BIM Enabled Decision Making for in-Building Rescue Missions

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ABSTRACT

As hazardous situations occur in public spaces, decision making for rescue is always the most important but challenging task. Nowadays, this issue has lead to the necessity of computer-aided approaches. This research considers the fire situation in public spaces, and the rescue plan is influenced by various attributes such as geometry and material of building elements, the spread of fire and smoke, the behavior of endangered people and their escape routes. The authors combined network analysis with Building Information Model (BIM) to facilitate the decision making for rescue operations. Building geometry is retrieved efficiently from BIM for network generation and route finding, and material properties are acquired for fire risk analysis by using the Revit API (Application Program Interface). Rescue routes based on graph networks for rescuers can be calculated depending on actual building conditions. Risks based on building materials are expected to be adapted into network edge costs for lowest risk route finding. It is expected that the accuracy and efficiency will be greatly improved for decision making in in-building rescue operations.

INTRODUCTION

With the transportation modes being integrated in to a system of services, the convenience for transport has been significantly improved,. In such busy transport systems, if one component of the transportation system has an accident, it may cause serious consequence, such as monetary lost or human casualties. As transportation hubs connect different modes of transport, the physical infrastructures usually have complex characteristics, such as geometrical lay out and large numbers of pedestrians. In such circumstances, the rescue operation is a big challenge to emergency management agencies. Building Information Models (BIM) is a popular concept in civil engineering. BIM can be use for the management of buildings or infrastructures through the entire life cycle. It is an intergraded design and visualization platform based on parametric CAD technology (Eastman et al. 2011). This research shows the method of applying BIM to traditional network analysis and decision making for in-building rescue operations. As utilizing the database of BIM, it can extract useful attributes, such as coordinates that facilitate network generation graphs by kinds of methods for meeting different environment situations and information of material. The flow of evacuees should also be considered so that conflict of evacuees and rescuers could be prevented. By constructing the bridge between BIM and conventional analysis of risk, a more precise and efficient decision is expected.

CURRENT LITERATURE

This section is divided into three parts. The first is the introduction of research for facility and indoor evacuation. The second part is about applications of BIM in emergency situation, the last part is about graph theory for constructing graphs.

Facility and indoor evacuation. There has been many research on in-building emergency decision making, some of which discuss pedestrian simulation models, such as cellular automata models (Chu 2009; Pelechano and Malkawi 2007) and agent based evacuation models (Shi et al. 2009), while some develop real time response systems which try to use real-time 3D GIS for the development and implementation of GIS-based intelligent emergency response systems (GIERS) that aim at facilitating quick emergency response to terrorist attacks on multi-level structures (e.g. multi-story office buildings) (Kwan and Lee 2005).

BIM and its application in emergency. There have been research efforts on the integration of BIM with traditional building evacuation. Wang (Wang et al. 2012) had develop an API (Application Programming Interface) (Autodesk 2012)which estimates the capacity of building evacuation and calculate evacuation time. It checks whether the public space meets the standard and serves as a reference for design modification. Nepal et al. (Nepal et al. 2012) proposed using Geography Markup Language (GML) and XQuery to search spatial and relational attributes from BIM. Rueppel and Stuebbe (Ruppel and Stuebbe 2008) proposed a solution for response and recovery to support rescuers in finding the shortest way within a public building and provide them with information in their particular spatial context. Information of BIM is exported and prepared for use on mobile devices. In 2010, Ruppel et al. (Ruppel et al. 2010) presented a concept to set up a new BIM-based Immersive Safety Engineering Environment (ISEE) to model emergency situations in buildings.

Graph theory. The straight MAT algorithm developed by Lee (Lee 2004), based on Yao and Rokne's research (Yao and Rokne 1991), produces skeleton graph of an 3D indoor space. Taneja et al. used the straight MAT concept to transform IFC-based information into geometry networks, which enables indoor navigation assistance (Taneja et al. 2011). Chu and Yeh implemented the visibility graph method as part of their optimal placement method of emergency evacuation guidance signs (Chu and Yeh 2012). A visibility graph is a network whose vertices are the vertices of obstacles and whose arcs connected all vertex pairs that are visible to each other. When the graph is constructed, the network of the space is derived and shortest paths between origin and destination pairs can be found by using the shortest path algorithms, such as Dijkstra's algorithm (Dijkstra 1959).

OBJECTIVE

During an emergency such as an earthquake or fire disaster, there is the need to have rescue decisions quickly and efficiently made. This research utilizes the property of information integration in BIM, enabled with the network construction algorithms to automatically generate road networks from the BIM. The proposed approach takes the indoor geometry and properties from the BIM to construction the road networks on which decisions are made upon. By comparing the characteristics of networks generated from different algorithms, a compromised algorithm is proposed and investigated. The proposed hybrid algorithm is expected to facilitate more effective and accurate decisions.

APPROACH

To achieve the objective, the process in Fig. 1 is proposed. First is the selection step that fetches the geometrical layout of the interest area from the BIM model to reduce complexity. The resulting model is a Clean BIM with reduced information, and the region of interest to be analyzed is extracted by cross sectioning. The objects in the BIM model are then picked up and by using the Revit API the xy coordinates of nodes, which are the base of network construction, are extracted. The network/graph is constructed with weights on its edges for a best route analysis. The following sections describe these steps in more detail.

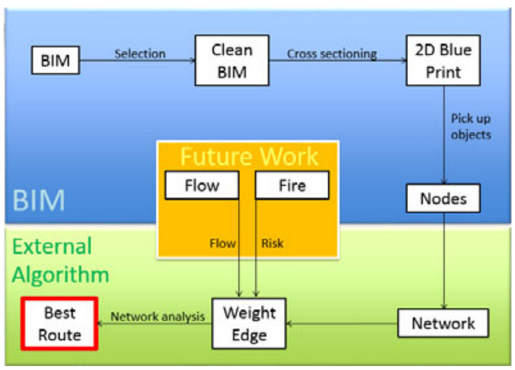


Figure. 1 Process of Proposed Work.

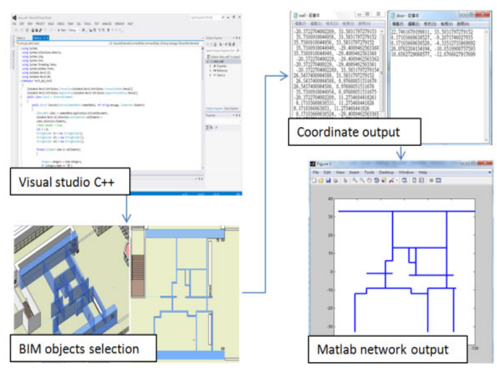


Figure. 2 Process of Constructing Real Network Directly from BIM.

Information from BIM. Objects' information from BIM is first selected by using the Revit API together with Microsoft's Visual C++. In this research, Revit API is used for the selection of doors and walls. The xy coordinates is taken form BIM using the Revit API. The geometry is then ported to Matlab. The process is shown in Fig. 2. The in-building geometry layout serves as the input for road network construction.

Network construction. In the following, pseudo code for the two network graph construction algorithms are discussed. Some nomenclatures are introduced first. We define obs to be the set of obstacles' coordinates, such that $obs=\{V,E\}$, which V is the set of walls' end vertices $V=\{V_1,V_2,...,V_n\}$ and E represents the set of edges (walls) that $E=\{e_1,e_2,...,e_m\}$ in $ei=(V_i,V_{i+1})$. Vertices of doors stores in d matrix, which $d=\{V_{d1},V_{d2},...,V_{dn}\}$

1. Visibility graph construction
   (1). Start from each vertices in *obs* and *d*, and check if they are visible to each other.

- visibility check: If the connection link between two vertices does not cross any edges *E* in *obs*, then two vertices are visible. The road network of two nodes exist (Fig. 3).

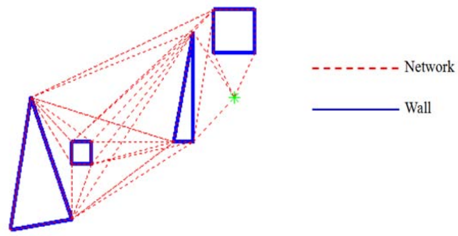


Figure 3. The Concept of Visibility Graph

(2). If two vertices are visible to each other, then record the relation in the OD matrix *M*.
(3). *M* represents the final network.

2. Approximate MAT construction

Use the concept of Medial Axis Transform with modification to make this algorithm more suitable for the research cases.

The variables definition in approximate MAT is the same as visibility graph. However, in this algorithm the new set *LL* is defined, which $LL=\{L,V'\}$. *L* is defined as the set of links formed by concave vertices and convex vertices (Fig. 4 and Fig. 5). $L=\{L_1,L_2,...,L_m\}$, which $L_i=(V_i,V_j)$, V_i, $V_j \in obs$. The mid points of links *V'* are also stored in the *LL* set. $V'=\{V'_1,V'_2,...,V'_n\}$.

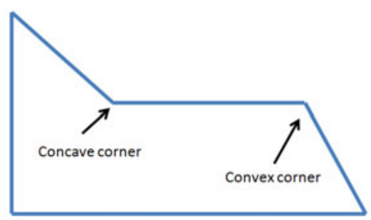


Figure 4. The Definition of Concave and Convex in The Polygon

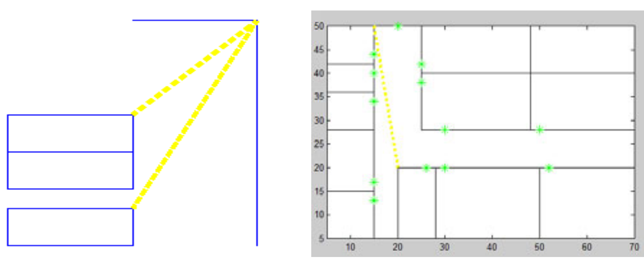


Figure 5. The Links Formed by Concave and Convex Vertices.

(1). Define the types (convex or concave) of vertices in *obs*. Produce rays, which are the bisectors of the interior angles of convex vertices in *obs* and put them into *L1*.
(2). Let the rays in *L1* cross each other (the ray couldn't penetrate any edge e_i), pick up the intersection point that is the closest to the origin vertex of ray.

(3). Make rays which are bisectors of concave corners which formed by parent rays (in *L2*) and the intersection points (in *L2*) as starting points. Save the new points and rays into *L1*.
(4). Go back to step 2, define segments formed by origin points in *L1* and new intersection points generated from step 2, and save these segments to *L4*.
(5). If any ray in *L1* cannot find end point (intersection point) in step 4, then check whether the origin point of the ray can connect to the center points of links between pairs of convex and concave vertices (in *LL*) and save these segments to *L4*.
(6). Once executing step 5, save the connection segments between the mid points of links in *LL* into *L4*.
(7). Add links between doors (vertices in d matrix) and segments in *L5*, save them into *Ld*
(8). Combine *L5* and *Ld* as the final network.

Path analysis. After construction of the network, the location of evacuees could be defined in this layout and assign numbers of doors as exits. It is planned in future studies to add weight values calculated from evacuee flow and fire risk simulation models, to the network edges, so that the edges costs would be higher if the edge has high flow or risk value. The edges' costs could be transform into length that we could get the optimal exit of each evacuee's and their best escape route to the exit by using the built-in Dijkstra's Algorithm in Matlab.

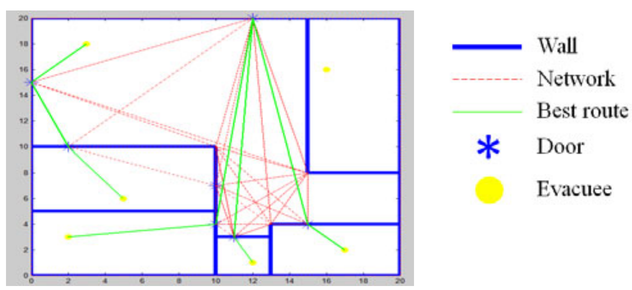


Figure 6. Evacuation Path from Each Evacuee to The Nearest Exit. (Two Exits assigned)

CASE STUDY

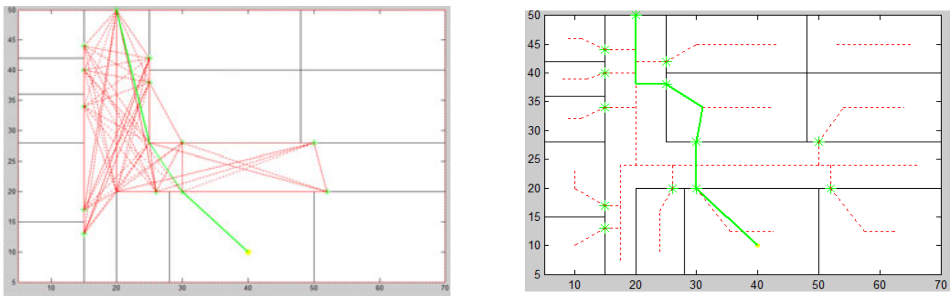
In this section, the proposed network construction process is tested with two cases, one in small scale (Table 2 and Figure 7) and the other larger in scale (Table 3 and Figure 8). In both cases, the visibility graph network and approximate MAT network are both constructed to compare the construction performance. The parameters of both cases are shown in Table 1. As shown in Table 2 and Table 3, the network construction time for both problem has great difference using the different algorithms; Visibility Graph takes significantly longer time for the case with larger scale. In addition, case scenarios with the same problem settings are tested against the networks to compare the efficiency for path analysis in terms of running time and the final path length (costs). For the small scale case, the path analysis's running times are both fast, but the Visibility Graph approach gives smaller total cost. For the case with larger scale, the path analysis has a factor of 5 difference in running time, and the total length of the path also shows the consistent result as in the small scale problem.

Table 1. Layout Parameters for Both Scales

	Numbers of Walls	Numbers of Door
Small Scale	41	13
Larger Scale	484	144

Table 2. In Small Scale Analysis

	Network construction time (seconds)	Path analysis time (seconds)	Path length (costs)
Visibility Graph	5.887312	0.025039	46.1371
Approximate MAT	1.812181	0.015260	52.436

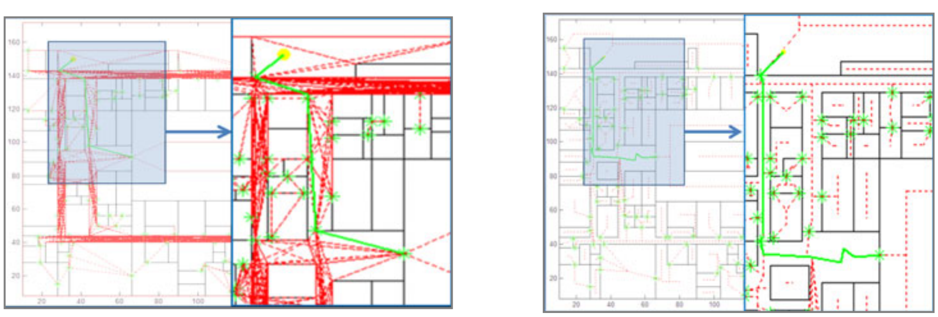


(a) (b)

Figure 7. Small Scale Path Analysis (a) Visibility Graph. (b) Approximate MAT.

Table 3. In Large Scale Analysis

	Network construction time (seconds)	Path analysis time (seconds)	Path length (costs)
Visibility Graph	3953.317449	2.491234	86.9646
Approximate MAT	685.421663	0.464410	102.0666



(a) (b)

Figure 8. Large Scale Path Analysis (a) Visibility Graph. (b) Approximate MAT.

As there is larger number of links in the Visibility Graph network, both network of its construction time and path analysis time are much longer than the Approximate MAT. However, the results for path seeking length of the Visibility Graph analysis is better than the Approximate MAT network; lower path costs are produced using the Visibility Graph as the vertecis and edges are more optimal in terms of geometry. As this is still an ongoing research, the next step is to propose a hybrid algorithm that adapts the Approximate MAT network to analyze the rough path routes of evacuees in the first pass of analysis for the overall tendency. Once given the rough path, a problem of a smaller scale could be formed in the proximity of the rough path. A second pass analysis could be carried out for a more detailed path analysis using the Visibility Graph. In particular, when there is the need for a more precise decision, the Visibility Graph approach could give decisions with better resolution. The visibility graph could be used for the analysis in the small scale areas, so that the calculation in large scale could be prevented and could also get the best result efficiently.

CONCLUSION AND FUTURE WORK

In this paper, the authors presented the method of constructing path networks directly from a BIM model. The concept and procedure of two network construction algorithms are presented. The case studies show the characteristic of different network construction methods and its performance. It could be verified that visibility graph network is more suitable in small scale path analysis and approximate MAT network for large scale problems. However, accuravy of path of visibility graph is better than approximate MAT. The authors propose a hybrid algorithm that combines the two kinds of network construction, in order to improve the efficiency of path analysis as the future work.

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