, a powerful platform which can be adopted to incorporate BIM into 3D GIS is presented and the simulation scenario of occupant evacuation in fire environment can be implemented effectively on it.

The research demonstrated that it is possible to transfer (high level of geometric and semantic) information acquired from IFC-based BIM models into the

3D GIS environment. The results also demonstrated that the 3DGIS-BIMs integration platform provide a sufficient multi-level and amount of geospatial and indoor information for the seamless data fusion and management tasks to support the fire response management processes considering both indoor and outdoor situations.

## EVACUATION MODEL

The research aimed to assess the applicability of an implementation of an industry standard BIM (IFC) in a geospatial context in order to investigate whether the processes of occupant evacuation and fire response management can benefit from such an implementation. This paper proposes an agent-based evacuation model to represent occupant behaviors.

Firstly, the building plane divided by 0.5m×0.5m fine grid based on the hypothesis that each person occupies a 0.4m×0.4m space, which is the typical size of each person's space (Burstedde 2001). As a representation of the occupants, the agents make decisions on behavior at each time instant according to certain rules. They search for corresponding rules with the change of environment so as to adjust themselves.

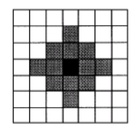

**Figure 1. Von Neumann Neighborhood（r＝2）**

The Von Neumann neighborhood (Neumann 1996) (as shown in Figure1) was select as the neighborhood of each individual. The current behavior of each individual is totally decided by the environmental parameters within the neighborhood. Basically, there are many properties relevant to occupant evacuation, such as health, gender, reaction time, familiarity, cooperatives, etc.. In the model, present status, relative properties and behaviors rules are specified for all occupants. No matter how complicated behaviors are, all factors will finally be represented by the action of agent, i.e. walking speed and routine. Hence, the walking simulation of every occupant is actually the process that the occupant's velocity and movement direction at each time step and the location to arrive at the next time step are decided by various impact factors.

Health and mobility are two main factors to consider occupant's present status. Health is a numerical value which evaluates the body condition of occupants and it declines when occupants are injured by the heat fire releases or toxic gas. When it falls to zero, the occupant dies. Mobility quantifies the move capacity for occupants and it decreases when occupants meet congestion or get hurt. When mobility falls to zero, it means the occupant is trapped in fire field.

Normally free walking speed can be regarded between 1.2m/s and 1.8m/s. Also some experimental data suggests that it varies as a function of age (Ando et al. 1988). Under the fire environment, each agent has to determine the walking speed toward next position. The speed depends upon the age, gender, profession, health etc. Currently, it is considerable difficult that all these influence factors could be consider in a model. Only those main factors, rather than all factors, are considered in the evacuation model.

During crowd evacuation, density is usually the most important factor. It is obvious that occupants move slowly when the density gets high. Based on the analysis of experimental data, Nelson and MacLennan (1996) proposed the following model to represent the relationship between move speed and flow density:

$$Speed = \begin{cases} 1.19, & 0 < density < 0.54 \\ 1.4 \times (1 - 0.266 \times density), & 0.54 \le density < 3.8 \\ 0.01, & density \ge 3.8 \end{cases} \quad (1)$$

Hence, a basic velocity could be expressed as the function of crowd density within certain space area (∆x×∆y) shown as follows:

$$u_b = f(D_0) \quad (2)$$

Where, $D_0$ is the density in person/ m$^2$.

Thompson and Marchant (1994) calculated the speed reduction due to proximity of others with the help of speed density curve presented by Ando et al. (1988). If $d_p$ is the inter person distance (m), then

$$d_p = \sqrt{1/D_0} \quad (3)$$

The basic velocity $u_b$ could be calculated by Thompson equation:

$$u_b = \left[ U_0 \frac{d_p - 0.25}{0.87} \right] \quad (4)$$

Where, $U_0$ is the average free flow walking speed (1.2 m/ s). The speed is unimpeded.

Actually, besides crowd density, other factors, such as psychology, individual character etc, should also be taken into account since they reflect physical and environmental situation of occupants and influence the move speed as well. The variable "adjust_speed" $u_k$ which summarizes all the critical factors is defined as follows (Jianyong, Shi. et al. 2009):

$$u_k = \lambda \times u_b \quad (5)$$

Where, λ is the adjust coefficient. For example, the psychology influence on walking speed is considered by a suggested psychology influence factor $\beta$ ($\lambda=\beta$).It is a quite complex problem to determine the psychology influence. One key factor is the panic to the fire scenario. In the model, considering the panic level of occupants caused by fire, $\beta$ could be formulated as the function of danger eject factor (fire danger) of grids within the neighborhood (Jianyong, Shi. et al. 2009).

$$\beta = f(q) = \begin{cases} 1.3 & if\ q \le 0.5 \\ 1.1 & if\ 0.5 < q \le 0.8 \\ 1.0 & if\ q > 0.8 \end{cases} \quad (6)$$

Where $q = 1/\overline{p}_k, \overline{p_k} = n^{-1} \cdot \sum_{(i,j)} p_k$ which means the mean value of fire danger eject factor of grids within the neighborhood, n is the grid number. If $\overline{p_k} = 0$, then q =1.

It is discovered from many fire hazard cases, that fumes caused by fire is the main factor that threatens human life. When occupants evacuate in fire environment, the growth and spread of smoke will affect both body conditions and strategy options. Thus, it is an important consideration that interaction between occupants and fire field can be represented and the evacuation model and fire simulation model must be properly integrated.. The development of fire simulation models makes it possible to find out relevant quantity distribution in field without practical experiments. Thus, the FDS (Fire Dynamics Simulator developed by NIST) model was utilized to achieve calculation data with respect to fire field. FDS provide the calculation model of combustion products. Through FDS simulation, values of various quantities (soot density, etc.) at any point in fire field can be calculated as a function of time. Therefore, as part of simulation results, volume fraction of toxic gases such as CO, CO2 is attainable for researchers. FDS model is also capable of calculating temperature property at gas phase and solid obstructions. From these data, the hazard assessment for thermal radiation can be made.

In addition, some experimental data (Gottuk et al. 2002) has indicated the relationship between the duration occupants are exposed to certain volume of toxic substances and the corresponding hazard to human body. Referring to this, it is possible to make estimates of potential toxic hazard of combustion products.

## CASE STUDY

Currently, evacuation simulation is the hot topic in the field of fire safety research, and is one of core part of the performance-based fire design. Basically, existing simulation models are always suitable for indoor space of buildings. Up to now, there are few reports that can be found to considerate the interaction between the indoor environment and surrounding situation of the building. Therefore, on basic of the integrated 3DGIS and BIM platform (as shown in Figure 2), an underground tube station is taken as case to investigate the evacuation process.

To achieve the integration goal of geospatial information and building information, a virtual simulation platform was established based on a 3D GIS, while the BIM model information of tube station can be obtained from IFC model which is derived from Autodesk Revit software, and transferred into the 3D GIS environment. The fumes level and fire scenario are simulated by fire dynamic simulation program (FDS). On the basis of the integrated environment and AFESM (Agent-based Fire Evacuation Simulation Model), a simulator program for occupant evacuation in fire environment is developed. The system frame is shown as Figure 3.

The simulator is capable of converting IFC model into CFD model used by

FDS, and acquiring calculation results of fire and smoke movement. All of these results date, such as fire source, spatial temperature distribution, as well as height and density of smoke layer etc., can be transferred into the three-dimensional BIM model of building already merged into 3D GIS environment. All of elements of buildings organized in BIM models as a hierarchy tree, such as doors, walls, stairs and corridors etc., can be identified by AFESM. Thus, evacuation route could be determined in terms of building layout and fire scenario. Figure 4 shows the simulation results of evacuation process in tube station under fire conditions.

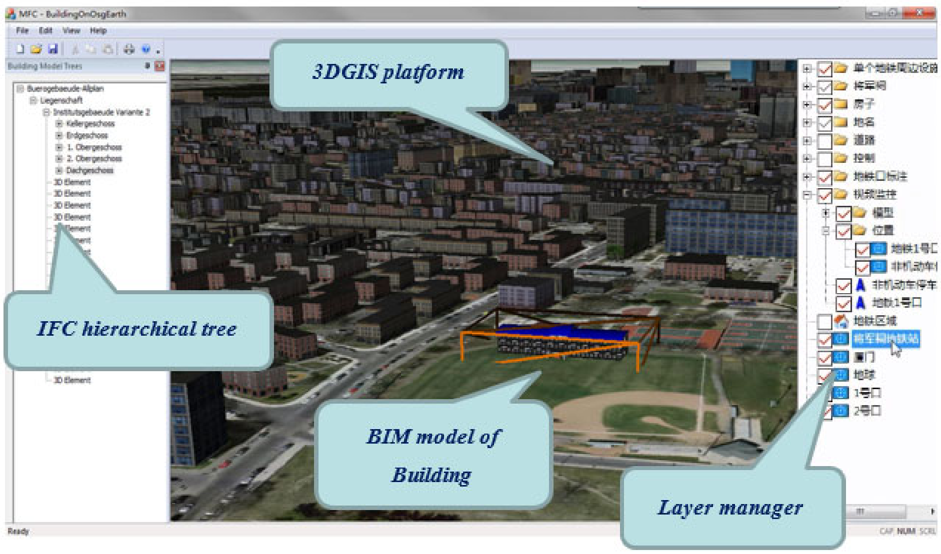


**Figure 2. The integrated 3DGIS and BIM platform**

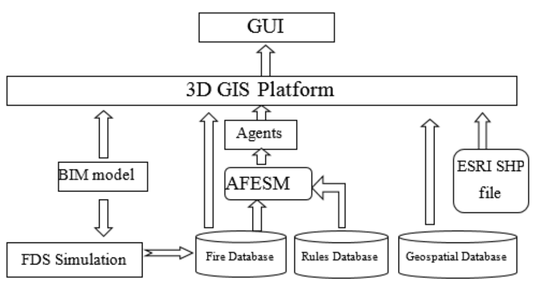


**Figure 3. System Frame Plan of AFESM**

a) Entering into BIM model of tube station from aboveground

(b) Evacuation and Fire scenario simulation

**Figure 4. Evacuation simulation under fire condition based on the integrated 3DGIS-BIM platform**

## CONCLUSION

With development of the society, it becomes more and more important to simulate the evacuation process considering not only indoor environment but also outdoor situations, especially for large-scale public buildings. In this paper, a basic Agent-based evacuation model is constructed firstly. On the basis of the integration of evacuation simulation model and CFD (Computational Fluid Dynamics) fire simulation model, a simulation model for occupant evacuation in fire environment, is proposed. Then, a powerful platform which can be adopted to incorporate BIM into 3D GIS is presented and the simulation scenario of occupant evacuation in fire environment can be implemented effectively on it. Through simulation, the occupant behaviors and fire safety performance of different architecture plans can be investigated and analyzed in case of emergency. The research demonstrated that it is possible to transfer (high level of geometric and semantic) information acquired from IFC-based BIM models into the 3D GIS environment, as well as the 3DGIS-BIMs integration platform provide a sufficient multi-level and amount of geospatial and indoor information to support the fire response management processes considering both indoor and outdoor situations.

With further development of ICT technology and method of evacuation study, more complex psychological aspects of escape movement will be considered and more effective 3DGIS-BIM integration approaches could be developed. Further efforts are being carried out to improve the flexibility and validity of this integration platform.

## ACKNOWLEDGEMENTS

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## REFERENCES

Ando, K., Ota, H. and Oki, T. (1988). Forecasting the flow of people, (in Japanese), RRR, Railway Research Review, 45(8): 8-14.

Burstedde C, Klauck K, Schadschneider A et al. (2001). Simulation of pedestrian *dynamics using a two dimensional cellular automaton. Physica A , ,295 (324) : 507-525

Gottuk D. T. and Lattimer B. Y., Effect of combustion conditions on species production, The SPFE Handbook of Fire Protection Engineering, NFPA, Quincy, MA, 2002: 2-54 - 2-82.

Gwynne S, Galea ER (1997). A review of methodologies and critical appraisal of computer models used in the simulation of evacuation from the built environment, Society of Fire Protection Engineers: 1-93.

Isikdag, U., Underwood, J., and Aouad, G. (2008). An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes. Advanced Engineering Informatics, 22(4): 504-519.

Jianyong, S., Aizhu, R. and Chi, C. (2009). Agent-based evacuation model of large public buildings under fire conditions, Automat. Constr. 18: 338-347

Kim T.J (2010). Planning for knowledge cities in ubiquitous technology spaces: opportunities and challenges, in: J. Symonds (Ed.), Ubiquitous and Pervasive Computing: Concepts, Methodologies, Tools, and Applications, IGI Global: 1613-1625.

Kim, H., and Jun, C. (2009). Extending a pedestrian simulation model to real-world applications, In T. Kolbe, H. Zhang and S. Zlatanova (Eds.), International Archives of Photogrammetry, Remote Sensing and Spatial, Information Sciences (Vol. XXXVIII-3-4/c3: 35-39).

Kwan, M.P., Lee, J (2005). Emergency response after 9/11: The potential of realtime 3DGIS for quick emergency response in micro-spatial environments. Computers, Environment and Urban Systems, 29(2): 93-113.

Lee, J. (2009). GIS-based geocoding methods for area-based addresses and 3D addresses in urban areas. Environment and Planning B: Planning and Design, 36(1), 86-106.

Lee, J., Zlatanova, S. (2008). A 3D data model and topological analyses for emergency response in urban areas. In S. Zlatanova and J. Li (Eds.), Geospatial information technology for emergency response (ISPRS book series) London: Taylor and Francis Group: 143-168.

Madritsch T., May M. (2009). Successful IT implementation in facility management, Facilities 27 (12) 429-444.

Nelson H.E, MacLennan H.A(1996). Emergency movement, The SFPE Handbook of Fire Protection Engineering, 2nd ed. pp. 3-286–3-295.

Neumann J (1966). Theory of Self-Reproducing Automata. Burks A W, ed. Urbana: Univ of Illinois Press.

OGC (2008). OpenGIS_ City Geography Markup Language (CityGML) Encoding Standard, OGC project document no: OGC 08-007r1, G. Groger, T. H. Kolbe, A.Czerwinski and C. Nagel (Eds.).

Shen W., Hao Q. et al. (2010). Systems integration and collaboration in architecture, engineering, construction, and facilities management: a review, Advanced Engineering Informatics 24 (2):196-207.

Thill, J.C., Dao, T. H. D., et al. (2011). Traveling in the three-dimensional city: Implementation issues and applications in route planning, accessibility, and location analyses. Journal of Transport Geography, 19(3): 405-421.

Thompson P A, Marchant E W (1994). Simulex; Developing New computer Modeling Techniques For Evaluation, Fire safety science – proceedings of the fourth international symposium: 613-624

Wing R. (2006). RFID applications in construction and facilities management, ITcon 11(7):11-721.