Building Evacuation Simulation in Dynamic Environments to assess Strategies and Building floor plan designs

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by

SHREYA
2021710001

shreya.k@research.iiit.ac.in

International Institute of Information Technology, Hyderabad
(Deemed to be University)

Hyderabad - 500032, INDIA
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International Institute of Information Technology, Hyderabad

CERTIFICATE

It is certified that the work contained in this thesis, titled "*Building Evacuation Simulation in Dynamic Environments to assess Strategies and Building floor plan designs*" by *Shreya (2021710001)*, has been carried out under my supervision and is not submitted elsewhere for a degree.

Date: 25-05-2024

Dr. K. S Rajan

Professor & Registrar

International Institute of Information Technology

Hyderabad, India

To my loving parents, **Surendra Prasad and Anita Devi**

&

also to my cherished companion, **Whisky**

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Abstract

Accidental fires in public and large buildings pose significant risks, demanding effective evacuation strategies to ensure the safety of occupants and minimize property loss. This study aims to address the challenges associated with building evacuations by integrating spatial, temporal, and path planning approaches specifically for 2D building plans. By incorporating a geospatial framework, the study enables the evaluation of dynamic changes in the building environment and their impact on evacuation outcomes. The current studies do not show how the cascading effect of the person in the queue and space constraints, static or dynamic, affect the evacuation times and can exacerbate the disaster. Also, the presence of multiple exits, if any, can change the outcomes. This research studies how spatial arrangement and floor plans play an important part in evacuation strategies and advocates for their integration into building planning and design processes. The study delves into the impact of obstacles on evacuation processes, by introducing a subspace model that significantly improves computation time in various geometric spaces. The findings emphasize the hindrance of obstacles, either static or dynamic, on evacuation efficiency and propose efficient path generation to mitigate increased evacuation times.

The primary objective of this study is to evaluate dynamic changes in the building environment during evacuations and assess their impact on evacuation outcomes. It also addresses the challenges associated with building evacuations during accidental fires in public and large buildings. The focus is on ensuring occupant safety and minimizing property loss by developing effective evacuation strategies. The technical approach adopted in this study involves the integration of spatial, temporal, and path planning methodologies for 2D building plans within a geospatial framework. The study employs a computational approach that combines occupancy-based path planning. This allows for a complete evaluation of dynamic changes in the building environment, highlighting the interactions between individuals and their chosen paths toward their respective exits. Notably, the study focuses on time-dependent path planning to

recognize the evolving nature of emergencies, incorporating dynamic elements to enhance the accuracy of evaluating the building environment in emergency scenarios. The study explores the effectiveness of integrating floor plans into path generation and people flow analysis, recognizing the influence of spatial arrangement on evacuation strategies.

The proposed method employs a graph-based path generation approach using the subspace model for an effective methodology for evacuating occupants by adapting to changing paths based on a 2D structural plan. The path planning accounts for not just current position to the main exit, but incorporates other conditions like crowding and lag on some path segments, time delays in utilizing alternate exits like windows, and finally reaching to the Evacuation point. The study shows that in comparison to the base scenario, the adverse situation resulted in a more than **12x increase** in evacuation time for the **89 building occupants**. This underscores the impact of changed dynamics and emphasizes the necessity for well-planned alternative exits with sufficient capacity. The study gives the influence of main exit capacity and alternate exit access time on overall evacuation time, calling for comprehensive evaluation and appropriate definition of capacities for doors and windows. The subspaces offer a clear line of sight to the exit and are integral to the evacuation path. In scenarios with obstacles, the approach, where the main door served as the primary exit, resulted in only a marginal increase of **215 seconds for 70 occupants** compared to clear spaces. However, when obstacles led to disconnection of the network, alternate exits like windows were used, causing an almost **4x rise** in evacuation time to **996 seconds** in Case 2. In cases with critical node blockage, the last person took around **1295 seconds** to exit, a **6x increase** compared to the base scenario with obstacles. This gives the need for strategic planning of alternate exits to reduce delays and optimize people flow rates. The study called for further work to seamlessly integrate the proposed method with static and dynamic components of indoor spaces, emphasizing the development of an occupant-friendly information dissemination model. The use of an agent-based model facilitated dynamic decision-making and adaptation to changing graph networks. The study's technical approach thus encompasses a holistic evaluation of evacuation strategies, considering spatial path planning aspects, with practical implications for building design and emergency planning.

In conclusion, this study significantly advances the field of evacuation planning and modeling by addressing the complexities associated with building evacuations during accidental fires. The outcomes clearly indicate the improved effectiveness of evacuation plans, highlighting the importance of cascading effect due to the presence of many occupants at one place. This happens due to the holding capacity of the edge. Due to this cascading effect the evacuation time increases to more than 6 fold in several cases.

Moreover, the research's real-world applications are evident in the practical implications it provides for building design and emergency planning. By integrating these innovative approaches into emergency systems, accurate and timely information can be provided to evacuees, thereby improving overall safety. In summary, this research significantly enhances our understanding of fire evacuation strategies, providing practical solutions and considerations that can be applied to real-life scenarios, ultimately contributing to the advancement of safety measures in public and large buildings.

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List of Symbols

tt_Lib2	Thomas Thomassen's extensions
ws	WallSurface
gs	GroundSurface
w	Window
d	Door
bi	BuildingInstallation
ws-1_w-1	windows on the wall surface 1
ws-1_d-1	doors on the wall surface 1
gml parent ID	parent ID
gml ID child	element ID
_	gml ID separator
-	individual ID separator
X_0, Y_0	origin
X_d, Y_d	destination
X_0	source node
Y_d	target node
//	comment out the line
*	to select the table
P	potential shortest path
i	path available
k	each individual
$\in$	“m” belongs to i denotes the final path chosen.
Pmk	shortest path for a given user k
P_0	known path / traditional path / Physical layout of the plan.
E_0	no of exits
Y_0	Count of people
T_i	time taken by the i^{th} person
k	segment of the path

q	position of person
L_{iq}	lag time taken by the i^{th} person at position q in the queue
q_{ik}	position of the i^{th} person in the queue to enter segment k
e_k	edge capacity of the k^{th} segment
t_{ik}	time taken by the i^{th} person in the k^{th} segment

Chapter 1

Introduction

1.1 Indoor Evacuation Network and GIS

An *indoor evacuation network* refers to the infrastructure and systems designed to facilitate the safe and efficient movement of people within buildings or enclosed spaces during emergency situations. It involves the planning, implementation, and designing of various components to make sure the effective evacuation of occupants. The primary objective of an *indoor evacuation network* is to provide accessible routes for individuals to evacuate from the building in case of emergencies such as fires. This network includes elements such as exit signs, evacuation plans, emergency lighting, fire alarms, and designated evacuation routes. One crucial aspect of an indoor evacuation network is the proper identification and placement of exit signs. These signs should be clearly visible and strategically located throughout the building, guiding occupants toward the nearest exit points. Illuminated exit signs are particularly important in low-light or smoky conditions. Emergency lighting is another integral component of an indoor evacuation network. It ensures that essential pathways, staircases, and exit routes are adequately lit during power outages or situations with limited visibility. Emergency lighting not only guides occupants but also helps prevent panic and confusion. Effective communication systems play a vital role in an *indoor evacuation network*. Fire alarms, public address systems, and emergency messaging systems provide timely alerts and instructions to occupants during emergencies. Clear and concise communication is crucial for directing individuals to the nearest exit routes and informing them about potential hazards or safe evacuation points or areas. Another important consideration in an *indoor evacuation network* is the accessibility for individuals with disabilities or mobility challenges. The design should accommodate their needs, Additionally, alternate evacuation plans and protocols should be in place to ensure the safe evacuation of each and every individual.

GIS (Geographical Information System) is a powerful system that enables the storage, analysis, manipulation, and presentation of geographical data. When applied to the analysis of evacuation networks, *GIS* opens up numerous valuable applications. One key application of *GIS* in relation to evacuation networks is indoor route planning and evacuation strategies. By utilizing *GIS*, emergency planners can identify optimal evacuation routes within buildings or facilities, considering factors such as exit locations, capacity, and accessibility. This helps ensure a smooth and efficient evacuation process during emergencies. *GIS* facilitates navigation systems specifically tailored for evacuation scenarios. These systems can provide real-time guidance and instructions to individuals during evacuations, considering dynamic factors such as blocked pathways or changing conditions. *GIS*-powered navigation improves the efficiency and safety of evacuation movements. Path planning is a crucial aspect of evacuation management, and *GIS* plays a vital role in optimizing evacuation routes. By analyzing geographical data, *GIS* can calculate the most efficient paths for evacuation, taking into account various factors such as distance, traffic congestion, and the availability of safe evacuation points.

1.2 Motivation

The motivation behind developing an effective indoor evacuation network stems from the critical need to prioritize the safety and well-being of individuals within buildings or enclosed spaces during emergency situations. The primary goal is to ensure that occupants can evacuate quickly, efficiently, and safely in the event of a fire, or other hazards. By establishing a well-designed indoor evacuation network, building owners, managers, and emergency planners demonstrate their commitment to protecting human lives. Such a network minimizes potential harm during emergencies. These emergencies can occur unexpectedly and in various forms. Having a robust indoor evacuation network in place equips occupants with the resources that help them to evacuate without confusion or delay. An effective indoor evacuation network aligns to create inclusive and accessible environments. Ultimately, the motivation behind investing in an indoor evacuation network is to save lives, protect property, and enhance overall resilience. By prioritizing safety through a well-planned network, buildings, and their occupants can effectively respond to emergencies, minimize panic, and facilitate an organized evacuation process.

1.3 What, Why, and How?

Based on the understanding of the Indoor Evacuation network, this thesis tries to address the following research questions

What was addressed?

An attempt is made to integrate the inputs from the floor plan to generate a network with an option of new exits emerging in addition to the main exits as part of an evacuation strategy.

Why is it important?

Provides info on evacuation time delay & When and why will the evacuees use the alternate exit?

The basis for the Approach?

Given a 2D building floor plan, To Generate the potential paths to one or more exits and the Choice of the Exit.

1.4 Objective

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

a) To auto-generate an evacuation network, given a building floor plan for free and obstructed space

b) To identify the optimal path and assess the impact of people movement patterns on the *time to evacuation* along the path.

c) To determine if an evacuee will use an alternate new emerging exit like a window for evacuation

d) Do obstacles that emerge along the evacuation path significantly contribute to path chosen by the evacuee in the evacuation process ?

This Thesis assumes the availability of a space model from IndoorGML and develops the possible evacuation networks that emerge from such data.

1.5 Structure of the Thesis

The thesis primarily focuses on the intricacies of indoor evacuation networks, integrating Geographic Information Systems (GIS) for optimal path planning during emergencies. This thesis begins with an introduction to the Indoor Evacuation Network and GIS, outlining motivations, objectives, and the overall structure in *Chapter 1*. The literature review in *Chapter 2* provides a comprehensive exploration of evacuation methods, identifying research gaps, and acknowledging limitations. *Chapter 3* details the preparation of analysis-ready data, covering the full and subspace models, safe points, and addressing data issues. *Chapter 4* delves into the path planning approach, discussing the base space plan, path capacity, and presenting results for base cases and scenarios involving critical node blockage. *Chapter 5* extends the path planning approach to near real scenarios, introducing a redefined space model and scenarios with obstacles and multiple exits. The thesis proceeds to *Chapter 6*, where a simulation of a campus building is conducted, presenting a simulation matrix and results for different cases. Finally, *Chapter 7* concludes the thesis by summarizing key findings, insights, and the potential impact on evacuation planning, contributing valuable knowledge to the field. The overall thesis emphasizes the importance of considering obstacles, multiple exits, and critical node blockages in developing effective evacuation strategies for enhanced safety in emergency situations.

Chapter 2

Literature Review

2.1 Background

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 face the challenge of ensuring the safety of building occupants while also considering design constraints that may be impacted by the provision of multiple exits. However, a deeper understanding of safety can contribute to more suitable designs. A geospatial model of indoor floor plans can significantly improve the comprehension and evaluation of evacuation paths by enabling visualization and the assessment of multiple computational models. Recent years have witnessed the derivation of indoor navigation paths based on floor plans (Yang and Worboys, 2015), which have been further extended to incorporate data models such as CityGML or IFC (Kolbe et al., 2005). Although these approaches provide paths from rooms to building exits, they typically assume independent static paths for each person without considering factors such as crowding or movement delays that occur when all occupants rush towards the exits during emergencies. In emergency situations, relying solely on quantitative measurements like distance, direction, and angles may prove inadequate and difficult for individuals attempting to move hastily. However, if these spaces can be qualitatively captured and shared as part of the evacuation path, it could facilitate smoother movement for people and allow for path redefinition based on the changing environment within the building. A semantic indoor space model proposed by Maheshwari and Rajan (2016), which combines ontology for indoor spaces with geometric and semantic characteristics (as defined in Maheshwari et al., 2019), can be integrated with the path generation approach to provide a more informative and easily comprehensible path accessible to all building residents. Similarly, Xiong et al. (2015) have explored the use of semantic information in indoor path planning by combining geometric and semantic details of building components. Path planning within indoor spaces has been extensively studied using algorithms like Dijkstra's and Bellman-Ford's shortest path algorithms (Ramón et al., 2013; Botsis and Panagiotopoulos, 2021; Clementini and Pagliaro, 2020). While these algorithms provide insights into the nearest exits, optimization criteria vary, including considerations of least risk (Mirahadi and McCabe, 2019) or identifying the best-known path to evacuees among multiple exit options within a building (Liu et al., 2016). Geospatial technology, coupled with computational algorithms, has been employed to develop and verify building compliance with emergency regulations (Ramón et al., 2013). Indoor navigation approaches, as demonstrated by Mortari et al. (2014), utilize displacement techniques for route generation and could potentially be extended for evacuation purposes due to their inclusion of topological information. Sun and Liu (2011) introduced a continuous framework encompassing structure and topology, leveraging grid graph-based modeling for path planning. The availability of Building Information Modeling (BIM) models for buildings has opened avenues for automatic indoor path generation. This can be achieved through techniques such as straight skeletons (Fu and Liu, 2019) or by generating a geometric topology network from spatial connections and building spaces represented in an IFC file (Taneja et al., 2011). Yenumula et al. (2015) utilized BIM-based signage information to identify accessible exits during fires by assessing the impact of smoke on visibility. Liu and Zlatanova (2011) proposed a door-to-door approach, while Ma et al. (2017) explored the use of BIM over schematic-based evacuation plans for floors. Evacuation path planning in emergency situations is a complex task that requires a wide range of information, encompassing both static and dynamic factors. One critical concern for evacuees is ensuring their escape in spaces that may have obstacles. To address these challenges, a geospatial model of a 3D floor plan proves invaluable, as it not only incorporates the spatial geometry of the environment but also includes the precise location and dimensions of various objects. This model enables a visual representation and understanding of how a graph should be generated to establish obstacle-free paths. Semantic, geometric, and topologic transformations are essential in deriving appropriate navigation structures. (Khan et al. 2014) describe a multistep transformation process and sub-spacing approach to automatically obtain an indoor Geography Markup Language (GML) Level of Detail (LoD) 4 dataset from existing semantic 3D building models based on Industry Foundation Classes (IFC). The 3D model serves not only to represent obstacles but also to indicate that individuals cannot cross over obstacles beyond their physical limits and must navigate around them, resulting in increased travel time along the evacuation path. Consequently, the generation of new networks and paths becomes necessary. IndoorGML LoD 4 is important for fulfilling the requirement of indoor spatial information, serving as a connection between indoor and outdoor environments. The interoperability between Building Information Modeling (BIM) and Geographic Information Systems (GIS) offers significant benefits for various applications, including path planning for evacuation and urban planning. The integration of semantic data enhances the process of urban planning. While research efforts have primarily focused on the integration of semantic models such as IFC and CityGML using a unidirectional approach for data conversion, (El-Mekawy et al.2012) investigated the potential of converting between IFC and CityGML and concluded that integrating these two systems can be challenging for various reasons. A review of relevant research papers is discussed in (Zhu et al. 2018), highlighting the independent operation of GIS and BIM systems while emphasizing the need for effective interoperability data. IFC and CityGML are widely studied and accepted for the exchange of building data, often in formats such as shapefiles, known as multipatches. An algorithm for extracting free multi-floor indoor space from a 3D building model is introduced. While many studies have focused on the conversion from IFC to CityGML, there has been limited discussion regarding the conversion process. Therefore, this paper presents the conversion from IFC to Shapefile using a Feature Manipulation Engine (FME). To enhance evacuation planning, (Liu et al. 2011) propose a door-to-door evacuation model that incorporates both geometric and semantic information, providing evacuation instructions while considering local environmental factors in corridors and common spaces. Liu et al. 2016 present a method for determining the best-known path from multiple exits in a building. The foundation for evacuation planning and navigation for evacuees lies in indoor navigation based on an ontology of indoor space. (Ma et al. 2017) introduce indoor navigation based on a two-level routing strategy, testing it with various complex scenarios. This work has been extended to 3D spaces, allowing for a more comprehensive understanding of the evacuation process. Similarly, A method proposed (S.Atyabi et al. 2019) for designing optimal routes for emergency evacuation in complex buildings and underground structures. The method involves creating a 3D model of the building and analyzing its indoor parameters to identify the safest and shortest routes for evacuation.

2.2 The Evacuation Methods Used in the Literature

In densely populated urban areas with multistoried buildings, evaluating evacuation strategies becomes essential. Engineers and architects strive to ensure the safety of building occupants while considering design constraints related to multiple exits. Recent advancements have extended indoor navigation paths based on floor plans, incorporating data models such as CityGML or IFC (Kolbe et al., 2005; Yang and Worboys, 2015). However, these approaches typically assume independent static paths for each person, disregarding factors like crowding and movement delays during emergencies. To address this limitation, qualitative information can be captured and shared as part of the evacuation path, facilitating smoother movement and allowing for path redefinition based on the changing environment within the building. The integration of a semantic indoor space model combining ontology, geometric, and semantic characteristics enhances the path generation approach (Maheshwari and Rajan, 2016; Maheshwari et al., 2019). Semantic information has also been explored for indoor path planning by combining geometric and semantic details of building components (Xiong et al., 2015). Path planning algorithms such as Dijkstra's and Bellman-Ford's have been extensively studied for indoor spaces, providing insights into nearest exits (Ramón et al., 2013; Botsis and Panagiotopoulos, 2021; Clementini and Pagliaro, 2020). Optimization criteria vary, considering factors like least risk or identifying the best-known path among multiple exit options (Mirahadi and McCabe, 2019; Liu et al., 2016). Geospatial technology and computational algorithms aid in building compliance verification with emergency regulations (Ramón et al., 2013). Indoor navigation approaches, utilizing displacement techniques and topological information, have shown potential for evacuation purposes (Mortari et al., 2014; Sun and Liu, 2011). Building Information Modeling (BIM) models enable automatic indoor path generation through techniques like straight skeletons or geometric topology networks (Fu and Liu, 2019; Taneja et al., 2011). BIM-based signage information has been used to identify accessible exits during fires by considering the impact of smoke on visibility (Yenumula et al., 2015). A door-to-door approach (Liu and Zlatanova, 2011) and BIM-based evacuation plans (Ma et al., 2017, S.Atyabi et al. 2019) further contribute to effective evacuation planning. Evacuation path planning in emergencies requires a diverse range of information, including static and dynamic factors. A geospatial model incorporating precise object location and dimensions in a 3D floor plan facilitates obstacle-free path generation. IndoorGML Level of Detail (LoD) 4 serves as an important anchor for connecting indoor and outdoor environments. The interoperability between BIM and GIS offers significant benefits for evacuation path planning and urban planning. While integrating semantic models like IFC and CityGML presents challenges, research has focused on addressing these issues. The conversion from IFC to Shapefile using a Feature Manipulation Engine (FME) enhances the extraction of multi-floor indoor space from 3D building models. These advancements contribute to a comprehensive understanding of the evacuation process, ensuring the safety of building occupants in emergency situations.

2.3 Research gaps and Limitations

These existing studies primarily focus on static evacuation paths and do not adequately address the dynamic nature of indoor environments. They do not account for changes that may occur during emergencies, such as the usability or accessibility of exits, or the effects of heavily crowded or occupied buildings on evacuation strategies. They often overlook factors like the time required for people to travel the path, the capacity of the paths, and the availability of alternative exits. Therefore, there is a significant gap in the research when it comes to generating optimal evacuation paths that consider the changing indoor environment and effectively facilitate the evacuation of building occupants. Addressing this gap is important to enhance the safety and efficiency of evacuation strategies in densely populated urban areas with multistoried buildings. By developing approaches that go beyond static paths and consider the dynamic nature of emergency scenarios, researchers can provide valuable insights into designing more effective evacuation plans. To bridge this gap, future research can explore the integration of qualitative information with geospatial models and semantic indoor space models. This integration would provide a more comprehensive understanding of the indoor environment and enable the generation of evacuation paths that are not only based on quantitative measurements but also account for qualitative factors. By capturing and sharing qualitative information about the spaces along the evacuation path, such as obstacles, room characteristics, and semantic details, individuals can easily comprehend and navigate the path during emergencies. Researchers can investigate the optimization of evacuation paths using algorithms beyond traditional shortest path algorithms. While Dijkstra's and Bellman-Ford's algorithms have been widely used, they may not consider critical factors like crowd dynamics, time delays, and the availability of alternative exits. Exploring novel optimization criteria, such as minimizing risk, maximizing efficiency, or considering the capacities of paths, can lead to more robust and effective evacuation strategies. The utilization of Building Information Modeling (BIM) models offers significant potential for automatic indoor path generation. However, existing approaches mainly focus on generating paths based on geometric representations and do not fully consider the dynamic aspects of the indoor environment during emergencies. Future research can search into refining BIM-based path-generation techniques by incorporating real-time data and monitoring systems. This integration would allow for the adaptation of evacuation paths in response to changing conditions, ensuring that the paths remain viable and efficient throughout the evacuation process. In summary, the existing research on evacuation strategies in multistoried buildings has made significant progress in understanding static paths and generating initial evacuation plans. However, there is a pressing need to address the dynamic nature of indoor environments, consider qualitative factors, optimize evacuation paths based on diverse criteria, and refine BIM-based path generation techniques. By filling these gaps, researchers can contribute to the development of more effective and efficient evacuation strategies that prioritize the safety and well-being of building occupants in emergency situations.

2.4 Conclusion

Evacuation strategies are important for various scenarios, including urban areas with high population density and multistoried buildings. Ensuring the safety of building occupants while considering design constraints is a challenge faced by engineers and architects. A geospatial model of indoor floor plans can greatly enhance the comprehension and evaluation of evacuation paths by enabling visualization and the assessment of multiple computational models. Recent advancements have extended indoor navigation paths based on floor plans, incorporating data models like CityGML or IFC. However, existing approaches often assume independent static paths for each person and do not consider factors like crowding and movement delays during emergencies. Quantitative measurements like distance alone may not be sufficient in emergency situations where individuals need to move quickly. Qualitative information about the indoor spaces can improve the evacuation path by facilitating smoother movement and allowing path redefinition based on the changing environment within the building. The integration of a semantic indoor space model, combining ontology for indoor spaces with geometric and semantic characteristics, can provide an easily comprehensible path accessible to all building residents. Path planning within indoor spaces has been extensively studied using algorithms such as Dijkstra's and Bellman-Ford's shortest path algorithms. These algorithms offer insights into the nearest exits, but optimization criteria vary, including considerations of least risk or identifying the best-known path among multiple exit options. Geospatial technology and computational algorithms have been employed to develop and verify building compliance with emergency regulations. Building Information Modeling (BIM) models have opened opportunities for automatic indoor path generation. Generating a geometric topology network from spatial connections can be used to generate evacuation paths automatically. BIM-based signage information can be utilized to identify accessible exits during fires by assessing factors like smoke visibility. Overall, the integration of geospatial models, semantic indoor space models, path planning algorithms, and BIM technology can contribute to the evaluation and enhancement of evacuation strategies. These approaches can lead to safer building designs, improved visualization of evacuation paths, and the automatic generation of optimized routes for efficient evacuations during emergencies.

Chapter 3

Analysis Ready Data

3.1 Full Space Model

3.1.1 Format: DXF and SHP

DXF (Drawing Exchange Format) is a file format primarily used in Computer-Aided Design (CAD) applications, particularly for representing 2D and 3D drawings. It serves as a standardized format for sharing design data across various CAD software. On the other hand, SHP (Shapefile) is a geospatial vector data format widely utilized in Geographic Information Systems (GIS). A shapefile comprises multiple files storing geometric and attribute data. It is a fundamental standard for storing geographic vector data, including points, lines, and polygons, making it a crucial tool for mapping, spatial analysis, and visualization within GIS software. While DXF is tailored for CAD-related designs and engineering drawings, SHP holds prominence in GIS for mapping and spatial analysis needs. The initial phase involved precise extraction of shapefiles, ensuring accurate acquisition from their respective sources. An effort was invested in maintaining the correct coordinate reference system (CRS) for each shapefile, an essential factor influencing spatial accuracy and alignment. Addressing topological errors took precedence, utilizing QGIS tools to enhance data accuracy and reliability, resulting in shapefiles with improved geometric integrity—an imperative foundation for subsequent modeling.The building drawing utilized in this study encompasses a total carpet area of **102.349 m²**, as illustrated in *Figure 3.1*. The floor plan was converted from DXF format to shapefile format in QGIS. The difference between the shapfile format and DXF format is given in Table 3.1.

Aspect	DXF Format in QGIS	SHP Format in QGIS
Usage	Importing and exporting for visualization and analysis.	Standard format for data storage,visualization,analysis, and editing.
Geometry	Supports various geometries including points, lines, and polygons.	Stores vector data such as points, lines, and polygons.
Attribute Handling	May contain attribute data associated with geometric entities, but less structured compared to SHP.	Includes attribute data storage, allowing for structured tabular data linked to spatial features (attribute table).
Styling	Can include styling information such as colors and line types.	Offers extensive styling options including symbols, colors, labels, and transparency settings.
Coordinate Reference System (CRS)	May or may not include CRS information. Allows defining or reprojecting the CRS of layers in QGIS.	Inherently includes CRS information. QGIS automatically recognizes and handles the CRS of layers.

Table 3.1. Difference between DXF and SHP Format.

The floor plan consists of six rooms, six internal doors, one external main exit, and twelve windows serving as alternate exits during adverse scenarios. The capacity of the main exit allows for the evacuation of two occupants at a time, while the alternate exit can accommodate one occupant at a time. For this study, the source points are determined by the centroids of the rooms. *Figure 3.1* depicts the floor plan, including notations such as nodes denoting source and destination inputs, the evacuation point, the evaluation or safe point for evacuees to reach, and the generated graph network.

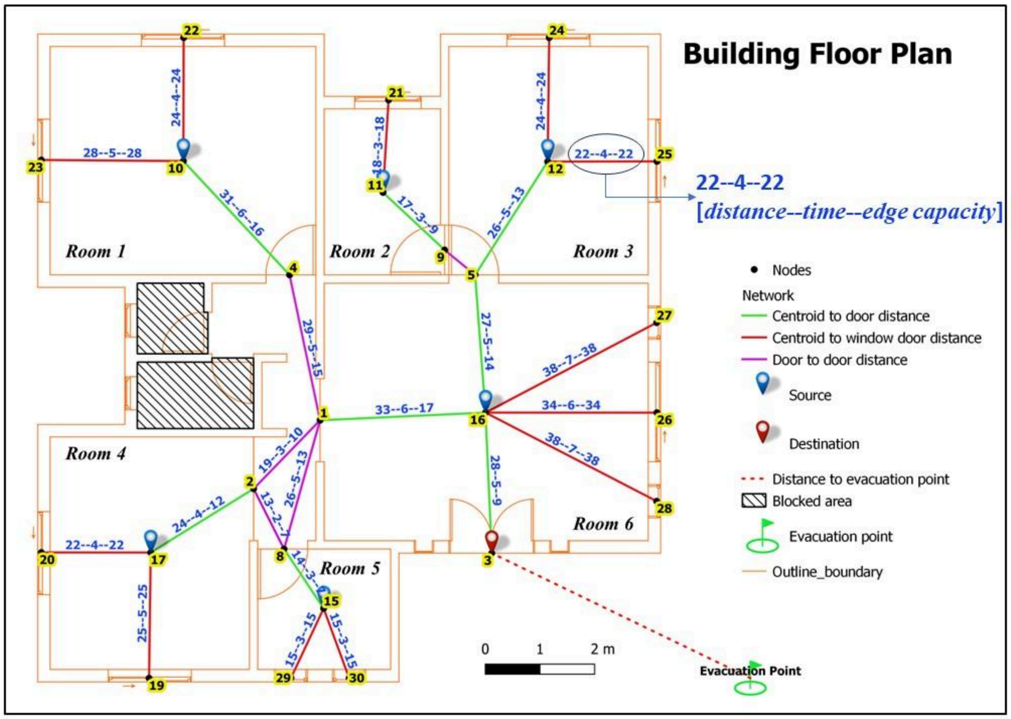

Figure 3.1. Building Structural Plan.

3.1.2 Space Occupancy

In this study, the occupancy of each room space is determined based on its unit area needed per person, maximum occupancy is considered to be the worst-case scenario. The occupancy level chart, illustrated in *Table 3.2*, is a crucial that provides a comprehensive view of the maximum number of occupants each room can accommodate based on its area. This information is vital for safety and emergency preparedness, enabling effective evacuation planning and ensuring that rooms are not overcrowded during critical situations. It may aligns with building codes regulations such as Fire safety - IS code 1641 (1988) and IS code 1644 (1988) for buildings taken into account during the preparedness, guiding compliance and aiding in the planning of infrastructure and facilities, including exits and safety equipment. Understanding the occupancy levels facilitates efficient resource allocation and allows for risk assessment, particularly concerning potential overcrowding risks, contributing to an overall safe and secure environment within the building. It is important to mark that the corridor and the shaded room have no occupancy. The parameter of occupancy plays an important role in this analysis, as it directly affects the optimization of evacuation paths and can potentially yield different outcomes if the actual occupancy is less than the room's capacity.

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**

Table 3.2. Occupancy Chart.

3.1.3 Space Node and Coordinates

In QGIS, a node is a crucial point within vector data that defines a specific location in a feature's geometry. It acts as a vertex where the lines of the feature intersect or change direction. For polygons, nodes represent the defining corners or bends in the outline of the shape. These nodes have coordinates associated with them, typically denoting their **X and Y positions** within the chosen coordinate system, such as **WGS 84** or **UTM**. The X-coordinate signifies the horizontal position (easting), while the Y-coordinate represents the vertical position (northing). Utilizing the Node Tool in QGIS allows for the selection, visualization, and potential modification of these nodes, aiding in precise editing and understanding of vector features. Handling of nodes is essential for accurate editing and manipulation of spatial data within QGIS, playing an important role in effective data creation, modification, and analysis. The extraction of nodes, representing key vertices within the shapefiles, played a pivotal role, serving as fundamental points crucial for defining significant locations and relationships within the data, ultimately enriching subsequent analyses and visualizations. Nodes were established at the centroid within the spatial confines, functioning as representative markers for individuals within the room. Concurrently, door center points were identified for each distinct room area including scenarios involving more than one exit from the building, including emergency or alternative exits like windows. A specific node termed the Evacuation Point, accessible from all exits, was designated as the final destination for simulations, refer *Figure 3*.1. These nodes are then utilized for the generation of graphs in the research study.

3.2 Subspace Model : Obstacles in space

3.2.1 Format: DXF, IFC, 2D to 3D

In the world of architectural drawing, involving transformations from DXF and IFC formats in 2D to elaborate 3D representations, a detailed illustration comes to life. During the conversion from Industry Foundation Classes (IFC) to SketchUp, attention was given to parameters and tagging, ensuring accurate preservation of specific attributes and characteristics for each element class, such as wall surfaces, ground surface etc. This approach proved instrumental in capturing and representing the original data intricacies faithfully. During visualization, careful consideration of the projection system for the building model added another layer of precision, ensuring the accurate placement and display of the 3D model within a specific coordinate space, significantly enhancing overall fidelity and utility of the visualization.The structure, spanning **102.349 m²** of carpet area, is intricately detailed in both 2D and 3D dimensions. Within this space, furniture claims **19.569 m²**, strategically positioned amidst six rooms, each graced with windows. So this subspace model accounts for the carpet area of **82.79 m²**. Notably absent from this layout are the ceiling lamps, yet the design accounts for various other elements such as beds, tables, chairs, and bathroom installations. In the transition to Industry Foundation Classes (IFC) format, the minutiae of interior details were meticulously preserved (The details are explained in Section 3.2.1.1), paving the way for semantic modeling such as *Standard space* (Room, Semi enclosed space)*, Connecting space* (Door/Window/corridor/junction/staircase) *and Composit space* (Hall). The resulting 3D representation, showcased in *Figure 3.2*, offers a glimpse into the spatial arrangement of these interior objects. Simultaneously, the 2D floor plan elucidates blocked windows and corresponding areas, acting as a vital reference for the network connections, subspaces, and nodes intricately woven into the building's structure and subspace formation using CityGML, as highlighted in *Figure 3.3*. The CityGML standard defines a conceptual model and exchange format for the representation, storage and exchange of virtual 3D city models. It facilitates the integration of urban geodata for a variety of applications for Smart Cities and Urban Digital Twins, including urban and landscape planning; Building Information Modeling (BIM); mobile telecommunication; disaster management; 3D cadastre; tourism; vehicle & pedestrian navigation; autonomous driving and driving assistance; facility management, and; energy, traffic and environmental simulations.

Integrated Indoor GML, following OGC (Open Geospatial Consortium) standards, and a graph-based model to simulate human behavior, allowing for the analysis of individual evacuation times from the first person to the last. This simulation model is developed using both space and subspace models showcasing the adaptability to changing graph networks, and is visually depicted in a 3D environment. These models can be further extended for Urban and landscape planning and also for disaster management.

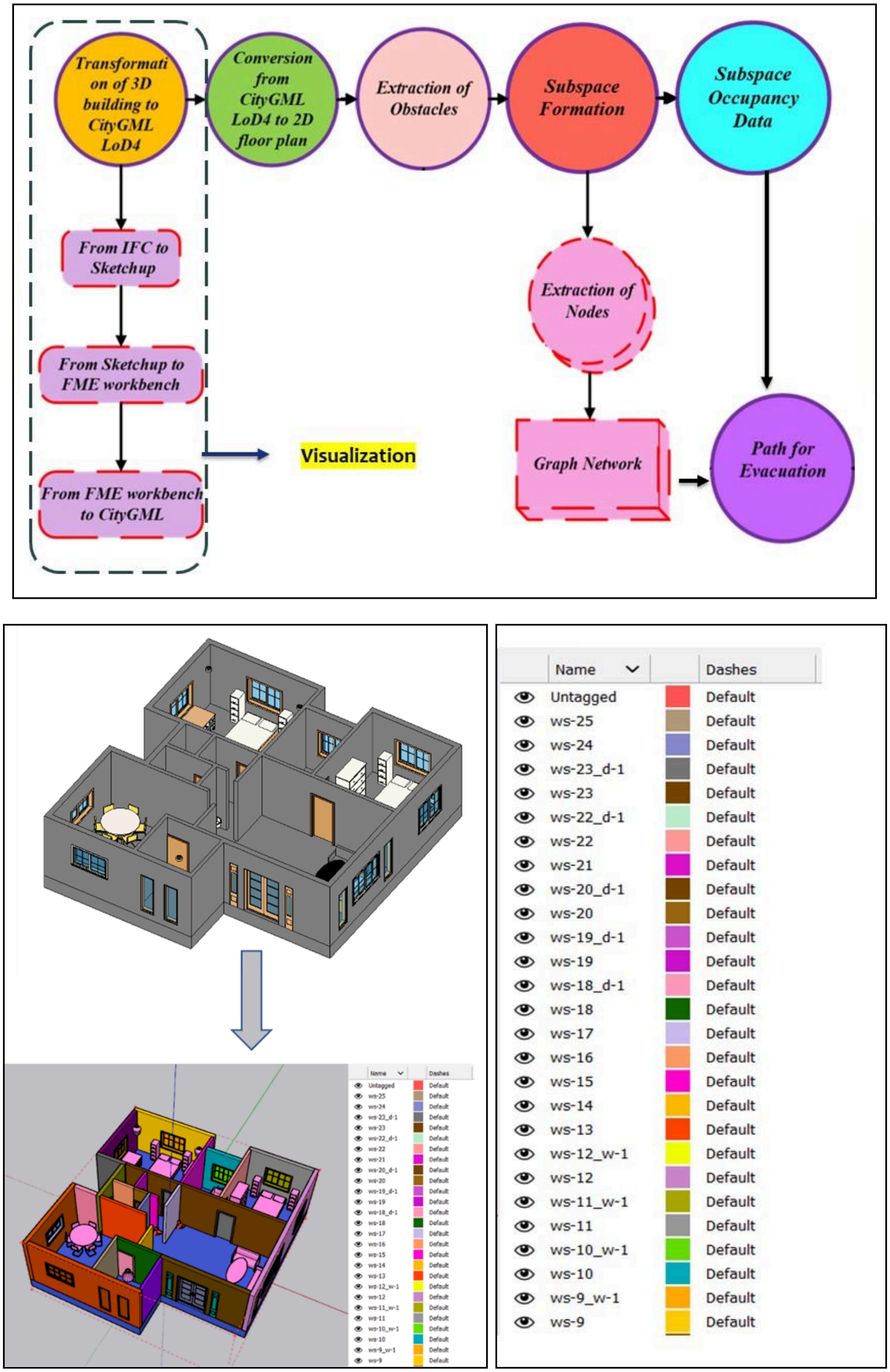

Figure 3.2.Flowchart for space model and IFC Conversion

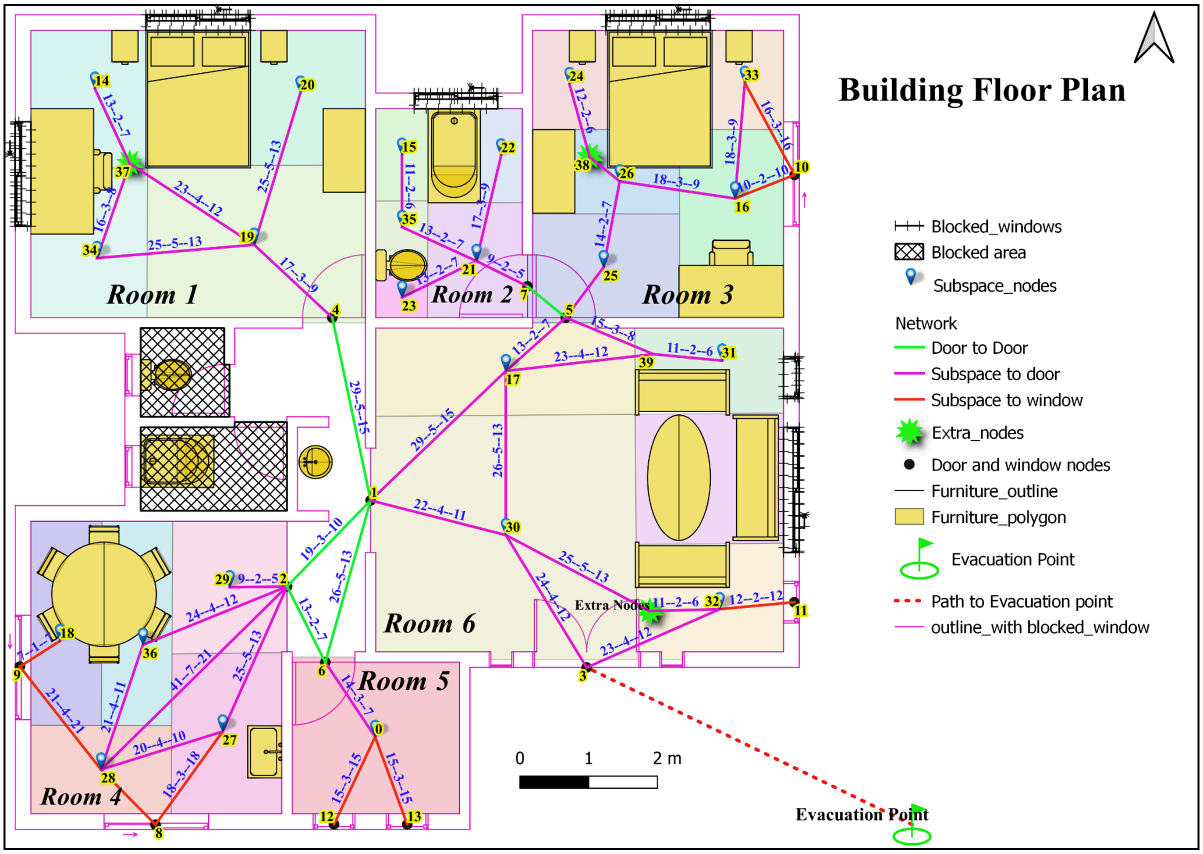

Figure 3.3. Building Floor plans with obstacles.

3.2.1.1 Transformation of the 3D building to CityGML LoD 4

IFC, which stands for Industry Foundation Classes, is a globally recognized standard for representing architectural, engineering, and construction (AEC) data. It serves as a structured format for exchanging information within the AEC industry. In contrast, SketchUp is a user-friendly content creation tool primarily used for 3D modeling and computer-aided design (CAD). It offers a broad range of drawing and design functionalities, making it a popular choice among designers and architects. To integrate the IFC data into the SketchUp workflow, the IFC file containing both semantic and geometric information is imported into the SketchUp Pro application. The SketchUp Pro model is then generated, utilizing a Cartesian (local) coordinate system for precise positioning of elements. A bounding box is generated around the 3D model using Thomas Thomassen's extensions such as DrawBoundingBox and tt_Lib2. This bounding box serves as a visual representation of the model's overall dimensions. In order to incorporate CityGML semantic elements into the SketchUp model, 3D model tags are utilized. These tags are assigned abbreviations that correspond to specific semantic elements. For example, "ws" represents WallSurface, "gs" represents GroundSurface, "w" represents Window, "d" represents Door, and "bi" represents BuildingInstallation. Additional abbreviations such as "ws-1_w-1" and "ws-1_d-1" are employed to indicate specific elements, such as "windows on the wall surface 1" and "doors on the wall surface 1" respectively. The tags are structured using a combination of parent and child element IDs. The parent ID, known as the gml parent ID, and the child element ID, known as the gml ID, are separated by an underscore (_), while individual IDs are separated by a dash (-). This notation ensures a clear and organized representation of the relationships between different elements within the SketchUp model. *Figure 3.2* visually depicts the conversion process from IFC to SketchUp, showcasing the integration of semantic tags within the SketchUp model. This conversion enables the utilization of the powerful 3D modeling capabilities of SketchUp while incorporating important semantic information from the original IFC file.

The Feature Manipulation Engine (FME) is a versatile spatial Extract, Transform, and Load (ETL) tool designed for seamless data integration. With support for over 400 different data formats, FME enables users to efficiently process, manipulate, and translate spatial data. Its graphical interface allows users to develop workflows visually, simplifying the integration, automation, and translation of data. In the context of this project, the SketchUp (.skp) file serves as the input data, and it is imported into FME as a reader file. FME provides the capability to handle SketchUp files and extract the necessary information for further processing. To facilitate this, a workbench is created within FME, utilizing a variety of transformers to perform specific tasks. This section outlines the specific transformers and their configurations used within the workbench to achieve the desired data transformation and integration. The FME workbench acts as a powerful engine, arranging the data transformation process according to the defined workflows and configurations. It allows for efficient manipulation of the SketchUp data, enabling tasks such as data extraction, attribute manipulation, spatial transformations, and format conversions.

CityGML, compliant with the Open Geospatial Consortium (OGC) standards, serves as an open data model for the exchange and storage of 3D city models. The Unified Modeling Language

(UML) object model defines the Geography Markup Language (GML), which forms the basis of CityGML. Within the CityGML framework, buildings are represented as objects, and their Level of Detail (LoD) specifies the complexity of their representation. There are five levels of detail in CityGML. LoD 0 represents the building footprint on the ground surface. LoD 1 involves a simple extrusion of the footprint, resulting in a block-like model known as the block model. In LoD 2, objects are further refined to resemble real-world structures. Building block models are equipped with roof surfaces, typically using standard roof forms. In LoD 3, buildings are enriched with elements such as doors, windows, stairs, pipes, lamps, and other architectural details. LoD 4 focuses on modeling internal interior objects, including furniture and equipment elements. To achieve the desired CityGML representation, a custom FME workbench is created using various transformers. The workbench incorporates transformers such as GeometryPartExtractor, Deaggregator, Aggregator, CityGMLGeometrySetter, and CoordinateSystemSetter. The GeometryPartExtractor allows the extraction of specific parts of the underlying geometry using a geometry query. Since the SketchUp objects were grouped and had multi-level aggregate geometry, which doesn't conform to the basic building geometry structure in CityGML, the Deaggregator transformer is used to flatten the levels and split them into individual faces. On the other hand, the Aggregator transformer combines the split components into a single multi-surface representation. The CityGMLGeometrySetter transformer is employed to define the CityGML geometry, ensuring that the appropriate Level of Detail (LoD) is set to represent the basic building geometry. The transformer is configured to assign the City Object Member designation to the transformed geometry. Additionally, the CoordinateSystemSetter transformer is used to reset the coordinate system to match the SketchUp coordinate system, ensuring accurate spatial representation in the CityGML model. The resulting FME workbench tree, showcasing the integration and arrangement of transformers, can be observed in *Figure 3.4*. The conversion process culminates in the generation of a final GML output, which can be visualized in various semantic data model viewers. In this study, the FZK Viewer tool is employed to visualize the semantic data models, as demonstrated in *Figure 3.5*. It is important to note that when viewing the GML output file, the appropriate spatial reference system should be selected carefully to ensure accurate spatial interpretation and alignment with other geospatial data.

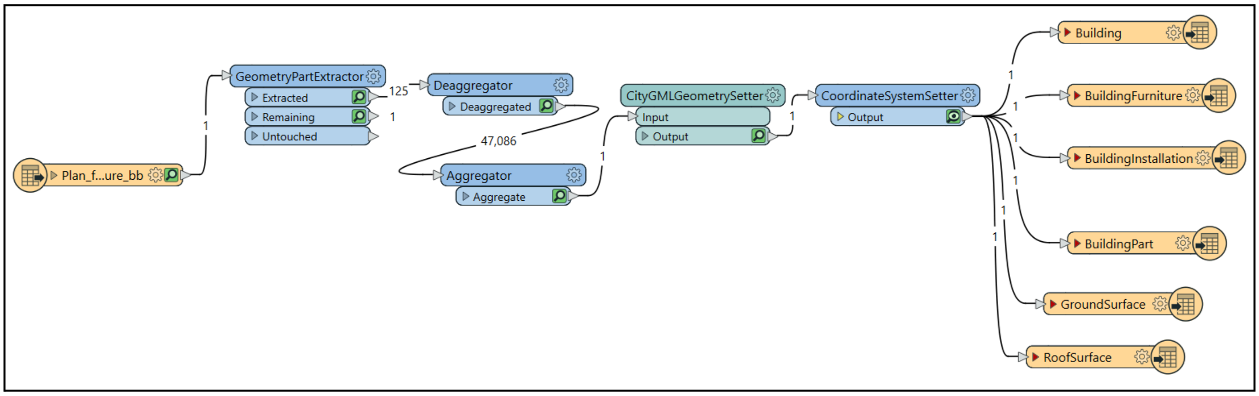

Figure 3.4. FME workbench tree

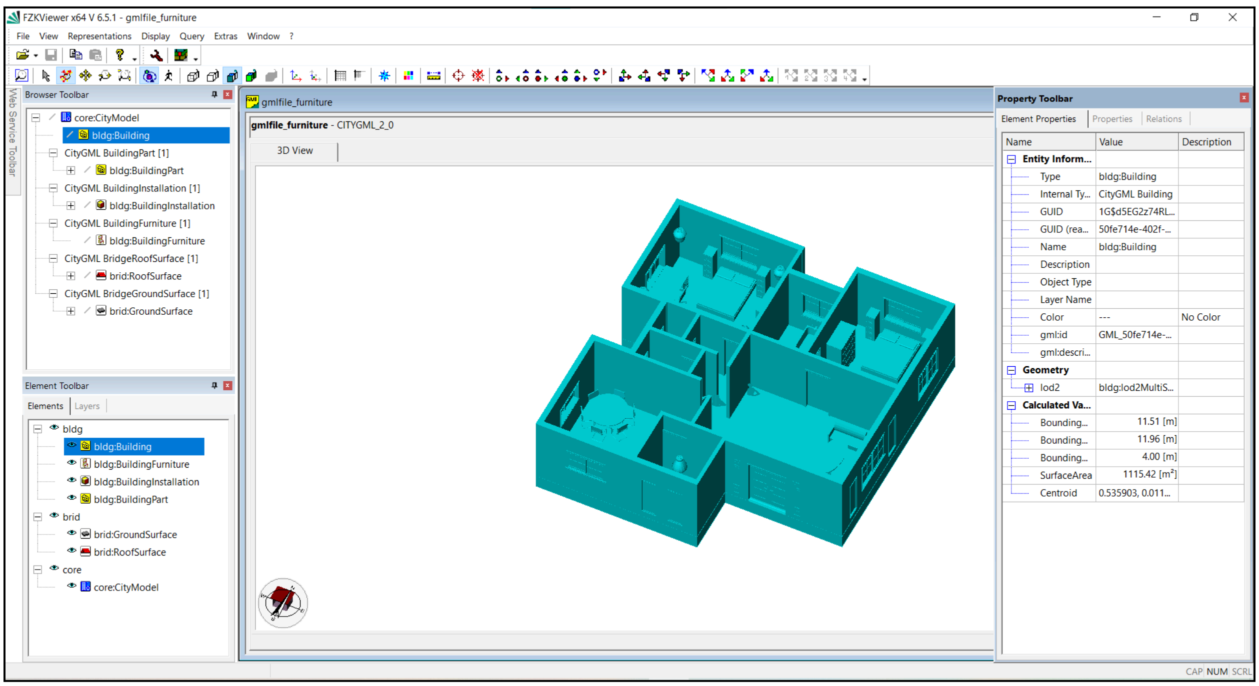

Figure 3.5. Visualization of the semantic data model

3.2.1.2 Conversion from CityGML LoD 4 to 2D floor plan

The conversion of CityGML Level of Detail (LoD) 4 data was executed using an output writer file that generated a shapefile output. This shapefile was then imported into QGIS, a powerful open-source Geographic Information System (GIS) software, utilizing the vector layer tool. During the import process, the projection system was carefully set up to ensure the correct orientation of the 2D floor plan and maintain spatial accuracy. The 2D floor plan resulting from the CityGML LoD 4 conversion comprises six distinct accessible room spaces, along with six doors and one main entrance. Additionally, the floor plan incorporates twelve windows, out of which six are obstructed and not accessible. It is worth noting that the floor plan may also contain blocked spaces that are not accessible for various reasons, such as physical barriers or restricted areas. To provide a visual representation of the 2D floor plan, including the furniture layout, *Figure 3.6* is included in the documentation. This image offers an overview of the floor plan, showcasing the arrangement of the accessible rooms, doors, windows, and furniture elements within the space. The furniture placement serves to indicate the obstacles and physical objects present within the room layout, aiding in understanding the spatial distribution and potential obstructions in the environment. QGIS proves to be a valuable tool for further analyzing and manipulating the 2D floor plan data. Its wide range of geospatial analysis capabilities allows for in-depth examination of the floor plan, enabling tasks such as spatial queries, measurements, thematic mapping, and more. The accurate projection setup ensures that the spatial relationships within the floor plan remain preserved, facilitating precise analysis and interpretation of the data.

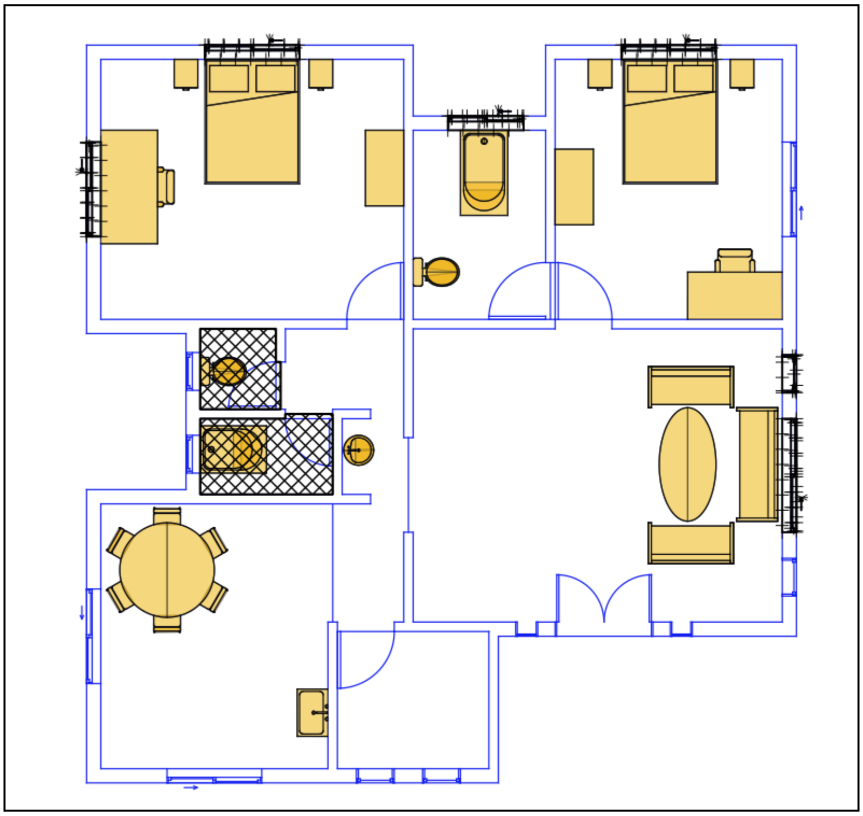

Figure 3.6. 2D floor plan with furniture in QGIS

3.2.3 Subspace model: Obstacles extraction and Sub-Space Formation

The generated 2D floor plan includes various furniture elements that may obstruct the evacuation path during emergency scenarios. Recognizing the significance of these obstacles, they are considered as potential barriers to movement and are categorized as obstacles within the evacuation context. To effectively analyze and address the impact of these obstacles on evacuation routes, the obstacles are extracted as mentioned in *Figure 3.6*. This extraction process involves outlining the boundaries of each obstacle, defining their spatial extent within the floor plan. By representing the obstacles as polygons, their specific locations and shapes are captured, enabling further analysis and modeling. Subsequently, these extracted polygons, representing the furniture obstacles, serve as the basis for generating subspaces within the floor plan *Figure 3.7*. The subspaces are derived by utilizing the boundaries of the obstacles and considering them as fundamental components in the division of the space. This approach allows for the identification and creation of distinct areas within the floor plan that are free from obstructions, ensuring unimpeded movement during evacuation scenarios. By incorporating the extracted polygons of the obstacles and the subsequent generation of subspaces, the floor plan analysis becomes more comprehensive and tailored to emergency situations. This approach provides a clear understanding of the spatial distribution of obstacles, enables the identification of potential congested areas, and facilitates the development of efficient evacuation strategies.The consideration of furniture elements as obstacles and their extraction as polygons emphasizes the importance of integrating evacuation planning and safety measures within the design and layout of buildings.

The subspace model employed in this study is primarily determined by the corner positions of obstacles within the building layout. Each subspace is designed to have an unobstructed line of sight to other subspaces, ultimately leading to the exit door. In order to ensure a clear line of sight between subspaces, an additional node, referred to as an extra node *Figure 3.8* is generated. The purpose of these extra nodes is to establish a clear visual connection between subspaces that might otherwise be obstructed due to the presence of furniture, walls, or other physical barriers. By introducing the extra node, any potential visual obstructions are effectively addressed, ensuring a continuous line of sight between interconnected subspaces. After the generation of the extra nodes, the subspaces are utilized to partition the overall space accordingly. This process involves dividing the space into distinct sections or compartments based on the layout and arrangement of the subspaces. The resulting split space, exemplified in *Figure 3.8 (a) and (b),* visually demonstrates the division of the space into separate and identifiable units. The concept of subspaces and the subsequent splitting of space play a vital role in various aspects of architectural and interior design analysis. By defining subspaces and ensuring uninterrupted lines of sight, architects and designers can evaluate factors such as spatial connectivity, accessibility, and the overall flow within a built environment. This approach facilitates the identification of potential areas of congestion, optimal placement of furniture and fixtures. The utilization of the subspace model and the subsequent splitting of space provide valuable insights into the spatial organization and layout of the building. This information can inform decision-making processes related to space planning, interior design, and architectural modifications. By considering the interconnectedness and visual accessibility of subspaces, stakeholders can enhance the functionality, safety, and overall user experience within the built environment.

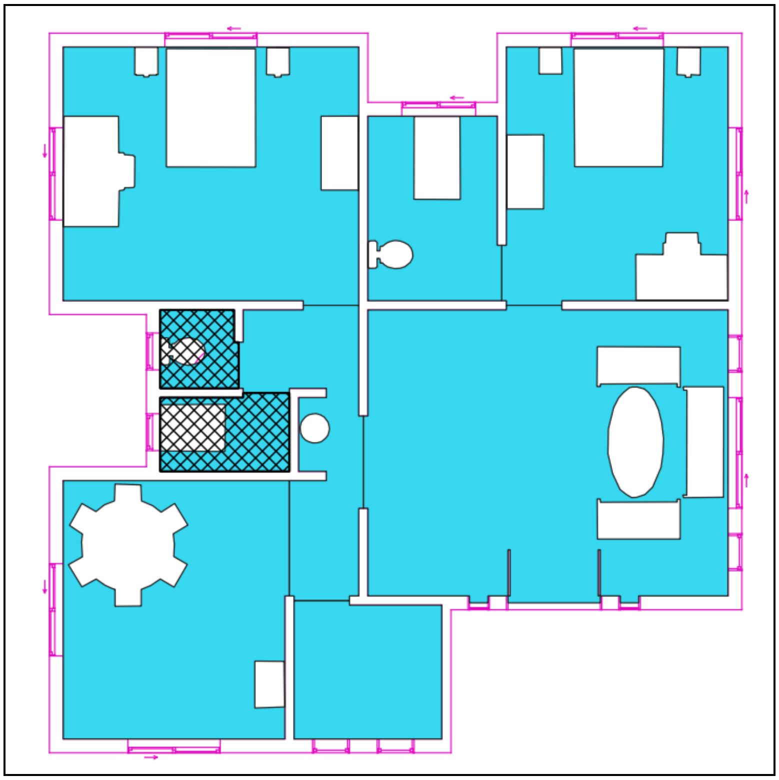

Figure 3.7. Extracted obstacles in the floor plan.

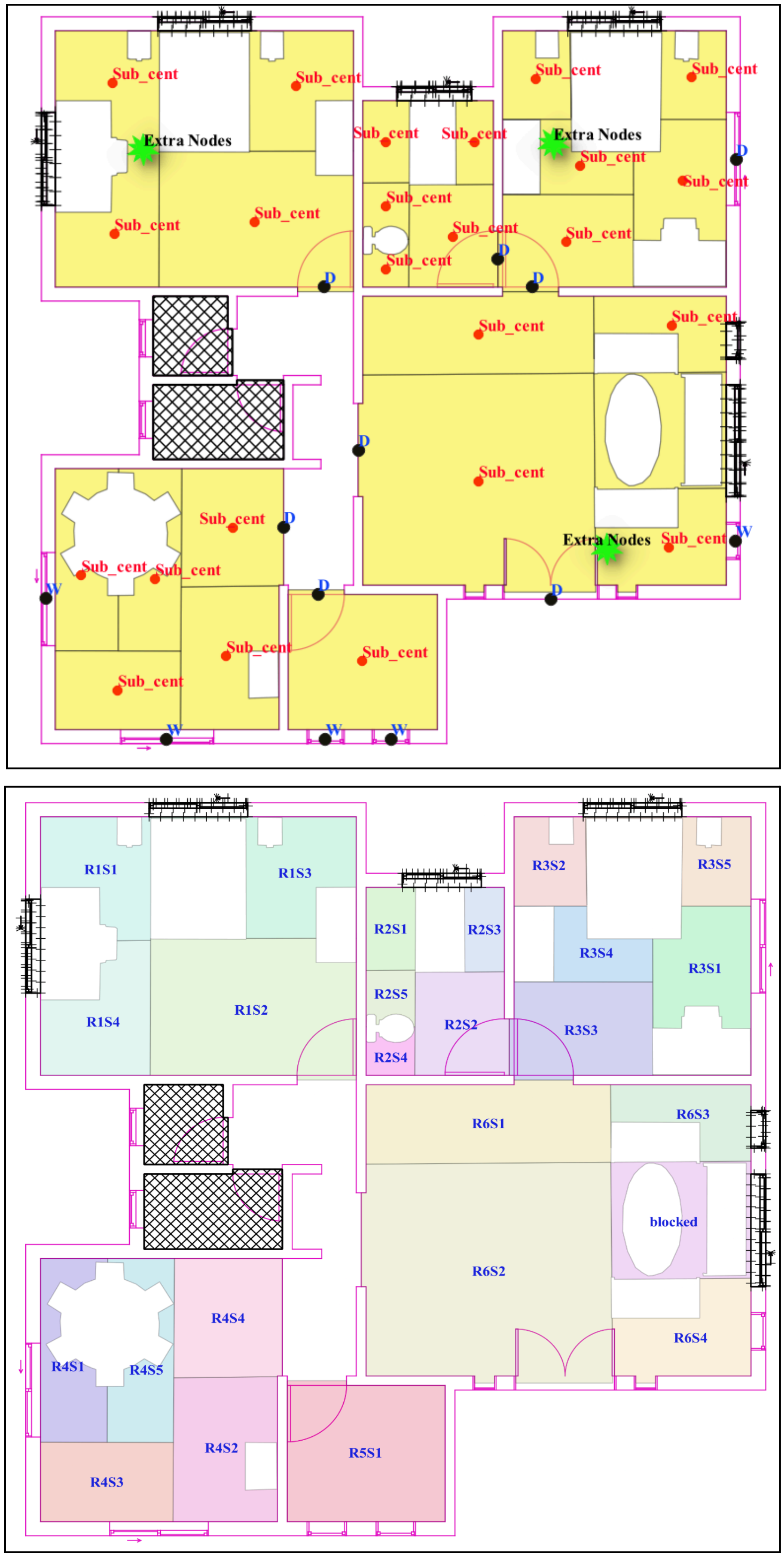

Figure 3.8 (a). Centroids at subspaces, doors, and windows with nomenclature.

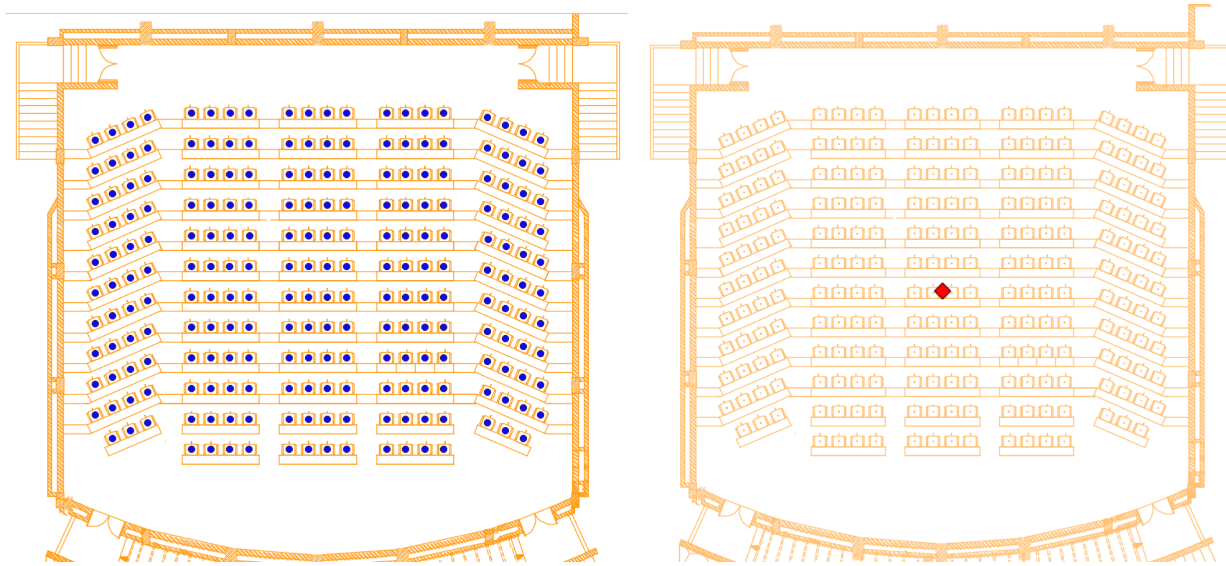

Figure 3.8 (b).Difference between subspace and full space.

3.2.2 Subspace Occupancy

This process involves partitioning the building floor plan into distinct subspaces based on specific criteria or functional areas. These subspaces are defined as separate regions within the overall building space. To determine the occupancy of these subspaces, a calculation is performed based on the area occupied by the individuals within each respective subspace. By analyzing the total area utilized by the occupants, an estimation of the occupancy rate for each subspace can be derived. This information is crucial for understanding the utilization and capacity of different areas within the building. For a comprehensive overview of the subspaces and their corresponding occupants, please refer to *Table 3.3*. This table provides a detailed breakdown of each subspace along with the individuals or occupants associated with it. The information contained in *Table 3.3* offers important understanding into the distribution of occupants throughout the building area.

Number of occupants based on sub-space model			
Notations	**Subspace**	**Occupancy Count**	**Total occupants**
Room 1	R1S1	2	15
	R1S2	7	
	R1S3	3	
	R1S4	3	
Room 2	R2S1	1	5
	R2S2	2	
	R2S3	1	
	R2S4	0	
	R2S5	1	
Room 3	R3S1	3	9
	R3S2	1	
	R3S3	3	
	R3S4	1	

	R3S5	1	
Room 4	R4S1	2	13
	R4S2	3	
	R4S3	3	
	R4S4	3	
	R4S5	2	
Room 5	R5S1	2	5
	R5S2	2	
	R5S3	1	
Room 6	R6S1	5	23
	R6S2	13	
	R6S3	2	
	R6S4	3	

Table 3.3. Subspaces with their number of occupants .

3.2.3 Subspace nodes

The process of subspace formation is important in extracting and identifying key nodes within a given floor plan. These nodes are positioned at the centroids of the respective subspaces, enabling a comprehensive understanding of the spatial layout and facilitating further analysis and decision-making. The extraction of nodes at the centroid of subspaces provides valuable information about the central points or locations within each designated area. These nodes serve as reference points that help capture the overall characteristics and properties of the respective subspaces, enabling a more detailed analysis of the floor plan. Moreover, nodes are also located at the centroids of accessible doors and windows within the floor plan. This additional step ensures that the nodes accurately represent the key entry and exit points within the building, which are crucial for evacuation planning and spatial connectivity assessments. By incorporating these door and window centroids as nodes, the resulting analysis becomes more comprehensive and accounts for the specific characteristics and attributes of these accessible elements. *Figure 3.8* visually illustrates the subspaces within the floor plan, with nodes located at the centroids of both doors and windows, as well as the subspaces themselves. This representation provides a clear overview of the spatial distribution of subspaces and highlights the central points within each area, facilitating further analysis. In certain scenarios where a direct line of sight between nodes of connected subspaces and/or exits is not possible due to physical obstacles or spatial constraints, additional nodes, referred to as extra nodes, are computed based on the geometry of the floor plan. These extra nodes serve as intermediate reference points, aiding in establishing clear visual connections between interconnected subspaces and exit routes. By introducing these extra nodes, any potential visual obstructions or limitations are addressed, ensuring a coherent and accurate representation of the floor plan's connectivity.

3.3 Safe Point: Evacuation Point

A "safe point" or "evacuation point" in a building evacuation model refers to a designated location outside the building, sufficiently away or in an open space that is considered safe during an evacuation or emergency situation. It's a predetermined area where individuals can gather to find safety, receive further instructions, or await further assistance refer *Figure 3.3*. The selection and identification of safe points are crucial in building evacuation planning and modeling. These points are strategically chosen based on factors such as accessibility, proximity to exits, structural stability, protection from hazards (like fire), and overall capacity to accommodate a certain number of evacuees safely. In the event of an emergency, occupants within a building are guided to move towards these predetermined safe points as shown in *Figure 3.9*, ensuring a coordinated and organized evacuation. These points serve as rendezvous locations, aiding in the accountability and management of individuals during the evacuation process. The existence and awareness of safe points is important in enhancing evacuation efficiency, reducing panic, and ultimately contributing to the safety and well-being of the building's occupants during emergencies. Building evacuation models integrate the concept of safe points to simulate and optimize evacuation strategies, improving overall safety protocols within structures.

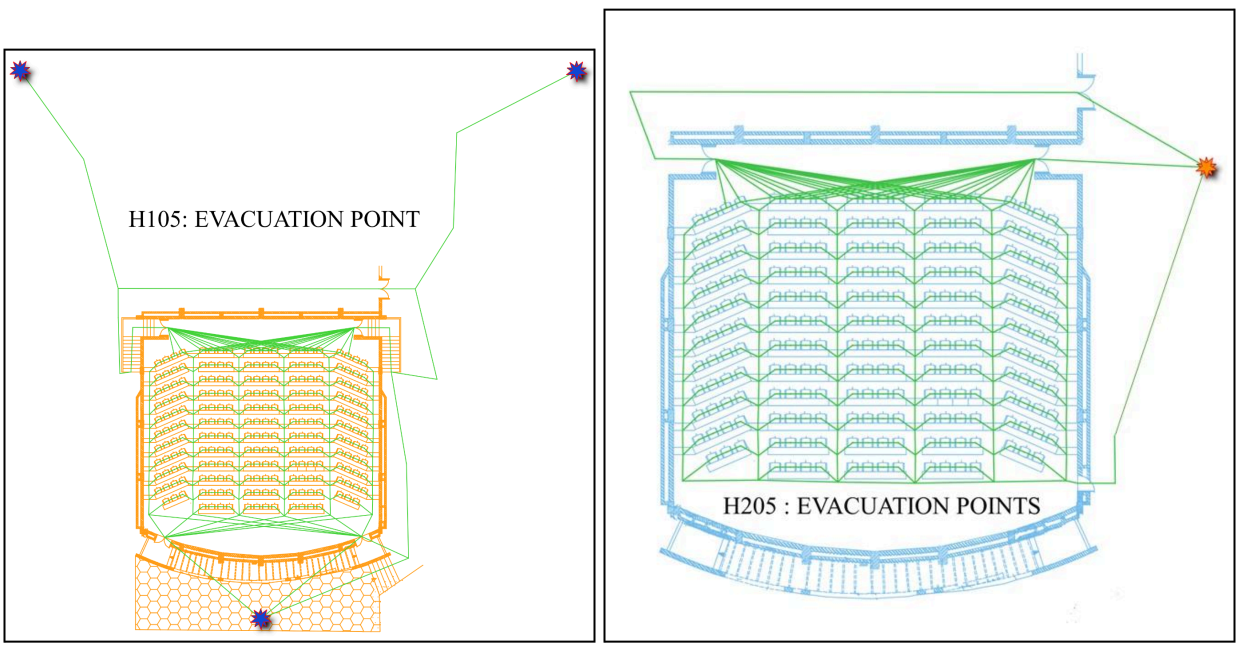

Figure 3.9. Evacuation points for H105 and H205 outside the affected area.

3.4 Issues with the data

When working with building floor plans, transitioning from the CAD-oriented DXF format to the more GIS-friendly shapefile format often introduces data format challenges. DXF primarily contains vector-based geometric and attribute data, while shapefiles are specifically designed to store geographic features and associated attributes. Converting from DXF to shapefile requires careful handling to ensure the accurate preservation of geometry and attributes during the process, ensuring data integrity and compatibility for effective utilization in GIS applications. Moreover, another hurdle is dealing with mismatched coordinate systems, such as WGS 84 and UTM. These systems differ in how they represent locations on the Earth's surface. While WGS 84 relies on latitude and longitude, UTM divides the world into zones, simplifying measurements. When integrating or overlaying data with different coordinate systems, misalignments can occur, necessitating data transformation or reprojection to a consistent coordinate system. In the context of building design, using a database is essential for generating a structured network that represents spatial relationships, connections, and attributes within the building. This network is crucial for modeling movement paths and analysis of network-related information. Simultaneously, identifying significant points or nodes within a space is important, known as node generation for a subspace model. These nodes could be centroids of rooms, key junctions, or exit points, playing a pivotal role in analyses such as optimizing evacuation routes.

3.5 Correcting the data issue

This transition from CAD-oriented DXF format to shapefile format requires careful handling to ensure the accurate preservation of geometry and attributes during the conversion process. Special attention must be given to maintain data integrity and compatibility for effective use in GIS applications. Aligning mismatched coordinate systems, such as WGS 84 UTM, is important. Data transformation or reprojection is necessary to bring all data into a consistent coordinate system. This alignment ensures precise spatial analysis and visualization in accordance with the requirements. In the case of databases it is essential for creating a structured network that passes from node to node and not to unwanted walls or space. This accurately represents spatial relationships, connections, and attributes within the building. This network is crucial for modeling movement paths. Concurrently, identifying significant points or nodes within a space is vital, a process known as node generation. These nodes need to be placed very carefully at the centroids. Regularly maintaining and validating data quality proved essential to overcoming these challenges and ensuring a reliable representation of building floor plans in QGIS.

3.6 Used Application

The workflow for this project is illustrated in the flow diagram presented in *Figure 3.10*. The process begins with the utilization of Revit 2022 in conjunction with IFC 3D building floor plan. The floor plan is then exported to SketchUp Pro 2021 software, where a tagging tool is employed to label each component of the 3D building, ensuring compatibility with CityGML standards. The resulting SketchUp file, saved with a .skp extension, is incorporated into the FME Workbench 2022.21 software as a reader file. Within the FME Workbench, transformers are employed to generate the desired output file in GML format. The transformers are configured to include various elements such as building parts, building installations, building furniture, roof surfaces, and ground surfaces. The resulting GML model can be visualized using the FZK viewer, allowing for the examination of different elements within the model. In the final stages of the workflow, the 3D building floor plan is exported as a flattened 2D floor plan. Subsequently, calculations and analyses are performed using QGIS software, leveraging the exported 2D floor plan as a basis for further computations.

Figure 3.10. Flow diagram of the software applications used.

Chapter 4

Path Planning Approach

4.1 Path Planning for Base Space Plan

4.1.1 Python and its libraries

The graph network was generated based on the previously extracted centroids using a combination of QGIS and Python programming. To begin with, the coordinates of the centroids were extracted from the attribute table in QGIS using a query. These extracted coordinates were then exported to a .csv file format, which served as the input for subsequent Python-based network generation. Python, being a versatile and powerful programming language, was utilized to generate the network within the QGIS environment. Various libraries such as NumPy, pandas, and matplotlib were employed to facilitate different tasks. NumPy, for instance, enabled simple calculations and mathematical operations on arrays, while pandas and matplotlib were utilized for data handling, exporting, and graph plotting, respectively. The first step in the Python workflow involved importing the .csv file and defining the necessary libraries. Next, connection points for each node were established based on the coordinates extracted from the CSV file. These connection points represented the latitude and longitude data of the interconnected graph. The Python-generated CSV output was subsequently imported back into QGIS, where it was joined with the point layer using the “join to other layers" functionality. This step ensured that the coordinate data aligned with the corresponding points in the QGIS environment. To create the graph network, the "XY to line" feature was utilized, which generated simple lines based on the starting and ending coordinates specified in the table data records. The table data record contains the origin (X_0, Y_0), and destination (X_d, Y_d). By accurately defining the origin and destination coordinates, the graph network was able to visually represent the connections and pathways between different points. It is important to note that the selection of an appropriate coordinate reference system (CRS) is must to ensure the accuracy and reliability of the network generation process. Properly aligning the CRS with the input coordinates helps to maintain the integrity of the spatial relationships and accurately represent the graph network within the desired geographic context. *Figure 4.6* illustrates the resulting network generated using Python, showcasing the interconnected nodes and their corresponding connections. This visual representation aids in understanding the spatial relationships and connectivity between different points within the environment, which is vital for effective evacuation planning and analysis. By integrating the capabilities of QGIS and Python, this study successfully generated a graph network that serves as a valuable tool for visualizing the connections and pathways within the evacuation environment. The combination of spatial data analysis and programming techniques provides insights into the structure and organization of the evacuation space, facilitating the development of efficient evacuation strategies.

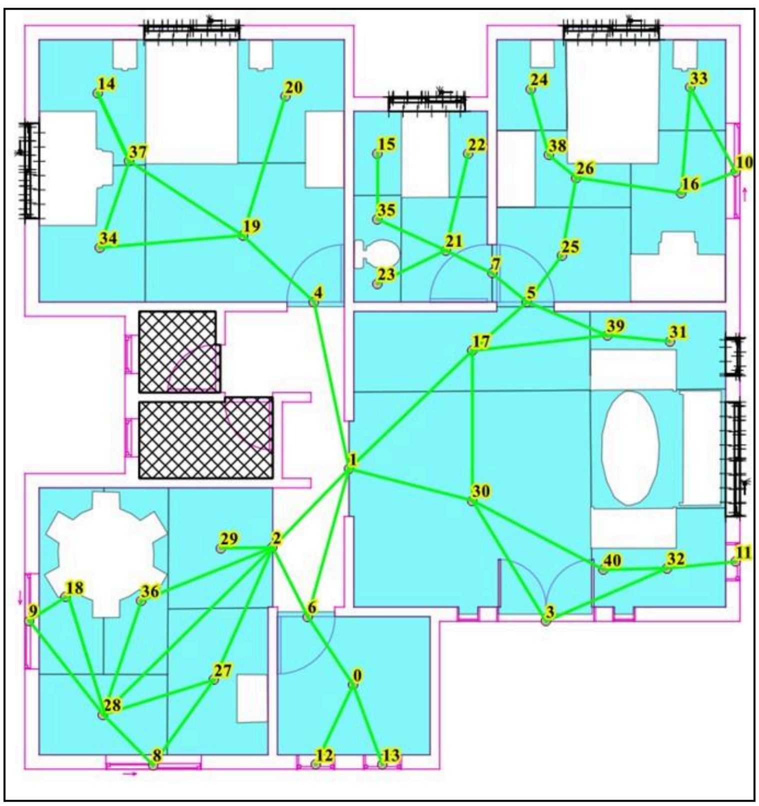

Figure 4.1. : Network generated using Python.

4.1.2 Framework of PgRouting

PgRouting adopts a data management approach centered around SQL within a PostgreSQL database. The architecture is SQL-based, meaning that the handling of data, particularly related to network graphs, relies on the Structured Query Language (SQL). In this context, the essential network data required for path computation and routing is organized and stored in SQL tables within the PostgreSQL database. These tables represent nodes, edges, and other relevant attributes, providing an efficient structure for data organization and retrieval. PostgreSQL, a widely used open-source relational database management system, acts as the underlying platform for storing this network data. When it comes to path computation and network analysis, pgRouting efficiently extracts the graph data using SQL queries. SQL queries are optimized for speed and precision, allowing for rapid extraction of the required network information crucial for effective path computation and comprehensive network analysis. The SQL-based approach significantly enhances the performance and flexibility of pgRouting, making it a powerful tool for various routing algorithms and network analytics. Framework of pgRouting with important components are shown in *Figure 4.2.*

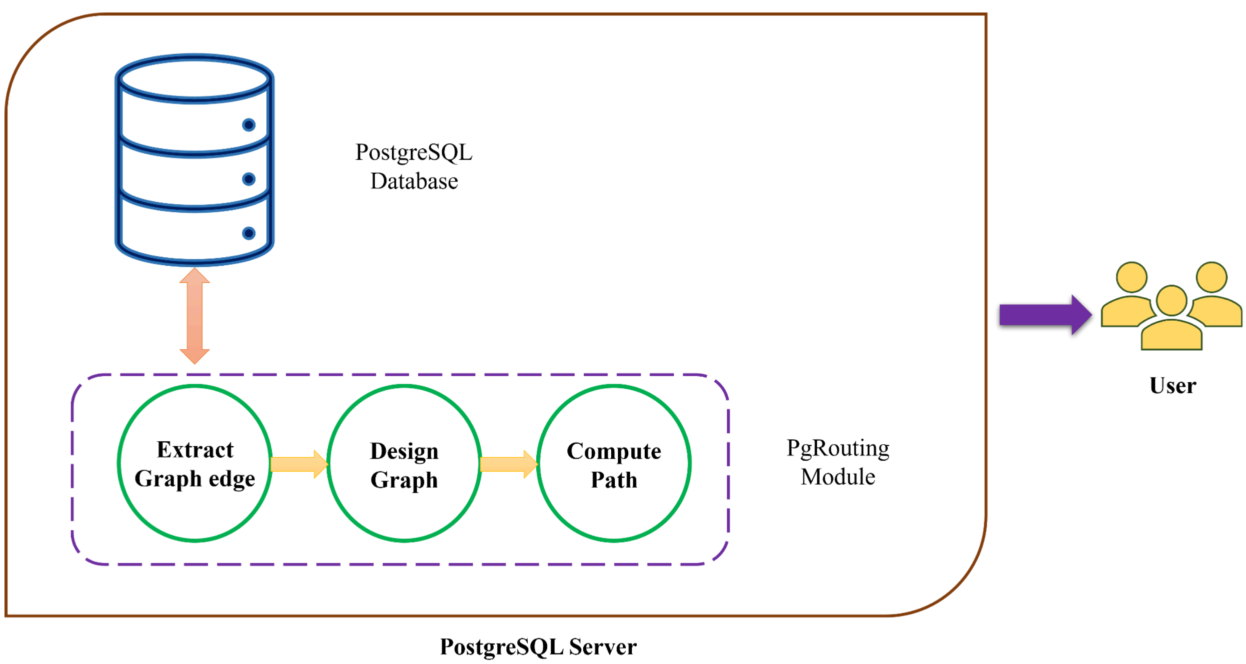

Figure 4.2. : Framework of PgRouting

4.1.2.1 PostgreSQL

PostgreSQL database, vital data regarding the edges and vertices of a graph is structured and stored in the format of SQL tables. In this context, "edges" represent the connections or relationships between different points in the graph, while "vertices" refer to these points themselves. The use of SQL tables allows for efficient organization and retrieval of this essential graph-related information, enabling effective graph-based operations and analyses within the database environment. The database schema for the network is explain in *Table 4.1*.

Name	Data Type	Description
gid	long int	A unique identifier assigned to every network.
source	long int	Source node of the network.
target	long int	Destination node of the network.
cost	real	The length of the network.
the_geom	geometry	Geometry of the segment: PostGIS attribute.

Table 4.1 Database Schema for Network.

4.1.2.2 pgRouting Module : Extension

PgRouting, functioning as an integral module or extension of PostgreSQL, encompasses a collection of path computation algorithms essential for routing and network analysis. When a user intends to determine a path between a source node (X_0) and a target node (Y_d), they initiate this process by formulating a request in the form of an SQL query directed at the PostgreSQL server. This SQL query encapsulates the specifications of the desired path algorithm to be employed. Upon receiving the query, the pgRouting extension undertakes the crucial task of extracting the relevant graph data from the designated edge table within the PostgreSQL database using SQL queries. This extracted graph data, constituting the network structure, is then utilized to compute the optimal path between the specified source (X_0) and target (Y_d) nodes using the specified path algorithm. Finally, the computed path is retrieved and conveyed back to the user, offering the desired routing information and fulfilling the user's request.

4.1.3 Query Structure

This is the structure of the Query used in postgreSQL.

```
// Changed the actual table names to edges for base_network_final, point for base_point_before_final

// The edge geometry column is multilinestring but contains only one linestring in it we alter type of column and extract that one line string with help of st_geometryn

select * from all_nodes_merged;
ALTER TABLE all_nodes_merged RENAME TO point;
select * from point

select * from network;
ALTER TABLE network RENAME TO edges;
select * from edges

 --select * from point
 --select * from edges

alter table edges
alter column geom TYPE geometry(linestring,32644) USING ST_GeometryN(geom, 1);

// adding source and target columns to edge data and update them with vertices ids

alter table edges add column source int;
alter table edges add column target int;
update edges
set source = point.id
from point
where edges.x_orig = point.X and edges.y_orig = point.Y;
update edges
set target = point.id
from point
where edges.x_dest = point.X and edges.y_dest = point.Y;


// At last pgr_dijkstra is run where in this below query we have source and target as 1 and 2 respectively. Refer to st_collect() and pgr_dijkstra() documentation to know what exactly these functions ouput
```

```
select st_astext(st_collect(e.geom)) from pgr_dijkstra('select id, source, target, dist_m as cost from edges', source, destination, false) as r, edges as e where r.edge = e.id;

--select pgr_version()

select * from pgr_dijkstra('select id, source, target, dist_m as cost from edges', source, destination, FALSE) as r, edges as e where r.edge = e.id;

// This is for adding the total distance

select sum(cost) from (select * from pgr_dijkstra('select id, source, target, dist_m as cost from edges', source, destination, FALSE) as r, edges as e where r.edge = e.id) as temp

--for all sum values (many source to one target)

select * from original_seats;
ALTER TABLE original_seats RENAME TO vertices;
select * from vertices

--select Array_agg(source) from vertices V1 to V7

select start_vid, sum(cost) from
(select * from pgr_dijkstra('select id, source, target, dist_m as cost from edges', ARRAY [V1, V2, V3,V4,V5,V6,V7], V5, FALSE) as r, edges as e where r.edge = e.id)as temp group by start_vid;
```

4.1.4 Generated Network

The creation of a graph network as illustrated in *Figure 4.3* is an important component in evacuation planning, as it provides a visual representation of the connections and relationships between different points within a given environment.

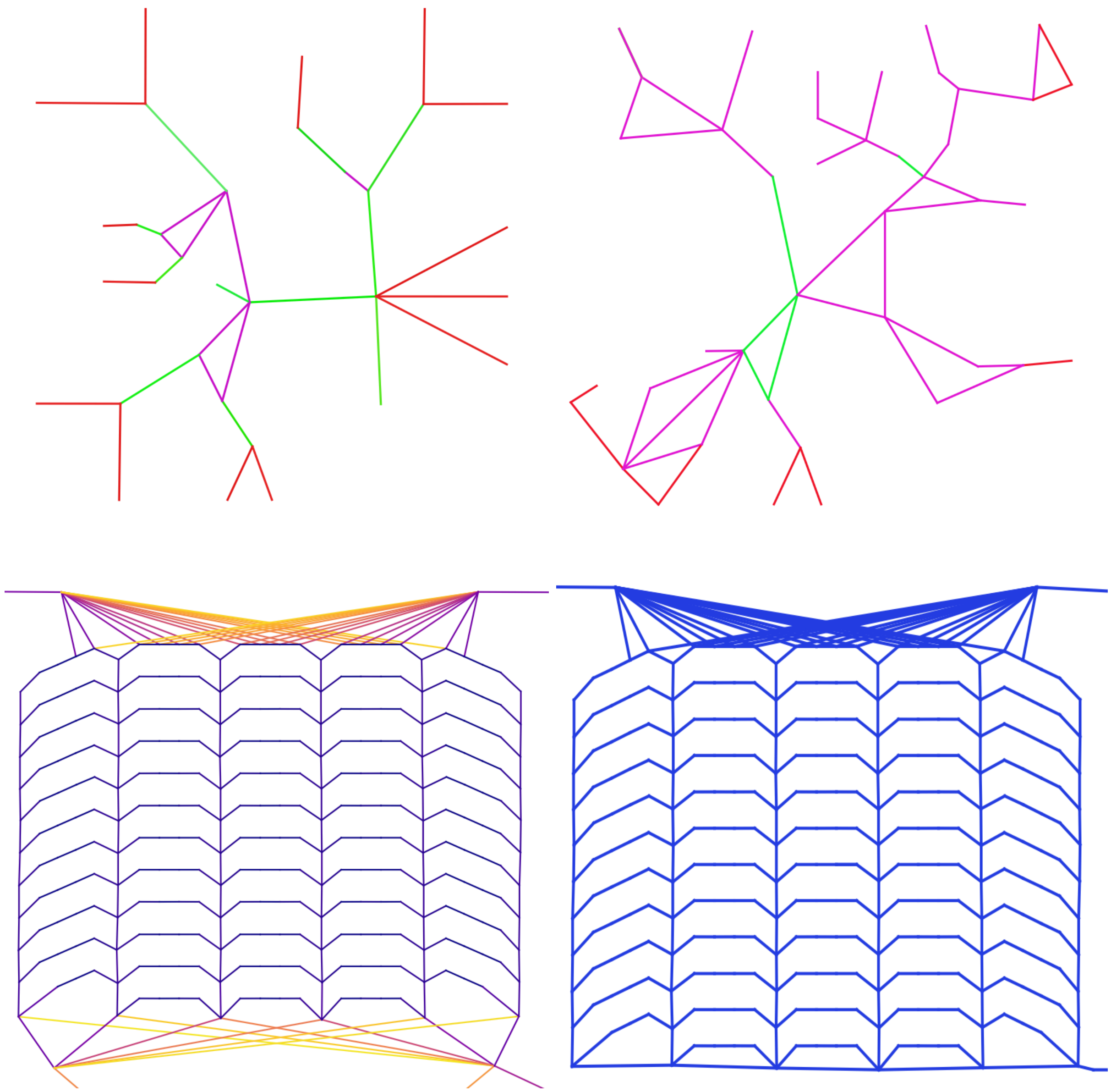

Figure 4.3. : Generated Networks for all possible nodes indicating the full connected network

4.2 Path Capacity : Edge Capacity

Path or edge capacity refers to the ability of a specific path to accommodate a certain number of people at a given moment. To determine the path edge capacity, an average speed of **6 km/h** per person is assumed, taking into account the typical movement behavior during evacuations. This allows for the calculation of each occupant's travel time to the exit and, thereafter, the estimation of the last person's exit time. The Hold/Lag time was assumed to be **300sec/5min** for alternate exits such as window and 2sec for door exits to open(1sec) and go (1sec) as it doesn't take much time to step out of the window. The path edge capacity is equals to distance by capacity of door, such as 1 person per window and 2 person per door. In cases where alternate exits such as windows are considered, a hold time is incorporated into the corresponding path link to account for any delays in accessing these exits. This recognizes the additional time required for evacuees to reach and utilize such emergency exits. The proposed approach allows for incorporating a pass-through capacity at specific nodes. This capacity estimate helps to determine the rate at which people can flow through these nodes during evacuations. By considering factors such as occupancy, travel times, delays at alternate exits, and flow rates of people through specific nodes, the approach allows for a thorough evaluation of evacuation scenarios. In *Figure 3.1*, the graph is depicted using lines of different colors, representing the generated network. This network takes into account the main exit as well as the alternate exits, highlighting only the shortest paths. The distance from the centroid to the door is represented by *green* color, the distance from the centroid to the window is marked in *red*, and the door-to-door distance is marked by *purple* color. These networks are labeled to indicate the ***distance-time-edge capacity***. The capacity of an edge within the network is directly linked to the rate of people flow at the exits. However, it's important to acknowledge certain limitations regarding the flow of people based on the capacity of the edges. If the number of occupants exceeds the capacity of the edge with the lowest capacity within the path , it means that not all occupants can be evacuated within the shortest time shown. These considerations highlight the need to account for the capacity constraints during evacuation planning. By understanding the limitations posed by the capacity of the evacuation routes, it becomes essential to optimize evacuation strategies to ensure that the available paths can accommodate the expected number of occupants within a reasonable timeframe. By using this information, evacuation processes can be effectively managed, taking all individuals' safety and well-being into consideration.

4.3 Evacuation path

To generate optimal evacuation paths, an algorithm proposed earlier is employed within the PostgreSQL database management system. The calculation of distances between nodes is important in evacuation planning. It provides valuable information about the spatial relationships and accessibility within the network, helping to identify the most efficient routes for evacuees to reach safety. By incorporating additional factors such as time and edge capacity, the analysis becomes more comprehensive, considering both spatial and temporal aspects as well as the capacity limitations of individual edges. PostgreSQL's powerful database capabilities enable efficient calculations and processing of large amounts of data, making it suitable for complex analyses within the evacuation context. The integration of PostgreSQL with the graph network facilitates seamless interactions between the network data and the algorithm, enabling the generation of accurate and efficient evacuation paths. The database system stores and organizes the network data, allowing for quick retrieval and computation of distances, times, and capacities between nodes. In this approach, the room spaces are designated as source nodes, and the doors or windows located on the building periphery serve as exits. By employing the Dijkstra algorithm, the set P is generated, which comprises all potential shortest paths for each combination of source and destination. Within this set, each path (Pi,k ∈ P) represents one of the available options for each individual or user, denoted by k. The final path chosen by a specific individual k is represented as Pmk, where m ∈ i signifies the selected path from the available options. By considering distance, time, and edge capacity within the graph network, the study aims to develop a comprehensive and reliable framework for evacuation planning. This approach enables the identification of efficient and safe evacuation routes, taking into account both the spatial layout of the network and the limitations imposed by time and capacity constraints. The time taken by the individual is calculated in the equation [1].

$$T_i = \sum_k T_{ik} + L_{iq} + \sum_k \left\{ \frac{(q_{ik} - e_k) + |(q_{ik} - e_k)| \times T_{ik}}{2} \right\} \qquad [1]$$

The equation above provides a method for calculating time for individuals. It combines lag time and path edge capacity. In this equation, T_i represents the time taken by the i^{th} person, where k is a segment of the path. For lag time calculation, L_{iq} represents the lag time taken by the i^{th} person who is at position q in the queue. The third part of the equation represents the edge capacity, which is binary; it will be 0 if the segment is empty or have space, otherwise, it will have some value. The third part of the equation also includes q_{ik} which represents the position of the i^{th} person in the queue to enter segment k. e_k is the edge capacity of the k^{th} segment, and t_{ik} is the time taken by the i^{th} person in the k^{th} segment.

The network generated in this study serves as the basis for calculating distances, times, and edge capacities within the evacuation environment. By extending previous methodologies and employing an algorithm within PostgreSQL, the study aims to generate optimal evacuation paths that consider multiple factors simultaneously. These factors are distances between nodes that are calculated to provide information about the spatial relationships and accessibility within the network, Time taken to traverse different paths, the capacity of edge as mentioned in section 4.2 and dynamic conditions such as unforeseen incidents (e.g., fire) that can affect the availability of certain paths as mentioned in section 5.3. This ensures adaptability in the cace of emergencies. In the event of an emergency, the previously computed shortest path may become unavailable to the user. This is due to unforeseen incidents such as a fire or other emerging conditions, which can result in the blockage of a node or an edge within the network. While a blocked edge disconnects only the path that includes the affected edge, a blocked node disrupts all the edges connected to it, as depicted in *Figure 4.4*.

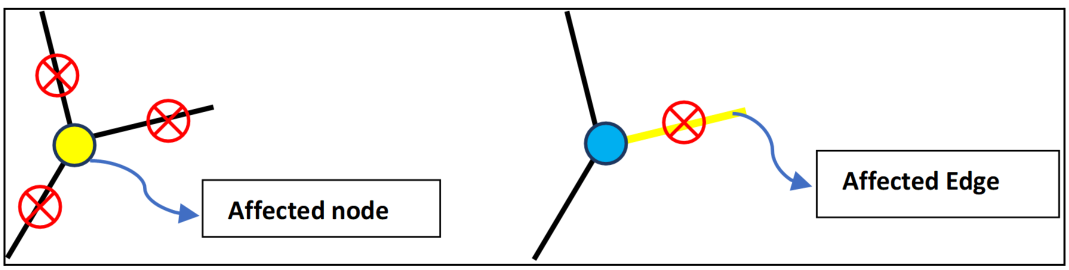

Figure 4.4. Node and Edge affected.

4.4 Base Case

In this study, a base scenario is established to represent an unobstructed environment where individuals can freely move through the available paths. This unrestricted movement is facilitated by all the structural elements such as doors and windows. To calculate the shortest path to the main exit, the Pgrouting module in PostgreSQL is utilized. The base case scenario represents an unobstructed flow of occupants, allowing them to exit without encountering any blockages along the path.

4.4.1 Assumptions

In this scenario, the assumption is made that there are no obstructions along the pathway, and only time delay is taken into account. Furthermore, it is assumed that there is a singular shared exit in this particular case.

4.4.2 Result

As an illustration *Figure 3.1* , consider room 1, which has an occupancy of 20 individuals. However, the capacity of the edge leading to the door is limited to 16 occupants at a time as described in *section 4.2*. This implies that there will be a delay or lag in the evacuation process. If there were no lag, the total time from source to destination could simply be the sum of individual travel times. In the **presence of lag**, first occupant took only **26 seconds** to reach the main door. However, in same case, the last occupant in the queue requires **254 seconds** to exit. This discrepancy highlights the impact of capacity limitations on evacuation times. *Figure 4.5* depicts the base scenario, where evacuees are utilizing the main exit. It is important to note that if alternate exits were chosen, the evacuation times would be longer. By considering such scenarios and analyzing the effects of lag and capacity restrictions, the approach provides meaningful perspectives into evacuation planning. It enables the estimation of evacuation times, ensuring that appropriate measures can be taken to mitigate delays and improve overall evacuation efficiency.

Figure 4.5. Timestamp for Base Case Scenario: No Fire Blockage

4.4.3 Summary

The analysis reveals that capacity limitations, illustrated in Room 1's evacuation scenario, significantly affect the efficiency of the process. The imposed lag due to restricted exit capacity results in a notable increase in total evacuation time. In certain scenarios, pathway blockages may give rise to the emergence of new alternate exits, such as windows. This, in turn, can result in disturbances to the existing network path.

4.5 Base Case : Critical Node blockage (Fire)

In the adverse case scenario of a fire in the building, the path to the main exit and the designated evacuation point is blocked. This scenario represents a critical situation where multiple edges converge, making it the worst-case scenario. To simulate this scenario, the blockage is implemented at the most crucial point, resulting in the disruption of the main graph. *Figure 4.6* showcases the process of path identification, where representative agents are assigned to each room. The number of agents corresponds to the potential exits available for that specific space. The agents can be classified into two types: normal agents, who follow the known path (P_0) leading to the main exit, and special agents, who choose one of the alternate paths. The activation of special agents occurs when the traditional path (P_0) is disrupted, and their behavior is influenced by the prevailing conditions. Multiple evacuation agents are present in each space, and their selection of exits and paths relies on the graph or sub-graph appropriate for their specific choice. By deploying various types of agents and utilizing the available graph structures, the approach ensures flexibility and adaptability in the evacuation process, effectively catering to diverse scenarios and optimizing evacuation routes for individuals in different spaces.

4.5.1 Assumptions

In this particular scenario, it is assumed that there are multiple exits available, and the presence of lag along the path is attributed to the blockage of critical nodes.

4.5.2 Result

The result shows multiple sub-graphs are generated of a single combined graph. A sub-graph connects the alternate exits of Room 1, Room 4, and Room 5, while a larger sub-graph connects the alternate exits of Room 2, Room 3, and Room 6 as shown in *Figure 4.6*. Since the primary graph network is no longer accessible, the agents in each room select the available alternate exits and windows as their evacuation routes. The evacuation time for the last person in this adverse scenario is significantly increased, reaching 3195 seconds. This substantial increase in evacuation time compared to the base scenario indicates the severity of the situation and the challenges posed by the blockage. *Figure 4.6* provides a visual representation of the agents' movement during this scenario, depicting their paths as they navigate toward the available exits. By simulating such adverse scenarios and analyzing the behavior of agents, this approach provides valuable insights into emergency situations. It allows for the evaluation of evacuation strategies, the development of a backup plan to ensure the safety and efficient evacuation of occupants during critical events.

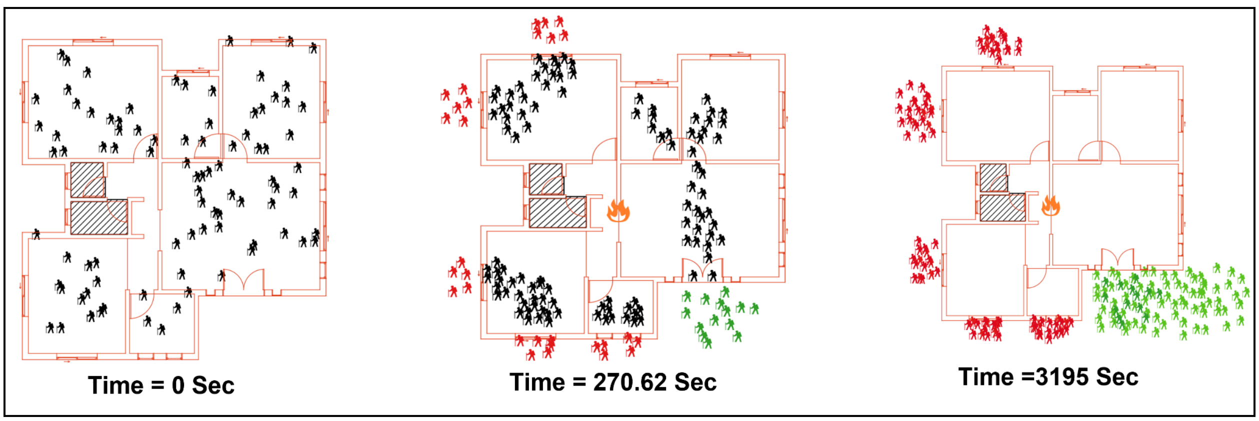

Figure 4.6. Timestamp for Adverse Case Scenario: Fire Blockage at critical point

4.5.3 Summary

The study's outcomes reveal the generation of multiple sub-graphs within a unified network. Notably, one sub-graph links alternate exits of specific rooms, while a larger sub-graph connects exits from others. In this adverse scenario, with the primary network inaccessible, occupants select alternate exits and windows, resulting in a significant increase in evacuation time. This stark contrast from the base scenario underscores the severity of the situation, highlighting challenges posed by critical node blockages.

Chapter 5

Path Planning In Near Real Scenarios

5.1 Redefined Space Model

This is the new version of section 4.3 as the same base model has been now introduced with the real world scenarios. The infusion of real-world scenarios involves incorporating objects or obstructions along the pathways. There are several exits based on the situations of the individuals in the space model. The space model, expounded in Section 5.2, undergoes a comparative analysis with the model outlined in Section 4.3. Subsequent sections provide detailed information: Section 5.2 navigates a space model featuring a single exit, Section 5.3 illuminates the plan's adaptation to include alternate exits, and Section 5.4 explores the emergence of a new exit stemming from the blockage of critical nodes.

5.2 Space with Obstacles Considering One Exit

In the base scenario, the evacuation process is analyzed considering the presence of obstacles within the space *Figure 3.3*. The number of occupants in this scenario is set at 70, taking into account the reduced available space due to the placement of obstacles such as furniture within the model. The **occupancy count of 70 occupants** is based on the remaining unoccupied area within the subspace after accounting for the presence of obstacles. This count is used for the evacuation calculation in this particular scenario. It is important to note that the number of occupants can vary based on the specific configuration of obstacles and the size of the space. To analyze the evacuation process, a graph is generated, as shown in *Figure 5.1*, depicting the variation in time as the evacuation progresses. The graph illustrates the impact of obstacles on the evacuation process, particularly in terms of the door capacity and the delay caused by the positioning of obstacles within the space. In this scenario, with a door capacity of two, the graph demonstrates fluctuations in the evacuation process due to the presence of obstacles. These obstacles create constraints and affect the flow of occupants towards the exit door.

5.2.1 Assumptions

Each subspace centroid is assumed to have an unobstructed view of the exit door, allowing occupants to evacuate through the designated exit route. Only one exit is present and the lag is incorporated. The result has been compared with the base case occupants featuring a total of 89 individuals calculated based on the area. In Section 5.2.2, the presence of obstacles leads to a reduction in areas, resulting in a fixed occupant count of 70. This count is then compared with the 70th individual in the base case scenario.

5.2.2 Result

As a result, the time taken for the **seventieth occupant** to exit the space is recorded as **215 seconds**. To provide a comparison, the evacuation time for the base case without obstacles, considering the same number of occupants, is approximately **194 seconds**. This indicates that the presence of obstacles within the space leads to a longer evacuation time due to the additional challenges and hindrances faced by occupants in navigating around the obstacles. Analyzing the differences in evacuation times between scenarios with and without obstacles provides valuable insights into the impact of obstacles on evacuation efficiency. By identifying areas of delay, strategies can be developed to optimize evacuation plans and improve overall safety during emergency situations. It is important to consider that the results obtained from this analysis are specific to the given scenario and assumptions made. Real-life evacuation scenarios may involve more complex factors and dynamics that can influence evacuation times. Therefore, further studies and simulations may be required to assess a wide range of scenarios. In conclusion, the base scenario with obstacles provides insights into the evacuation process considering the presence of obstacles within the space. The occupancy count of 70 occupants takes into account the reduced available space due to obstacles. The graph analysis reveals fluctuations in the evacuation process, particularly due to the door capacity and the positioning of obstacles. Comparing the evacuation time in scenarios with and without obstacles highlights the impact of obstacles on evacuation efficiency. These findings can contribute to the development of effective evacuation strategies, space design considerations, and obstacle placement guidelines to enhance emergency preparedness and ensure the safety of occupants during evacuations.

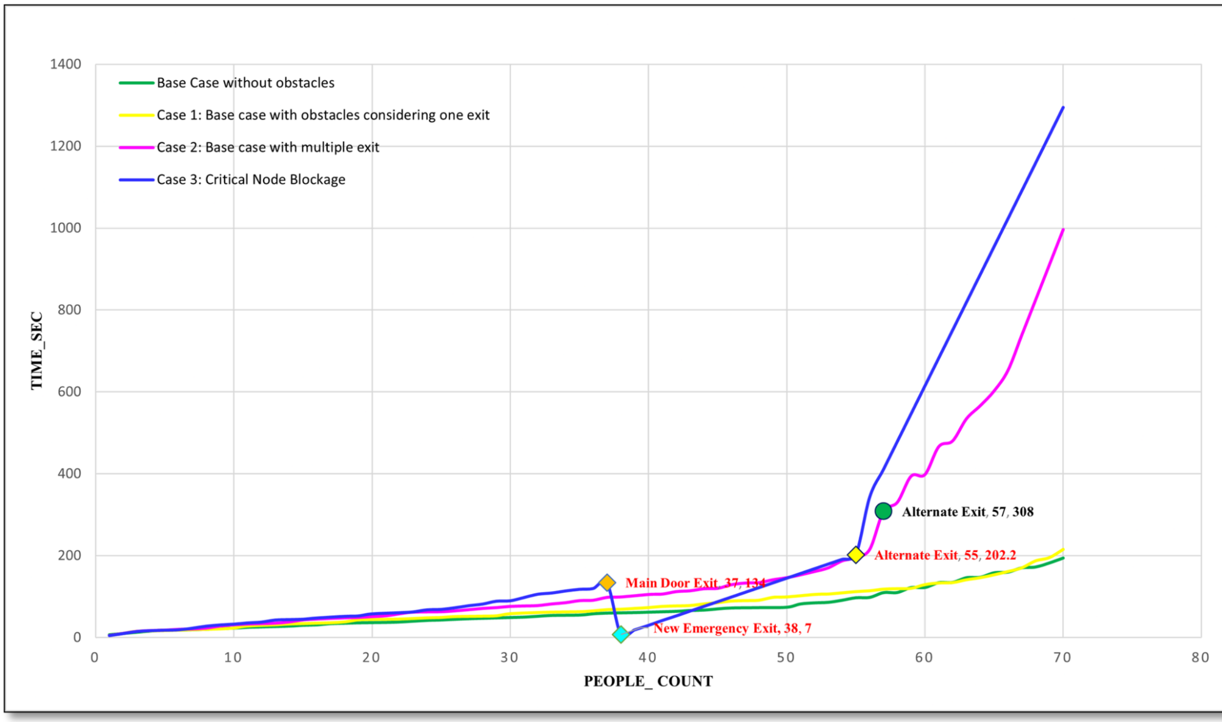

Figure 5.1. : People Count v/s time graph for Base case, Static, Dynamic, and both (Static and Dynamic).

5.2.3 Summary

This difference underscores that the presence of obstacles within the space leads to a prolonged evacuation time, as occupants face additional challenges navigating around obstacles. Analyzing these variations in evacuation times provides view into the hindrances posed by obstacles on evacuation efficiency. The base scenario with obstacles offers insights into the evacuation process within a constrained space. The analysis, considering a reduced occupancy of 70 due to obstacles, reveals fluctuations influenced by door capacity and obstacle positioning. Comparing evacuation times in scenarios with and without obstacles shows the impact of obstacles. In certain scenarios such as in section 5.3, pathway blockages may give rise to the emergence of new alternate exits, such as windows. This divides the path network in several new graphs.

5.3 Space with Obstacles Considering Multiple Exit

In this analysis, a specific scenario is considered where a blockage occurs at node 5 due to displacement of some material during rush, as shown in *Figure 5.2*. This blockage restricts the occupants from using the main door as an exit route. As a result, occupants are required to find an alternate exit, which in this case is window node 10. Consequently, the path generation needs to be regenerated to accommodate this change in the evacuation route. It is important to note that this situation can also occur in other space models with different configurations. In this dynamic condition, there is a possibility of any internal exit or node within the network becoming nonfunctional or acting as an obstacle, impeding free movement. If a blockage occurs at a particular node, it hinders the occupants' ability to evacuate through the main door. In this illustrated case, this needs the opening of an alternate exit - a window of Room 3. The process of finding a new evacuation path occurs dynamically and can apply to other building space models as well. The presence of multiple exits, including windows, provides additional options for occupants to evacuate when faced with obstacles or congested paths. However, it is essential to carefully evaluate the suitability and safety of using windows as exit routes in specific situations, considering factors such as the accessibility of windows, and the physical capabilities of occupants. The analysis presented in this scenario offers insights into the impact of blockages and the utilization of alternative exits on evacuation times. By considering different scenarios and configurations, it becomes possible to assess the effectiveness of evacuation plans and identify potential areas of improvement. These findings can inform decision-making processes related to building design, emergency planning, and the implementation of mitigation strategies to enhance occupant safety during evacuations. It is worth noting that the results obtained from this analysis are specific to the given scenario and assumptions made. Real-life evacuation scenarios may involve various complexities and uncertainties, such as different types of blockages and occupant behaviors. Therefore, it is crucial to conduct further studies and simulations to explore a wide range of scenarios, validate the findings, and refine evacuation strategies based on specific building layouts and emergency scenarios.

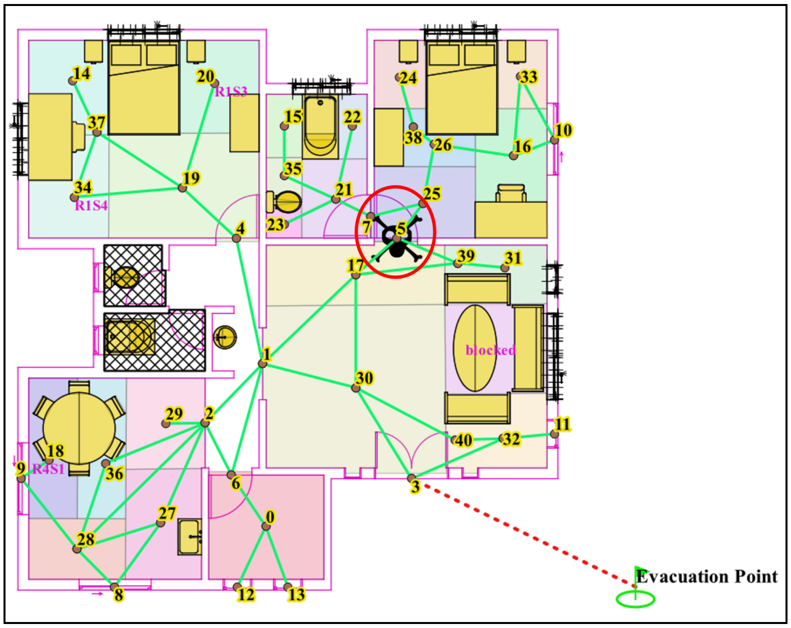

Figure 5.2. : Floor plan with blocked node.

5.3.1 Assumptions

There are multiple exits present in the case and each subspace centroid is assumed to have an unobstructed view of the exit door, allowing occupants to evacuate through the designated exit route. The node 5 is blocked to showcase alternate exit.

5.3.2 Result

As illustrated in *Figure 5.1*, due to delays, it **takes approximately 996 seconds** to evacuate the seventieth person. The abrupt increase at the **green point (Alternate exit 57, 308)** in *Figure 5.1* is attributed to the creation of a new opening within the room. This scenario highlights the significance of considering alternative exit routes and the potential for blockages during evacuations.

5.3.3 Summary

During evacuations, it is important to consider the availability of multiple exits, including windows, in addition to the main door. In certain situations where blockages occur, occupants may need to use alternative exits, requiring a regeneration of the evacuation path. The analysis presented in this scenario demonstrates the impact of such blockages on evacuation times, with a specific example showing a prolonged evacuation time for the seventieth person. These findings underscore the importance of considering alternative exit routes and potential blockages in evacuation planning and building design.

5.4 Critical Node blockage (Fire) : Emergence of New Exit

In cases where critical node blockages occur and no other exits are available for some occupants in the space model, it is observed that people's behavior changes. In such situations, occupants may resort to removing or dragging obstacles that can be easily manipulated. This paper presents one such case, as depicted in *Figure 5.3*, where window node 12 is replaced with an emergency door to examine the outcomes.

By introducing the emergency door at node 12, occupants from Room 4 now have an alternative exit route. As a result, they pass through the emergency door to evacuate. However, it is important to note that this scenario represents an exceptional case, and the behavior of occupants in real-life situations may vary based on several factors, including their awareness, physical capabilities, and the availability of emergency procedures and guidance. The extended distance contributes to the overall evacuation time as well. It is important to recognize that this adverse case highlights the challenges that can arise when occupants are faced with limited or no alternative exits. In such situations, occupants may resort to unconventional measures, such as removing or manipulating obstacles, to ensure their own safety. This behavior underscores the critical role of occupant awareness, training, and emergency preparedness in facilitating effective evacuations.

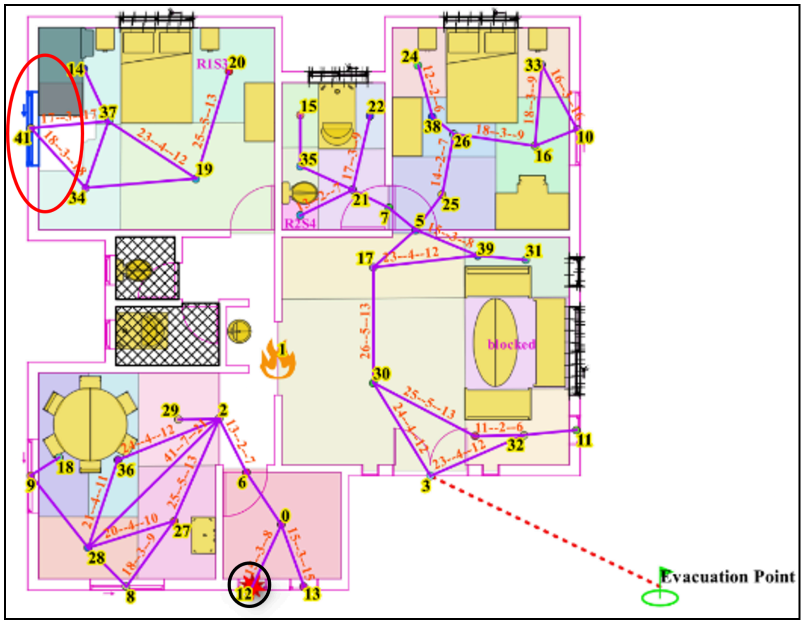

Figure 5.3. Floor plan with removable furniture and alternate exit as a door

5.4.1 Assumptions

In this case the critical node is blocked due to fire and the new exit emerges.There are multiple exits present in the case and each subspace centroid is assumed to have an unobstructed view of the exit door, allowing occupants to evacuate through the designated exit route. It is worth noting that the results obtained in this analysis are specific to the given scenario and assumptions made. Real-life evacuation scenarios may present additional complexities, such as varying occupant behaviors, diverse physical capabilities, and unforeseen obstacles.

5.4.2 Result

The analysis of this adverse case reveals that it **takes approximately 1295 seconds** for the last person to be evacuated. This prolonged evacuation time can be attributed to several factors. Firstly, the delay occurs due to the time required for occupants to remove or drag furniture obstacles in their path. This additional task significantly impacts the overall evacuation time. Secondly, the path taken from one room to another may be longer when occupants have to navigate through multiple spaces to reach the emergency door. In this instance, the graph depicted in *Figure 5.1* displays a sudden decrease and subsequent increase in both the static and dynamic scenarios. The drop is observed at the **orange point (Main door exit 37, 134)** as a result of the introduction of the **(New Emergency exit 38, 7)** at the **Cyan Point**. However, the graph rises again at the **Yellow point (Alternate exit 55, 202.2)** due to the opening of windows and the removal of obstacles in Room 1.

5.4.3 Summary

The findings presented in this case emphasize the need for comprehensive emergency planning and preparedness. It is crucial to consider various scenarios, with critical node blockages, when designing evacuation strategies and building layouts. It is essential to evaluate the impact of furniture placement and room layouts on evacuation times. Optimizing the arrangement of furniture and fixtures within spaces can help minimize obstacles and streamline evacuation routes. This case with critical node blockage illustrates the behavioral changes exhibited by occupants when no other exits are available in the space model. The introduction of an emergency door as an alternative exit leads to a prolonged evacuation time due to the time required for obstacle removal and the increased path length. This case underscores the importance of occupant awareness, emergency preparedness, and comprehensive evacuation planning. Addressing factors such as furniture placement, room layouts, and occupant training can contribute to more effective and efficient evacuations.

5.5 Summary for all the cases

This chapter shows various evacuation scenarios within a space, revealing multiple sub-graphs generated within a combined graph to illustrate distinct evacuation routes. In adverse scenarios where the primary graph network is blocked, people evacuate through alternate exits such as windows, significantly increasing evacuation time to 3195 seconds, indicating the severity of the situation. The presence of obstacles within the space increases evacuation time, with the seventieth occupant taking **215 seconds** to exit compared to **194 seconds** in a base case without obstacles, focusing the impact of obstacles on evacuation efficiency. During potential blockages and considering alternate exit shows delays in evacuation, as given by a scenario taking approximately **996 seconds** for the seventieth person to exit. Analysis of an adverse evacuation case, where the last person takes approximately **1295 seconds** to evacuate, reveals factors such as obstacles and longer paths between rooms influencing evacuation dynamics.Changes in evacuation dynamics, such as sudden decreases followed by increases, are observed due to factors like the introduction of new exit points and obstacle removal.

Chapter 6

Simulation: Campus Building

6.1 Simulation Matrix

Path computation for the shortest path calculation to the main exit is obtained using the Pgrouting module in PostgreSQL. Here, the seat spaces are considered source nodes, and the doors as the destination node. Using the Dijkstra algorithm, all potential shortest paths for each source-destination combination are obtained. The Matrix of this study is given below. Here E_0 is no of exits, Y_0 is the Count of people whereas P_0 is the Physical layout of the plan.

$$\mathbf{E_0\ Y_0\ P_0}$$

In this study Y0 and P0 are constant, and only E0 is varying.

6.2 Results

6.2.1 Cases for Himalaya 105

6.2.1.1 Only one exit is available [E_1 Y_0 P_0]

In this particular case, the evacuation process is determined by the number of available exits. The study considers a total of 230 occupants, with only one exit accessible for evacuation. The available exit options include door numbers 70, 71, 72, or 74. To evaluate the evacuation process, the study measures the time taken by the last person to exit through each door. For door number 70, the last person exiting from H105 takes 157 seconds. Likewise, for door 71, door 72, and door 73, the last person takes 165 seconds, 194 seconds, and 198 seconds, respectively, to evacuate. These times are calculated by considering the delay caused by the cascading effect in the queue. Based on the analysis of these four doors, it is observed that **door 70** exhibits the shortest evacuation time among the options. Therefore, it can be concluded that door 70 is the most efficient exit point considering the time taken by individuals to evacuate. The evacuation pattern is visualized in *Figure 6.1* (a), (b), (c), and (d), providing a heat map representation of the evacuation process through the different doors. These figures illustrate the movement and flow of individuals during the evacuation process, offering insights into the evacuation patterns within the studied area.

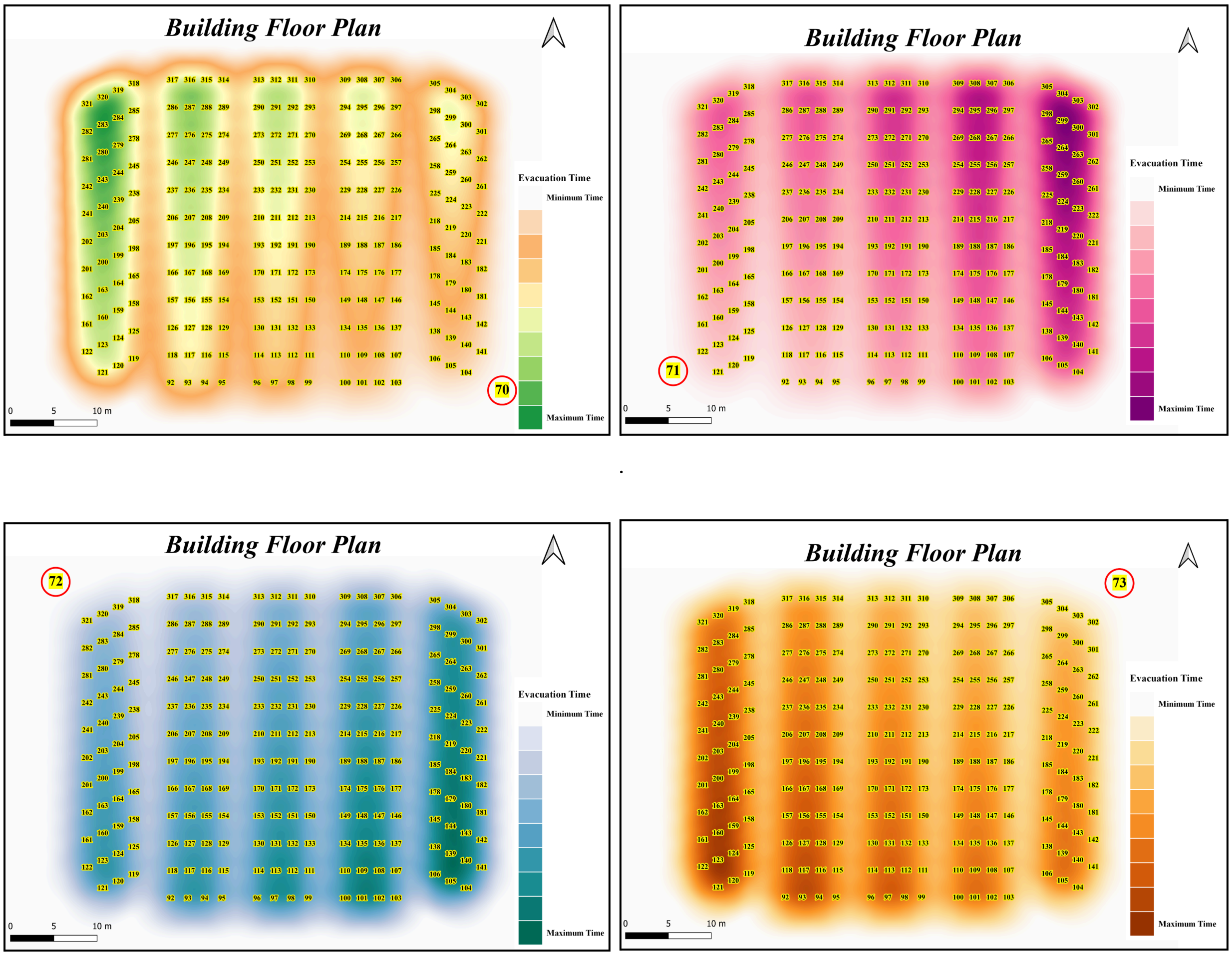

Figure 6.1. Building floor plan with maximum and minimum time through (a) Door 70 (b) Door 71 (C)Door 72 (d) door 73

6.2.1.2 Only two exits are available [E_2 Y_0 P_0]

In this scenario, we consider the presence of two exits with various combinations of pairs. The possible combinations of exits include door 70-door 71, door 70-door 72, door 70-door 73, door 71-door 72, door 71-door 73, and door 72-door 73. Each combination represents a different evacuation route within the studied area. For each combination, the study calculates the time taken by the last person to evacuate through the specified pair of exits. The recorded times for the respective combinations are as follows: **127 seconds**, **119 seconds**, **149 seconds**, **156 seconds**, **125 seconds**, and **170 seconds**. After analyzing these six combinations, it is determined that the paired **door 70-door 72** demonstrates the shortest evacuation time of **119 seconds** as mentioned in *Figure 6.2*. In *Figure 6.2 (a)* the path generated in green shows the minimum time taken from the position to the door exit where as red shows the maximum time taken by the individuals. Thus, this combination proves to be the most efficient in terms of the time taken by individuals to exit the evacuation zone. By considering the various exit combinations and evaluating the evacuation times, this study provides insights into the optimal routes for evacuating individuals.

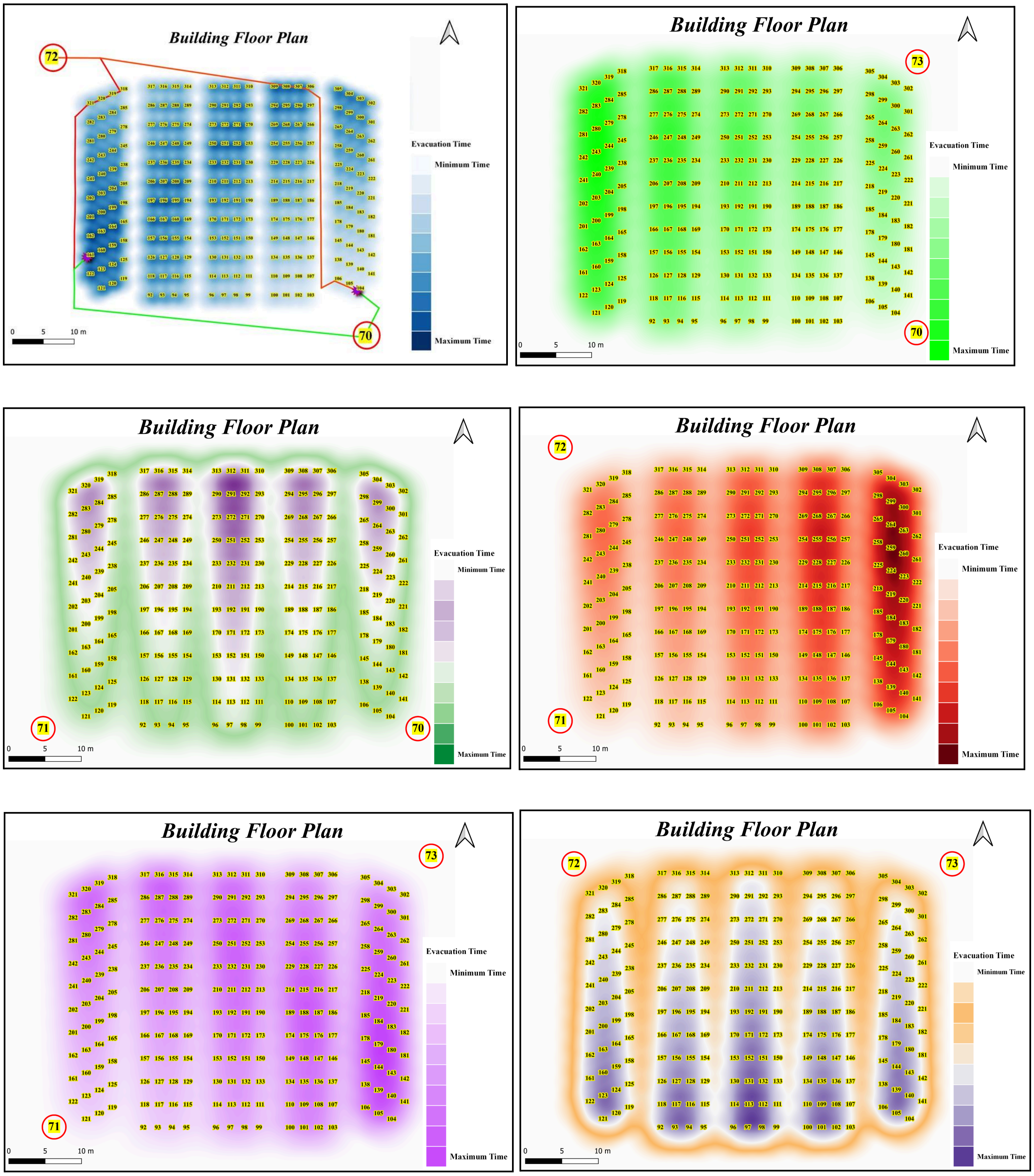

Figure 6.2. Building floor plan with maximum and minimum time through (a) door 70-72 (b) door 70-73 (c) door 70-71 (d) door 71-72 (e) door 71-73 and (f) door 72-73

6.1.2.3 Only three exits are available [E_3 Y_0 P_0]

In this case, the number of exit doors has been increased to three, leading to multiple combinations of exits. The potential combinations include door 70-door 71-door 72, door 70-door 71-door 73, door 72-door 71-door 73, and door 73-door 72-door 70. By computing the path computation matrix, the study determines the time taken for individuals to evacuate through each exit combination. The recorded times for the respective pairs are 102 seconds, 107 seconds, 125 seconds, and 119 seconds. On the basis of these results, it is obtained that the pair **door 70-door 71-door 72** exhibits the minimum evacuation time for individuals as in *Figure 6.3*. This combination proves to be the most efficient in terms of the time taken for individuals to exit the area.

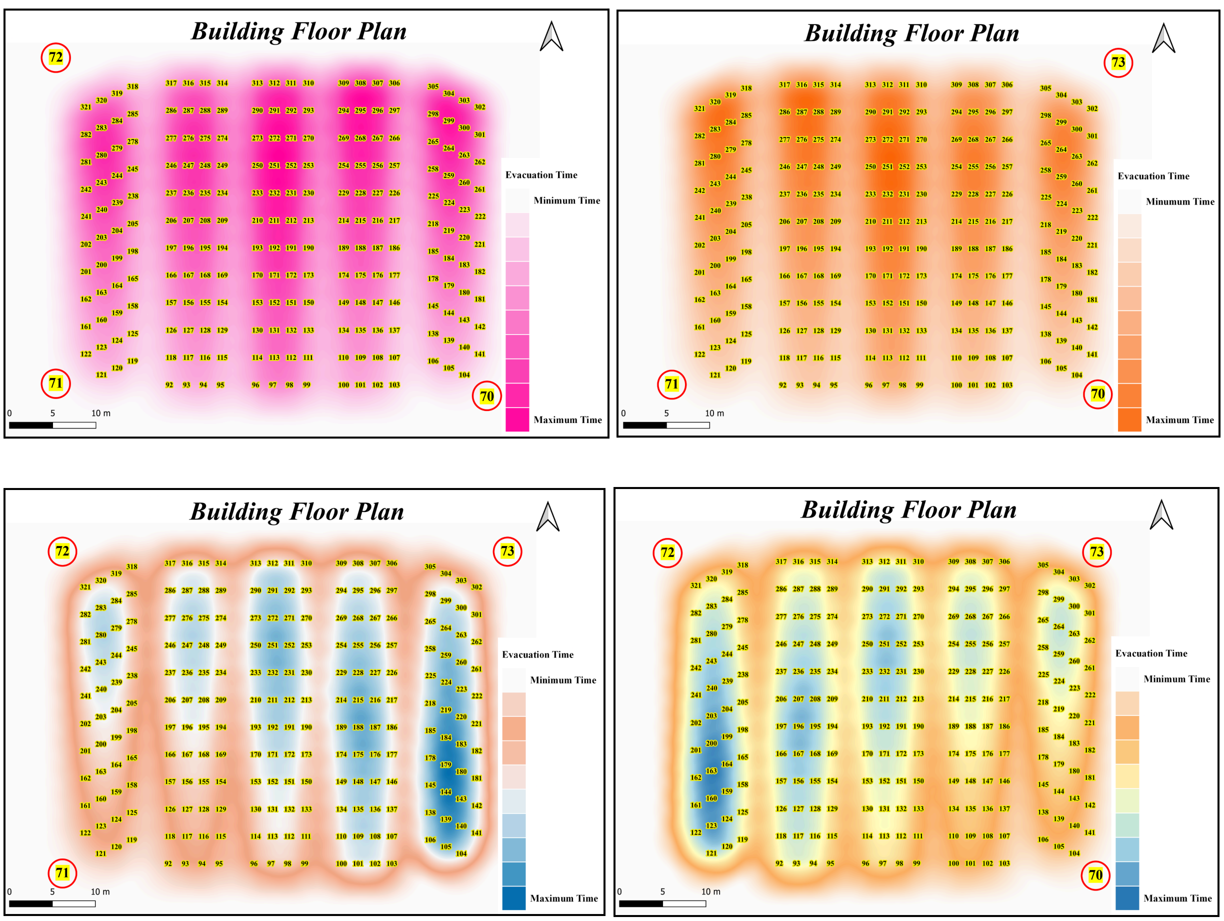

Figure 6.3. Building floor plan with maximum and minimum time through (a) door 70-71-72 (b) door 70-71-73 (c) door 72-71-73 and (d) door 73-72-70

6.1.2.4 All four exits are available [E_4 Y_0 P_0]

In this study, the number of exits plays an important role in determining the evacuation time. This specific case considers four exits, where all exits are available for evacuation. The occupancy level is at 100%, meaning all seats are occupied. Recorded time for the last person to evacuate from the area **without lag: 93 seconds.**

The time taken by the last person to evacuate from the area **with lag** is recorded as **144 seconds**. *Figure 6.4*, displayed below, illustrates the range of evacuation times, highlighting both the maximum and minimum durations taken by individuals to evacuate from space. This visual representation provides a clear understanding of the variability in evacuation times observed in the study.

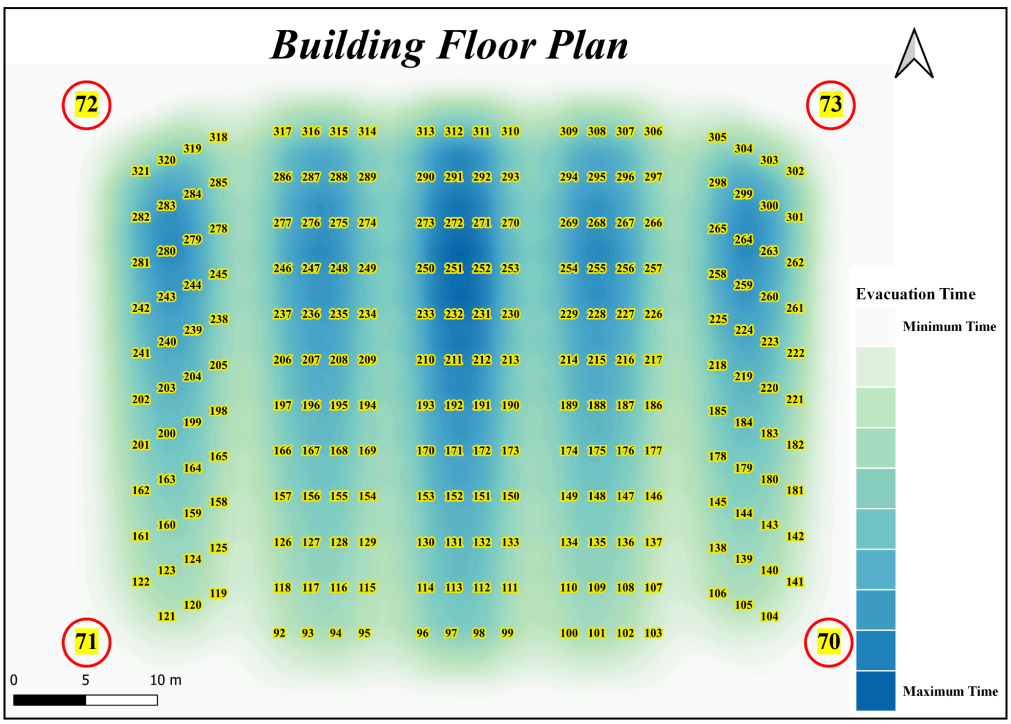

Figure 6.4. Building floor plan with maximum and minimum time through all the doors

6.2.2 Cases for Himalaya 205

6.2.1.1 Only one exit is available [E_1 Y_0 P_0]

In this particular case, the evacuation process is determined by the number of available exits. The study considers a **total of 230 occupants**, with only one exit accessible for evacuation. The available exit options include **door numbers 70, 71, or 308**. To evaluate the evacuation process, the study measures the time taken by the last person to exit through each door. For **door number 70**, the last person exiting from H105 takes **152 seconds**. Similarly , for **door 71** and **door 308**, the last person takes **159 seconds** and **193 seconds**, respectively, to evacuate. Based on the analysis of these three doors, it is observed that **door 70** has the shortest evacuation time among all. Therefore, it can be concluded that **door 70** is the most efficient exit point considering the time taken by individuals to evacuate. The evacuation pattern is demonstrated in *Figure 6.5 (a), (b), and (c)*, providing a graphical representation of the evacuation process through the different doors.

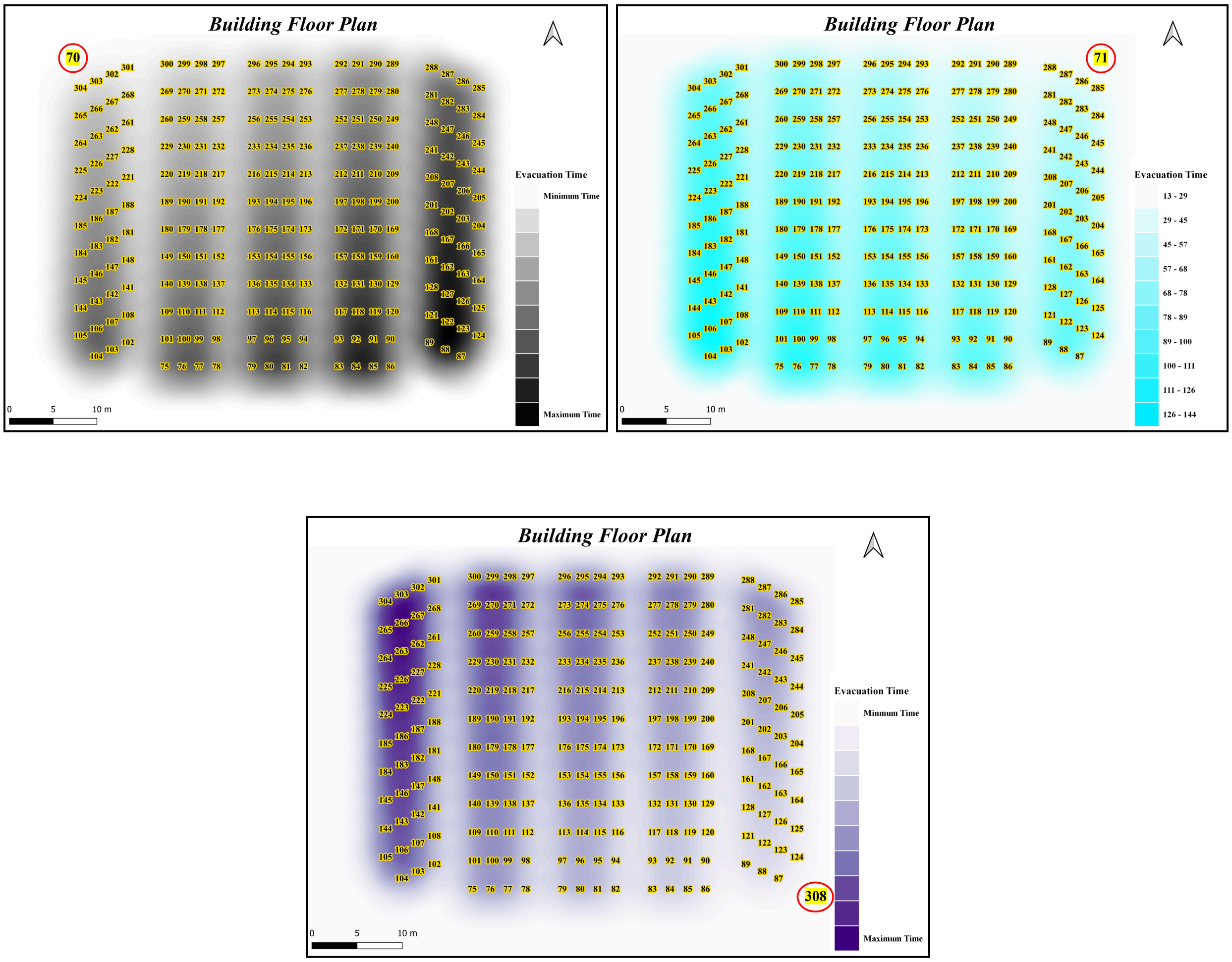

Figure 6.5. Building floor plan with maximum and minimum time through (a) door 70 (b) door 71 and (c) door 308

6.2.1.2 Only two exits are available [E_2 Y_0 P_0]

In this scenario, we discuss the evacuation time for two exits, leading to various combinations of exit pairs. The potential combinations include **door 70-door 71, door 70-door 308,** and door **71-door 308**. Each combination represents a different network for evacuation within the studied area. For each combination, the study calculates the time taken by the last person to evacuate through the specified pair of exits. The recorded times for the respective pairs are as follows: **128 seconds, 104 seconds,** and **155 seconds**. After the analysis of these three combinations, it is determined that the paired **door 70-door 308** gives the shortest evacuation time of **104 seconds** as in *Figure 6.6*. Thus, this combination proves to be the most efficient in terms of the time taken by individuals to exit the evacuation zone.

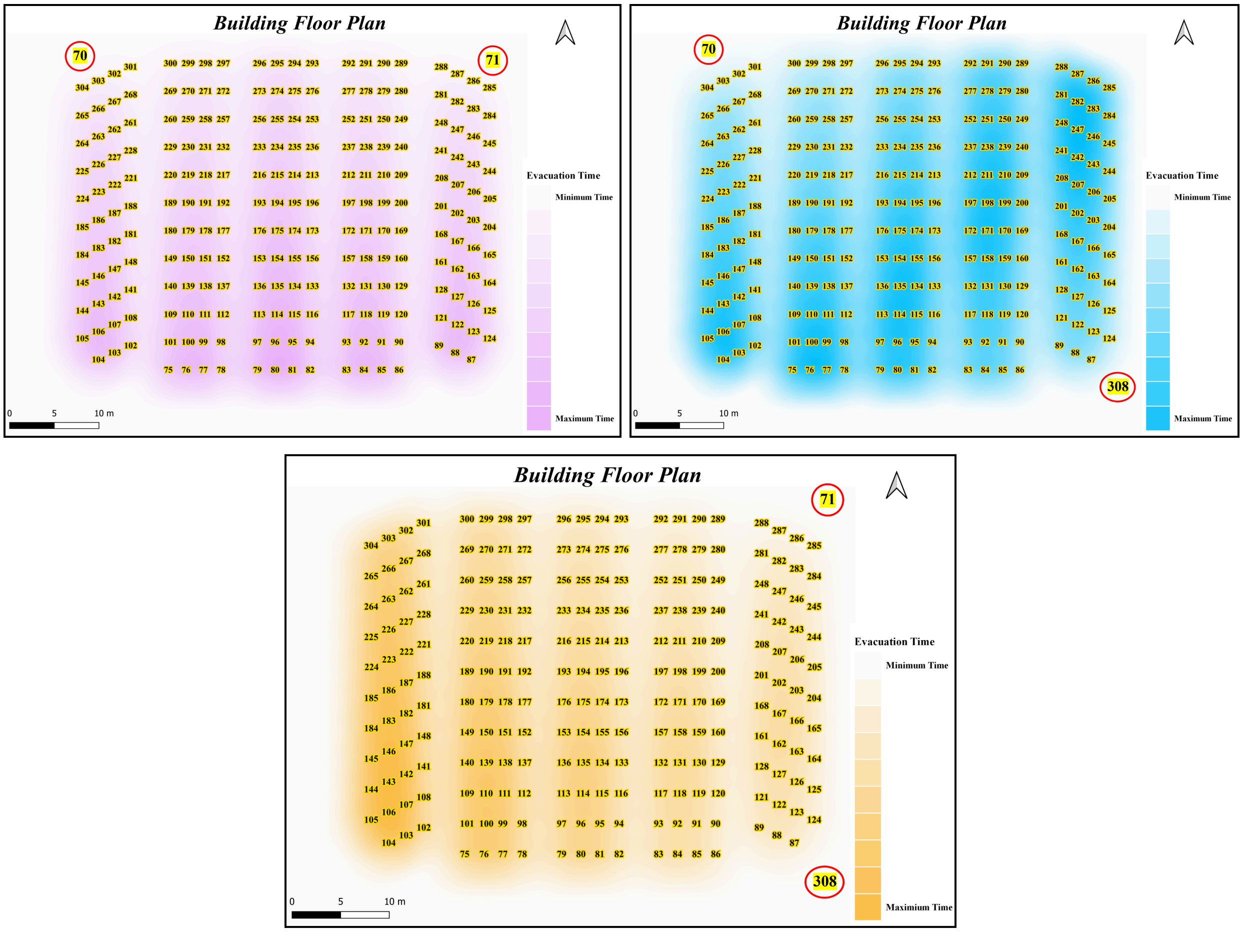

Figure 6.6. Building floor plan with maximum and minimum time through (a) door 70-71 (b) door 70-308 and (c) door 71-308

6.2.1.3 All three exits are available [E_4 Y_0 P_0]

In this particular case, there are three exits available, meaning all exits are accessible for evacuation. The occupancy level indicating full capacity is at 100%. Recorded time for the last person to evacuate the area **without lag : 96 seconds**.

The recorded time taken by the last person to evacuate from the area **with lag** is **137 seconds**. *Figure 6.7*, presented below, illustrates the range of evacuation times, showing both the maximum and minimum durations taken by individuals to evacuate.

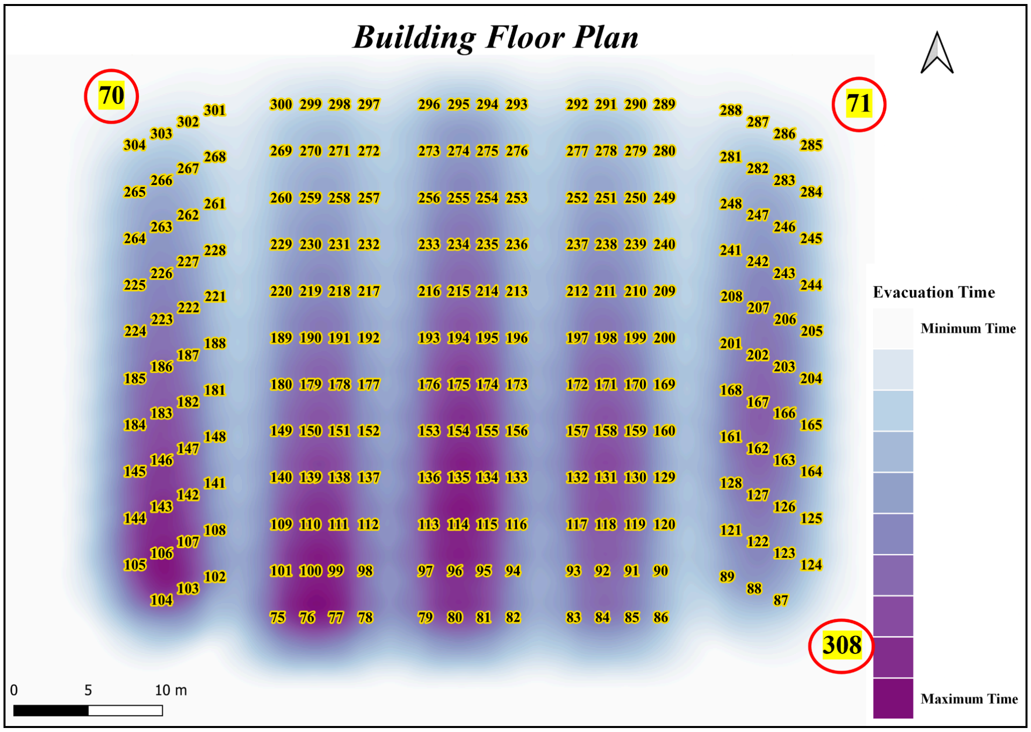

Figure 6.7. Building floor plan with maximum and minimum time through all the doors

Chapter 7

Conclusion

The study's initial focus lies in introducing a novel methodology that effectively simulates the evacuation of building occupants, considering dynamic path changes to exits using a 2D structural plan. It's highlighted that during adverse scenarios, where rapid evacuation is critical, considering alternative exits becomes imperative. The results clearly show that such adverse conditions significantly prolong evacuation times, underscoring the importance of flexible evacuation plans that adapt to changing dynamics. Intriguingly, the study showcases that the presence of obstacles in the evacuation path only marginally extends evacuation times. However, the scenario takes a different turn when occupants utilize alternate exits, demonstrating a significant increase in evacuation duration. This reveals the critical role of carefully planning and considering alternate exits to streamline the flow of evacuees, reducing delays and ensuring a smooth evacuation process. Building on these findings, the study emphasizes the necessity of meticulous planning and evaluation of exit capacities and access times. An understanding of how these factors directly influence evacuation times is crucial. By optimizing these parameters, more efficient evacuation strategies can be developed, ensuring the safety and well-being of occupants during emergencies. The research also delves into the realm of multi-floor evacuations, indicating an avenue for future exploration. Additionally, incorporating real-time simulations, understanding crowd dynamics, vulnerability assessments, and evacuation drills present exciting opportunities for further research. These avenues promise to enhance evacuation strategies and emergency response plans, ultimately reinforcing safety measures and optimizing responses during critical situations. Moreover, the study underscores the pivotal role that exit availability plays in evacuation efficiency. Multiple exits are showcased to significantly enhance the evacuation process, suggesting that this aspect should be a focal point in the design and evaluation of evacuation plans. It becomes evident that increasing the number of exits can substantially reduce evacuation times, enhancing overall safety and potentially mitigating risks during emergencies.

The proposed work focuses on the conversion of a 3D to 2D structure for evacuation modeling of occupants, with an emphasis on subspaces that emerge due to the presence of obstacles in the spaces. These subspaces provide clear lines of sight to the exit and are integral parts of the evacuation path. In comparison to the base scenario without obstacles, the current approach with obstacles, where the primary exit was the door, only resulted in a slightly higher evacuation time of 215 seconds for 70 occupants, compared to 194 seconds in clear spaces without obstacles. This marginal increase in evacuation time can be attributed to the longer path lengths required to navigate through the subspaces. In some cases, spaces may have multiple exits, such as doors, windows, or emergency exit doors. When obstructions occur, leading to a disconnection in a part of the network, occupants may utilize alternate exits, such as windows, for certain spaces. The results indicate that in case 2, where occupants utilize alternate exits, it takes approximately 996 seconds to evacuate, resulting in nearly a four-fold increase in evacuation time. This highlights the importance of properly planning and considering alternate exits to reduce delays in accessing them and to ensure smooth flow rates of people across these exits. Furthermore, an adverse case with critical node blockage was examined, where no other exits were available for some occupants, except for an emergency door that replaced a window node. In this scenario, occupants had to remove or drag obstacles to create a pathway toward the emergency door. The evacuation time significantly increased, with the last person taking approximately 1295 seconds to exit, which represents a six-fold increase compared to the base scenario with obstacles. This emphasizes that dynamic changes, such as blockages and the position of obstacles, can lead to vastly different outcomes in evacuation scenarios. To enhance the proposed method, future work should focus on seamlessly capturing and integrating the static and dynamic components of indoor spaces. This integration would involve considering both the physical layout of the space and the potential changes that may occur during an evacuation, such as occupants manipulating obstacles. Additionally, developing an occupant-friendly information dissemination model would be valuable. Such a model could provide occupants with real-time guidance and instructions during an evacuation, ensuring that they make informed decisions and follow the most efficient routes. It is essential to recognize that the results obtained from this study are specific to the assumptions and scenarios considered. Real-world evacuation situations may involve various complexities, including diverse occupant behaviors, physical capabilities, and unforeseen obstacles. Therefore, further research is required to validate the proposed method and explore a wide range of scenarios to ensure its effectiveness in different contexts. In conclusion, the proposed work addresses the conversion of 3D to 2D structures for evacuation modeling, emphasizing the importance of subspaces that emerge due to obstacles present in the spaces. The study demonstrates that incorporating obstacles in the evacuation path only marginally increases evacuation times compared to scenarios without obstacles. However, when alternate exits are involved or critical node blockages occur, significant delays in evacuation can be observed. These findings highlight the need for careful planning of alternate exits and considering dynamic changes that may affect evacuation outcomes. Future research should focus on integrating static and dynamic components of indoor spaces and developing occupant-friendly information dissemination models to enhance evacuation strategies.

It is evident that the number of exits has a significant impact on evacuation time. In the scenarios, the time taken for the last person to evacuate varied based on the available exits. In the case with only one exit, door 70 proved to be the most efficient, requiring the shortest time for individuals to evacuate. When two exits were available, the combination of door 70 and door 308/ door 71 and door 73 resulted in the fastest evacuation time. In the scenario with all three exits accessible, the evacuation time was further reduced. The study demonstrated that having multiple exits significantly improved the efficiency of the evacuation process. These findings emphasize the importance of considering the number and distribution of exits when designing and evaluating evacuation plans. Increasing the number of exits can help decrease evacuation times, enhance safety, and potentially mitigate the risks associated with emergency situations. By understanding the impact of exit availability on evacuation times, this study provides valuable observation for designing evacuation strategies and optimizing emergency response plans in various settings.

The study findings present several future research opportunities in evacuation planning and emergency response. These include exploring multi-floor evacuations, utilizing real-time simulations, understanding crowd dynamics, assessing vulnerabilities, and conducting evacuation drills. By further investigating these areas, we can enhance evacuation strategies, improve response plans, and ensure the safety of individuals during emergencies.

Future work should also focus on integrating static and dynamic components, along with developing occupant-friendly information. 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.

In 3D evacuation planning dynamic environmental factors must be considered by incorporating real-time hazards like spreading fire, smoke, flood water levels or structural collapses, and including environmental changes due to disasters, such as debris blocking paths or increasing water level. By utilizing Internet of Things (IoT) devices and sensors for real-time monitoring of building conditions and human movements to provide up-to-date information for evacuation plans, and developing VR-based training programs to prepare occupants and first responders using realistic 3D simulations. Optimization algorithms should be improved to dynamically adapt to changing conditions, employing machine learning techniques to predict bottlenecks and optimize the flow of evacuees based on historical data and simulations in case for flood or any other hazards. Scalability are also essential, requiring the expansion of frameworks to handle large-scale evacuations in settings like stadiums, airports, or entire cities, and creating customizable templates for various building types and disaster scenarios. Interdisciplinary collaboration with urban planners, architects is necessary to integrate evacuation planning into new building designs and develop guidelines that incorporate advanced strategies.
Finally, post-evacuation analysis should be implemented with tools to identify areas for improvement and update plans based on actual events and drills, continuously refining simulation models and strategies through data collection and feedback loops.

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LIST OF PUBLICATION

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

2. **Shreya** and **Rajan, K. S**.: Modelling Evacuation Strategies Under Dynamic Conditions Due To Obstacle Locations Based On A Semantic 3d Building Models, Int. Arch. Photogramm.RemoteSens.SpatialInf.Sci.,XLVIII-1/W2-2023,671–677,https://doi.org/10.5194/isprs-archives-XLVIII-1-W2-2023-671-2023, 2023.

3. **Shreya** and **Rajan K.S** Accepted for Poster Presentation for title "Enhancing Disaster Management with INSroute - Integrating Spatial Planning and Efficient Evacuation Strategies in Public Buildings" at FOSS4G-Asia Seoul during November 28 - December 02, 2023 at Seoul, South Korea.

4. **Shreya** and **Rajan K.S**: To be Submitted, Journal paper title "Evaluation of path planning algorithms for incorporating human behavior during disaster evacuation in indoor built environments" *Environment and Behavior 2024*