18th International Conference on the Application of Computer
Science and Mathematics in Architecture and Civil Engineering
K. Gürlebeck and C. Könke (eds.)
Weimar, Germany, 07–09 July 2009

BIM-based Immersive Evacuation Simulations

Prof. Dr.-Ing. U. Rüppel * and M.Sc. P. Abolghasemzadeh

* *Institute for Numerical Methods and Informatics in Civil Engineering*
Technische Universität Darmstadt (TUD)
Petersenstraße 13, 64287 Darmstadt, Germany
E-Mail: rueppel@iib.tu-darmstadt.de

Keywords: building information model, emergency management, fire safety, evacuation simulation, immersive environment, virtual reality.

Abstract. *The changed global security situation in the last eight years has shown the importance of emergency management plans in public buildings. Therefore, the use of computer simulators for surveying fire safety design and evacuation process is increasing. The aim of these simulators is to have more realistic evacuation simulations. The challenge is, firstly, to realize the virtual simulation environment based on geometrical and material boundary conditions, secondly, to considerate the mutual interaction effects between different parameters and, finally, to have a realistic visualization of the simulated results. In order to carry out this task, an especial new software method on a BIM-platform has to be developed which can integrate all required simulations and will be able to have an immersive output BIM ISEE (Immersive Safety Engineering Environment). The new BIM-ISEE will integrate the Fire Dynamics Simulator (FDS) for fire and evacuation simulation in the Autodesk Revit which is a BIM-platform and will represent the simulation results in the immersive virtual environment at the institute (CES-Lab). With BIM-ISEE the fire safety engineer will be able to obtain more realistic visualizations in the immersive environment, to modify his concept more effectively, to evaluate the simulation results more accurately and to visualize the various simulation results. It can also give the rescue staff the opportunity to perform and evaluate emergency evacuation trainings.*

1 INTRODUCTION

The worldwide changed security situation after 9/11 in the world has shown the importance of emergency management plans in public buildings and facilities. Especially, public buildings with high population density, like airports, hospitals, schools etc., are in extreme situations, like explosions or big combustions, very critical cases. These hazards could be caused by technical or unintentional human failures as well as by planned terror attacks. After the 9/11 attacks on the World Trade Center in New York City a new phenomenon can be observed in a number of similarly attacks. The targets of these attacks were public infrastructures instead of military bases or governmental buildings. For example, the Madrid train bombings in March 2004 [1], the London bus attacks in July 2005 [2], the thwarted attacks at Heathrow in UK in August 2006 [3], the failed bomb attacks on two German trains also in August 2006 [4] and the Mumbai terrorist attacks on Indian hotel and tourist industry [5] corroborate this hypothesis [6]. Therefore, the security and safety of public facilities play more and more a bigger role in the society. As a response to these new situations many countries and regions have established new regulations, especially for their sensible facilities, to reduce the potential danger. The EU liquid regulations since 2005 [7] and the additional security measures for Lufthansa passengers are only some of these new regulations [8].

Therefore, the fire safety regulations and emergency evacuation have been increasingly studied during planning of public buildings in the last eight years. In extreme emergency situations - like combustions in public facilities, the rescue and the evacuation of endangered people have highest priority for the rescue staff. This demands a computer-aided emergency management and decision-making support. Conventionally, the fire safety assessment process is generally a paper-based process regarding official fire safety regulations. For example, in Germany the fire safety planning is specified in "fire safety regulations and guidelines" by "Federal Ministry of Transport, Building and Urban Affairs". In order to ensure these regulations, a general model building regulation[1] has to be verified and, depending on the use of the building, additional regulations must be observed [9]. At this step of planning, computer simulations for fire safety planning are unusual. But they shall be used as an additional survey in cases of very special buildings with uncommon architectures like Frankfurt airport [10] or LOOP 5, a big shopping mall in Weiterstadt (see Figure 1).

Figure 1: Shopping mall LOOP5 in Weiterstadt with an uncommon architecture [11]

Nevertheless, because of the recent security demands on public buildings, the use of computer simulations for surveying the fire safety design and the evacuation process is increasing. The aim of these simulators is to achieve more realistic evacuation scenarios. There are many different computer simulators, which can be used to model several fire safety parameters in an evacuation simulation. The challenge is, to realize the virtual simulation environment based on geometrical and material boundary conditions, to consider the mutual interaction effects of different parameters (especially the human factors) as well as the visualization of the simulated results.

There are different parameters which influence the evacuation process, including the geometry of the building elements, spread of fire and smoke inside the building, stability of buildings structure and the resulting behavior of the endangered persons. Each of these

[1] Musterbauverordnung

parameters can be simulated based on various computer methods. The actual challenge is here to control and manage these interacting parameters from a unique interface and so to create a realistic simulation and visualization. In this way the fire safety engineers will be able to run the necessary simulation models with different evacuation scenarios and to control the safety factor of the building.

The new approach presented in this paper is, firstly, to find out a suitable way for combination of building information and different simulations, secondly, to realize the mutual influences among the required simulations like the interaction between persons and their environment, thirdly, to represent a visualization method, which enables the visual evaluation as well as an emergency evacuation trainings for the security staff.

2 Approach

In order to carry out the combination of building information and different simulations, a special Immersive-Safety-Engineering Environment on a BIM-platform has to be developed which can integrate all required simulations and in this way achieve an immersive output. Through this integration the fire safety engineer should be able to obtain more realistic results in the immersive environment, to modify his concept more effectively, to evaluate the results more accurately and to have a unique visualization for various simulations.

To achieve this aim, simulators should be selected which can realize the mutual interaction effects of evacuation parameters. These simulators should also offer an interface which makes the combination with building information models possible. Finally, the BIM-ISEE has to be able to display the simulation results in an immersive virtual manner (see Figure 2).

In the next sections the details of this approach and their relationships will be explained.

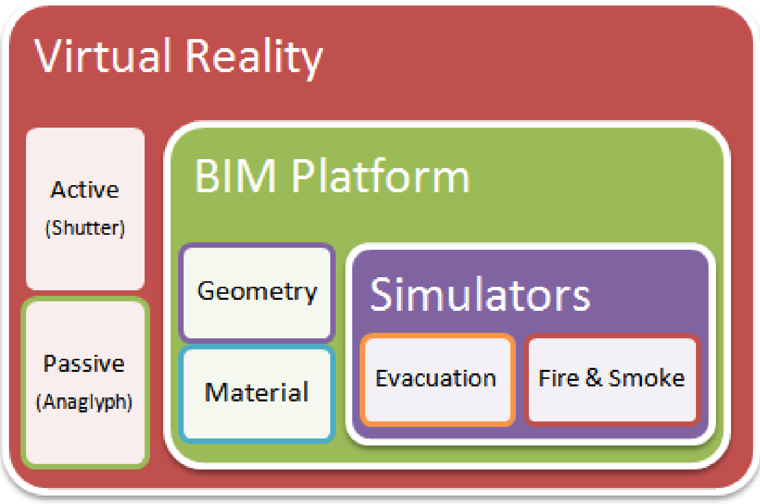

Figure 2: The ISEE architecture

3 Building Information Model (BIM)

BIM is the process of generating, managing and using building data during its life cycle [12]. It is a new Computer Aided Design (CAD) paradigm that employs intelligent graphic and data modeling software and creates optimized building design solutions. Also BIM encompasses the use of three-dimensional, real-time, intelligent and dynamic modeling. BIM is a collection of single database of fully integrated and interoperable information that can be used by all members of the design and construction team and, ultimately, by owners or operators throughout a facility's life cycle [13].

Every generated model for fire and evacuation simulation requires information about geometries (i.e., size, shape and position) and also about materials of building elements as boundary conditions, which are available in BIM. Therefore, it will be a good idea to integrate these simulations in the Building Information Model.

There are several researches about combination of BIM and different simulators. The solutions that they offer are generally to export the Building Information Model into standardized information schemas as Green Building XML, Industry Foundation Classes (IFC), etc. The problem here is that these schemas do not represent all required information from BIM that a fire and evacuation simulator needs. Furthermore, these schemas are being permanently updated and hence the export tools have to be adapted to them. In addition, the users don't have enough flexibility. This means that if any changes have to be made in BIM, they have to regenerate the information schema. Thus, it will be a good solution to develop an interface inside of a BIM program which can access directly to the whole building information and feed the suitable simulators with it.

For this purpose a BIM-interface is currently developed within the ISEE, which is able to integrate suitable simulators with the BIM program Autodesk Revit. The Autodesk Revit platform for BIM is a design and documentation system that supports the design, the drawings and the schedules required for the relevant building project [14].

4 FIRE SIMULATION

The development of fire-spreading inside a building is a very complicated process. Therefore, the spreading process is usually simplified in simulation methods like cellular automata, random variables etc. [15] . There are different methods to simulate the spreading of fire and smoke as well as the temperature inside the buildings. One of the most popular ways is to generate the simulation based on numerical methods like CFD (Computational Fluid Dynamics). For this aim there are already some simulators like SMARTFIRE, developed at Greenwich University, or the Fire Dynamics Simulator (FDS) from National Institute of Standards and Technology (NIST) in the USA which is used within this research project.

FDS is an open source program. It uses a form of the Navier-Stokes equations that is appropriate for low-speed numerical solutions. This tool has been developed to solve practical fire problems in fire protection engineering, but at the same time also to study the design of fire and smoke handling systems and sprinkler/detector activation. With this simulator the residential and industrial fire can also be reconstructed. Moreover this simulator is able to parallelize the calculation process using the Message Passing Interface (MPI) [16].

Numerical method

Burning behavior of the material, heat and mass transfer to and from solid surfaces, is usually handled with empirical correlations. The behavior of fire-driven fluid flow is very similar to the meteorological flow, which is intensively studied by Joseph Smagorinsky at Geophysical Fluid Dynamics Laboratory (USA) [17]. Thus the fire-driven flow can be considered as a turbulent flow with a high Reynolds number and it can be modeled with Large Eddy Simulation (LES). The Reynolds number (Re) is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces.

$$Re = \frac{\rho v d}{\mu} \tag{1}$$

The Large Eddy Simulation is a technique to solve Navier-Stokes equations which are nonlinear partial differential equations governing turbulent fluid flow [18].

Definition of fire source

The fire can be basically modeled as the ejection of gaseous fuel from a solid surface or a vent. In this way it is possible to model most of the fire sources in buildings. Different fire properties can be defined in FDS as the primary burned area and the thickness of the burning object like carpet, couch etc. Also the Heat Release Rate per Unit Area (HRRPUA) can be set under FDS which is a critical factor in predicting contribution of a burning material to the growth of a fire [19]. It is also possible in FDS to define a history for a fire source, i.e., establishing a dependency between time and fire properties. Thus a fire source can burn out if necessary. Furthermore FDS offers the opportunity to define the production rate and density of smoke (see Figure 3).

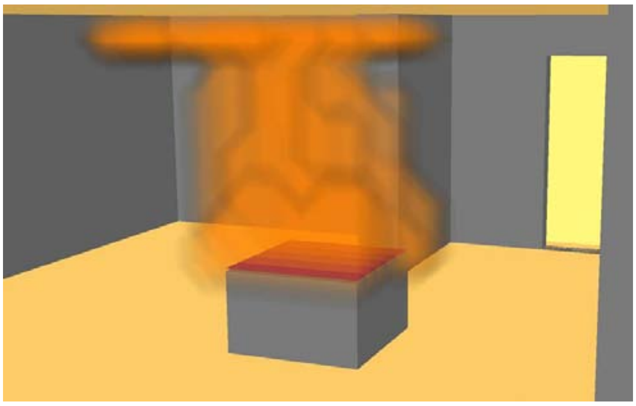

Figure 3: Fire spread in FDS

Additionally, with the currently developed BIM-interface within this research, besides generating obstructions and openings, the user should able to define and set sprinklers, nozzles, heat and smoke detectors, position of fire source and simulation time. The required meshes and the other needed settings to build the FDS model will be generated automatically from the developing BIM-interface in Autodesk Revit.

5 Evacuation simulation

RiMEA[2], a German initiative to establish guidelines for microscopic evacuation analysis, suggests that a computer simulation of the evacuation process should be able to determine the duration of evacuation from buildings and facilities and to survey the design and performance of escape and rescue routes. This survey process should be based on a computer aided simulation in which each person is individually modeled. The Movement of persons and their interaction with the physical obstructions should be based on empirical studies, observations and evaluations of similar events in form of simplified mathematical rules using reconstructed evacuation models [20].

There are different methods to simulate evacuation processes from buildings. One of the most common ways is to generate the simulation based on Molecular Dynamics (MD) method

[2] Richtlinie für Mikroskopische Entfluchtungsanalysen/Evakuierungs-analysen

which is a deterministic method. In Molecular Dynamics method atoms and molecules are able to interact for a period of time by approximations of known physics [21].

Several simulators have been already developed based on MD techniques like EXODUS, produced at Greenwich University, or FDS+Evac from VTT (Technical Research Centre in Finland) which is used within this research project. FDS+Evac is an evacuation simulator based on FDS, i.e., it uses the FDS engine to simulate the persons movement and their interaction with each other (called social interaction), physical obstructions and fire. The force on each person and its components are given in the following equation:

$$f_i = \frac{m_i}{\tau_i}(v_i^0 - v_i) + \sum_{j \neq i}(f_{ij}^{soc} + f_{ij}^{c} + f_{ij}^{att}) + \sum_{w}(f_{iw}^{soc} + f_{iw}^{c}) + \sum_{k} f_{ik}^{att} \qquad (2)$$

The developing BIM-interface allows the user to set various parameters for an evacuation simulation with FDS+Evac. The most important of them are persons with their attributes, doors and exits.

Persons

In FDS+Evac persons can be defined in groups. The user in BIM-ISEE should have the possibility to define new groups and assign them to any room. By the definition of each group the following attributes should be set via BIM-ISEE: fire detection time, reaction time, velocity of person's movement and their known doors (see Figure 4).

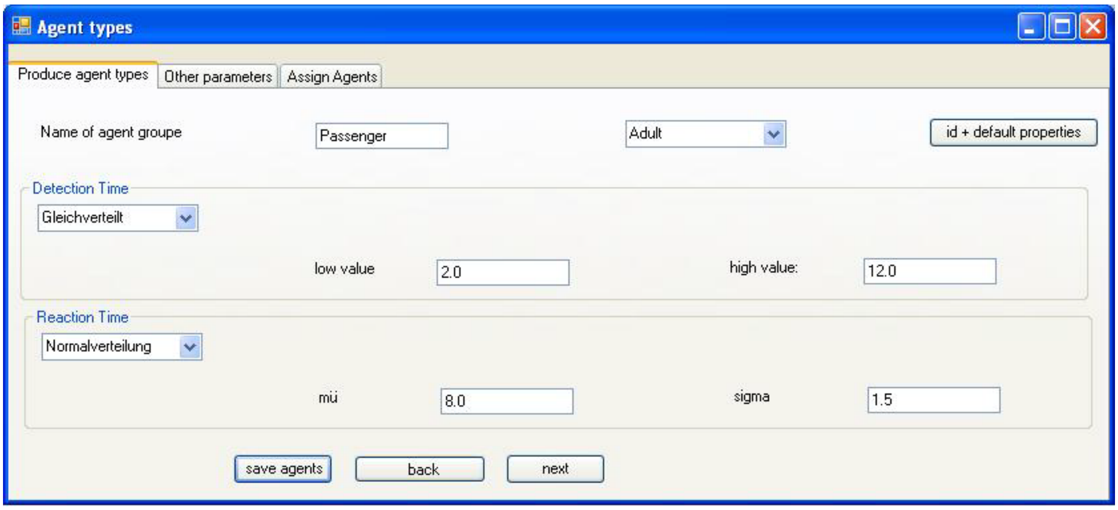

Figure 4: Definition of persons for FDS+Evac model in BIM-ISEE

Doors and Exits

Doors and exits must be defined additionally to the FDS model. They should be not only holes in walls but also openings that people can run away through (doors) or leave the building (exits), i.e., if they reach these points, they are saved. Thus the user has to explicitly determine in the building model which opening has to be considered as a door and which one as an exit.

The required meshes and the other needed settings to build the FDS+Evac model will be generated automatically from the developing BIM-interface in Autodesk Revit.

6 Visualization

2D visualization

There are various methods for visualization of a computer aided simulation. The simplest one is the 2D visualization, i.e., displaying objects on a plan view. This visualization method can be generated relatively fast, it has low hardware costs and it is strongly used by portable devices. But it’s not a useful way to display an evacuation simulation by the fire safety planning because it cannot be put over how a 3D-object is placed in the space, how the smoke will affect person's ability to see objects and how the spreading process of smoke and flame is in the vertical direction.

3D visualization

Another visualization method is the 3D visualization which can display 3D-objects, the intensity of smoke and also three-dimensional movements. This method is very popular for displaying the results of simulation models which contain three-dimensional objects and translations like fire and evacuation simulations. Nevertheless, it should be remembered that although this visualization method uses 3D objects, it has 2D effects, i.e., the user has a 3D environment but not an immersive feeling.

Immersion in Virtual Reality

The immersive visualization method with Virtual Reality (VR) technology makes it for the observer possible to have an immersive feeling in a virtual environment. With this visualization method it will be easier and more suggestive for a fire safety engineer to study the evacuation process and development of fire and smoke inside buildings, instead of executing dangerous and expensive tests in real environment [22]. The VR technology can not only be useful by fire protection planning but it can also give the rescue staff the opportunity to perform and evaluate emergency evacuation trainings [23].

With VR technologies each eye receives a slightly different view of a 3D-object. It produced the correct views for the left and the right eye and it delivers each view to the appropriate one. If these two (stereoscopic) views are suitably constructed, the observer’s brain reconstructs a true three-dimensional vista and gives him an immersive feeling [24].

There are various methods for stereoscopic views. One way of getting stereoscopic display is using LCD shutter glasses (also called active stereo). In active stereo the shutter glasses alternately black out the left and right eye in quick succession and the alternation of eyes is synchronized with the display screen so that the left and right eye see their appropriated images.

As an alternative many systems employ passive stereoscopic techniques which have less immersion effect in comparison with active stereo, but it is cheaper and more portable. Passive stereo displays the left and right eye images simultaneously superimposed on each other. Viewers have to wear special filtering glasses that only allow the appropriate image into each eye. The two most usual passive methods are anaglyph (red-blue) and polarization.

The Darmstadt Civil, Environmental and Safety Engineering Lab (CES-Lab) at the institute can perform both above mentioned stereoscopic methods (active and passive), so that studying of the evacuation simulations in an immersive environment is possible.

There are different software tools which can be used to display the simulation results in VR like SmokeView, produced at NIST, or Autodesk NavisWorks. This research project employs the software tool SmokeView, because it is an open source tool and it has a good conjunction to FDS as well as a possibility to display both VR technologies. SmokeView can be started as an external tool directly from the BIM-interface when the evacuation simulation is ended.

7 Summary and Conclusion

Because of the recent security demands on public buildings, the use of computer simulators for surveying fire safety design and evacuation process is increasing. The aim of these simulators is to have more realistic evacuation simulations. The challenge is, firstly, to realize the virtual simulation environment based on geometrical and material boundary conditions, secondly, to considerate the mutual interaction effects between different parameters and, thirdly, to have a realistic visualization of the simulated results.

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