

ON THE WAY OF INTEGRATING EVACUATION APPROACHES

A. Vanclooster^a, Ph. De Maeyer^a, V. Fack^b

Ghent University, Krijgslaan 281, B-9000 Ghent, Belgium

^a Dept. of Geography - (Ann.Vanclooster, Philippe.DeMaeyer)@UGent.be

^b Dept. of Applied Mathematics and Computer Science - Veerle.Fack@UGent.be

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ABSTRACT:

With the growing pressure on available urban space and the construction of more and more complex building infrastructures, the navigational task for building users is getting increasingly difficult. As people react more impulsive under stressful situations, emergencies can exacerbate way finding problems. Additionally, leadership and familiarity with the (topological structure of a) building can influence the ease of finding appropriate evacuation routes.

In research, two separate and distinctive techniques for modelling evacuation paths have been developed: evacuation simulation modelling through complex computer simulations and 3D network modelling based on graph theory. Taking into account a global user perspective, the 3D network modelling approach has the advantage to preserve a close connection with the semantic building structure. Following this approach, existing three dimensional evacuation routing algorithms tend to use Dijkstra's shortest path algorithm. However, as more factors, compared to path length, influence evacuation situations, literature acknowledges a void in representing more realistic, complete and accurate emergency situations. This paper presents a first step in creating such integral algorithm by implementing capacity constraints based on user flow control on a 3D geometric network model. In the future additional topics such as zonal partitioning can be added to the algorithm, moving to an integration of both evacuation approaches.

1. INTRODUCTION

People tend to get lost more easily in building environments compared to outdoor space, partly because of a more complicated recognition of landmarks in the indoor environment (Gartner *et al.*, 2009). Consequently, the construction of increasingly complex building in the last decennium was not beneficial to the navigational tasks in these building environments. Additional difficulties will arise in emergency situations as people are getting anxious and often react impulsive when searching for an exit. Furthermore, the familiarity with a building layout and the pressure of a moving crowd, affects the mode of movement and consequently magnifies the problem in retrieving suitable evacuation routes.

In literature, evacuation scenarios are considered both from the 3D modelling world as well as from research in evacuation simulations. Existing implementations of three dimensional shortest paths are mostly restricted to the elementary Dijkstra shortest path algorithm, occasionally adjusted with minor modifications (Gilliéron *et al.*, 2004; Lee, 2004; Kwan and Lee, 2005). Both Meijers *et al.* (2005), Lee (2007) and Lee and Zlatanova (2008) acknowledge a gap in today's indoor network applications, as the implemented algorithms mostly consider distance as main parameter in calculating paths. Responding to this pressing situation, a more integral algorithm has been developed based on existing mathematical evacuation algorithms.

First, a short introduction on the principles and characteristics of evacuation will be discussed, followed by a discussion on the two main approaches in evacuation scenarios. In the remaining part, an integral building evacuation algorithm is proposed.

2. EVACUATION APPROACHES

2.1 Scenario's and influencing factors

Evacuation is a greatly studied research topic, both in psychology as well as in mathematics and geomatics. In the following part some fundamental terms and characteristics will be explained. Conceptually, an evacuation is the procedure of moving people away from an emergency situation to a safe place. In case of a building evacuation, this movement is directed towards the outside of the building (a total evacuation). Although in large buildings (both high-rise and horizontally elongated buildings), an assembling of groups of people in safe refuges for certain amounts of time is necessary to complete the evacuation within an appropriate timing, as the evacuation of large buildings can exceed certain time limits. In the following paragraphs, a total evacuation will be considered when discussing evacuation procedures.

Unless organised for training purposes, evacuation is mostly a reaction to an emergency situation (figure 1). Since a total evacuation of all visitors or users in the affected building is necessary, the *cause* of the emergency situation will not considerably affect the evacuation procedure. Trained personnel will maybe need to know the reason of emergency to act appropriately, but once started evacuating, the type of emergency doesn't influence the evacuation scenario. On the other hand the *location* of the emergency can be an important factor which needs consideration. In case of rapid expanding fires, the evacuation of persons in the immediate vicinity of the fire may require priority over the complete evacuation of the building.

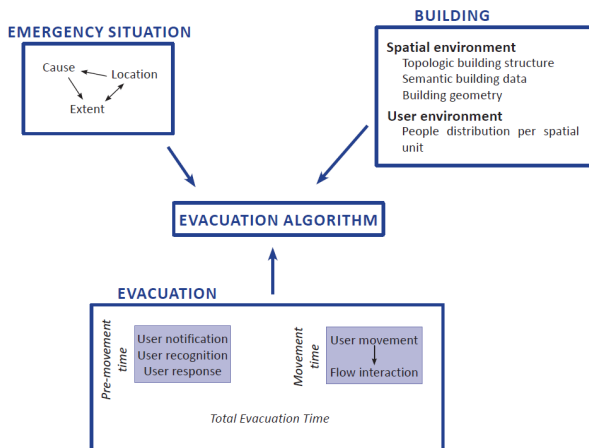


Figure 1. Crisis management scheme

The evacuation time of a building, the *Required Safe Evacuation Time (RSET)*, is defined as the time for the last person in the building to leave this building (Cepolina, 2004). The main part of this RSET consists of the detection of and the response to an emergency situation (pre-movement time). Evacuation scenarios often only deal with the actual movement from the current position at the beginning of the hazard to a safe refuge. In these situations, the pre-movement time will be neglected, for reasons of immeasurability. Pre-movement times depend on parameters such as the type and the extent of emergency situation, the number and quality of detectors, the warning system in the building, ... (Kuiper, 2001).

$$t_{\text{evacuation, individual}} = t_{\text{pre-movement}} + t_{\text{movement}}$$

$$t_{\text{pre-movement}} = t_{\text{recognition}} + t_{\text{response}}$$

$$t_{\text{evacuation, building}} = t_{\text{detection}} + (t_{\text{exit last evacuee}} - t_{\text{exit first evacuee}})$$

2.2 Existing approaches for indoor navigation and evacuation algorithms

In research environments two approaches to indoor evacuation scenarios are currently accepted:

1) Originating from the 3D modelling environment, navigation and evacuation is based on graph networks (Gilliéron *et al.*, 2004; Karas *et al.*, 2006; Jun *et al.*, 2009), while the visualisation of 3D problems is currently achieved by CityGML (Kolbe, 2008). Different network options are proposed, mainly related to Lee's (2007) "Node Relation Structure (NRS)" and "Geometric Network Model (GNM)". The coarse networks as defined by Gwyne *et al.* (1999) can also be seen as part of this approach.

2) In the evacuation simulation world, crowd simulation modelling methods (fine networks in Gwyne *et al.* (1999)), have been developed to predict emergency situations and evaluate interior design for planning purposes. Examples are agent based approaches (Hajibabai *et al.*, 2007) and cellular automata (Park *et al.*, 2007; Jun and Kim, 2009). As they originate from psychological research, they consequently incorporate more human related factors and behaviour.

As both approaches predict crowd behaviour under certain circumstances (whether or not emergency related), a real connection with the real time building environment is however missing (Jun and Kim, 2009). Therefore an integration with sensor networks is needed, as proposed by Jensen *et al.* (2009). Becker *et al.* (2008, 2009) already developed a conceptual integration of sensor coverage for indoor tracking and the topological structure of buildings using different contexts.

Gilliéron *et al.* (2004) endeavour to make this connection using map matching algorithms. Sensor coverage is based on the latest developments in indoor tracking technologies using for example RFID's (Jensen *et al.* 2009), or other LBS applications (Lee and Zlatanova, 2008). Stoffel *et al.* (2006) compared multiple indoor positioning systems identifying geometrical (angulation, lateration), scene analysis (fingerprinting, image analysis) and proximity sensing (sensor based) methods. The technical support necessary for actual implementing navigational applications, using tracking and provision of evacuation routes to the end users, is beyond the scope of this research. However, these two research fields must be taken into account when developing new algorithms for indoor navigation and evacuation.

Despite a shared interest in analysing evacuation situations, both network models and fire simulation models have been developed largely separate from each other. Originating from different points of view, both models are incomplete in one or more particular interests of urban planning. Existing indoor navigation models are for instance often limited to networks without a connection to the actual building structure, while evacuation simulation models lack a thorough semantic model of urban space.

Researchers following the network approach typically modify the existing 2D routing algorithms to the three-dimensional aspect. When covering these evacuation algorithms, a modification of Dijkstra's shortest path algorithm with distance or time as edge weights is often used. Other influencing parameters, such as human related factors with regard to emergency situations are often listed (Pu and Zlatanova, 2005), but there is currently a lack of implementation in suitable algorithms. Meijers *et al.* (2005), Lee (2007) and Lee and Zlatanova (2008) acknowledge this deficit in the implementation of more impedance variables. On the other hand, most of these variables -related to the individuality and physical state of human beings (gender, age, queuing, leadership, ...)- are taken into account by the crowd movement modelling approach. However this second approach, often developed from the individual user perspective, lacks a thorough semantic model from the building environment leading into complex and in-transparent calculations making the correspondence with reality unsure and difficult. An integration of both approaches is not yet assessed, as this requires answers on related topics. Questions such as the domain of use of the algorithm (evacuation and emergency response versus risk management and planning), number of users (1 route for multiple user groups versus multiple routes for a single user), user types and behaviour need to be solved first.

3. 3D EVACUATION ALGORITHM IN BUILDING ENVIRONMENTS USING THE 3D GNM

As previously stated, the developed navigational algorithm is based on the graph network approach, which mostly consider distances or time as costs on the edges. By adding numerous other parameters, taking into account the complexity of evacuation in buildings, the elaborated algorithm combines in several previously cited properties. Lee and Zlatanova (2008) already created a 3D shortest path based on the Dijkstra algorithm enhanced with environment and human factors. The actual calculation is however based on static data and only available for analysis of a single user at a time. With the proposed algorithm the movement of multiple flows from one node to another over one or more edges is made possible, since

it is based on a capacity constraints algorithm with user flow control (cited by Hamacher and Tjandra (2001)). The procedure takes into account features of the spatial environment, including the topological building structure, the semantic structure and the building geometry, as well as the user environment, with the distribution of people per spatial unit (figure 1). There is no information needed regarding specific user characteristics, since a global person approach is used compared to the crowd simulation modelling.

As a starting point for the development of the algorithm, some principles are accepted to be determinable. First of all, the distribution of people in each room (location and number) needs to be known. Secondly, the calculated evacuation routes can be visualised to the evacuating people, who follow the imposed directions. People are also expected to move directly once understanding the evacuation scenario, making it possible to discard the pre-movement in the calculation of the egress time.

The main part of the algorithm is listed below - moving the crowd from all rooms to an exit, based on the merging of incoming flows and adapting velocities of outgoing flows to the velocity of predecessors. Starting from a list of shortest paths, distance-based only, to a selected exit, the procedure loops through each subpath moving the crowd from one node to the following. In every loop the incoming and outgoing flow times are compared, after calculations of user densities and velocities according to room types, following the approach of Fahy (1994). This procedure allows the optimization of minimal time by moving persons using a maximum capacity on each edge.

Algo(ArrayList<Path> sortedpathlist, int selectedexit)

- a. Loop through the sorted paths from smallest to largest distance to the exit
- b. EdgePassing(Path selpath, int posinselpath)
 - Loop through all edges of path (#edges in list)
 - Check incoming flows (c):
 - if passingnodeid != source node
 - Check outgoing flows (d):
 - if passingnodeid != source node
 - Calculate times: only first loop
 - if passingnodeid == source node
- c. Incoming flows
 - CalcIncomingTimes from adjacent nodes
 - SortNodeMov: sort incoming node movements in passingnodeid from smallest to largest (until reached selected nodemovement as part of selpath)
 - Attach waiting times (loop until selnodemovement)
- d. Outgoing flows
 - Loop from first nodemov in sortedlist until selnodemov
 - Only when this path has not reached exit, otherwise times are already calculated and fixed
 - Calculates first outflow, according to the speed of the predecessor
 - EdgePassing with current sourcenode as new selpath, until reached the exit

End: calculation of outflow times for original selnode

Output: Result object (source node, exit node, TimeFrame for reaching exit, population)

Based on previously stated principles, the algorithm has the following characteristics:

1) The algorithm works for both 1 user and multiple users. The evacuation time is always the time needed for the last person to

leave the building, depending on maximum capacity flows on the edges and obstacles along the way.

2) As it is a capacity constrained algorithm, the algorithm aims at guaranteeing a maximum flow on each edge based on user densities to accelerate the evacuation (figure 2).

3) Based on the 3D Geometric Network Model (figure 2) as developed by Lee (2007), it creates a strong relationship with the real building structure. However in large, multifunctional rooms, this approach should be avoided, since one node with a certain capacity doesn't predict the actual movement of the people in that room. Further research needs to be carried out to tackle this.

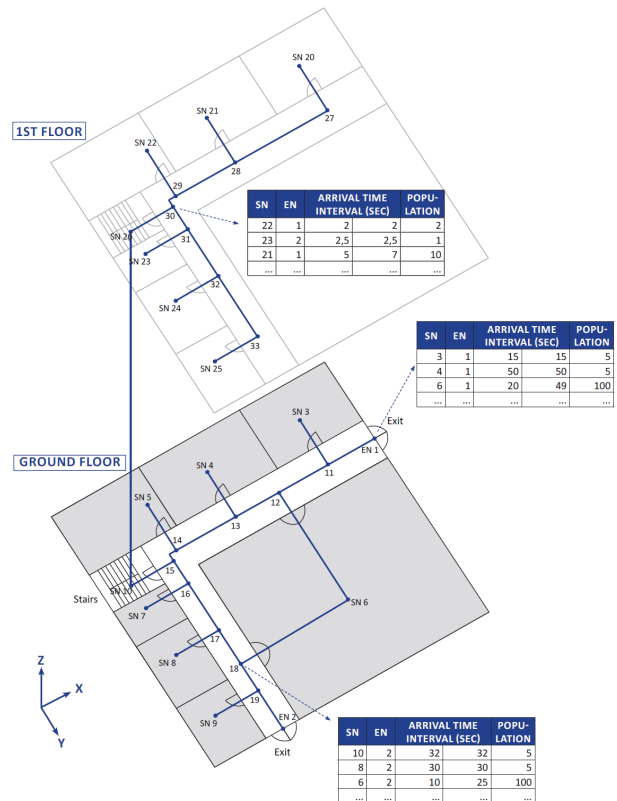


Figure 2. Implementation on a test network

Although at this stage some first promising results already have been achieved (figure 2), future enhancements are being considered. People prefer routes that are easier to describe instead of theoretically 'optimal routes'. Simpler paths already exist greatly in two dimensional street networks (Grum, 2005), but a three dimensional implementation is still on barren grounds. Also a prioritising during evacuation of people closest to incident site can enhance the real-world correspondence. Since especially the reaction of people in evacuation scenarios is crucial to the evacuation time, evacuating everybody at once can work counterproductive. It is much more common to implement a more zonal evacuation procedure, with primary attention to people nearest to the emergency site. Other enhancements can incorporate the recognition of isolated parts of networks and the dynamically changing and growing of prioritising zones. The optimization of the algorithm in further research will allow to create even more realistic indoor routing.

4. CONCLUSIONS

Current research on evacuation simulation modelling and algorithms comprises modelling approaches from the three-dimensional network world as well as crowd simulation computer models largely developed for building fire

simulations. As is indicated, the 3D network modelling approach, starting from a global user perspective, has the advantage to retain a close connection to the actual building structure and the incorporation of semantic data. In the second part, a capacity constrained flow algorithm on a three dimensional geometric network model has been created. The algorithm is based on a crowd flow control mechanism with maximization of capacities on the network edges depending on crowd densities and semantic building information. Tests are being carried out on a test building, with underlying 3D geometric network as topological model. Some adaptations and enhancements to the developed algorithm are being pointed out.

REFERENCES

- Becker, T., Nagel, C., Kolbe, T.H., 2008. A multilayered space-event model for navigation in indoor spaces. In Lee, J., Zlatanov, S.: *3D Geo-Information Science*. Springer-Verlag, Berlin, pp. 61-77.
- Becker, T., Nagel, C., Kolbe, T.H., 2009. Supporting contexts for indoor navigation using a multilayered space model. In: *2009 Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*, Taipei, Taiwan, 6 p.
- Cepolina, E.M., 2004. Building evacuation: two different approaches. In: *Proceedings of the European Transport Conference*, Strasbourg, France, 12 p.
- Fahy, R.F., 1994. Exit 89: an evacuation model for high-rise buildings-model description and example applications. In: *Fire Safety Proceedings of the Fourth International Symposium*, Ottawa, Canada, pp. 657-668.
- Gartner, G., Huang, H., Schmidt, M., Li, Y., 2009. Smart environment for ubiquitous indoor navigation. In: *Proceedings of the 2009 International Conference on New Trends in Information and Service Science*, Beijing, China, pp. 176-180.
- Gilliéron, P.-Y., Büchel, D., Spassov, I., Merminod, B., 2004. Indoor navigation performance analysis. In: *Proceedings of the 8th European Navigation Conference GNSS*, Rotterdam, Netherlands, 9 p.
- Grum, E., 2005. Danger of getting lost: optimize a path to minimize risk. In: *CORP 2005 GEOMultimedia 05 Tenth International Symposium*, Vienna, Austria, pp.711-717.
- Gwyne, S., Galea, E.R., Owen, M., Lawrence, P.J., Filippidis, L., 1999. A review of the methodologies used in evacuation modelling. *Fire and Materials*, 23, pp. 383-388.
- Hamacher, H.W., Tjandra, S.A., 2001. Mathematical modelling of evacuation problems: a state of the art. In: *Pedestrian and Evacuation Dynamics*, Springer, Berlin, pp. 59-74.
- Hajibabai, L., Delevar, M.R., Malek, M.R., Frank, A.U., 2007. Agent-based simulation of spatial cognition and wayfinding in building fire emergency evacuation. In Li, J., Zlatanov, S., Fabbri, A.G.: *Geomatics Solutions for Disaster Management*. Springer, Berlin, pp. 255-270.
- Jensen, C.S., Lu, H., Yang, B., 2009. Graph model based indoor tracking. In: *2009 Tenth International Conference on Mobile Data Management: Systems, Services and Middleware*, Taipei, Taiwan, 10 p.
- Jun, C., Kim, H., 2009. An indoor crowd simulation using a 2D-3D hybrid data model. In Gervasi, O., Taniar, D., Murgante, B., Lagana, A., Mun, Y., Gavrilova, M.: *Proceedings of the 2009 International Conference on Computational Science and Its Applications*, Suwon, Korea, Springer, Berlin, pp. 397-412.
- Jun, C., Kim, H., Kim, G., 2009. Developing an indoor evacuation simulator using a hybrid 3D model. In: Lee, J., Zlatanov, S., (Eds.) *3D Geo-Information Sciences*. Berlin: Springer-Verlag, pp. 173-178.
- Karas, I.R., Batuk, F., Akay, A.E., Baz, I., 2006. Automatically extracting 3D models and network analysis for indoors. In: Abdul-Rahman, A., Zlatanov, S., Coors, V. (Eds.) *Innovation in 3D-Geo Information System*. Berlin: Springer, pp. 395-404.
- Kolbe, T.H., 2008. Representing and exchanging 3D city models with CityGML. In Lee, J., Zlatanov, S.: *3D Geo-Information Science*. Springer-Verlag, Berlin, pp. 15-31
- Kwan, M.P., Lee, J., 2005. 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, pp. 93-113.
- Kuiper, F.A., 2001. Evacuation of Airport Terminal Buildings – Possibilities for Computer Simulation. Master thesis, TU Delft, 152 p.
- Lee, J., 2004. A spatial access-oriented implementation of a 3-D GIS topological data model for urban entities. *GeoInformatica*, 8(3), pp. 237-264.
- Lee, J., 2007. A three-dimensional navigable data model to support emergency response in microspatial built-environments. *Annals of the Association of American Geographers*, 97(3), pp. 512-529.
- Lee, J., Zlatanov, S., 2008. A 3D data model and topological analyses for emergency response in urban areas. In Zlatanov, S, Li, J.: *Geospatial Information Technology for Emergency Response*. Taylor and Francis, London, pp. 143-168.
- Meijers, M., Zlatanov, S., Pfeifer, N., 2005. 3D Geo-Information Indoors: Structuring for Evacuation. In: *Proceedings of Next Generation 3D City Models*, Bonn, Germany, 6 p.
- Park, I., Kim, H., Jun, C., 2007. 2D-3D hybrid data modeling for fire evacuation simulation. In: ESRI International User Conference 2007, San Diego, USA. http://gis.esri.com/library/userconf/proc07/papers/papers/pap_1731.pdf (accessed 2 Sep. 2010).
- Pu, S., Zlatanov, S., 2005. Evacuation route calculation of inner buildings. In van Oosterom, P., Zlatanov, S, Fendel, E.: *Geo-Information for Disaster Management*. Springer, Berlin, pp. 1143-1161.
- Stoffel, E.P., Lorenz, B., Ohlbach, H.J., Rosner, M., 2006. NL navigation commands from indoor WLAN fingerprinting position data. Technical report of REVERSE-Project, Munich, Germany, 22 p. <http://reverse.net/deliverables/m30/a1-d7.pdf> (accessed 2 Sep. 2010).

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