An evacuation system for extraordinary Indoor Air Pollution Disaster Circumstances

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Abstract

The problem of evacuating the buildings through the shortest path with safety has become more important than ever in a case of indoor air pollution incidents (i.e. fire, gas leak, airlessness, smother) taken place in complex and tall buildings of today's world. In this paper, it is aimed to present a 3D interactive human navigation and evacuation system which generates an optimum path in 3D modeled buildings and provides 3D visualization and simulation. The system generates and transmits the guiding expression to the mobile devices such as PDA's, laptops etc. via internet. In order to evaluate its performance in a case of extraordinary indoor air pollution circumstance, the system was tested on a complex building model by using GPRS and WIFI internet connections based on the web technologies.

Keywords: Indoor pollution, indoor disaster, evacuation, network analysis, simulation, navigation.

Introduction

The complex and tall buildings of modern world have become highly vulnerable to various human-induced disasters such as fire, indoor air pollution incidents and terrorist attacks (bombing, sabotages etc.) where evacuation is critical. According to World Health Organization, nearly thirty per cent of all new and remodeled buildings in the world may be subject to indoor air pollution incidents[1]. Besides, indoor air pollution is considered to be one of the most dangerous disasters among the top environmental risks to public health. The primary sources of extraordinary indoor air pollution disasters are chemical releases, radioactive materials and toxic gases.

In a case of indoor air pollution disaster, people inside the building should be evacuated from the structure as soon as possible. However, it can be very difficult to organize a quick evacuation procedure due to complexity of modern buildings and the great numbers of people that can be inside the buildings. In addition, critical problems such as airlessness, huddle, smother, trample and inaccessibility of exits may arise during the evacuation procedure. Therefore, an efficient evacuation system should be developed and implemented for quick and safe emergency evacuation from complex buildings[2].

In last few decades, many geo-information based evacuation systems have been developed for earthquake, floods and other outdoor disasters; however, their performances are limited in case of emergency evacuations in micro-scale environments such as large public buildings, shopping centers, underground metro-subways and garages[3, 20]. Evacuation of the buildings has become even more important issue especially after 9/11 attacks. On September 11, 2001, approximately 14,000 occupants were successfully evacuated from the two World Trade Centre (WTC) towers[4]. Thus, developing GIS-based emergency management systems for the buildings is very crucial to provide quick and safe evacuation from the complex internal structure of buildings.

There are number of recent studies in the field of building evacuation systems using GIS techniques. Lee[5] developed a topological data model, Node-Relation Structure (NRS), where "Straight Medial Axis Transformation" technique was used to obtain the 3D network model of a building. Gillieron and Merminod[6] generated a topological model for personal navigation applications for indoor usage by implementing route guidance and map matching algorithms. Meijers et al[7] proposed a semantic model representing the 3D modeling of interior structures of the buildings to be used for an intelligent computation of evacuation routes. Kwan and Lee[8] developed GIS-based "Intelligent Emergency Response System" where two types of uncertainty were evaluated: (1) street network uncertainty (vehicle movements in 2D space) and (2) route uncertainty within the building (occupant movements in 3D space). The results from the study indicated that 3D representation of the internal structures of the buildings significantly improved the overall speed of evacuation operations.

In this study, 3D interactive human navigation and evacuating system was developed to provide the occupants with dynamic, specific and accurate evacuation guidance based on indoor geo-information. This system provides limited real-time response feature by sending the guidance to occupants with interactive instructions.

Evacuation Process

Extraordinary indoor air pollution (EIAP) incidents happen suddenly and cause fatal consequences such as airlessness, excessive temperature, explosions, smoke and toxic gas leakages. Main reason for EIAP is generally fire in which the most of the people die due to smothering rather than burning. Table 1 indicates the number of people died due to various reasons after a residential fire incident[9]. Thus, the major death cause was breathing in smoke, followed by combination of burning and smothering.

Table 1
Number of people died due to various reasons after a residential fire incident[9]

Reason of Death	Number of people died	Percentage
Smoke Inhalation	101	36
Smothering	8	3
Burned Bronchus	8	3
Burning	53	19
Combination of burning and Smothering	69	25
Others	20	7
Injuries due to heart attack stroke and falling	20	7

There are three main stages in extraordinary indoor air pollution incidents. In the first stage, occupants are not affected by smoke, gas or temperature; therefore, this stage is the most appropriate stage for evacuation. In the second stage, the occupants are heavily exposed to smoke, toxic gas and excessive temperature. In the last stage, the death becomes inevitable. In previous studies, the behaviors of the occupants are analyzed in two main stages during a disaster[10]. The first stage is the pre-movement time or response time and the second stage is the movement time or action time.

Pre-movement Time: Pre-movement time is defined as the period between the time alarm systems works and the time people react to escape from the building. Table 2 compares the main factors that triggered occupant evacuation in buildings in England and USA[11, 12]. This indicates that the effect of alarm systems in initiating people to react is quite lower than it is expected.

Table 2
The main factors that triggered occupant evacuation in buildings[11, 12]

Main Factors that triggered Occupant evacuation	England %	USA %
Smoke	34.0	35.1
Shouting and Voices	33.0	34.7
Flames	15.0	8.1
Noise	9.0	11.2
Alarm	7.0	7.4
Others	2.0	2.8

A study conducted in a shopping mall indicated that when occupants are informed by announce system, the most of the time spent on evacuation procedure was realization of a need to evacuate, rather than movement time[10]. Figure 1 indicates that the percentages of realization, response and reaction times were 65%, 16% and 19% respectively. Therefore, pre-movement time is 81% of the total evacuation time.

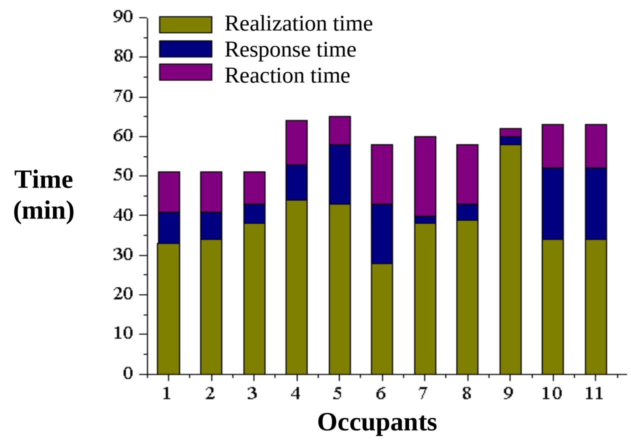


Figure 1: Occupant behavior time[10]

The studies also indicated that when an alarm system sounds, occupants spend the most critical time period to understand the reason of the alarm rather than evacuating the building. Also, studies indicated that the occupants give different responses based on the type and method of alarm system or content and time of the announce[13]. Uncertainty and insufficient information during the event may delay the evacuation procedure.

Movement time: Movement time is the period between the time people react to escape from the building and the time they reach out of the building or some safe place in the building[10]. Movement time varies based on two main factors including exit preferences and smoke problem.

Exit Preferences: Current evacuation systems assume that occupants use the closest exit in a time of emergency evacuation. Table 3 indicates the results from a study where the preferences of the occupants were investigated in a building where there was one emergency exit door and one entrance door located in opposite locations to each other. As seen in the table 3, most of the guests use the entrance which they are more familiar with[14] while almost all of the occupants use the emergency exit door. People use the closest exit only if they know the building well[15, 16]. When the guidance of the evacuation systems is insufficient, people consider various factors in choosing the evacuation path.

Table 3
Exit preference rates of people[16]

Exit preference	Guest	Occupant	Total
Entrance Door	37	1	38
Emergency Exit Door	24	13	37

Smoke problem: The previous studies reported that when occupants encounter a smoke problem, they keep moving through the smoke if the sight distance is more than 20 m; however, they hesitate and do not take the risk when sight distance is less than 20 m [17]. Thus, smoke is a serious problem which reflects the movement time in evacuation process (Figure 2). People slow down in smoke and they cannot determine an optimum evacuation path or cannot follow a straight route due to diminished sight distance[18]. However, it can be sometimes necessary to pass through a smoke area for survival. Based on a previous study, table 4 indicates the percentages of occupants returning back due to low sight distance in smoked zones[17].

Figure 2: The effects of smoke on visibility of evacuation lightings

Table 4
The percentage of returning occupants with respect to various sight distances[17]

Sight distance	England %	USA %
0-2	29.0	31.8
3-6	37.0	22.3
7-12	25.0	22.3
13-30	6.0	17.6
31-36	0.5	1.3
37-45	1.0	0
46-60	0.5	4.7
>60	1.0	0

Evacuation-Systems

Current evacuation systems: The current evacuation systems can be subdivided into three main groups: sensors to detect heat, smoke, or radiation; alarm system to alert people at the early stages of a disaster; and evacuation lighting to allow occupant to continue to occupy. The current evacuation systems are not sufficient for modern buildings which are designed higher and more complex than ever before. They are developed based on pre-determined scenarios, so they are not flexible or dynamic. The current systems are not intelligent enough to consider all the incidents happening at the time or after the evacuation process. For example, they may direct the people to blocked exits or places where there are gas leakages. This leads to crowds, indoor traffic density, reduction in evacuation process and blockings in the exits. They also provide insufficient evacuation information, especially for people who are not familiar with the building. The current systems become useless when sight distance is very low due to smoke and electricity cuts (Figure 3) [2].

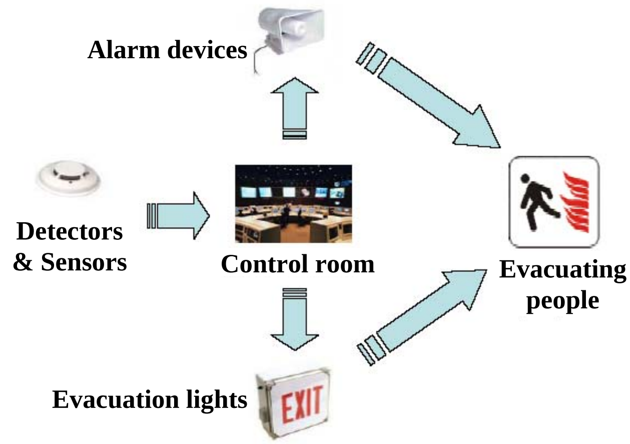


Figure 3: The components of current evacuation systems[2]

Optimum evacuation systems: Extraordinary and emergency incidents are not static but dynamic and variable events. However, traditional evacuation instructions are generally insufficient in dynamic evacuation process. Thus, Optimum Evacuation Systems (OES) should be in dynamic nature. Besides, OES should consider the status of individuals and groups and provide evacuation system specific to the individuals and groups. OES should obtain accurate information about the incidents happening during the evacuation process and provide this information to occupants. To consider various factors such as capacity of exits and to determine an optimum and safer route with less people, OES should have enough intelligence. In order to operate OES, some key information should be continuously provided:

- Damaged areas, chemical and gas leakages, smoked zones, electricity cuts.
- Real-time location of the people, population density, ages, genders, disabilities, stairways etc[2, 19].

To be able to provide such a dynamic navigation and optimum evacuation system, seven important components are necessary (Figure 4):

1. System for indoor positioning
2. Communication connection
3. GSM System
4. 3D inner model of the building and road network model
5. Information about the people in the building (such as age, gender etc)
6. Real-time information from the detectors
7. Central Evacuation System consisting of necessary software and hardware to perform shortest path calculations and to deliver the paths to the users.

The advanced feature of this system is the usage of cell phones or any other mobile devices. Today, almost everybody has a mobile device and user information such as age and gender can be easily obtained from registration info. Mobile devices can be used to supply people with interactive and graphical evacuation instructions. Evacuation instructions can be sent from central computer to mobile terminals with either video streams or evacuation directions, or combination of both. Cell phones can be integrated into an Indoor Positioning System so that location of the occupants and population density can be monitored in the buildings.

Proposed 3D Model: In this study, 3D interactive human navigation and evacuating system is proposed to provide dynamic, specific and accurate evacuation guidance based on indoor 3D geo-information system. This 3D geo-information system can be defined as a mathematical and model infrastructure of an optimum evacuation system. Once integrating with listed technical components, the model can be divided into three modules including network, simulator and navigation modules.

3D Network Analyses and Simulation: By using 3D Network Analyses and Simulation component, it is possible to view the 3D building model and complete network on the screen (Figure 5). When a user selects two entities, optimum path between them and cost is calculated and displayed (Figure 6). Afterwards, user can continue to next stage called "Simulation Stage". In the simulation stage, a floating cursor moves over the path in order to simulate a walking person with respect to the given orders. In this procedure, first, the turns and descending and ascending ways are calculated between nodes and floors and instructions are defined respect to the calculations. Then, according to the path and calculations, moving person is simulated on the screen by a floating cursor over the path line step by step and also direction instructions are spoken by computer by using the text speech algorithms and written on the screen (Figure 7). Simulation module can be also used for evacuation education and trainings.

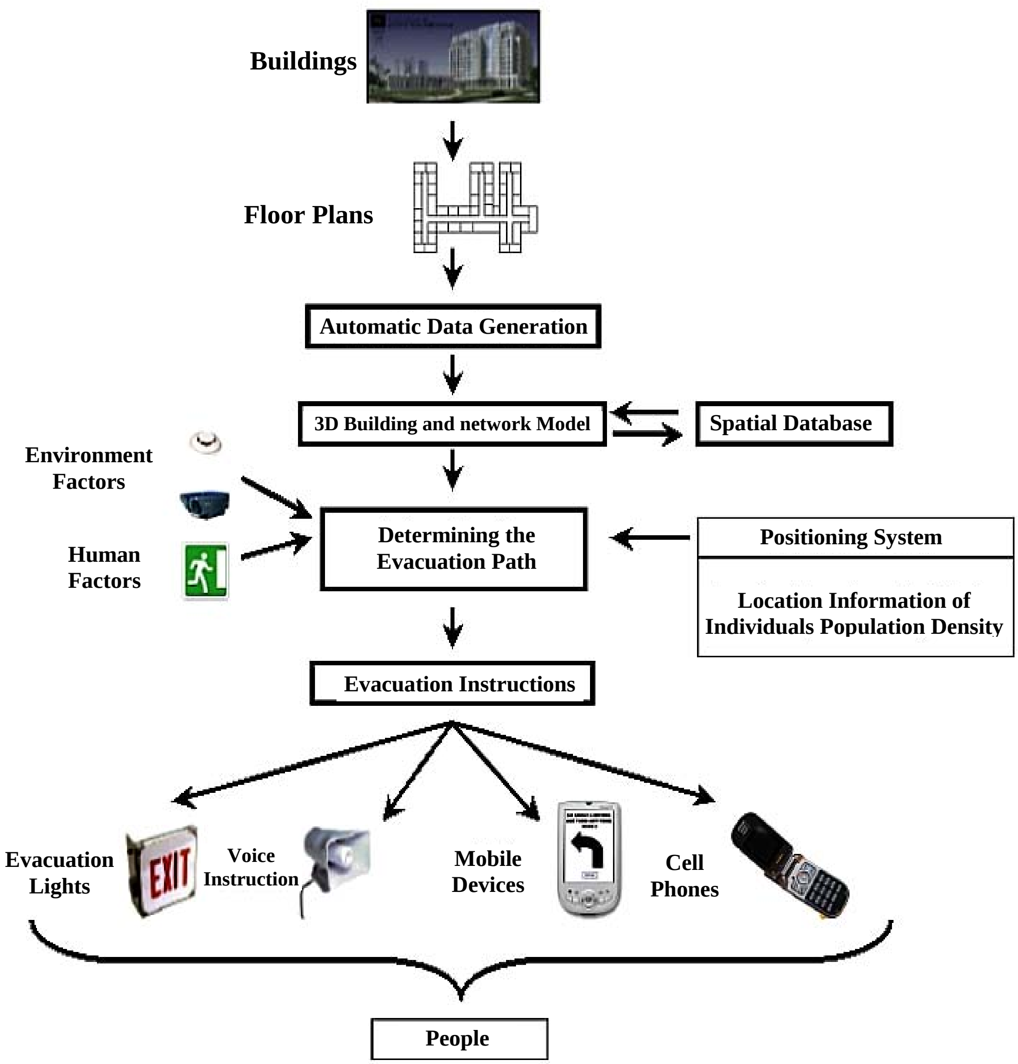


Figure 4: The components of optimum evacuation systems[2, 19]

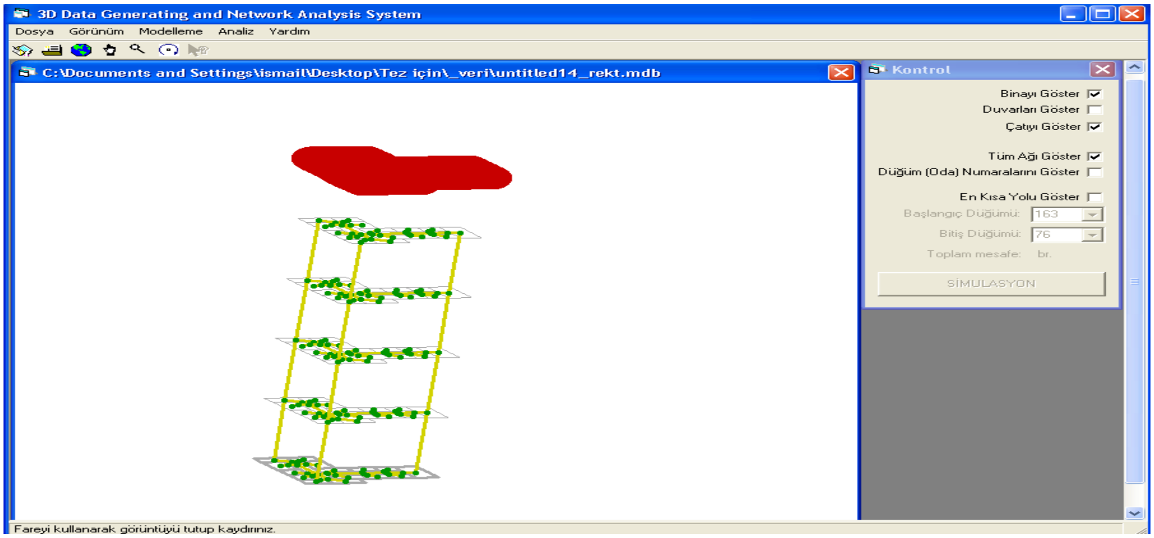


Figure 5: 3D Building and Network Models

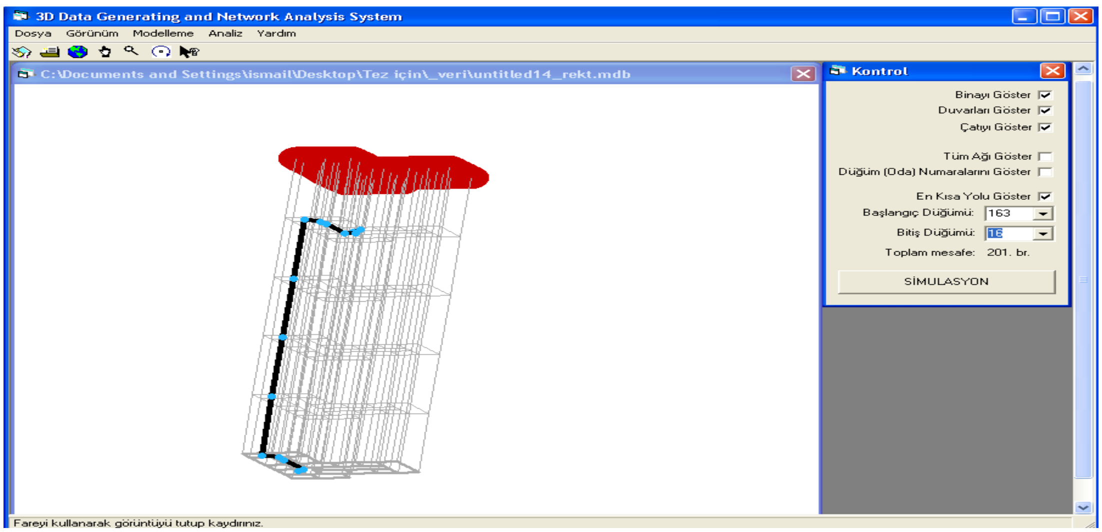


Figure 6: Optimum path between two entities

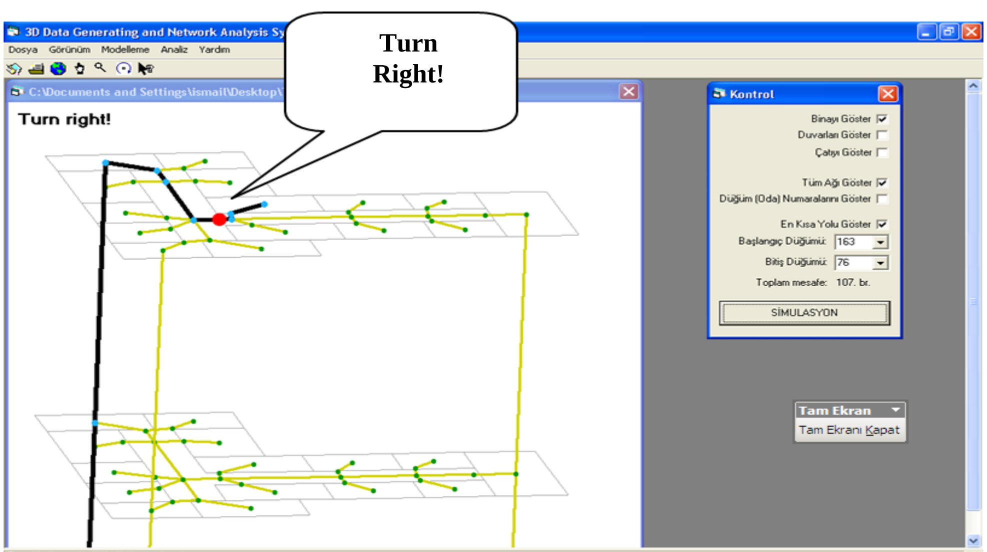


Figure 7: Audible and Visual Simulation

Navigation: The other component of the system is navigation component which provides online and real-time navigation to the user via internet. Navigation component is a server side component and it is developed with ASP and VBScript technologies. This component also contains a database application. Once the complete model is generated, database can be used for online navigation.

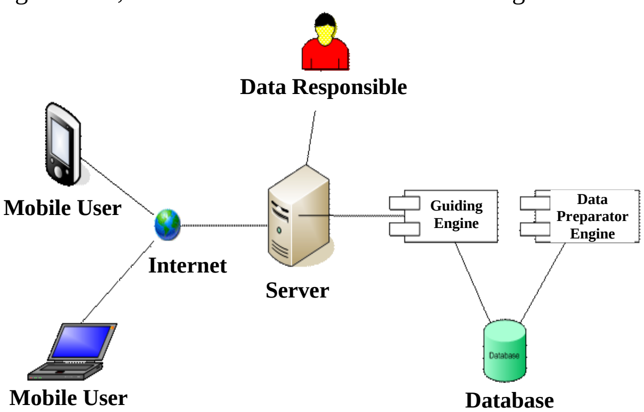


Figure 8: System Architecture of Navigation Module

The component was designed to be used by occupants in a building over internet. Since the occupants evacuating the building are mobile, it was considered to be online system over internet. In order to supply software independency, system was designed and developed in web based; so, the only prerequisite component for users is a web browser enabled mobile device and internet connection. While the network analyses and guiding engines are deployed on the server side, users can revoke web services via internet (Figure 8).

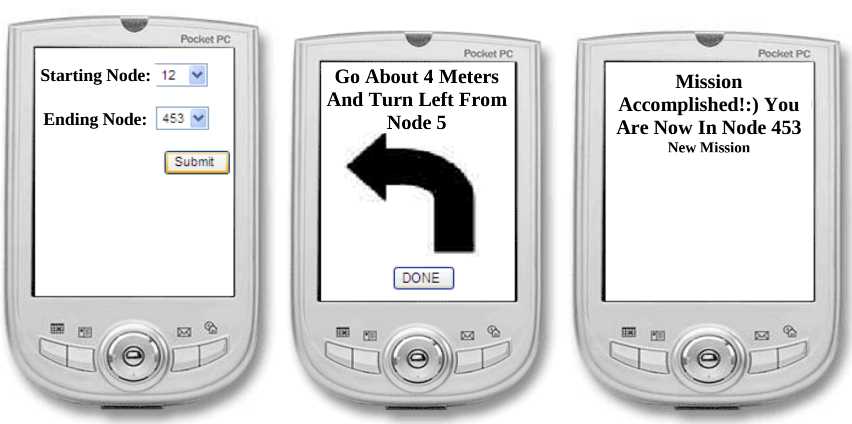
In this stage, user may have a mobile device such as a PDA or a laptop computer. The only prerequisite is to have a HTPP protocol enabled web browser and internet connection via either WIFI or GPRS. When there is an available internet connection, user can open the web page which is designed for navigation process. This page, first, needs variables defining current location and target location of the occupant (Figure 9a). When the parameter selection is completed, server side listener activates the processes in order to store the parameters in the database. The listener application checks the database periodically. When the data entry process occurs, it defines the shortest path and stores it step by step. Any modification on the database triggers processes and returns the direction information to the user via ASP web pages.

After the user gets the instructions, the system requires follow-up information of whether the user arrives or completes the task. In that case, the user approves the received task from web page and sends that information back to the server (Figure 9b). Since locating the user is not possible without special indoor instruments, current version of the system works with user interaction. When the user approves all the tasks sent by the server, it indicates that target destination is reached (Figure 9c). When this application is integrated with 3D computer graphics, the system can provide more realistic evacuation instructions (Figure 10).

The test of the system was successfully performed in 2 building blocks of Yildiz Technical University, Istanbul (Figure 11). In the test, a windows mobile 5 based handheld device and wireless connection were used.

Conclusion

The modern buildings are designed higher and more complex than ever before which make them vulnerable to many potential disasters such as terrorist bombings, fire, toxic gas leakage and chemical and radioactive releases. Most of these disasters cause life threatening indoor air pollution which requires people inside the buildings to be evacuated as soon as possible. Considering the complexity of modern buildings and the great numbers of people inside, it is rather difficult to organize such a quick emergency evacuation. Very often, serious problems such as huddle, trample and inaccessibility of exits are observed during the evacuation procedure.



(a) (b) (c)

Figure 9: Human navigation by using mobile devices

Figure 10: Navigation by using 3D interactive computer graphics

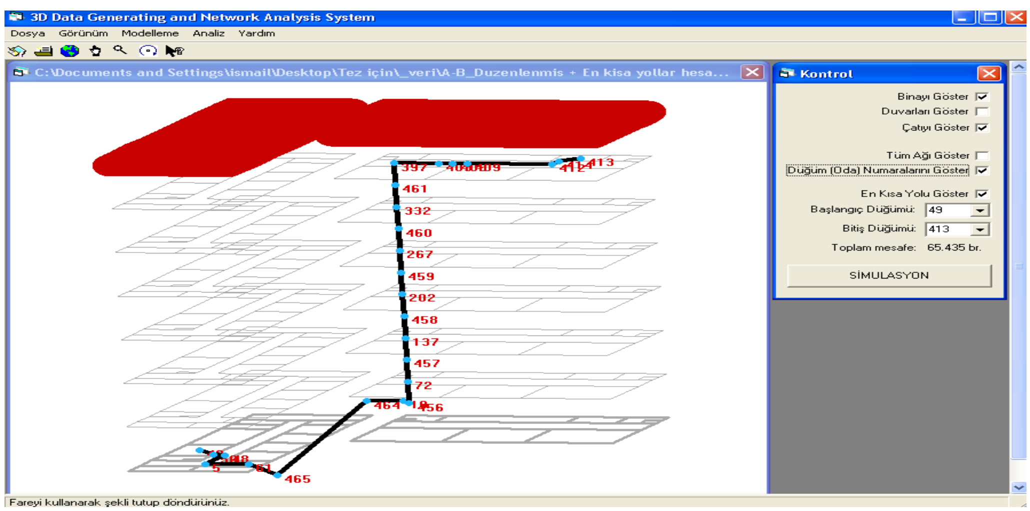


Figure 11: The shortest path between the current location and target location of the occupant in two building blocks of Yildiz Technical University

Many evacuation systems have been developed to make minimal losses in these disasters. 3D geo-information has been widely used in all the Disaster Management phases such as Mitigation, Preparedness and Recovery phases. However, it has not been really applied to the Response phase in extraordinary indoor pollution circumstances. In this study, 3D interactive human navigation and evacuating system is developed to provide dynamic, specific and accurate evacuation guidance based on indoor geo-information and to send these guidance to people with interactive instructions. Proposed 3D Geo information system, integrating with technical components of optimum indoor evacuation system, can be used to increase the efficiency, accuracy and speed of evacuation procedure and the most importantly save more lives in case of extraordinary indoor air pollution events. The current version of the system has some opportunities for future enhancements. The advanced features of improved cell phones and other mobile devices (e.g. processor, graphical interface, memory and communication) and support of GSM service providers can put "Location Based Services" forward for real-time and person-based navigation in evacuation procedure.

References

1. U.S. Environmental Protection Agency, Air & Radiation Pub., No. ANR-445-W, Indoor Air Facts No. 4 (revised), Sick Building Syndrome, 1 **(1991)**

2. Pu S. and Zlatanova S., Evacuation route calculation of inner buildings, Geo-information for disaster management, Springer Verlag, Heidelberg, 1143-1161 **(2005)**

3. Lee J., 3D GIS in Support of Disaster Management in Urban Areas, *Directions Magazine*, article_id 2049, December 18, **(2005)**

4. Gershon R.R.M., Hogan E., Qureshi K.A. and Doll L., "Preliminary Results from the World Trade Center Evacuation Study - New York City, 2003", *Morbidity and Mortality Weekly Report*, **53 (35),** 815-817 **(2004)**

5. Lee J., 3D Data Model for Representing Topological Relations of Urban Features, Proceedings of the 21st Annual ESRI International User Conference, San Diego, CA, USA **(2001)**

6. Gillieron P. and Merminod B., Personal navigation system for indoor applications, 11th IAIN World Congress **(2003)**

7. Meijers M., Zlatanova S. and Preifer N., 3D geoinformation indoors: structuring for evacuation, In Proceedings of Next generation 3D city models, 21-22 June, Bonn, Germany, 6 **(2005)**

8. Kwan M.P. and Lee J., Emergency response after 9/11: the potential of real-time 3D GIS for quick emergency response in micro-spatial environments, Computers, *Environment and Urban Systems*, **29,** 93-113 **(2005)**

9. Holborn P.G., Nolan P.F. and Golt J., An Analysis of Fatal Unintentional Dwelling Fires Investigated by London Fire Brigade between 1996 and 2000, *Fire Safety Journal*, **38(1)**, 1-42, **(2003)**

10. Purser D.A. and Bensilum M., Quantification of a behaviour for Engineering Design Standards and Escape Time Calculations, *Safety Science*, **38**, 157-182 **(2001)**

11. Wood P.G., The behaviour of people in fires, Fire Research Note, No. 953, Building Research Establishment, Fire Research Station, Borehamwood, U.K., 113 **(1972)**

12. Bryan J., Smoke As a Determinant of Human behaviour in Fire Situations: Project People (National Bureau of Standards, Washington), NBS GCR 77-94 **(1977)**

13. Bryan J., Human behaviour in Fire, *Fire Protection Engineering*, **16**, 4-16 **(2002)**

14. Mawson A., Is the concept of panic useful for scientific purposes? In Second International Seminar on Human behavior in Fire Emergencies, National Bureau of Standards, Washington, **(1980)**

15. Gwynne S., Galea E.R., Lawrence P.J. and Filippidis L., A Review of the Methodologies Used in the Computer Simulation of Evacuation from the Built Environment, *Building and Environment*, **34**, 741-749 **(1999)**

16. Sime J.D., Movement towards the Familiar Person and Place Affiliation a Fire Entrapment Setting, *Environment and Behaviour*, 697-724 **(1985)**

17. Bryan J., Behavioural Response to Fire and Smoke, the SFPE, Handbook of Fire Protection Engineering 2nd Ed., National Fire Protection Association, Quincy, MA, 241-262 **(1995)**

18. Jin T., Visibility through Fire Smoke – Part 5, Allowable Smoke Density for Escape from Fire, Report No. 42, Fire Research Institute of Japan **(1976)**

19. Karas I.R., Evaluating Topological Relationships of the Objects in 3D GIS and Network Analysis, Ph.D. Thesis, Yildiz Technical University, Geodesy and Photogrammetry Engineering Dept., Remote Sensing and GIS Programme, Istanbul **(2007)**

20. Lee J. and Zlatanova S., A 3D Data Model and Topological Analyses for Emergency Response in Urban Areas, In Geo-Information technology for emergency response, eds. Zlatanova S. and Li J., Taylor and Francis, Bristol, PA, 143-168 **(2008).**

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