Modeling & Simulating the Evacuation of a Building Based on Building Floor Plan and Evacuation Strategies

Shreya and K.S. Rajan
Lab for Spatial Informatics, IIIT Hyderabad, Hyderabad, Telangana-500032, India

Keywords: Building Evacuation, Evacuation Strategies, Floor Plan, Path Planning.

Abstract: Accidental fires in public and large buildings not only cause property loss but also can lead to loss of lives. During such emergencies, building evacuation depends on a range of factors including floor plans, exits available, obstructions if any, the occupancy levels of the building, and so on. The study here brings together the spatial, temporal, and path planning possibilities to evaluate fire evacuation strategies for 2D building plans. It provides a geospatial framework to assess the impacts of dynamic changes in the building environment and its impact on evacuation outcomes. In this study, occupancy-based path planning using Pgrouting over an IndoorGML formatted data is combined with modeling their interactions over the path toward the exit to assess the outcomes. This computational approach over the time-dependent path provides interesting insights into determining the number of paths and the need for one or more exits during an emergency. The study shows that integrating the floor plan into path generation and people flow can be a powerful tool for assessing the building environment.

1 INTRODUCTION

Evacuation strategies are important in many situations even in regions that may not be affected by earthquakes or other natural causes. As urban areas get more densely populated with multistoried buildings that have many people either living or working from these, it is important to evaluate the evacuation strategies in these buildings. Engineers and Architects need to demonstrate that their designs of the building are safe for the residents. While they may be also concerned that providing multiple exits can affect their designs, a better understanding of safety can help improve the designs suitably. On the other hand, a geospatial model of the indoor floor plans can help improve the understanding by not only visualizing but allowing for multiple computational models to be evaluated using geospatial models of the evacuation paths. Indoor navigation paths have been derived, in recent years, based on floor plans (Yang and Worboys, 2015) and have also been extended to data models like CityGML or IFC ((Kolbe et al., 2005). While these approaches provide for a path from say a room to the building exit, they are generally independent static paths for each person assuming no crowding or delay in movement when all the occupants rush to the exit in an emergency.

In an emergency, a path based on quantitative measurements like distance, direction, and angles is not of much use or can be rather difficult to comprehend by people trying to move in a hurry. If these spaces can be captured qualitatively and shared as part of the evacuation path to the users, it might make it easier for people movement and re-defining the paths depending on the changing environment in the building. A semantic indoor space model proposed in (Maheshwari and Rajan, 2016) based on combining the ontology for indoor spaces with geometric and semantic characteristics of the space, as defined in (Maheshwari et al., 2019), can be combined with the path generation approach to provide for a more informative and comprehendible path, that can be used by all residents of such buildings. An attempt at using semantic information in indoor path planning is presented in (Xiong et al., 2015) by combining both geometric and semantic information of building components.

Path planning in indoor spaces has been studied based on shortest path (Ramón et al., 2013; Botsis and Panagiotopoulos, 2021; Clementini and Pagliaro, 2020) algorithms like Dijkstra's and Bellman-Ford's algorithms. While these shortest path algorithms

Shreya, . and Rajan, K.
Modeling Simulating the Evacuation of a Building Based on Building Floor Plan and Evacuation Strategies.
DOI: 10.5220/0011992600003473
In *Proceedings of the 9th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2023)*, pages 230-236
ISBN: 978-989-758-649-1; ISSN: 2184-500X

provide a good idea of the nearest exit, the optimality was considered based on different criteria like least risk (Mirahadi and McCabe, 2019), the best-known path to the evacuee from among paths to multiple exits (Liu et al., 2016) in a building. Geospatial technology with the computational algorithms to develop and verify whether a building satisfies the emergency regulations is presented in (Ramón et al., 2013). Indoor navigation approaches, as in (Mortari et al., 2014) use displacement techniques to generate routes and may be extendable for evacuation purposes as they do contain topological information. Paper (Sun and Liu, 2011) introduced a continuous framework that talks about both structure and topology, using a grid graph–based modeling for path planning.

On the other hand, the availability of BIM models of the buildings has led to exploring these datasets for indoor path generation automatically based on straight skeletons (Fu and Liu, 2019) or generating a geometric topology network from the building spaces and spatial connections as represented in an IFC file (Taneja et al., 2011). In (Yenumula et al., 2015), they used the BIM-based signage information to indicate the exits that can be accessible during fires by assessing the effect of smoke on the visibility of the signages, while (Liu and Zlatanova, 2011) presents a door-to-door approach and (Ma et al., 2017) talks of using BIM over a schematic based evacuation plan for the floors.

While all these studies do work on different aspects of evacuation paths, their computation, and representation, these are mostly static paths and do not consider the changes in the indoor environment like whether the exits are useable or reachable from a given location in the building. This needs to be evaluated as heavily crowded or occupied buildings may need multiple exits for evacuation of the residents in the shortest time. Also, the changes can affect the evacuation models by affecting the time along the path considering lags in people flow and capacity of the paths in addition to the availability of additional exits if any. This paper attempts to address some of these issues in the generation of the optimal path for evacuation for each occupant of the building for a given 2D floor plan considering that the graph network connecting these spaces may change in adverse conditions.

1.1 Objective

In this study, an attempt has been made to integrate the inputs from the floor plan generated network with an option of new exits emerging in addition to the main exits as part of an evacuation strategy to assess –

a) How the capacity of the path links or edges can delay the evacuation time based on the people's movement pattern
b) How to determine if an evacuee will use an alternative new emerging exit like a window

This paper assumes the availability of a space model from IndoorGML, whose description is out of the scope of this paper and develops on the possible evacuation networks that emerge from such data.

2 METHODOLOGY

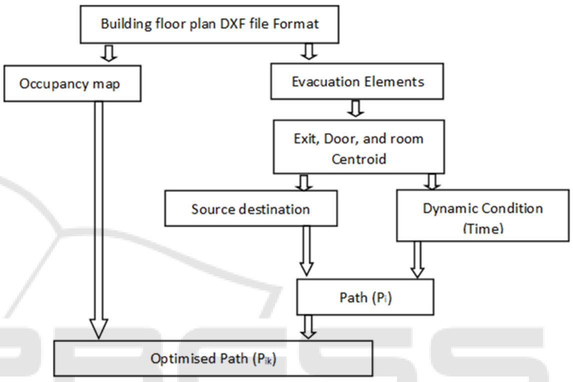


Figure 1: An overview of the methodology and its components.

2.1 Building Plan for Node Generation

A building floor plan in Autodesk Revit Architecture software is created with attribute information such as door windows. The structural element of the building contains six spaces denoted as a room, twelve windows, and seven doors including one main exit. All the rooms are accessible from one space to another. This building plan, originally in DXF file format, was imported into QGIS. This DXF file was preprocessed in terms of topological consistency so that it has the right number of polygon geometries, location of doors, windows, etc. The building floor plan was adjusted in QGIS according to the coordinate reference system so that it lies on the same plan of projection. Nodes were generated at the centroid of the room, representative points for the occupants of the room, and door center points for each room space. In addition, to account for more than one exit from the building, including emergency or alternate exits like a window, the final destination for the simulations is a node called the Evacuation point away from the Building that is reachable from all the exits, as shown in figure 3. These nodes are further used for graph generation.

2.2 Primary Graph Network

The generated nodes are identified as the potential sources, intermediate nodes, and destination nodes such as main exits and windows as alternate exits. The graph is then generated using the source and destination pair of coordinates assigned to form the primary network layer. The generated graph network *G* can be seen in figure 3. Each path link is characterized by its actual edge length and used in calculating the path edge capacity.

2.3 Occupancy and Path Edge Capacity

As the approach here is to estimate the impact on the people flow movement in the context of an emergency, it is assumed that the spaces (or rooms) are fully occupied to their maximum capacity. Hence, the occupancy of each space is estimated based on the unit area needed per person. For the path edge capacity, an average speed of 6 kmph is assumed per person to account for the movement behavior during evacuations. This allows for computing each occupant's travel time to the exit and hence estimating the last man's exit time. While the case of emerging exits is like a window, a hold time is also added to the link concerned to account for the delays in accessing such exits. The proposed approach also allows for a pass-through capacity to be added at the specific nodes for estimating the rate of flow of people.

2.4 Evacuation Path Generation

2.4.1 Shortest Path for the Base Scenario

In this study, a base scenario is defined as one that has no obstruction and allows for the free movement of people through the paths. This is possible from all the structural elements such as doors and windows. Path computation for the shortest path calculation to the main exit is obtained using the Pgrouting module in PostgreSQL. Here, the room spaces are considered source nodes and the doors or windows on the building periphery as the exits. Using the Dijkstra algorithm, all potential shortest paths for each source-destination combination are obtained, denoted by set P. Each path, ($P_{i,k}$ ε P) denotes the *i* paths available to each user or individual *k*. The shortest path for a given user *k* is P_{mk}, where *m* ε *i*, denotes the final path chosen.

2.4.2 Evacuation Path for the Adverse Scenario

In case of an emergency, the shortest path computed in the earlier sub-section may be not available to the user. Here, we consider that an untoward incident like fire or another emerging condition can lead to a node or an edge blockage. While the later disconnects only the path that consists of the blocked edge, an affected node disconnects all the edges that are connected to it, as shown in figure 2. In this paper, the case of node blockage is considered as the edge case can be a special case of the same. The set P* is the updated available set under changed circumstances. An agent-based approach is used to evaluate the options from the set P* and decide on the optimal path to take considering the existing and alternate exits available and the parameters computed earlier for the graph and its link edges including lag due to link capacity. The agent aims to minimize the time taken to the final exit point.

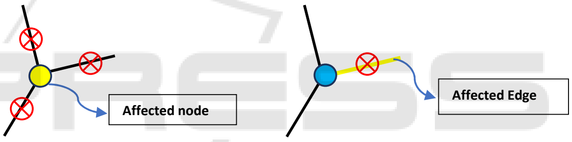


Figure 2: Affected node and edge.

3 DATA

3.1 Floor Plan

A building floor plan covering a total carpet area of 102.349 m^2 as shown in Figure 3 is used for this study. The building floor plan was converted to shapefile format from DXF. It consists of six rooms, six internal doors, one external main exit, and twelve windows which act as an alternate exit during the adverse case. The exit door has the capacity to carry two occupants at a time whereas the alternate exit has the capacity of one occupant at a time. In this study, the number of spaces is taken as rooms denoted by its centroids as the source points. Figure 3 shows the floor plan followed by notations such as nodes that are used for source and destination input, evacuation point, the evaluation or safe point for evacuees to reach, and the generated graph network. Network graph notations are described in section 4.1.

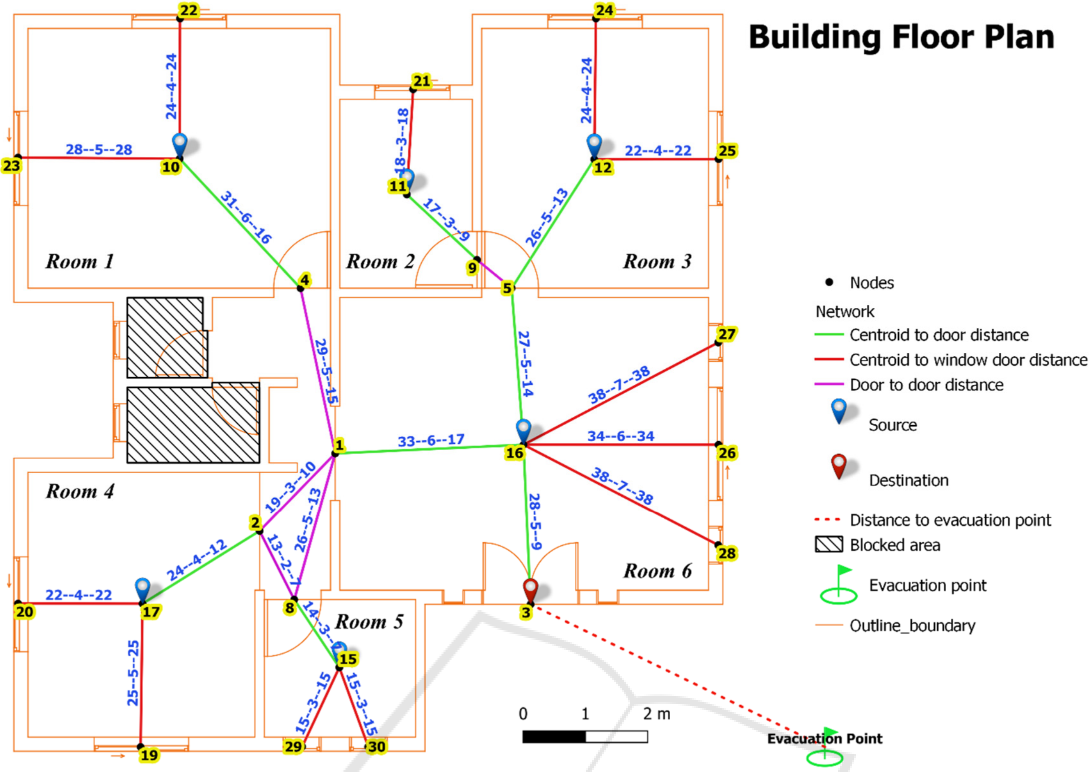


Figure. 3: Building Structural Plan.

Table 1: Occupancy count of room.

Number of occupants based on the floor Space Model						
Room 1	Room 2	Room 3	Room 4	Room 5	Room 6	**Total**
20	6	15	15	5	28	**89**

3.2 Occupancy

The occupancy is derived from the area of the room space, as the model is evaluated for a worst-case scenario of maximum occupancy. Table 1 shows the occupancy in each space. There is no occupancy in the corridor and the shaded room. It has to be noted that occupancy is a key parameter here, and if it is less than the capacity of the room it will affect the path optimization and can lead to a different outcome.

4 RESULTS

4.1 Network Generation Including Edge/Path Capacity

In figure 3, the line in different colors indicates the generated graph. This graph accounts for the main exit and the alternate exits and shows the shortest paths only. Centroid-to-door distance is marked in green, the centroid to the window is marked with red, and the door-to-door distance is marked with purple. These networks are assigned labels, indicating the *distance—time—capacity* of the edge. The capacity of an edge is proportional to the rate of people flow at the exits. There are some limitations to people flow based on the capacity - if the number of occupants is greater than the least capacity edge of the path P_{mk} then not all the occupants can be evacuated in the shortest time shown.

4.2 Path Identification

Path identification is shown in figures 4 and 5 which have some representative agents for every room and are uniquely equal to the number of potential exits for a given space. Agents can be broad of two types – a normal agent who uses the known path (P_0) to the main exit only; and a special agent who uses one of the alternate paths. These special agents are activated when the traditional or known path (P_0) is disturbed and their behavior is dependent on the conditions. There are multiple evacuation agents in each space. Each agent uses the graph or sub-graph appropriately for the choice of exit and the path to be followed.

4.2.1 Base Scenario

The base case scenario is the free flow for exiting the occupants with no blockage in between the path. For example, room 1 has an occupancy of 20 and the capacity of an edge-to-door is 16, which means that the edge can hold only 16 occupants at a time hence there will be a lag. If lag was not there, then it could have been just the addition of all the time from source to destination. If there was no lag it could have taken only 22 seconds for an occupant to come out of the main door instead of 254 seconds for the last position. The base scenario is shown in figure 4 and the evacuees are using the main exit as alternate exits will take longer evacuation times.

4.2.2 Adverse Scenario

An adverse case scenario of fire in the building is considered. The fire blocks the path to the exit and to the evacuation point. The implemented scenario shows the blockage at the most critical point, where most of the edges are merging, representing the worst-case scenario. For this scenario, as the node is affected all the connected edges are dropped resulting in multiple graphs being generated instead of one main graph. In this case, there are four graphs connecting alternate exits for room 1, room 4, and room 5 along with one larger sub-graph for room 2, room 3, and room 6 towards the main exit. The alternate exits, and windows, are chosen by the agents as these room spaces are disconnected from the primary graph network. The evacuation time of the last person was at 3195 seconds, comparatively quite large from the base scenario. The movement of the agents is depicted in figure 5.

4.2.3 Cumulative Count

In the base case scenario, evacuees took minimum time for the exit as there is no lag or time delay for opening/breaking exits, whereas in the adverse case, scenario evacuees took maximum time due to time delay/lag in breaking/opening the window and coming out of it. Figure 5 shows cumulative count graph results with a cascading effect that occurred during the evacuation. The linearity of the graph indicates that evacuees took minimum time for the exit as there is minimal to no lag or time delay and the non-linearity of the graph shows that evacuees took maximum time due to time delay/lag in breaking/opening the window while exiting.

5 CONCLUSION

The study proposed an effective methodology for the evacuation modeling of the occupants based on the changing paths to the exit based on a 2D structural plan. Compared to the base scenario, the adverse scenario took more than 12x times for evacuation of the 89 occupants of this building. This indicates that changed dynamics can have very different outcomes and the provision of alternative exits with decent capacity needs to be planned well. Also, it should be noted that the capacity of the main exit and the access time at the alternate exits affects the evacuation time hence there is a need to evaluate these for different cases and define the appropriate capacity of these doors and windows. The use of an agent-based model

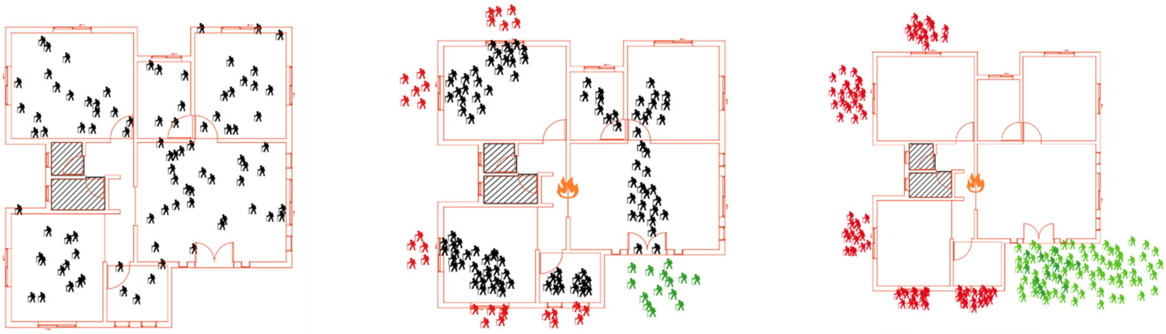
Time = 0 Sec

Time = 64 Sec

Time = 127 Sec

Base Case Scenario: No Fire Blockage

Figure 4: Base case scenario.



Time = 0 Sec

Time = 270.62 Sec

Time =3195 Sec

Adverse Case Scenario: Fire Blockage at a critical point

Figure 5: Adverse Case Scenario.

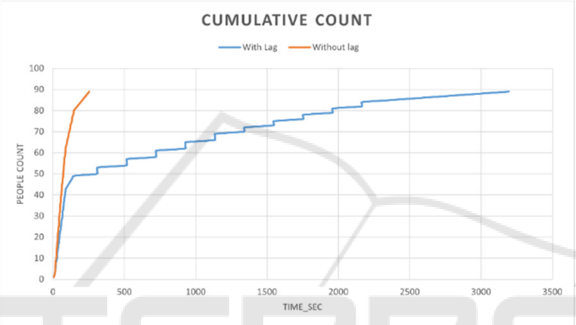


Figure 6: Graph: Cumulative Count.

to evaluate options provides for dynamic decision-making in such situations or scenarios and adapts to the changing graph networks. The adoption of a space model fully can further help define the pass-through spaces, occupied spaces, and their respective constraints in a better way. Also, with the increasing use of location sensors, it will be good to integrate these models with a real-time people positional model and crowding behavior to see how the scenarios will evolve in varying ground conditions.

REFERENCES

N. Maheshwari, and K.S. Rajan., “A semantic model to define indoor space in the context of an emergency evacuation,” Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.—ISPRS Arch. 2016, 41, 313–318.

N. Maheshwari, S. Srivastava, and K.S. Rajan, "Development of an Indoor Space Semantic Model and Its Implementation as an IndoorGML Extension", ISPRS International Journal of Geo-Information, vol. 8, 2019.

Ramón, A., Rodrıguez-Hidalgo, A. B., Navarro-Carrión, J. T., & Zaragozı, B. (2013). A methodology for evacuation route planning inside buildings using geospatial technology. In Data Management and Security. Applications in Medicine, Science, and Engineering (Vol. 45, pp. 155-166). WIT Press.

Botsis, D., & Panagiotopoulos, E. (2021). Determination of the shortest path in the university campus of Serres using the Dijkstra and Bellman-Ford algorithms. ΧΩΡΟ-ΓΡΑΦΙΕΣ, 6(1).

Clementini, E., & Pagliaro, A. (2020). The Construction of a Network for Indoor Navigation. In GISTAM (pp. 254-261).

Mirahadi, F., & McCabe, B. (2019). A real-time path-planning model for building evacuations. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 36, pp. 998-1004). IAARC Publications.

Liu, C., Mao, Z. L., & Fu, Z. M. (2016). Emergency evacuation model and algorithm in the building with several exits. Procedia Engineering, 135, 12-18.

Kolbe, T., Gröger, G., and Plümer, L. (2005). CityGML: Interoperable access to 3D city models. In van Oosterom, P., Zlatanova, S., and Fendel, E., editors, Geo-information for Disaster Management, pages 883–898, Berlin, Heidelberg. Springer

Yang, L. and Worboys, M. (2015). Generation of navigation graphs for indoor space. International Journal of Geographical Information Science, 29(10):210–218

Mortari, F., Zlatanova, S., Liu, L., & Clementini, E. (2014). " Improved Geometric Network Model"(IGNM): A Novel Approach for Deriving Connectivity Graphs for Indoor Navigation. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences, 2(4).

Sun, J., & Li, X. (2011, June). Indoor evacuation routes planning with a grid graph-based model. In 2011 19th International Conference on Geoinformatics (pp. 1-4). IEEE.

Fu, M., & Liu, R. (2019). Automatic generation of path networks for evacuation using building information modeling. In Computing in Civil Engineering 2019: Visualization, Information Modeling, and Simulation (pp. 320-327). Reston, VA: American Society of Civil Engineers.

Taneja, S., Akinci, B., Garrett, J. H., Soibelman, L., & East, B. (2011). Transforming IFC-based building layout information into a geometric topology network for indoor navigation assistance. In Computing in Civil Engineering (2011) (pp. 315-322).

Yenumula, K., Kolmer, C., Pan, J., & Su, X. (2015). BIM-controlled signage system for building evacuation. Procedia Engineering, 118, 284-289.

Liu, L., & Zlatanova, S. (2011). A" door-to-door" path-finding approach for indoor navigation. Proceedings Gi4DM 2011: GeoInformation for Disaster Management, Antalya, Turkey, 3-8 May 2011.

Ma, J., Jia, W., & Zhang, J. (2017, May). Research of building evacuation path to guide based on BIM. In 2017 29th Chinese Control And Decision Conference (CCDC) (pp. 1814-1818). IEEE.

Xiong, Q., Zhu, Q., Zlatanova, S., Du, Z., Zhang, Y., & Zeng, L. Y. (2015). Multi-level Indoor Path Planning Method. *International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences*.