3D indoor "door-to-door" navigation approach to support first responders in emergency response

PhD Research Proposal

Liu Liu, MSc

GIST Report No. 55

GIS TECHNOLOGY

TU Delft Delft University of Technology

Challenge the future

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Summary

Indoor navigation is a fast developing area, but researchers are facing various challenges. One of them is the real-time navigation in 3D complex environments. This PhD research proposes a new approach for 3D indoor navigation, named "door-to-door", to support the first responders in emergencies in complex buildings. In this research, we address three problems: (1) automatic 3D network generation from 3D semantic-rich models of complex buildings (which have irregular shapes & interior space subdivided by columns, counters etc.); (2) navigation of indoor pedestrians in the most natural movement (i.e. "door to door" routes); (3) a dynamic routing, which considers prediction of hazards development and pedestrian behaviors. The goal of the research is to investigate the added value of the new 'door-to-door' approach.

To achieve this goal the research will be structured as follows. Firstly, algorithms to derive automatically a 3D navigation model indicating indoor "door to door" elements (the direct walking way or a proximate route between two exits) will be developed from 3D semantically-rich models of complex buildings (CityGML and IFC). A 3D data model will be designed and implemented to manage the 3D navigation model and provide link between network generation algorithm and the data model. Besides, an indoor optimal path-finding algorithm considering prediction of indoor changes and dynamic route adjustment will be devised. To integrate the 3D navigation model with the path-finding algorithm, a prototype system making use of database and visualization software will be developed. The benefits of the new 3D navigation approach will be assessed by being compared with other well-known counterparts.

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1 Introduction

Currently, more and more complex buildings have arisen in cities. Most of them are commonly located in downtown, surrounded by complicated traffic networks, and the stories are connected by the elevators or stairs within complex internal structures. The complex internal structure and limited numbers of entrances on the ground impedes the rescue and evacuation. In case of emergencies (such as fire and terrorist attacks), it may cause unnecessary casualties and damages. On September 11th, 2001, the terrorist attacked the United States World Trade Center (WTC) and the Pentagon, which led to the collapse of the WTC, serious damages of the Pentagon's structure and a large number of casualties. This event impels people to pay attention to the emergency response in high and complex buildings. If we can get the accurate real-time information, which is quickly distributed to the remaining people in the building and the first responders, it is possible to minimize the impact of the disaster.

Indoor navigation approaches are actively developed in the last years for rescue and evacuation from buildings. Fire alert systems and light- & sound-based evacuation systems are commonly available in all large buildings. Many of the public buildings are even equipped with modern systems allowing for tracking people. Yet such ways are apparently not sufficient for evacuation or rescue processes. A successful indoor navigation process relies on: an up-to-date navigation model of buildings, accurate indoor positioning, adjustable navigation routes concerning real-time indoor changes and prediction of building conditions and pedestrians. The most significant factor in the process is the accurate and up-to-date navigation model of buildings.

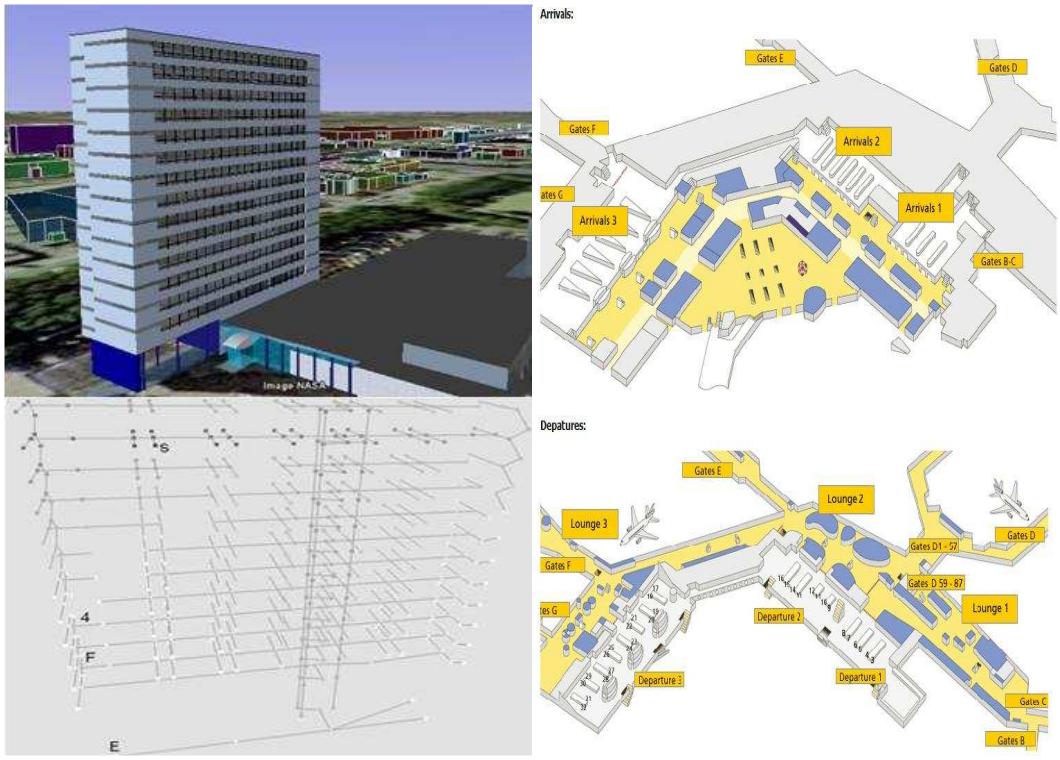
At present there are various representations of buildings for navigation (Lee, 2004; Kwan and Lee, 2005; Lamarche & Donikian, 2004; Li & He, 2008; Li et al, 2010). However, the main problem in these methods, as often discussed, is that they are always on the basis of 2D pre-defined floor plan or pre-defined simple 3D models of buildings. "Pre-defined" means those representations merely represent the static state of buildings, which can not take changes within indoor environment into account. For instance, when a part of a building is unavailable during a disaster (e.g. fire), the pre-defined navigation plans would be ineffective and the rescue process may be disturbed.

3D building represented as a collection of 2D floor plans has also insufficiencies. Multi-story buildings may have intermediate levels within certain floors. It is impossible to use 2D plans to exactly represent this complexity. How to exactly represent these indoor structures becomes a tough problem. Another flaw of using 2D plans is the plans may neglect some semantics of indoor environments (such as what are doors). Besides, use of 2D plans may fail to represent correctly vertical indoor environments (such as configuration of stairs, elevators and escalators.

Compared with 2D plans, 3D digital building models have many merits. Based on 3D digital models, pedestrians may obtain better navigation guidance (by 3D visualization). 3D models can represent features of vertical spaces (such as ceilings, ramps, obstacles in air and other intermediate levels) in complex buildings. Furthermore, 3D models allow advanced analysis to be better performed (e.g. gas /

plume / smoke diffusion analysis). Besides, indoor real-time changes can be better represented by changes of geometry and semantics of 3D building models. On the basis of a 3D navigation model, predicted indoor changes could be taken into account (e.g. 15 minutes later a corridor will be "blocked" by smoke spread or floor collapse).

The currently proposed 3D navigation models are demonstrated on simple (regular-structured) buildings (Fig. 1a) and fail to provide automatic approaches for creating/obtaining models for complex interior structures (Fig. 1b). The changes (unavailable corridors, exits, etc.) in the environment due to smoke, water or other types of damages are represented only on the network for navigation. Thus, the link with the geometry of the building is disturbed and may lead to a loss of important information. For example, windows on the first floor and second floor, which are not normally included in the network for navigation, might be omitted as options for escape.



(a) (b)

Figure 1 (a) a regular-structured building (from work of Meijer et al , 2005); (b) Schiphol airport with complex structure, Amsterdam (from Website: http://intertraffic.ru/english/Schiphol)

From current literature, it is not found any approach deriving 3D navigation model from 3D digital model of complex buildings (which have irregular shapes and interior space subdivided by columns, counters etc. see in Fig. 1b). Generally, automatic derivation of network from complex 3D building models is one of the most critical obstacles presently. Another open problem is current routing algorithms pay little attention on predict indoor changes to deal with real-time variations.

This research intends to develop a new approach for navigation that allows for fast and flexible navigation in 3D complex environments. We will investigate a new 'door-to-door' approach, which we expect will provide faster and more "natural" routes than existing approaches. 'Door to door' means the direct walking way from a door to the next visible door or the shortest possible way between two invisible doors. As shown in Fig. 2, the straight medial axis (as used in many of the navigation models) of a corridor is D1-M1-M2-M3-M4-D4. However, a person would most probably follow the routes D1-D2 and D1-S1-D3 (the dash lines). In the second case the person will see D3 after reaching S1, if he can't see the exit D3 immediately. This approach will result in a new type of graph, where the doors are represented as nodes and the edges represent the spaces to pass through. We expect that this approach will also allow us to deal with complex 3D buildings.

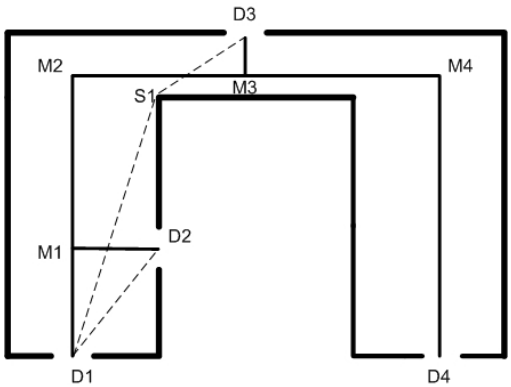


Figure 2 An example of the door to door way (based on visibility criterion)

The goal of this research is to develop robust algorithms for the 3D navigation data model (from 3D semantic models) and a corresponding routing algorithm, which will ensure re-structuring and re-routing in real time taking into account different construction elements of buildings and the development of hazard. A data model will be designed to manage the navigation model in DBMS. The merits of the new 3D navigation approach will be assessed with respect to current well-know approaches.

Following this introduction, section 2 of this proposal summarizes background for this research. Several essential parts of indoor navigation are introduced, including models for indoor navigation, path-finding algorithms and requirements to indoor navigation models.

Section 3 is used to describe the main content of this planned research. It refines objective, main research question as well as related sub-questions. The research methodology is elaborated in the section, which also determines the sub-division of this research.

Section 4 involves some specific practical issues, such as Software and Tools, Data Source, Supervision, Education, Conference and Visit issues, and Time planning.

Section 5 indicates the proposed deliverables in the course of this research. Section 6 is the references of this proposal.

Section Appendix introduces some other issues closely related to this research but outside the main scope, which are indoor positioning techniques and visualization.

2 Background

In this chapter, we will introduce the essential components of a complete indoor navigation system and current related research. Two main components are models for indoor navigation and path-finding strategies/algorithms. At present many researchers are working on these topics. From the literature review, it will be helpful to investigate the pros and cons of these studies and elicit the way we can forward to conduct indoor navigation better.

In the following sub-sections, firstly we will introduce several typical indoor navigation models, including dual graph, navigable space, regular-grid and sub-division. Their pros and cons are also provided. Secondly, several path-finding algorithms are investigated. After that, we will propose requirements to indoor model for navigation. According to the properties of a favourable indoor navigation model, the comparison of different models will be given. For the purpose of navigation, an indoor navigation model should support indoor positioning and 3D visualization functions in some way (e.g. to provide interfaces).

2.1 Models for indoor navigation

The internal structure of buildings is always described by geometrical models (such like CAD models) and 3DGIS data models (Lee, 2001a). For instance, CityGML is an international OGC standard for semantic 3D city models which provides a common information model for the representation of 3D urban objects. CityGML can represent urban terrain and 3D objects in five levels of detail (LOD). LOD0 is the coarsest level used to represent regional landscape. Buildings are represented from LOD1. LOD1 can express city and region. Building geometries in LOD1 do not have notations for the elements of the building. Usually the geometry is also very simple, i.e. the buildings are represented as blocks with flat roofs. LOD2 focuses on city districts and has more details. In LOD2, buildings semantics as roofs, ground and walls is preserved. LOD3 mainly serves for architectural models with detailed facades and roofs, vegetation and transportation objects (Open Geospatial Consortium, 2008). LOD 4, which specifies architectural models (interior of buildings), will be used for representation of indoor environments (e.g. rooms, stairs and furniture). LOD 4 could provide semantically-rich, object-based building models. Kolbe et al (2005) apply CityGML to various disaster management applications and demonstrate how the connectivity between rooms for pedestrian access can be extracted using the shared openings (doors) between rooms.

Another group of digital building models is Building Information Models (BIMs) which are developed for covering all stage of the building lifecycle (from design to maintenance). Industry Foundation Classes (IFC) is an industry standard of BIM (International Alliance for Interoperability, 2010; Nagel et al., 2009; Isikdag & Zlatanova, 2009), which restores both geometric and semantic information. Due to the abundant 3D geometric and semantic information (thickness, material, direction of opening etc.) of BIMs, it is possible to automatically derive required navigation

models from BIMs. These two types of models (CityGML & BIM) will be extensively used in our research.

In the following sub-sections, we will introduce several typical indoor navigation models, which are dual graph, navigable space, regular-grid and sub-division. Also, their pros and cons will be given.

2.1.1 Dual graph

Several researchers (Lee, 2001a; Lee, 2004; Kwan & Lee, 2005; Pu & Zlatanova, 2005; Boguslawski & Gold, 2010) classified the 3D model of buildings as the geometry and the logical model (such as topological model) which represents the connections between the sub-units in buildings. The topological model is used to compute the shortest available path and the geometry model is used for visualization. Researchers always focus on the connectivity structure within urban buildings. In order to conduct reliable and fast computation, many researchers adopt graph model to represent connectivity relationships within interior buildings (Lee, 2004; Kwan & Lee, 2005; Lamarche & Donikian, 2004).

There are several types of derived graph model of buildings. The first group of methods is the Dual Graph proposed by Lee (2001a), which uses a Node-Relation structure (NRS) to represent the connectivity of buildings based on Poincaré Duality theory. Poincaré Duality converts "Room - Door" relations in primal space to "Node - Edge" relations in dual space (Munkres, 1984; Corbett, 1985) (Fig. 3). In order to represent indoor environments more accurate, Lee (2004) extends the NRS to Geometric Network Model (GNM), which introduces geometrical metric. Lee (2004) also mentions a skeleton-abstraction algorithm to help construct 3D GNM (Fig. 4). That is the Straight-Medial Axis Transformation (S-MAT) modelling method (Eppstein & Erickson, 1999; Choi & Lee, 2009), which can abstract linear features from simple polygons (such as corridors) (Fig. 4c).

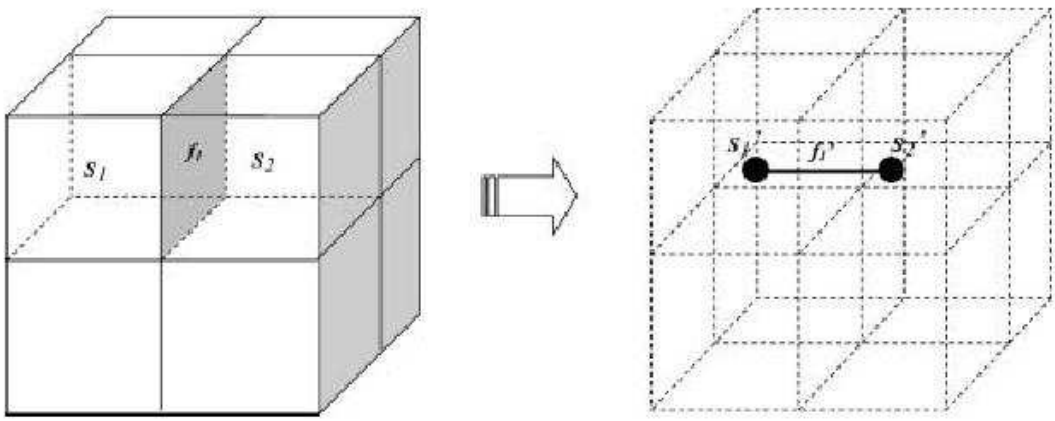


Figure 3 Duality of 3D objects (from Lee's work, 2005)

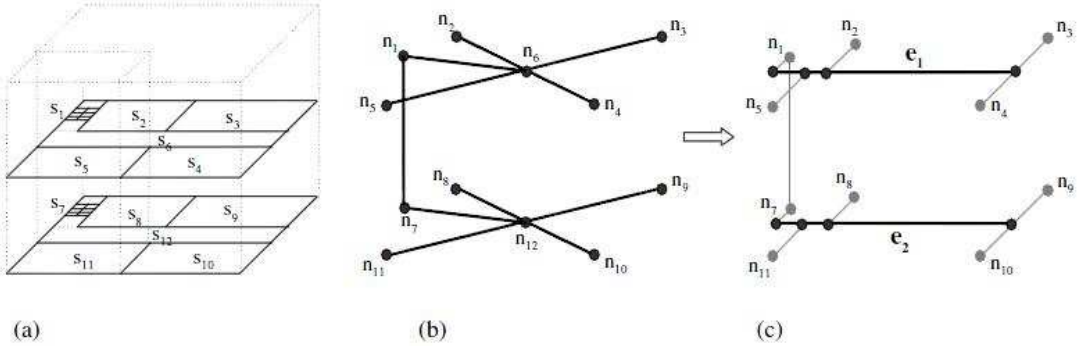


Figure 4 (a) a simple building model; (b) corresponding logical model (based on connectivity); (c) the geometric network. (from work of Kwan & Lee, 2005)

Another method named Multilayered Space-event model provides a multilayer representation for different spatial models, such as topographic space for 3D buildings and sensor space for sensor range partition (Becker et al., 2009). In the model, each space layer is divided into primal and dual spaces on one hand, and also divided into topology and geometry spaces on the other hand (Fig. 5).

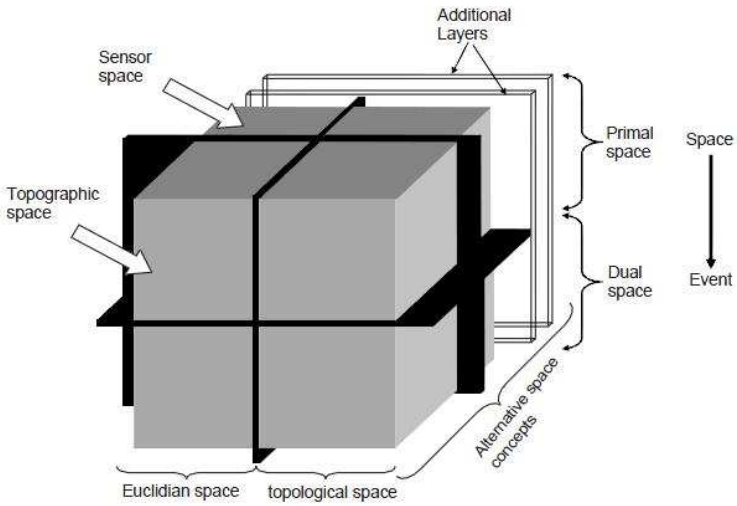


Figure 5 Various concepts of space (from work of Becker et al, 2009)

Various layers of the topological space models are connected by so called "joint-state" edges, which represent there is space overlap of two nodes from different space models (Fig. 6). At a time only one "joint state" edge and related nodes are active. Ultimately, "space-event" (people's movement) is expressed by topological space representation. In the dual space of topographic space layer, a dual graph could be derived by the same way as Lee (2004) mentioned.

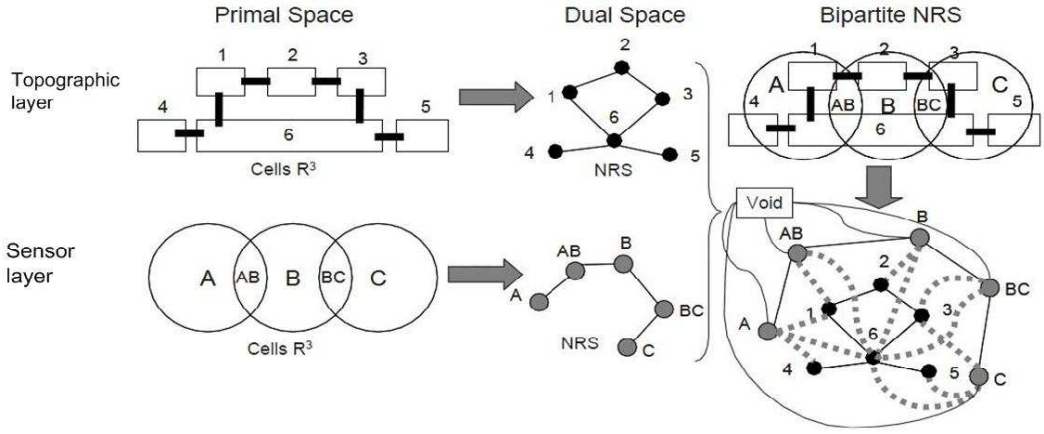


Figure 6 The Multilayered Space-event model (from work of Becker et al, 2009)

Due to the multi-layer structure, the "joint state" edges which link different space layers is helpful to explore model-aid positioning, which means to improve indoor positioning results by using indoor geo-information. For instance, if we know a person is in a node of the dual graph of sensor space, then it is possible to narrow down searching scope to locate the position of the person by making use of "joint state" edges of the node in topographic space.

Dual Graph model is accepted by many researchers (Lee, 2004; Meijers et al., 2005; Li & He, 2008; Becker et al., 2009; Boguslawski & Gold, 2010). It indeed has benefits: 1) it contains geometry and explicit topology of buildings and it may contain semantics (as with CityGML), 2) it can be generated automatically; 3) indoor route calculation (e.g. shortest path) can be conducted readily and fast (Kwan & Lee, 2005). Musliman (2008) proves that Dual Graph could support dynamic changes (insert or delete edges quickly) as well.

Except for the apparent merits of Dual Graph (DG) model, we summarize some deficiencies of this kind of navigation model. DG model may ignore some semantics (e.g. columns in rooms, intermediate floors) of complex indoor environments. Then it may not represent accessibility within buildings accurately. For instance, it may create weird networks for corridors. A medial-axis algorithm is mostly applied to overcome this problem, however it fails for large arbitrary shaped spaces.

The DG generally represents the structure of the building and not the way of walking. As shown in Fig. 2, compared with the "door to door" route D1-S1-D3, the DG route would be D1-M1-M2-M3-D3. It is obviously that DG model could not provide "door to door" routes. Furthermore, it may have problems to represent stairways. For example, Lee (2005) utilizes a node located at a stairway (elevator) to represent the stair at a particular floor and uses an edge to indicate the vertical connectivity between two floors. Apparently, the abstraction of stairways overlooks their shapes. Perhaps stairways of a complex building are complicated and they should be divided into several cells to construct a graph model. All this reveals that current DG models have problems to accurately represent indoor environments of complex buildings.

2.1.2 Navigable space

Navigable space model (Slingsby & Raper, 2008; Schaap, 2010) intends to construct topologically-connected and navigable spaces (surfaces) to point out where

pedestrians are able to move. The approach for navigable space model could reconstruct a 2.5D model from 2D plan with limited height and surface constraints. The group of models can provide some specific semantics (e.g. time and pedestrian-dependent properties within indoor environments) for navigation (see in Fig. 7).

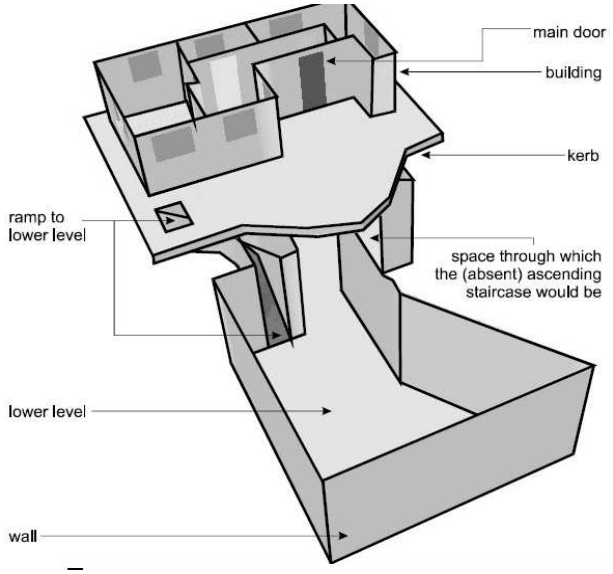


Figure 7 The space accessible to a pedestrian who starts just outside the building and cannot negotiate steps of any size (from work of Slingsby, 2008)

It is relatively easy to locate pedestrians in this model, because the position could be pointed out in one piece of surface of the model. Navigable space model is semantically-rich but the derivation of the network might be challenging for complex surfaces (Shaap, 2010). It could provide the accessible space for diverse users, but there is no "door to door" style route in it. The possibilities to automatically generate navigable spaces of various levels might be another problem.

2.1.3 Regular-grid model

The group of regular-grid graph models has two sub-types: 2D and 3D grid graphs. By overlapping discrete 2D grids with a 2D plan, the membership value of each grid is assigned according to the underlying cellular unit (such as rooms). Then a grid-based graph could be generated: the nodes represent the grids and edges of a certain node represent link relationships between the node and its neighbours (Li et al, 2010). On this type of graph, static shortest path analysis could be easily conducted (Fig. 8). Besides, it is convenient to conduct 2D diffusion analysis (smoke, flood etc.) on 2D grid graph models.

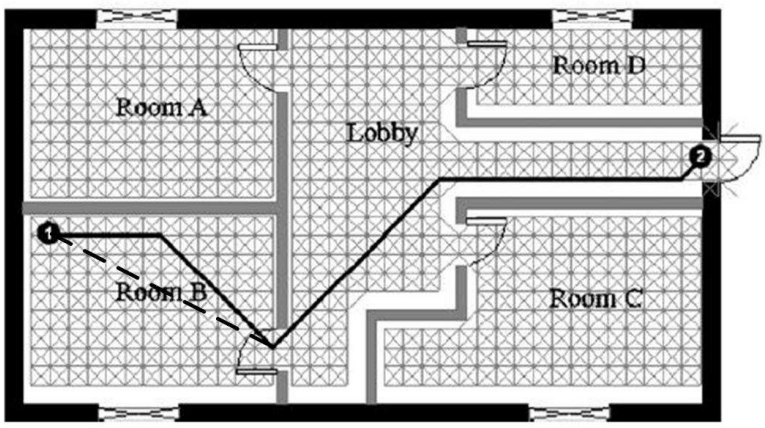


Figure 8 Overlap of the grid graph and cellular units and example of a shortest path (from work of Li et al., 2010)

For cross country movement planning, Bemmelen et al. (1993) provide an extended raster approach to make more free directions be used for moving through a raster terrain. With different number of nodes on the sides of a raster cell, the number of directions to be used also varies. In this way, the nodes in centre of grid cells are unnecessary. There are two kinds of nodes: data nodes related to raster cells and search nodes located on the sides of the cells. As shown in Fig. 9, directions to be followed vary according to the different points emitting lines (i.e. corner search node & intermediate search node). It is obvious that the extended raster approach is more beneficial to path-finding in a plane since the extended raster approach provides higher degrees of freedom to movement. As shown in Fig. 8, the shortest path-finding result could be improved by the approach (the dash line).

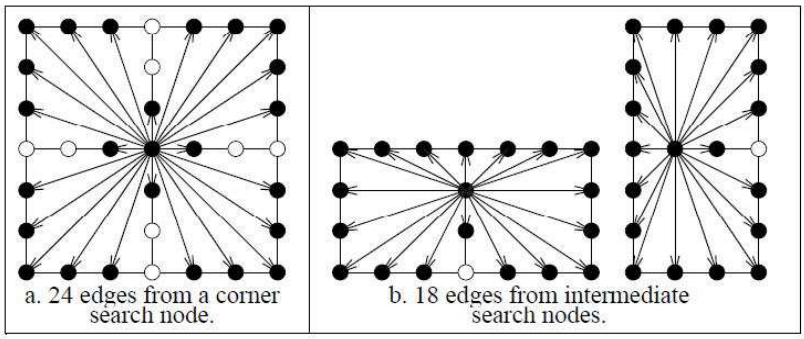


Figure 9 Edges from corner search node & intermediate search node (From work of Bemmelen et al., 1993)

Basically 3D grid graph is the extension from the 2D grid graph. The purpose of 3D grid-based (voxel) graph is to represent the 3D structure of indoor space. Then in a floor, intermediate levels (e.g. ramps and obstacles in air) could be measured. Yuan & Schneider (2010) propose a model called LEGO graph based on 3D voxels. This method computes the accessible parts of indoor environments with consideration of constraints of widths and heights of pedestrians. LEGO-graph only provides all feasible or possible paths with different accessible widths and heights (Fig. 10a). Yet they have not proposed an algorithm to compute optimal navigation routes.

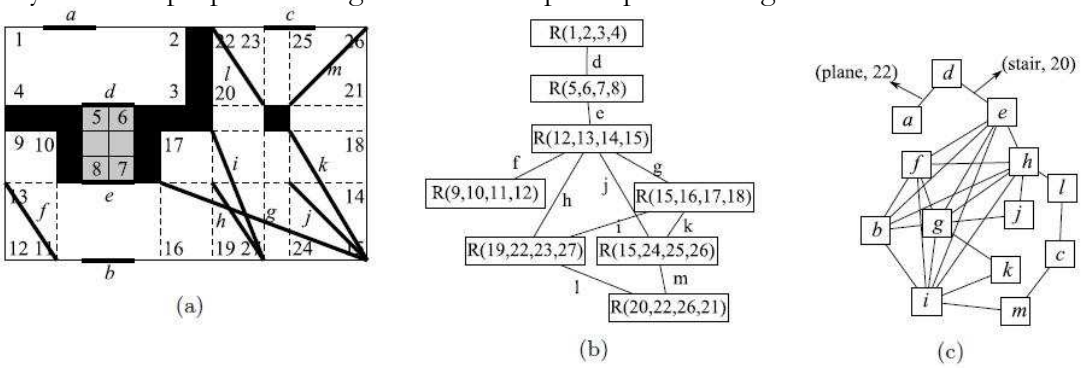


Figure 10 (a) An example of a floor plane; (b) the graph representing the connectivity of blocks; (c) the corresponding LEGO graph (form work of Yuan & Schneider, 2010)

Bandi & Thalmann (1998) give a more specific solution. They discretize space into 3D voxels and compute an obstacle-free feasible route with consideration of

surmountable and insurmountable obstacles and "hole area" (i.e. insurmountable obstacles may be encompassed in a closure of reachable grids) in space (Fig. 11).

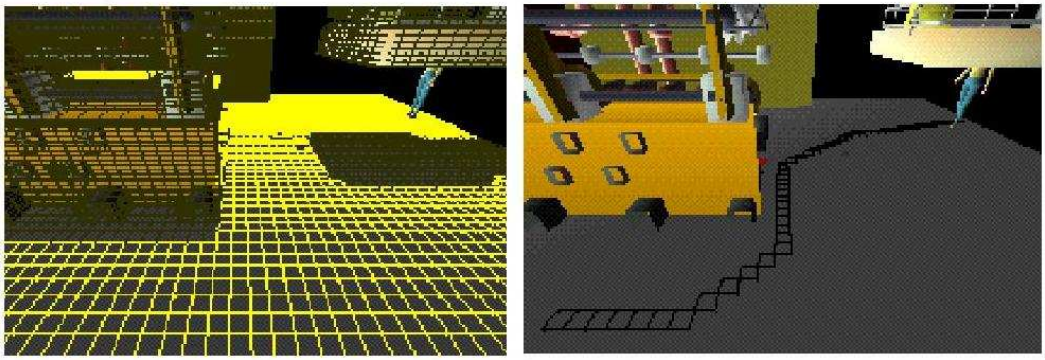


Figure 11 Reachable regions and the generated path (from work of Bandi & Thalmann, 1998)

Generally, regular-gird graph can readily point out the membership (e.g. corridors, rooms and stairways) of a grid/voxel. Besides, 3D grid graph can concern height constraints for indoor navigation. Current 2D and 3D grid models could be derived from 2D plans or 3D geometry automatically. The path-finding computational efficiency of grid model depends on required granularities and different algorithms. Fine-grained grid graph might provide the 'door to door" navigation routes for pedestrians.

2.1.4 Sub-division

The last group of methods could be summarized as 2D plan-based subdivision. This type of method concerns subdividing 2D plans into cells according to certain criteria (e.g. distances between walls, visibility etc.). There are different criteria to sub-divide indoor space in literature. With consideration of passing bottlenecks in a 2D plan, Lamarche & Donikian (2004) apply constrained Delaunay triangulation algorithm and Convex Cell optimisation to subdivide a 2D plan. The subdivision locally conserves bottleneck information (Fig. 12). All paths would be pre-computed along key points on free edges (i.e. edges which are not walls) of each cells.

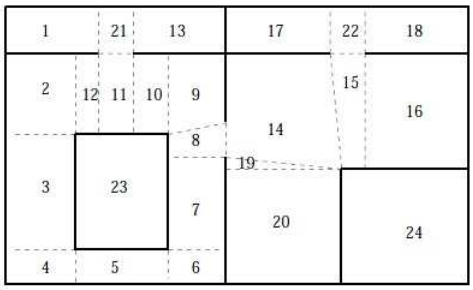


Figure 12 2D plan subdivision based on constrained Delaunay triangulation & Convex Cell optimisation (from work of Lamarche & Donikian, 2004)

A different way is given by Lorenz et al. (2006). For buildings with simple rooms and corridors, indoor space (2D plan) is decomposed into cells to build a graph structure. As shown in Figure 13, cell centres are connected with doors. However, the graph may result in some unnecessary tortuous paths. For instance, if there could be a direct connection between two doors, it is unnecessary to pass through a cell centre

(e.g. a node of the corridor). Besides, there is no completely automation of the cell decomposition.

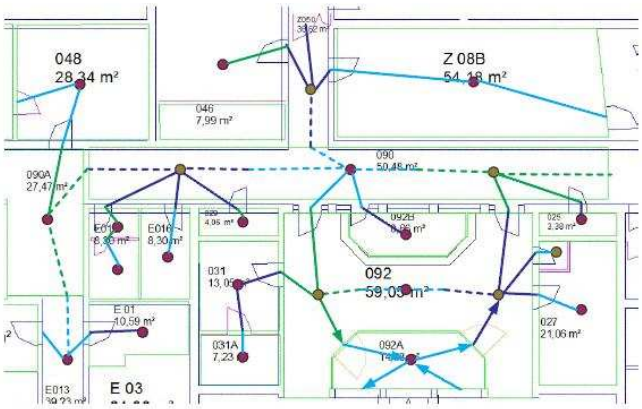


Figure 13 Cell centres and paths overlaid with a floor Plan (from work of Lorenz et al., 2006)

Another subdivision method is proposed by Stoffel et al. (2007). This method partition a plan into non-overlapping convex sub-regions (cells) according to visibility criterion. Therefore, boundary nodes, which represent the openings on the shared surface of two room units, are mutually visible if they are in a same sub-region (see in Fig. 14). Accordingly, a navigation graph could be generated, which indicates the possible paths between boundary nodes.

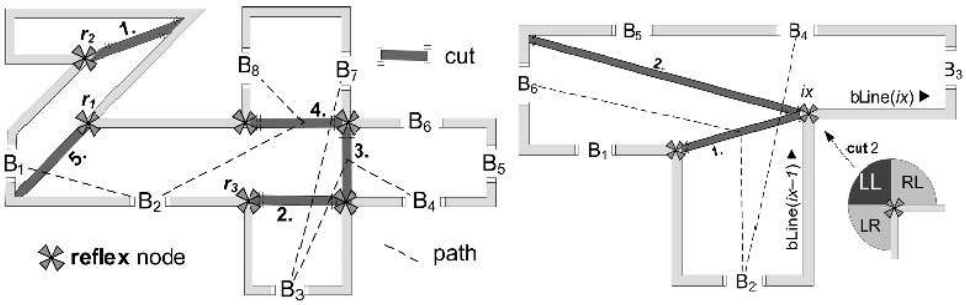


Figure 14 Visibility partitioning result (from work of Stoffel et al., 2007)

The 2D sub-dividing methods are interesting because they can consider visibility and/or width constraints, people could be guide directly to openings. Based on appropriate sub-division of indoor space, it is helpful to generate "door to door" routes.

2.2 Path-finding algorithms

After a strategy for indoor navigation is determined, the next problem for navigation is how to choose optimal route. The key problems of optimal route generation are network representation, cost functions, algorithm strategy, etc. After traffic cost function is determined, a corresponding routing algorithm will be devised. It depends upon which kind of "optimal" routes will be derived. For instance, shortest, fastest or safest routes could be considered respectively.

Many routing algorithms are developed, e.g. breadth-first, Dijskra, A*, etc. The classic Shortest Path algorithm is Dijkstra algorithm (Dijkstra, 1959). Other heuristic algorithm such like A-Star, D-Star (dynamic A-Star) algorithm (Stentz, 1994; Stentz, 1995) are developed on the basis of it. Nowadays, there are various path-finding algorithms applied to graph-based representations (especially in road network).

Bellman (1958) introduces a dynamic programming approach to solve the minimum travel time problem. In this problem, an optimal path (whose cost is travel time) between a set of locations linked by road should be determined. Besides, only a finite number of iterations will be required in this iterative algorithm.

Zlatanova & Baharin (2008) provide an initial solution for navigation on road network which are managed in Database Management System (DBMS). The emergency response network model of this solution is conceived to represent Network (spatial characteristics of road network), Event (conditions may influence road network), User (context of users), Route (the final optimal route) Route Calculation Algorithm. The routing is based on A* provided by the pgRouting extension of PosGIS.

Visser (2009) proposes a path-finding approach which concerns changes in road environments and predicts future situations. As shown in Fig. 15, the red point is the start point and the green one is the goal. From the area impacted by a plume (in pink), the route considering prediction of the plume development seems longer than the route not considering the dynamic changes. This approach can automatically generate routes within disaster areas with consideration of the changing gas plume and temporary closed roads. Tests show that the estimation of travel time is more accurate. Yet his method is only applied in 2D road network (the plume is also considered as a 2D object).

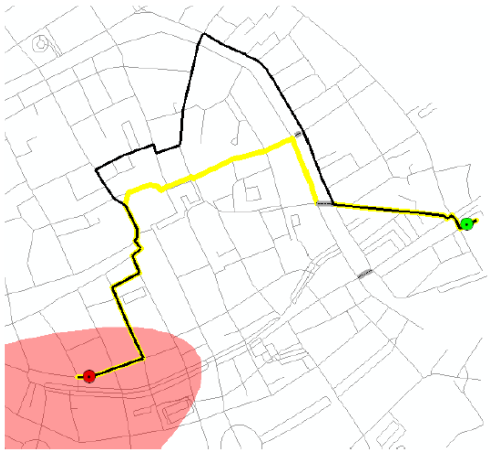


Figure 15 The route considering the plume (black) vs. normal route (yellow) (from the work of Visser, 2009)

Wu et al. (2007) proposed a path planning algorithm within indoor environments for visually impaired. This method consists of three parts: cell decomposition, cactus tree-based path planning for building, floor and area, and A* based path. Here the "cactus tree" is a non-linear data structure of relationships between indoor elements representing for path searching. Relationships in the tree are conveyed by objects being "left", "right" and "branches (below or equal)" to others (Wu et al. 2007) (Fig.

16). After cell decomposition of 2D indoor space, cactus tree-based search can be used in path planning in a floor, area or between regions.

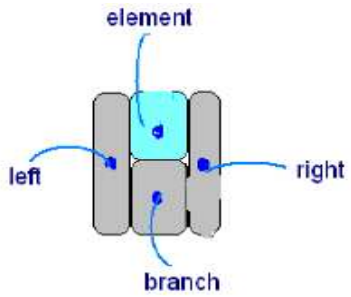


Figure 16 The cell structure of Cactus Tree (form work of Wu et al. 2007)

Ramesh (2008) offers an approach called Hierarchical Path-finding algorithm. In the algorithm, the sub-graphs of a graph model are classified into high-dangerous areas, medium-dangerous areas and low-dangerous areas in terms of the dangerous degree. The crowds in high- dangerous areas have higher passing precedence.

For the weighted region problem, Mitchell & Papadimitriou (1991) employed the "continuous Dijkstra" technique. The basic idea is "wavefront" that propagates from a source point. A wavefront with distace *d* is a set of points. The length of the shortest path from source point to the points is equal to *d*. In this way, shortest paths resemble rays of light. After building Constrained Delaunay Triangulation, Bemmelen et al. (1993) assumed the wavefront would initially spread in a circular way and through the weighted triangulated map. When a region boundary is crossed by the wavefront, Snell's law of refraction of light will be applied. The vertexes or positions on edges hit by wavefront could be used to retrace the shortest path from a given point to the source. Therefore, it provides a continuous (non-discrete) way for path planning.

Holland (1975) proposed genetic algorithms to mimic the evolutionary processes in nature, which is named the Simple Genetic Algorithm (SGA). SGA operates a serial of potential solutions for an optimization / searching problem in a plane. Its main components are: a population of binary strings, control parameters (just as genes in nature), a fitness function, genetic operators (crossover and mutation), selection mechanism, and a mechanism to encode the solutions as binary strings (representing the optimization problem's variables) (Srinivas et al., 1994). Every string (consisting of 0 & 1) encodes a solution to the optimization (searching) problem. Determining whether the crossover and mutation will be implemented is based on the fitness function. After the operations of crossover and mutation, SGA creates the subsequent generation from the strings of current population. Until a required result is obtained, the generational iterations are stopped and final result is given (Fig. 17). However, how to choose parameters -- crossover rate, mutation rate and the size of initial population is still a problem. Currently there are no unified fast and effective rules for the selection of the parameters (Buckland, 2002). It could be done by testing. Thus, SGA could not guarantee that the optimal solution (or even a solution) can be obtained.

```
Simple Genetic Algorithm ()
[
initialize population;
evaluate population;
while termination criterion not reached
  [
  select solutions for next population;
  perform crossover and mutation;
  evaluate population;
  ]
]
```

Figure 17 The structure of SGA (from work of Srinivas et al., 1994)

Existing indoor path-finding approaches seldom concern changing factors within indoor environments. In indoor environments, time and safety are vital factors in emergencies (Pu & Zlatanova, 2005). Environment, event and human factors should be considered for indoor path planning (Zlatanova & Baharin, 2008). For instance, crowd flow velocity changes over time on connectors (corridors and stairways) of buildings. The environment factors also should be considered. Better solution of changes prediction for accident development and crowd flow would be helpful to indoor navigation processes (rescue & evacuation). Individual parameters (e.g. physical ability) critically limit indoor route selection as well.

With a selected navigation model of a crisis building and a suitable indoor path-finding algorithm, it is possible to automatically provide optimal navigation routes based on real-time indoor geo-information. The optimal route selection should incorporate prediction of indoor hazards / obstacles with dynamically adjustment of current route within buildings to avoid the hazard areas and highest population density spots.

2.3 Requirements to indoor model for navigation

To be able to provide effective and accurate navigation within indoor environments, we propose an indoor navigation model has to hold the following properties:

- Considering door-to-door movement.
- Automatic generation of network from original geometry;
- Dynamic routing capacity (re-computing alternatives and prediction);
- Semantically-rich;
- Supporting indoor positioning & 3D visualization

"Semantic-rich" is related to keeping useful navigation information. Since in an emergency situation, the most interesting question to evacuees is "where are the exits?" By means of affluent semantics, required knowledge could be readily abstracted (such as "what are doors?"), which facilitates automation of navigation model generation.

"Automatic generation of network" means that the network for navigation should be automatically derived from any 3D geometry representation of a building. Under the emergency condition, the indoor environment is more and more difficult for evacuation with constant changes within building. Therefore, it should be possible to

derive a new network, which will incorporate new appropriate building elements (such as windows, doors, or other parts that can be used as exits) for specific users. Apparently this has to be fast and real-time computation.

"Dynamic routing capacity" means that the evacuation system should consider changing environment (smoke, blockages, crowds blocking areas and exits). Two kinds of routing are to be considered: 1) simple re-routing when user cannot continue due to blockages; and 2) re-routing by considering predicted future threats (plume, fire). For instance, in the latter case, edges in a graph will have time-varying cost.

"Door-to-door navigation" implies that the path-finding should represent the most natural movement in emergencies. This direct movement towards exits is named as door-to-door.

"Supporting indoor positioning & 3D visualization" indicates that the navigation model is unnecessary to focus on indoor positioning and visualization techniques, yet it should be compatible with other available technologies to serve indoor navigation.

According to the properties of a favorable indoor navigation model aforementioned, there is a comparison among the four kinds of models listed below:

Table 1 Comparison of different indoor navigation models

Properties	Models			
	Dual graph	Navigable space	Regular-grid models	Sub-division
'Door-to-door'	No	No	Conditional	Yes
Automatic generation from complex geometry	Conditional	Semi-automation	Yes	Yes
Dynamically routing capacity	No prediction	No	Yes	No
Semantic-rich	Partly	Yes	Yes	Partially
Supporting indoor positioning and 3D visualization	Unknown	Unknown	Unknown	Unknown

From Table 1, it is obvious that a Dual Graph (DG) model is difficult to provide "door to door" style routes for indoor pedestrian. Therefore, Dual Graph model is not taken into consideration in this paper. The only one fully supporting "door to door" navigation is the visibility subdivision method. In this way, people could obtain most natural movement guiding in emergencies. Yet current sub-divisions in literature are based on 2D plan, it could not take real-time changes and 3D indoor space into account. A 3D sub-dividing method has more potential to offer accurate route calculation. Therefore, we may concern that a 3D network on the basis of visibility partition is more suitable for navigating indoor pedestrians.

3 The PhD research

This chapter will introduce main parts and arrangement of this research, including motivation, research goal and methodology of the research. Section 3.1 explains problems existed in current navigation models, our requirements and possible contribution. The section 3.2 presents our research objective, which is to develop a 3D indoor navigation approach and an indoor optimal routing algorithm. After that, in section 3.3 research question and corresponding sub-questions are proposed, which focus on the added value of the design 3D navigation approach. Section 3.4 describes our methodology for this research, including literature study, development and testing algorithms of initial model generation, the refined model, development and testing of indoor optimal routing algorithm, integration, assessment of the navigation approach. In section 3.5 we clarify several topics related to this research yet outside its scope.

3.1 Motivation

From discussion in previous chapters, it is easy to find out existing navigation models has various problem. Generally, automatic derivation of the navigation model from complex 3D building models is one of the most critical obstacles presently. Another raised question is that "door to door" navigation routes representing the natural movement of pedestrians is neglected by most indoor navigation models. In order to concern indoor changes, we can not only statically derive navigation model from the geometry of buildings. Management of a navigation model is also required if the analysis involves a number of buildings in a region. Data management system (DBMS) will be a nice option for it. Besides, prediction for indoor accident (e.g. development of smoke) and crowds are often excluded in most path-finding algorithms.

To sum up, a 3D data model automatically derived from 3D geometry of complex buildings with up-to-date semantics is what we require. Secondly, based on the data model a dynamic 3D indoor path-finding algorithm considering prediction for indoor environments is also needed. Finally, calculated routes should be in accord with pedestrian "door to door" way as much as possible.

3.2 Research Objective

The objective of this research is to study and work on developing a 3D indoor navigation approach and an indoor optimal routing algorithm for the first responders in emergencies.

At first, a 3D network indicating indoor "door to door" elements is required. The algorithm of the network automatic derivation from 3D digital and semantic-rich models of complex buildings (e.g. BIMs, CityGML) will be designed. Then, a graph model (connectivity) also will be generated. All of the models (Geometry, network and connectivity) should be managed in a DBMS. A designed data model (3D navigation model) will make use of them to support indoor navigation. Furthermore,

an indoor path-finding algorithm considering prediction of indoor changes and route dynamic adjustment should be devised.

The 3D navigation model, the path-finding algorithm, suitable indoor positioning techniques and visualization approaches will be integrated into a prototype system. Then the prototype can provide real-time navigation instruction to rescuers. For the indoor positioning techniques, there are lots of approaches based on inertial systems (see in section Appendix). Besides, visualization either on computer displays (e.g. for control center) or cell-phone screens (e.g. for evacuees) would be explored and decided in future. Fig. 18 presents a brief workflow of this research. The blue parts are study contents of this research.

Before the research question is given, it is assumed that: (1) there are 3D semantic-rich geometry models of buildings such as CityGML or BIM data; (2) sensor data (smoke detector & monitor etc.) could be used for real-time update of the navigation model and crowd flows; (3) the navigation model aims to serve small groups of users (e.g. first responders). Yet the designed navigation model still should support analysis of crowd movement due to the possible congestion problem caused by crowds (evacuees) in buildings.

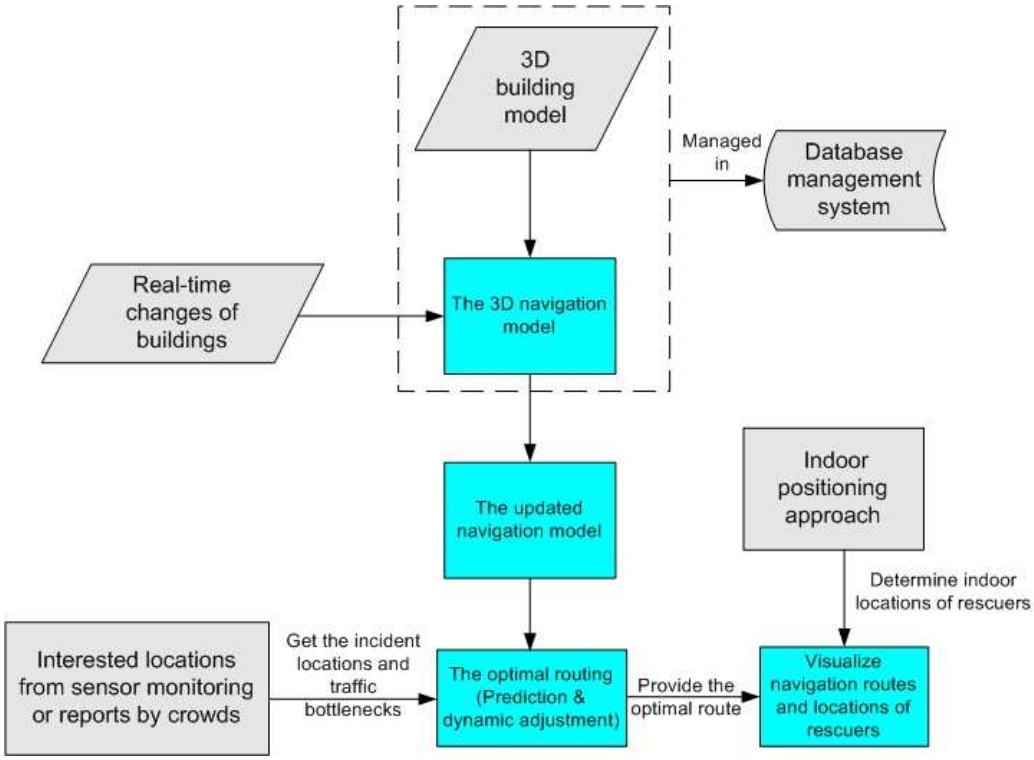


Figure 18 The work flow of this research

3.3 Research Question

The general research question of this research is derived from the objective:

What is the added value of the "door to door" 3D navigation approach of complex indoor environments, compared with current solutions?

Some research sub-questions are:

Construction of the 3D navigation model of complex buildings:

- What kind of digital model of buildings can be used as data source in this research?
- What kind of algorithms can be used to automatically derive and update the 3D network from 3D digital models of complex buildings?
- What kind of algorithm can be used to update the 3D network according to predicted indoor changes?
- What kind of data management model or schema that stores this model (including 3D geometry model, 3D network, and connectivity of buildings) will be used in this research?
- What kind of hierarchy of buildings should be taken into account in the 3D model?
- What information should be extracted from building data and added in the navigation model managed by the database?
- What kind of DBMS software (e.g. PostGIS or Oracle Spatial) will be used in this research?

Use of the model -- optimal route selection:

- What routing algorithm should be developed to be able to consider both prediction of indoor changes (e.g. hazards spread) and dynamic route computation?
- What kind of hierarchical structure could be used to support indoor routing?
- What are the criteria of an "optimal route" (safest, fastest or shortest etc.) for rescuers in emergencies? Or what factors impact the optimal route selection (e.g. to avoid hazards as smoke/water /fire)?
- Based on the navigation model of buildings, what factors limit the efficiency and accuracy of a path-finding algorithm (e.g. computation related to crowd flows)?

Assessment of the model:

- What are the criteria to evaluate the model and algorithms (network automatic generation & indoor routing)?
- How to compare with this model with other indoor navigation models?

Others:

- What kind of system architecture (e.g. web-based) should be applied in this research?

- Which kind of interfaces (e.g. for mobile units & control centre) should be selected or designed?

3.4 Research Methodology

The following parts elaborate our research methodology, which consists of literature study, development and testing algorithms of initial model generation, the refined model, development and testing of indoor optimal routing algorithm, integration, assessment of the navigation approach. The work flow is shown in Fig. 19.

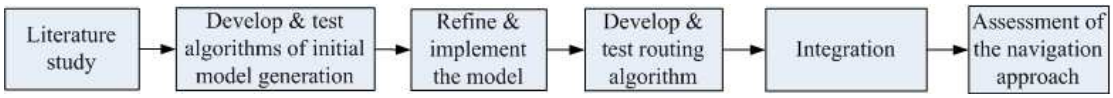


Figure 19 Work flow of research methodology

3.4.1 Literature study

In order to avoid redundant study compared with previous researches and know the state-of-the-art progress in indoor navigation, it is necessary to read literatures. From the literature reading, the background information and some preliminaries of this field should be clarified. The elements of indoor navigation process also should be abstracted. On the basis of them, basic thoughts about innovation of this research would be formed. Moreover, technology information regarding implementation issues should be paid some attention. Besides, it is necessary to investigate user requirements to specify innovative elements in indoor navigation compared with present approaches and evaluate their potential. The requirements can be obtained from literature review, observation in life and discussion with experts and potential users. Emphasis of this phase will be on indoor navigation models, path-finding algorithms and indoor positioning techniques and visualization technologies.

3.4.2 Development and Testing – algorithms to build initial model

In this phase we aim at automatic extraction and management of both the connectivity information and the metrics and will consider this model as a 3D navigation model. At first, it is necessary to find out a suitable approach which can reasonably and readily sub-divide the space of a 3D digital complex building according to visibility criterion. Then an algorithm which could automatically derive a 3D network supporting "door to door" navigation from the sub-division space will be developed. At present, there are two major types of 3D digital building models: BIMs and CityGML building model. Tests based on the two kinds of data will be implemented to determine which one will be proper for this research. A graph model for fast computation representing connectivity between pedestrian location and exits will be constructed based on the 3D network. The algorithm of automatic generation of the graph will also be developed. The network representing metrics and connectivity in 3D space will be update according to real-time indoor changes. The cost function of the graph is time-varying and it will be determined by current buildings' accessibility and predicted changes in routing phase. The work flow for

deriving the 3D navigation model of a crisis building is shown in Fig. 20. The 3D network and the graph will be a part of the navigation model.

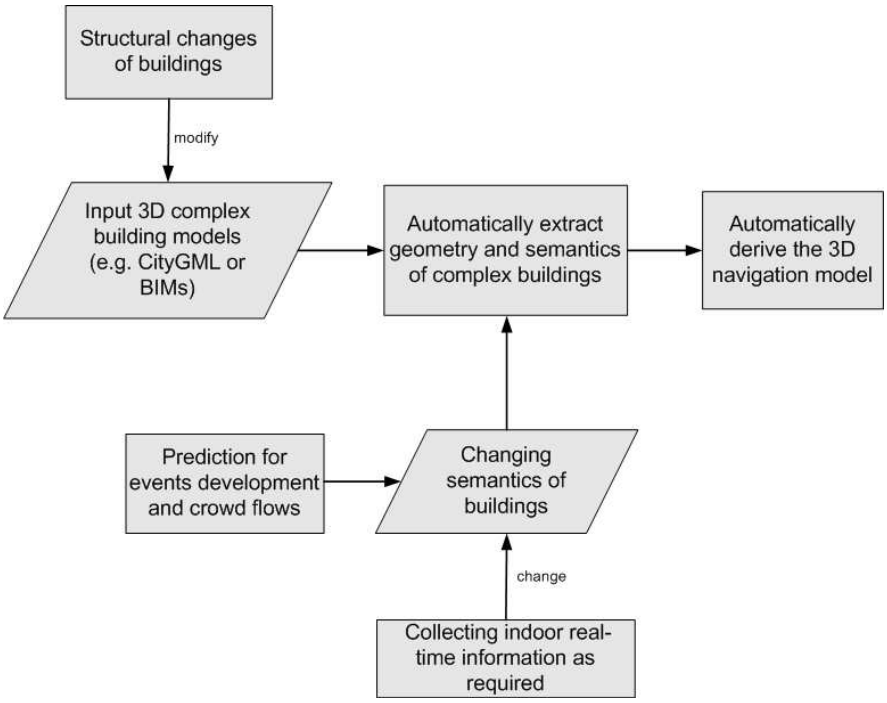
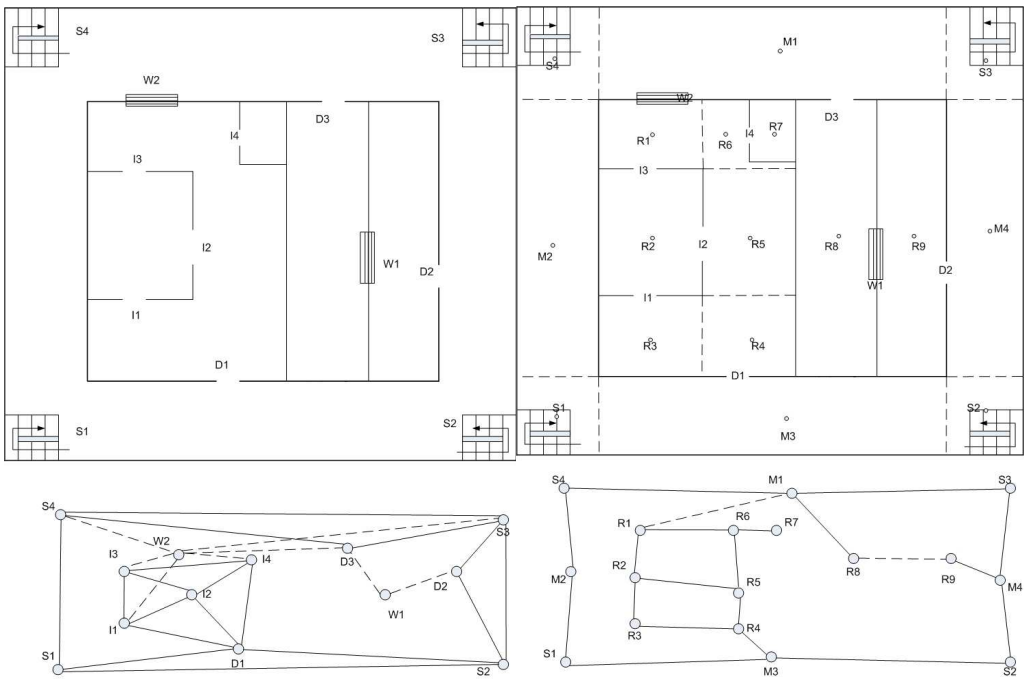


Figure 20 The framework for generating the 3D navigation model

To assess the generation algorithm of the 3D network (hereinafter referred to as "network generation algorithm"), some comparison tests will be implemented. Thus, at first criteria will be given to evaluate the algorithm. Then we will generate our 3D network and dual graph model (mainstream model) based on the same 3D digital building data for evaluation. Besides, various single buildings with different shapes will be used as input to test efficacy and stability of our algorithm. Network generation algorithm will be modified if test results demonstrate it is not satisfactory adequately.

The initial ideas of this phase could be depicted as follows:
As shown in Fig. 21, possible outlets of a floor plan are abstracted as nodes of a network (Fig. 21a). If two openings are mutually visible to each other, then there is a "visible" edge between them. Besides, a dual graph of the storey is built after the indoor space is sub-divided (Fig. 21b). Fig. 22 is the illustration of two floors of OTB building, TU Delft, which includes the geometry and the designed 3D network. As shown in Fig. 23, two intermediate nodes will be added in the network to build a new detour for pedestrians. Whereas the graph model derived from the network will not be changed.



(a) (b)

Figure 21 (a) the designed network of a floor plan; (b) the dual graph of the same plan

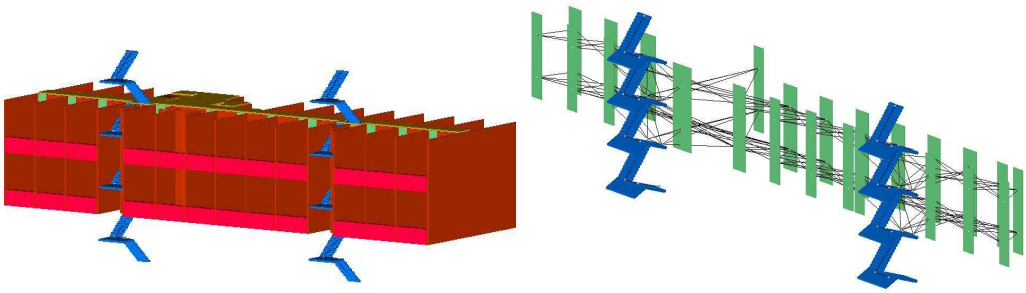


Figure 22 The geometry and 3D network of a part of OTB building

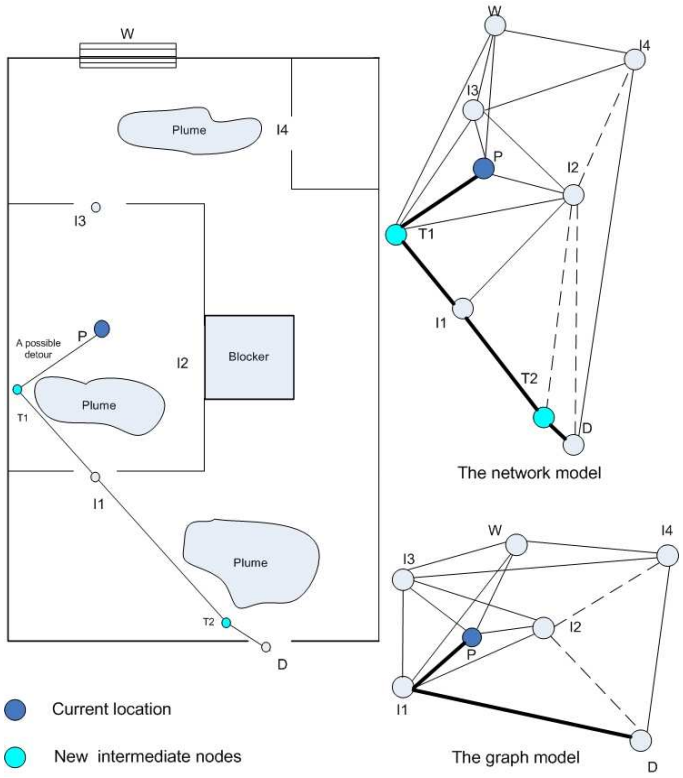


Figure 23 3D network & corresponding graph model

3.4.3 The refined model

In this phase, a data model will be designed for providing storage and management of the 3D navigation model. A UML model including the 3D geometry, network and graph will be designed at first. Then the model will be implemented in DBMS. It is necessary to preserve the consistency among the 3D network, the graph model and the 3D digital building model with respect to indoor real-time changes. Ultimately, the link between the network generation algorithm with the data model will be clear and easy to handle. It will be convenient to load geometry data of required buildings from DBMS and derive their 3D network by applying the algorithm.

3.4.4 Development and testing – indoor optimal routing algorithm

In the phase we concentrate on use of the 3D navigation model – indoor routing. Environment, events and human factors, and prediction of changes will be concerned. Therefore, an indoor routing algorithm will be developed: the first step is to delimit criteria of "optimal" (safest or fastest etc.) for identifying accessible routes. The next step is to define traffic cost function comprising current accessibility and estimation of future changes. Finally, the two complementary methods (prediction & re-computation) to response indoor changes will be used together to determine the optimal route. For instance, when unexpected blockages occur on the halfway of the calculated route, it is necessary to continue re-compute the new 'optimal' route immediately as previous steps. Several possibilities regarding indoor routing will be further explored (e.g. one group of rescuers to many different destinations or many groups to an identical destination).

After the routing algorithm is devised, some tests will be performed to verify the algorithm. The algorithm and other common-used routing algorithms will be applied on a same 3D navigation model for comparison. Improvements will be concerned according to test results.

The initial ideas regarding to the routing algorithm is depicted as follows:
As shown in Fig. 24a, a detour is given according to the prediction result. If prediction is inaccurate, a new route from current barrier location to a certain outlet should be re-calculated (Fig. 24b).

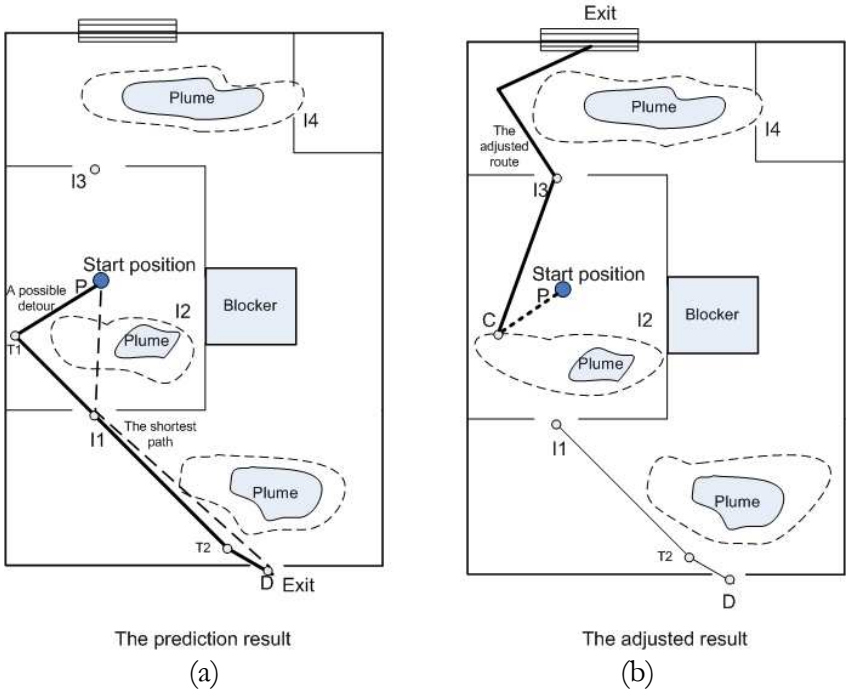


Figure 24 (a) Prediction; (b) re-computation in path-finding

3.4.5 Integration

In this phase we will design a prototype system which can provide indoor navigation service for rescuers. It will consist of 3D navigation model of buildings (in DBMS), navigation routing module (analysis module), indoor positioning & visualization module (provided by specific software). Therefore, we will design interface for our data model to specific positioning and visualization software. The route visualization results could be demonstrated on both computer displays and handheld mobile devices (e.g. Augmented Reality glasses, cell-phone screen, 3D stereo or 3D helmet screen etc.). Indoor routing test will be conducted on the prototype and the results will be analysed for improvements. Besides, web-based visualization will be concerned. User requirements and feasibility study in future will determine which kind of interface that we will design in this research. More detailed information on the visualization issue is presented in section Appendix.

3.4.6 Assessment of the navigation approach

It is necessary to evaluate the 3D navigation approach to outline its added value. In the first place, we will present criteria to assess the approach. According to the criteria, we will assess whether the data model well support the designed 3D network generation, routing function and visualization. Comparison tests are also required.

Thus, we will develop the designed 3D navigation model and certain common-used navigation models (e.g. Dual Graph) simultaneously to support indoor navigation. Our model will be compared with others on performance with respect to a same indoor environment. Furthermore, navigation results supported by the designed model will be demonstrated to users and experts. According to the comparison result and the feedback, certain modification will be carried out to complement the 3D navigation approach.

3.5 Issues outside research scope

There are some topics related to this research yet outside its scope, which are listed as following:

- Indoor Positioning Techniques
- 3D visualisation
- Polyhedral surface path planning
- Simulation & controlling of crowd flows

In general, it is assumed there are some specific software providing indoor positioning and 3D visualization of our results. Interface to support the software will be developed in our program. More information regarding the two topics can be viewed in section Appendix. In this research, we do not take account of a continuous solution (non-discrete) based on polyhedral surface of buildings. Besides, the indoor crowd flow can be regarded as a research object, i.e. how to simulate and control indoor crowd flows to support evacuation. Yet it is merely considered one impact factor to indoor individual navigation (one or several persons) in this research. No attention would pay on controlling crowd flows.

4 Practical Issues

4.1 Software / Tools and Data

For this research, we will compare and select appropriate software, which includes:

- DBMS environment: OracleSpatial, PostGIS etc.
- Programming language: C++, Java, SQL, PL/SQL etc.
- 3D industrial building models: IFC, CityGML etc.
- Related Standards: International standards (ISO, and OGC etc., see in Section 6) developed for the management of geo-information and the representation of urban objects are related to this research.
- GIS environment (for visualization): FME, ArcGIS, Bentley software etc.
- Extensions (may be needed yet to be selected): Visualization devices (e.g. 3D stereo & mobile platforms), communication tools (wireless to mobile platforms) and indoor positioning equipments.

Data collection is a time-consuming issue. The main purpose of this research is to develop and test a new navigation data model for the first responders in emergency response. We have no intention to put data collection in the research schedule. So the already available building data (such as TU Delft) is the first choice for initial tests. However, in this research we intend to develop the navigation model from 3D complex buildings (which have irregular shapes and interior structure). For instance, railway stations, airports and other large buildings (e.g. the building "De Rotterdam") could be taken into account. If there is no data of complex buildings, we may acquire such kind of data in certain way.

4.2 Supervision and education

The project will be promoted by Prof. Dr. Ir. P.J.M. van Oosterom. Mw. Dr. Dipl. Ing. Sisi Zlatanova will act as daily supervisor. It is agreed to meet at least once per month with the promotor. On every monthly meeting, opportunities and problems of this research will be discussed. Dr. Zlatanova will discuss with Liu Liu once per week about progress and problems of current research. Before each weekly or monthly meeting, Liu Liu will prepare an agenda. Liu Liu will take notes for both monthly and weekly meetings and summarize them as minutes and actions every time. Before the next meeting, the minutes of last meeting should be submitted to the supervisors. During the sabbatical leave of the supervisors, the monthly or weekly meetings will take place by telephone or E-mail contact.

To quickly get to know how to conduct a PhD research, Liu will take part in 'PhD Start UP' Delft programme. To improve the scientific writing of the PhD student, Liu will participate in the courses 'Research Design' (PROM-5), 'Scientific writing in English' (PROM-4) which are taught at Delft University of Technology at the Faculty of Technology, Policy and Management. Besides, other courses in MSc-programme such as 'Geo DBMS' (GE 1080), '3-D Geo-Information Systems' (GM 1020), 'Transportation and Spatial Modelling' (CT 4801) and 'Location Based Services' (AE4-E07) could be taken.

If more training or courses are needed, then this will be discussed with supervisors. During this PhD career, Liu should write a serial of scientific papers and finish the doctoral thesis.

4.3 Visits and projects

In order to get to know cut-the-edge knowledge, technologies and research results, some visits are also considered, which may include (but not limited to):

- Universities or research institutes: such like Berlin University of Technology (Technische Universität Berlin) and University of Munich, which has researchers working on topics related to this research. It is also worth to visit the Technical University of Eindhoven, where researchers are actively busy with the use of IFC models. For communicating some computational geometry issues (e.g. path-finding), the Utrecht University or Eindhoven University of Technology could be considered. Other visits will be planned as the research develops. The duration of each visit could be two or three weeks.

- Organisations: This research needs useful expertise in certain areas, to visit some specialized organisations will be helpful. For example, the fire brigades department or the police department.

- Companies: Some leading companies may also be engaged in the development of indoor navigation model. To visit these companies will also help this PhD research.

As the PhD research can be benefited from other projects and the findings in them, it is tried to cooperate in current on-going projects of OTB.

4.4 Reporting of results

In order to know the start-of-the-art advancements and demonstrate the achievements of the PhD research, several conferences are planned to attend. Between 2011 and 2013 one or two conferences per year will be attended. However, at present it cannot be pointed out which conferences should be attended. Generally, these conferences should be in the fields of '3D Geo-information' and 'crisis response', which may include (but not limited to):

- SDH (International Symposium on Spatial Data Handling);
- UDMS (The Urban Data Management Society);

- Gi4DM (International Symposium on Geo-information for Disaster Management);
- 3D GeoInfo (International Conference on 3D Geo Information);
- ISCRAM (International Conference on information systems for crisis response and management);
- ISPRS (International Society for Photogrammetry and Remote Sensing and Spatial Information Sciences);
- AGILE (Association of Geographic Information Laboratories for Europe);
- International Symposium on LBS & TeleCartography;
- Annual ACM Symposium on Computational Geometry;
- ACM SIGSPATIAL GIS;
- ICCGCV (International Conference on Computational Geometry and Computer Vision);
- COSIT (Conference on Spatial Information Theory);
- GI Science (International conference on Geographic Information Science).

Details of these conferences could be seen in section Appendix. Some other conferences related with 3D geo-information, emergency response will also be considered.

In order to summarize and demonstrate the achievements of this PhD research, several journal papers are also planned. At present, it is not determined to submit papers to which journals. Generally, these journals should be involved in the areas of computer-based modelling of indoor environments, urban optimal planning (especially from the technical perspective), and other computational aspects. These journals may include (but not limited to):

- International Journal of Geographical Information Science (IJGIS);
- ISPRS Journal of Photogrammetry and Remote Sensing;
- Computational Geosciences;
- Computers, Environment and Urban Systems;
- GeoInformatica;
- Environment and urban planning B.

More information about these journals could be seen in Section Appendix.

4.5 Time Planning

The following schedule is just a rough one. It is a time arrangement on the PhD research. The PhD research officially started on September 1st, 2010.

Sept. 2010 – Jan. 2011:
Literature study. This is the preparation phase for the PhD research, which helps me to understanding the background of the PhD research.

Writing of PhD proposal. Writing a draft version and get feedback from the supervisors.

Software preparation. To collecting technical information and get familiar with CityGML, PostGIS,

Outputs: regular reports on research progress, the first conference paper and the approved PhD proposal.

Feb. 2011:
Software preparation and tests for algorithm development. The whole month will be spent on conducting some tests about automation of 3D network generation with small-scale data (CityGML). Based on the test results, to start writing the second conference paper.

Outputs: a test report, the final presentation of the PhD plan.

March 2011:
Further development. Automation of 3D network generation should be improved for applying bigger simple-structured buildings. An initial algorithm will be given and its stability will be evaluated. Also, the second paper should be finished on time.

Outputs: 1 conference paper for Gi4DM.

April 2011:
Software preparation and tests for algorithm development. This month will be spent on becoming familiar with Oracle spatial and BIM data. Previous tests on 3D network generation could be conducted with BIM data. The suitable DBMS will be discussed and chosen in this phase.

Outputs: a test report.

May 2011:
To refine automatic derivation of 3D network. Some low-rise yet complex-structured building model could be used to verify the derivation algorithm of 3D network.

Output: regular reports.

June 2011:
To develop an initial algorithm to generate graph model from our 3D network. Tests will be performed with different single building models.

Output: regular reports.

July - Sept. 2011:
To complete derivation algorithm of 3D network. The algorithm will be able to handle most kinds of single buildings and automatically derive 3D network for them. Another conference paper related to indoor navigation based on our algorithm will be written.

Outputs: regular reports & 1 conference paper.

Oct. 2011:

User requirements investigation. To visit some specific emergency response department (like fire brigades, universities), and to collect their opinions and additional requirements. Besides, to visit some universities to communicate current research results.

Outputs: investigation reports.

Nov. 2011- Jan. 2012:

To perfect and test the algorithm of model derivation from 3D digital models of complex buildings. Besides, we are going to develop DG or another algorithm for comparison test. Comparing with other existing approaches, we would demonstrate pros and cons of our navigation model and attempt to improve it.

Outputs: different status reports, 1 conference papers, 1 journal paper.

Feb. – July 2012:

Design and implementation of the data model. A 3D data model (geometry, network & connectivity of buildings) stored in DBMS will be designed and implemented. Combined use of the data model and network generation algorithms will be investigated.

Outputs: regular reports, 1 conference paper.

Aug. 2012 – July. 2013

To develop and test an indoor optimal path-finding algorithm for individuals, which would incorporate future prediction with dynamic re-computation and support routing in our 3D navigation model. Comparison experiments will be performed on the designed navigation model and results will be analysed for further algorithm improvement.

Outputs: regular reports, 2 conference paper, 1 journal paper.

Aug. - Dec 2013:

Integration & assessment of the navigation model. To develop a prototype integrating the 3D navigation model, indoor path-finding module, the interface connected with certain indoor positioning devices & visualization module. Moreover, Comparison tests should be conducted. Model or prototype improvement also will be performed according to test results.

Outputs: regular reports, prototype.

Jan – June 2014:

Final preparation. Writing PhD Thesis and preparing PhD Defense.

Outputs: PhD Thesis, 1 journal paper.

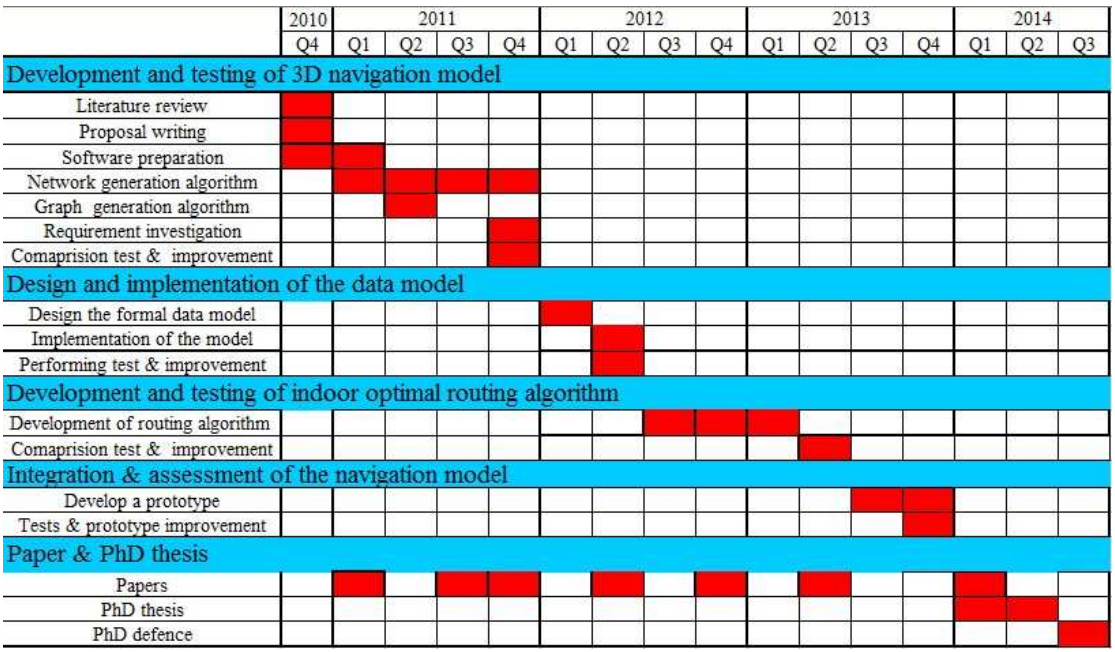


Figure 25 PhD time planning

5 Deliverables

5.1 Articles

It is expected that a number of articles and papers will be prepared for international journals and conferences:

- Regular reports inside the study group
- 2 or 3 papers per year in (international) conferences
  e.g. UDMS, Gi4DM, SDH, 3D GeoInfo etc.
- 2 or 3 papers in reviewed scientific journals
  e.g. IJGIS, GeoInformatica, Computers, Environment and Urban Systems, etc.
- PhD thesis

5.2 Research Results

Except for the output in the form of articles and papers, other types of outputs are to be anticipated from this research:

1. A 3D navigation approach:

   - Algorithms of model derivation of buildings (3D network & connectivity). An algorithm is designed for readily and automatically transform 3D digital model of complex buildings to the "door to door" 3D network. The generation algorithm of the graph model is constructed based on the 3D network.

   - A 3D data model. The data model is devised to link 3D geometry, 3D network and the graph model in a benign storage and management mode.

2. A indoor optimal routing algorithm for rescuers, which can incorporate future prediction with re-computation to provide optimal routes for rescuers according to indoor real-time changes;

3. A prototype system (with a GUI) which can provide real-time navigation service for rescuers in indoor environments. The prototype will integrate the 3D data model, the indoor routing algorithm and specific indoor positioning and visualization techniques. The users could be the first responders in the field with Cell-phones/ PDAs or coordinators with computers in the control room. Hence the interface could be designed in different ways, such as visualizing the whole representation of buildings and routes of rescuers on computer displays in the control room or demonstrating the current indoor scene related to rescuers and providing forward instructions in pedestrian navigation mode. We will make a choice in future depending on requirement investigation.

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Appendix

This section will introduce two closely related issues to this research yet which are out of the research scope. They are Indoor Positioning Techniques & Visualization. Beside, details of planned conferences and journals are given.

Indoor Positioning Techniques

For the purpose of indoor navigation, it is necessary to utilize indoor positioning techniques, especially for the first responders (rescuers). Acquiring indoor location information continues to be challenging given that the GPS signals have deep attenuation and distortion within indoor environments (Rantakokko, 2007).

Pseudolites is to generate virtual navigation satellites. A reference station is located in a benign environment that could receive signals from satellites (Rantakokko et al. 2007). A GNSS-like signal is transmitted to overcome limitations such as signal blockage in indoor environments. It remains to be seen whether sub-meter level accuracy can be achieved for many indoor scenarios within buildings.
Except for GPS receiver, there are other alternatives like Local Radio-based Positioning and Dead-reckoning systems etc.. Unfortunately, currently neither of these techniques can yield sufficient accuracy and availability alone at a reasonable cost (Rantakokko et al, 2007). Usually they are combined to work at indoor environments and generate relative accurate results.

Local radio-based positioning systems have many merits compared to GPS receivers. Positioning systems like Radio Frequency Identification (RFID) already exist on the market. It is likely that the radio-based positioning system will not provide the desired accuracy due to multi-path propagation and available suitable frequencies etc.

Infrastructure-Based Localization utilizes distance and angle measurements to determine a target's coordinates. Detectable tags by various kinds of sensors are pre-installed at known locations within buildings, which help to locate the locations of rescuers equipped by specific devices. But this type of methods may fail when the building structures change. For instance, RFID tags may not work in a building under extreme situations.

Localization with Wireless Sensor Networks requires no calibration except for the anchor nodes' positions. Besides, "no indoor landmarks" is required in this method. Yet such systems typically consist of nodes distributed quite densely in an open space, which may not be beneficial in rescue missions. Another "no indoor landmarks" method is to use Wi-Fi signals for positioning. Wi-Fi severs could independently let a person receive the coordinate of his current indoor location. With a Geo-decoding process, he would know which room / space he is in.

Another technique called "fingerprinting" always has a high accuracy. In this approach, mobile terminals have been moved around a building and the resulting received levels of signal strength (RSS) were recorded (i.e. a calibration process)

(Rantakokko et al. 2007). Yet a drawback of local radio-based positioning systems is that it doesn't work when the battery run down.

Currently main sensors for Dead-Reckoning systems are accelerometers, gyros, magnetometers and barometric altimeters. The inertial sensors (accelerometer and gyro sensors) measure the specific force vector and the angular velocity. A barometric altimeter measures atmospheric pressure and can provide elevation change estimate but the absolute error would grow with time during a shorter time period. It would be limited in fire scenes due to wind and temperature changes. Magnetometers are used to measures the magnetic field strength and estimate the heading for incident responders. With different combination of sensors, the packages mainly classified as Inertial Measurement Unit (IMU) and Micro Electro-Mechanical System (MEMS).

Dead reckoning (DR) is the process of estimating one's current position based upon a previously determined position. As shown in Fig. 26, the principle of DR is simple. In a certain coordinate system, the initial position P1 and the movement X12 are used to estimate the position of P2. Thus, the error of this method would grow over time with increasing travelled distance.

Dead reckoning only requires sensors to be carried or worn by the person being tracked, making it particularly attractive for localization in unprepared environments (Fischer & Gellersen, 2010). The accumulated errors in each measurement could be limited by resetting the estimated foot speed to zero at every step. Some researches (Ojeda & Borenstein, 2007; Fischer et al., 2008) show that good accuracy in challenging environments achieved. It seems that a beneficial mode for researchers is to couple dead reckoning with other localization techniques.

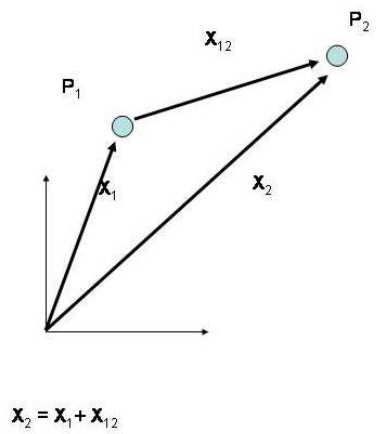

Figure 26 the principle of operation for a dead-reckoning system (from Rantakokko et al., 2007)

However, indoor positioning based on vision has a main defect: it is hard to move forward with poor visibility (e.g. too much smoke). Therfore, DR could be combined with other measures to achieve favorable results under certain condition. For instance, Fischer et al (2008) deployed ultra-sound beacons as landmarks to reduce the inherent error of DR. The simulation results showed a satisfactory guidance performance.

Another way is that pedestrians use the ultra-sound transmitters to detect the indoor walls and obstacles (Girard et al. 2010). That is, specific devices transmit signals and

they could receive the reflection from walls and obstacles to explore boundaries. After that, this result can be compared with an expected building model (such as a graph model) for positioning and navigation. The approach could be very suitable during indoor navigation, because it has several merits: 1) can be used in the building being full of smoke with poor visibility; 2) could detect unexpected obstacles; 3) still can work when the building is out of power.

There are some approaches based on detection of depth information, such as SwissRanger & Kinect The SwissRanger is a new type of depth vision camera using the Time-of-Flight (TOF) designed by MESA, which can provides stable distance information and high-resolution 3D image data in real time (from the website of MESA Imaging, URL: http://www.mesa-imaging.ch/index.php) (Gorte et al. 2008). Kinect is a technology developed by Microsoft, which sensor consists of RGB camera, depth sensor and multi-array microphone (from WIKIPEDIA, URL: http://en.wikipedia.org/wiki/Kinect). It also has the potential to be applied to indoor navigation (e.g. to detect depth information of a wall close to an indoor pedestrian).

In this research, it is assumed that several feasible indoor positioning approaches can be applied on the navigation model of buildings. It is also assumed that the positioning error from equipments can be partly corrected by comparing and matching with geographic information (i.e. the designed 3D navigation model). Tests would be conducted in reality to determine which indoor positioning technique we select in the future.

Visualisation Issue

Optimal (or shortest) route and indoor locations of pedestrians should be visualized on suitable devices (e.g. cell-phones such as Android & iPhone, or computers) to offer intuitive instruction for users. Visualization in this research is supposed to serve for rescuers. Thus, it helps trace rescuers within indoor environments. From the viewpoint of Augment Reality (AR), it contributes to provide real-time support to both rescuers in the field and coordinators in the control room.

There are different visualization ways for optimal navigation routes. For example, the routes for rescuers could be visualized on 3D geometry of building models, the 3D network of the models or 2D plans. Optimal (or shortest) and indoor locations route are always visualized on the graph model of buildings (Kwan & Lee, 2005; Pu & Zlatanova, 2005; Meijers et al, 2005; Li & He, 2008). Grid graph-based models often visualize route information on grid map (Li et al, 2010; Bandi & Thalmann, 1998). Those approaches are based on graph models and 2D floor plans. However, visualization on 3D geometric model of buildings is always neglected. Schaap (2010) gives examples of 3D visualization of outdoor routes by means of navigable surfaces.

In this research, the visualization interface either can be designed to visualize optimal routes only on one of these models, or can be designed to visualize results on the three models at the same time. For instance, they could be treated as several layers and overlapped on each other. By integrating the 3D network and 3D geometry model of buildings, the optimal navigation route could be highlighted on the 3D

network embedded in the 3D geometry model. In this way, it gives a good overview of the path to be followed and rescuers could get direct perception regarding the indoor environment and optimal routes.

Details of planned conferences & journals

Conference information:

- SDH (URL:http://isgis.lsgi.polyu.edu.hk/call.html) - International Symposium on Spatial Data Handling, it aims to present latest achievements in GISc research. Themes covered by the conference: Geospatial Database, GISci for Environmental and Urban Modelling, Location-Based Services, Spatial Decision Support Systems, Visualization of Spatial Data etc.
- UDMS (URL:http://www.udms.net/cms/index.php) - The Urban Data Management Society, presents new approaches and new technologies in the field of urban data management.
- Gi4DM (URL: http://www.gi4dm2011.org/) - The International Symposium on Geo-information for Disaster Management.
- 3D GeoInfo (URL:http://www.3dgeoinfo.org/) - The International Conference on 3D Geo Information, focuses on the fields of: Data collection and modelling, Data management (topological, geometrical, and network models of 3D geo information), Data analysis and visualisation.
- ISCRAM (URL: http://www.iscram.org/) - an international community working in the area of information systems and crisis management.
- ISPRS (URL: http://www.isprs.org/) - International Society for Photogrammetry and Remote Sensing and Spatial Information Sciences.
- AGILE (URL: http://plone.itc.nl/agile) - AGILE is the Association of Geographic Information Laboratories for Europe, which provides scientific forum where GIS researchers can exchange ideas and experiences at the European level.
- International Symposium on LBS & TeleCartography (URL: http://www.lbs2009.org/)- It focus on Location Based Services in the fields of Cartography, Geo-information, Computer Sciences, Telecommunication etc.
- Annual ACM Symposium on Computational Geometry (URL: http://www.computational-geometry.org/) - The topics of interest include: discrete and combinatorial geometry and topology, design and analysis of geometric algorithms and data structures, experimental evaluation of geometric algorithms and heuristics, and novel algorithmic applications of geometry in computer graphics, geometric modelling, geographic information systems, database systems, and other fields.
- ACM SIGSPATIAL GIS (URL: http://acmgis2010.cs.ucsb.edu/) - The conference presents original research contributions covering all conceptual, design, and implementation aspects of GIS ranging from applications, user interfaces, and visualization to storage management and indexing issues.
- ICCGCV (URL: http://www.waset.org/conferences/2011/tokyo/iccgcv/cfp.php) - The International Conference on Computational Geometry and Computer Vision. Topics of interest include Data structures, Geographic information systems, Path planning, Space Partitioning, Spatial and terrain analysis, and other fields.
- COSIT (URL: http://www.geosensor.net/cosit/) - Part of its interests includes semantics of geographic information, navigation by organisms and robots,

spatial and temporal reasoning, spatial and social networks, spatial data integration/interoperability, spatial decision-support systems, etc.

- GI Science (URL: http://www.giscience2010.org/) - The conference focuses on basic research findings across all sectors of the GIS field.

Journal information:

- Computational Geosciences - It publishes papers on mathematical modeling, simulation, numerical analysis, and other computational aspects of the geosciences. (URL: http://www.springerlink.com/content/101744/)
- Computers, Environment and Urban Systems – It is an interdisciplinary journal publishing cutting-edge and innovative computer-based research on environmental and urban systems, especially from the geospatial perspective. (URL: http://www.sciencedirect.com/science/journal/01989715)
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