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BIM-based immersive indoor graph networks for emergency situations in buildings

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Abstract

In the last decade, the significance of the emergency management in public infrastructures has increased due to changed security conditions worldwide and leads to the necessity of computer-aided emergency assessment process for extreme situations. In case of a fire in a building the evacuation and rescue of endangered people have highest priority for the rescue teams and are influenced by various parameters like geometry and material of building elements, the spread of fire and smoke, the behavior of endangered people as much as the escape routes they choose to exit from the building. Each of these aspects can be simulated based on different computer methods, but cannot be considered independent from each other. The challenges are to develop an integrated engineering environment based on Building Information Models (BIM), to generate the potential escape routes for endangered people (depended on the actual situation in the building) and to have a realistic visualization of results with an immersive system. This paper presents an approach to set up a new "Immersive Safety Engineering Environment" (ISEE) to model emergency situations in buildings and to experience these situations from endangered people's perspective. With ISEE escape routes based on graph networks for endangered people can be calculated depending on actual building conditions and the evacuation process can be visually evaluated. This leads to a higher degree of building fire safety.

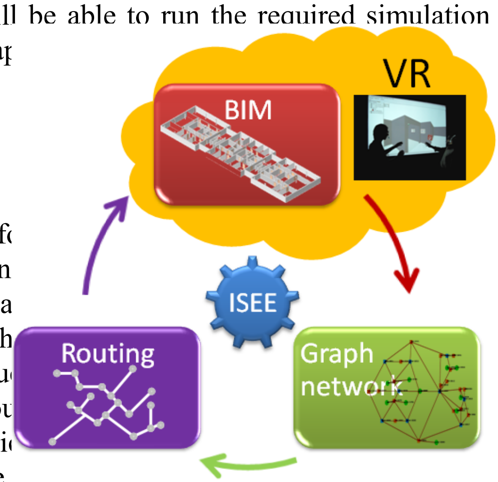
Keywords: BIM, emergency, fire safety, graph networks, immersive environment, virtual reality

1 Introduction

The security conditions of public infrastructures and facilities have changed in the last years. The mainly affected infrastructures are public buildings with high population density, like airports, train stations, hospitals, schools, hotels etc. Any unfortunate event in such infrastructures can lead to a disaster and bring the rescue staff into a difficult situation. Beside of technical or unintentional human failures, the probability of planned terrorist attacks is raised. A look at the last big attacks worldwide corroborates the sensibility of the emergency management in public infrastructures: 9/11 attacks on the World Trade Center in New York City, the London bus attacks in July 2005, the failed attacks at Heathrow in UK in August 2006, the thwarted bomb attacks on two German trains also in August 2006 and the terrorist attacks on Indian hotel and tourist industry in Mumbai. Therefore, it is necessary to plan emergency management and especially the fire protection design very carefully with a new quality in IT-based engineering methods (Rüppel and Abolghasemzadeh, 2009).

Conventionally, the fire protection assessment is a paper-based process regarding official fire safety regulations and guidelines. In order to ensure these regulations, normally a general model building regulation has to be verified and, depending on the use of the building, additional regulations will be necessary to observe. At this step of the assessment process, computer simulations are unusual and they are only conducted with limited functionality as an additional survey in cases of very special facilities with uncommon architectures. But the increasing significance of the emergency management in public infrastructures makes the demand of a computer-aided emergency assessment process necessary.

In extreme emergency situations, like combustions in public buildings, the evacuation and rescue of endangered people have highest priority for the rescue team. There are various parameters which influence the evacuation process like the construction of the building (geometry and material), spread of fire and smoke inside the building, structural stability of building and the resulting behavior of the endangered people (especially the escape route that they choose to leave the building). Each of these aspects can be simulated based on different computer methods. But these parameters could not be considered independent from each other. Therefore, a unique interface for the generation of realistic simulations and visualizations is needed which assumes the control and manage of these interacting aspects. The challenges here are, firstly, to realize a virtual environment based on geometrical and material boundary conditions of buildings, secondly, to generate the potential escape routes for endangered people in these virtual environment and, finally, to have a realistic visualization of the modeled building and the ability to experience the emergency situation from endangered people's perspective. In this way the fire safety engineer will be able to run the required simulation models with different egress scenarios based on various escap level of the building.



2 Approach

In order to carry out the combination of **B**uilding **I**nf tworks, a new **I**mmersive **S**afety **E**ngineering **E**nvironmen s to be developed which can integrate all required models a a stereo output in virtual reality (immersive environment). Th Figure 1. Regarding to the room polygons which are produ ribed in chapter 5 can be used to generate the needed rou ally the topological graphs must be generated using geometri etworks can be generated via routing network algorithms (see Figure 1). This graph networks can be used by routing algorithms for path calculations.

The path calculation should have an interface which makes the combination with BIM possible. Further it should be possible to display the simulation results in an immersive virtual manner. In the next sections the details of this approach and their relationships will be explained.

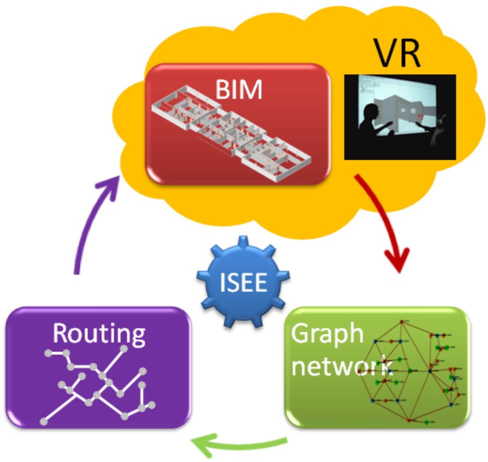


Figure 1. Generating graph networks and routings from BIM and visualization of results in ISEE

3 Building Information Modeling (BIM)

BIM is the process of generating, managing and using building data during its life cycle (Holness, 2008). It is a new Computer Aided Design (CAD) paradigm that employs intelligent graphic and data modeling software and creates optimized solutions for building design problems. 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 (Autodesk, 2009). Every generated model for fire and evacuation simulation as well as graph networks requires information about geometry (i.e., size, shape and position) and sometimes material information of building elements as boundary conditions, which are all available in BIM. Therefore, it will be a good idea to combine these simulations with the BIM.

There are several researches about combination of BIM and simulation systems. The solutions that they offer are generally to export the BIM into standardized information schemas as XML files, Industry Foundation Classes (IFC), etc. and then start the required calculations with external tools. This means that if any changes have to be made in the building model, the user has to regenerate the information schema, so that he cannot be always sure that he uses the up to date building model. Thus, it will be a good solution to develop an interface inside a BIM program which can access directly to the whole building information and feed the suitable calculators with it.

For this purpose a BIM-interface is currently developed within the ISEE, which is able to combine suitable calculators (e.g. calculators for indoor routing) with the BIM program Autodesk Revit. The Autodesk Revit platform for BIM is a design and documentation system that supports design, drawings and schedules required for the building projects (AUTODESK, 2009).

4 Indoor Routing

Graph networks are the basis of route calculation. In this chapter the fundamentals of indoor routing will be described. Routing characterizes the process of calculating a way from a defined starting point to a defined endpoint. A path can mathematically be defined as a sequence of differentiable pieces, which are parts of a curve made up of line segments.

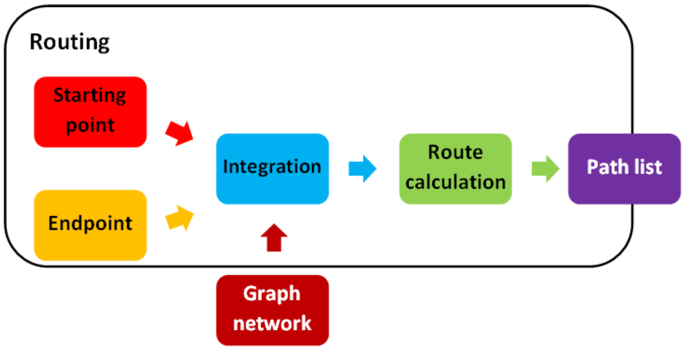


Figure 2. Process of route calculation

A path consists of a sum of edges leading from the starting point to the endpoint. These edges are defined by nodes which serve as first and second point of the edge. In order to enable route calculation on a graph, nodes and edges have to fulfill the following conditions:

Nodes (vertices) are

- possible starting points, endpoints or waypoints
- branching points or crossover points
- connections between rooms: doors, openings
- stairways or elevators as interconnection points

Edges

- represent possible paths
- are relations between nodes
- are subject to certain path costs

Routing calculates a path with minimal path costs (for example the shortest path) and displays the sequence of edges which describes this path. These path costs have to be defined individually. For the purpose of indoor routing for escape routes the fastest, the safest or the shortest path represent approaches for path costs. The shortest Euclidean path, thus the shortest geometrical distance, is examined as the most appropriate one.

5 Methods for generating graphs

The basis of route calculation is a graph with possible paths. As people walk inside of rooms bordered by walls and doors the graph has to cover only accessible areas. Precondition for automatic graph generation is a BIM. The topology of levels, rooms and doors must be in a hierarchic structure so that a door contains the information about which rooms it connects. In the first step a topological graph is generated. Then a separate graph can be generated for each single room with different methods for generation graphs and these graphs can finally be merged to one graph for a whole building by linking together the separate graphs through doors and stairways. In order to describe paths by nodes coordinates should be of the same coordinate system as in the BIM to identify nodes in rooms.

In the following methods for generating graphs out of a BIM are described and are qualitatively evaluated.

5.1 Door to Door Graph

Connecting the centres of rooms and doors enables a first approximation to the geometrical path lengths. For small rooms this enables similar paths to the path a user would take, whereas in halls the way is much longer because the path guides the user via the centre of the hall.

5.2 Mesh

A method to generate graphs automatically is to discretise rooms by covering them with a mesh of a certain raster. This mesh can consist of quadrates, hexagons or cubes (in 3D). Starting form the centre of the room all rooms are covered with nodes and these nodes are connected with edges if they are in accessible areas (see Figure 3). If squares are used, diagonal paths are only possible by using a staircase-like-path which is with a multiplier of √2 longer than the diagonal way. The graph can be improved by shortening the mesh width. However, this results in an exponentially increasing number of nodes and edges.

5.3 Quadtrees

To reduce the memory requirements for the graph the quadtree method can be used. If the area consists of accessible and non accessible parts, a given area is recursively divided in four parts with similar size. This results in quadrants of big size and small quadrants in areas close to walls and doors. The nodes of the graph can be generated from the centres of the quadrants (see Figure 3).

5.4 Straight Skeleton

In geometry, a Straight Skeleton is a method of representing a polygon by a topological skeleton. The Straight Skeleton is defined by a continuous shrinking process in which the edges of the polygon are moved inwards parallel to themselves at a constant speed (Haunert and Sester, 2008). As the edges move in this way, the vertices where pairs of edges meet also move at speeds that depend on the angle of the vertex. The Straight Skeleton is the set of curves traced out by the moving vertices in this process. The Straight Skeleton can be used for each room in a building. To link rooms together, doors have to be defined as new nodes which are connected to the graphs of the two rooms. Especially for long corridors or small rooms Straight Skeletons produce a graph similar to paths of human beings with use of only few nodes (see Figure 3).

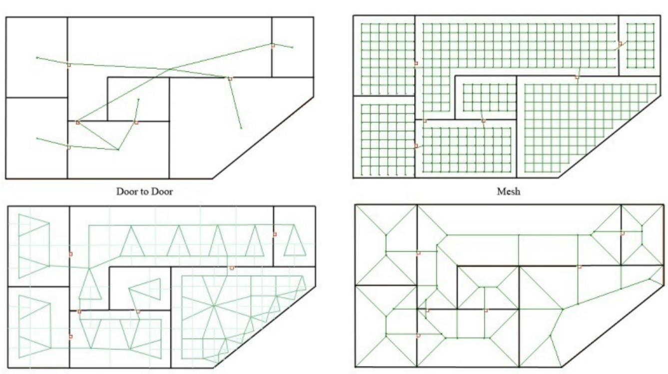


Figure 3. Methods for generating graphs

Analyzing these and some further methods for generating graphs we came to the conclusion that drawing graphs manually is not practicable. For indoor routing purposes the following demands are made on a graph: A combination of a graph with almost few nodes and edges, a generated path which is similar to a path a human being would choose and a graph which is nearly able to calculate the Euclidean distance is needed (Rüppel and Stübbe, 2009). First we tried out Straight Skeleton, which achieved the best looking paths for escape routes. But especially in halls more edges are needed than calculated. We currently work on a solution for this by using Corner Graphs (Yu, 2006) and combining both methods for graph generation. Based on a graph network a shortest path (e.g., an escape route) can be generated using routing algorithms.

6 Routing algorithms

The most common algorithm for route calculation is the Dijkstra algorithm conceived by Edsger Dijkstra in 1959. It is a graph search algorithm that solves the single source shortest path problem for a graph with non-negative edge path costs, producing a shortest path tree. This algorithm is often used in routing.

Having a given source node in the graph, the algorithm finds the path with lowest costs between that node and every other node in the graph. If the nodes of the graph represent rooms of one building the Dijkstra algorithm can be used to find the shortest route between one room and all the other rooms. A description of how the algorithm works can be found in (Ryan, 2009).

Other algorithms like A* algorithm are often based on the Dijkstra algorithm. The A* uses a distance-plus-cost heuristic function to determine the order in which the search visits nodes in the tree. Beside A* there are several algorithms like Floyd-Warshall or Bellman-Ford (Domschke and Drexel, 2007). A description of these algorithms would extend the scope of this paper.

7 Immersion in Virtual Reality

The immersive visualization method gives the observer an immersive feeling in a **V**irtual **R**eality (VR) environment. With this visualization method it will be easier and more suggestive for a fire safety engineer to study visually the evacuation process and development of fire and smoke inside buildings in a virtual environment, instead of executing expensive and partly dangerous real tests (Bukowski and Sequin, 1997).

With VR technologies each eye receives a slightly different view of a 3D-object. It produced the suitable views for the left and the right eye and it send each view to the appropriate one. If these two (stereoscopic) views are correctly constructed, the observer's brain reconstructs a true three-dimensional vista and gives him an immersive feeling (Zelle and Figura, 2004). There are different methods for stereoscopic views. Two common stereoscopic methods are LCD shutter system (also called active stereo) and anaglyph (also called passive stereo). The Darmstadt Civil, Environmental and Safety Engineering Lab (CES-Lab) at the institute can perform both stereoscopic methods so that studying of the emergency situations in an immersive environment is possible.

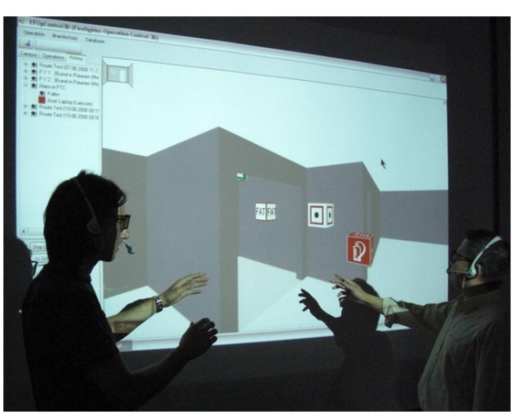


Figure 4. The Darmstadt Civil, Environmental and Safety Engineering Lab

8 Summary and Outlook

With ISEE the fire safety engineer will be able to obtain more realistic visualizations of models in the immersive environment, to modify his concept more effectively, to walk through the escape route in virtual reality and to evaluate them visually. ISEE can also give the rescue staff the opportunity to perform and evaluate emergency situations in a virtual training. Summing up the new approach covers, firstly, the development and integration of useful graph methods to generate routing networks in the BIM platform "Autodesk Revit Architecture" (by Autodesk), secondly, the display of the results in the CES-Lab with immersive methods, and, thirdly, the enabling of a "realistic" assessment and observation of the emergency situations in building according to the generated routing networks for the safety engineer. In our future work we will also combine simulations for the spread of fire and smoke with routing networks to realize their affect on egress process. So the behaviour of endangered people can be simulated, when they change their escape way regarding the actual temperature and smoke density on each possible route.

References

AUTODESK, 2009. Revit Architecture 2010 Metric Tutorials, http://images.autodesk.com/adsk/files/rac_tutorial_documents_m.zip, pp. 7 (accessed on December 08 2009).

BUKOWSKI, R. AND SEQUIN, C. 1997. Interactive simulation of fire in virtual building environments,pp. 35-44

DOMSCHKE, W., DREXEL, A., 2007. Einführung in Operations Research, 7. Auflage, Springer Verlag, Berlin

HAUNERT, J.-H., SESTER, M., 2008. Area Collapse and Road Centerlines based on Straigth Skeletons. In: Geoinformatica archive Volume 12, pp. 169-191

HOLNESS, G.V.R., 2008. Building Information Modeling: Gaining Momentum, ASHRAE JOURNAL, vol. 50, pp. 28

LEE, G., SACKS, R. and EASTMAN, C.M., 2006. Specifying parametric building object behavior (BOB) for a building information modeling system, Automation in Construction, vol. 15, pp. 758-776

RÜPPEL, U. AND ABOLGHASEMZADEH, P., 2009. BIM-based Immersive Evacuation Simulations. In: IKM Conference 2009, http://euklid.bauing.uni-weimar.de/ikm2009/papers/uploads/140/2-final-man_149.pdf, Weimar, Germany

RÜPPEL, U. AND STÜBBE, K., 2009. Supporting Fire Fighters during Rescue Missions by use of BIM and Indoor Navigation. In: Computation in Civil Engineering, EG-ICE Conference 2009, ISBN 978-3-83228-287-5 pp. 242-249, Berlin, Germany

RYAN, M., 2009. Software Workshop Java: Dijkstra's Algorithm, The University of Birmingham School of Computer Science, http://www.cs.bham.ac.uk/~mdr/teaching/modules04/java2/DijkstraAlgo.html, 2009 (accessed on November 18 2009).

YU, K., 2006. Finding a Natural-Looking Path by Using Generalized Visibility Graphs. In: PRICAI 2006: Trends in Artificial Intelligence, Vol. 4099, Springer Verlag, Heidelberg, pp. 170 – 179

ZELLE, J.M. AND FIGURA, C., 2004. Simple, low-cost stereographics: VR for everyone, ACM SIGCSE Bulletin, vol. 36, pp. 348-352