

**IIIrd Semester Project:**

**'Evaluation of simulation as a tool supporting emergency preparedness by testing evacuation scenarios in a hospital building'**



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**Operational Risk Management in Projects - Semester Project**

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# **Operational Risk Management in Projects**

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## Abstract

This study explores how computer agent-based simulation can help hospitals prepare for emergencies, especially with a special focus on evacuating patients and hospital staff. By using both methods as survey results and computer simulation the research reviews actual evacuation procedures, highlight main weaknesses and shows specific ways to improve. It pays special attention to making evacuation efficient; helping patients with limited mobility and prioritize patient care during emergencies.

The study gathers detailed data from medical and technical staff and later on from simulations created with Pathfinder software. The main findings show that hospitals need evacuation equipment and regular training to manage the complex hospital environment in different scenarios.

The results show that simulations present a flexible solutions to test new strategies and prepare for unexpected challenges by lower cost. This method provides practical advice for improving safety protocols in different situations and setups, including involving ill patients.

# 1. Introduction

The goal of this project is to ensure that patients and hospital staff can safely and quickly move to the exit during emergencies and under various scenarios. Dangerous incidents such as electrical failures or power outages have exposed the need for hospitals to maintain comprehensive and regularly updated emergency response scenarios. These incidents showed that evacuation procedures are inadequate in an environment where many patients cannot leave the building independently and may require evacuation using specialized beds or wheelchairs. [1] (Archea and John, 1979)

Human factors pose a significant challenge to emergency plans in hospitals. Medical staff work under constant pressure, making quick decisions while caring for patients during evacuation. Patients may be disoriented or critically ill, means, unaware of the severity of the situation. As the fastest route of evacuation may not be possible, patient movement typically requires additional staff and specialized equipment.

Computer simulations, especially models based on real-world situations, can help recreate the behavior of patients and staff in various unpredictable situations, such as fires or technical failures. These tools allow us to examine corridor and stairwell capacity, evacuation times for patients requiring assistance, and identify bottlenecks that may cause problems (Organization, 2025) [2].

Software such as Pathfinder is useful for simulating hospital setup, dimensions and allows for modeling evacuations, including beds, wheelchairs and other assisted patient movement. Each group requires different procedures, and simulations help make sure there are enough staff and equipment for a safe evacuation. Simulations give useful information that helps improve emergency plans and create procedures that can be adjusted to new, often unpredictable, situations.

This study looks at how pathfinder simulation tool can make hospitals safer and more resilient by testing scenarios with patients who have different mobility needs and problems like blocked evacuation routes. The main goal is to see how simulations can improve the evacuation plan, review emergency procedures to get better results in various hospital settings.

## 2. Literature Review

Hospital safety covers a broad range of danger possibility because patients often have limited mobility and hospitals must rely on strict clinical procedures. Recent studies point out that hospitals are very different from other multi-storage public buildings, not just in what they do but also in how they are organized and the risks they facing. Because of that factors, standard evacuation models and emergency plans need to be developed to fit the unique needs of healthcare settings.

### 2.1. Characteristics of Hospital Hazards

Research indicates that hospitals are exposed to a wide spectrum of hazards, including:

- \* Fires, especially started in technical rooms, server rooms, kitchens, or patient rooms
- \* Smoke in corridors and technical rooms may hindering the evacuation of bedridden patients,
- \* Power outages which may affecting the operation of life-support systems
- \* Natural disasters as floods or earthquakes, during which hospitals must also function as crisis centers.

## 2.2 Specifics of Hospital Evacuation

Most individuals inside a hospital cannot evacuate independently. This group includes:

- bedridden and wheelchair patients,
- elderly or cognitively impaired individuals,
- ICU patients,
- ventilated patients,
- psychiatric patients.

Research shows that evacuating patients requires significantly more resources than evacuating people in office buildings. Each patient requires usually individualized handling which is not accounted for in standard evacuation models for the general buildings.

## 2.3. Critical Infrastructure

Hospitals contain systems that are essential for patient survival. The literature stresses that infrastructure, such as:

- fire protection systems,
- medical gas distribution units,
- UPS systems and emergency generators,
- HVAC systems ensure sterile or pressure-controlled environments,
- diagnostic devices requiring stable power supplies,
- High-security biological areas

Must be fully considered in evacuation planning. Research also suggests that the failure of a single system (e.g., an electrical distribution room) can trigger a cascade of secondary problems. [3] These scenarios will be analyzed in further part as power outage which could lead to fire.

## 2.4. The Role of Simulations in Hospital Preparedness

In the past ten years, more studies have used computer simulations to look at hospital safety. Agent-based models, like the Pathfinder program used in this project, help researchers to:

- simulate moving hospital beds, wheelchairs and equipment,
- model delays that happen because of staff decisions,
- recreate different types of patient profiles,
- analyze how many people corridors and key junctions can handle
- evaluate critical situations where evacuation routes are blocked

Research shows that simulations could help estimate real evacuation times for patients who need extra help, which often take longer than hospital plans expect.[4] Studies also find that these tool let hospitals test different evacuation strategy and figure out how many staff and equipment is necessary for a safe evacuation.

## 2.5. Simulations Considering Patient Diversity

The greatest challenge in modeling hospital evacuations is the high heterogeneity of the patient population. Research indicates that:

- Bedridden patients require the most resources,
- Elderly individuals slow down evacuation groups,
- Cognitively impaired patients exhibit unpredictable behaviors,
- Staff decisions depend on clinical priorities

Modern agent-based models incorporate these differences, significantly improving the realism of simulated scenarios.

## 3. Project Boundaries

### 3.1 Research limitations

Although interest in this area is increasing, the literature still has several gaps:

- a lack of simulations incorporating unpredictable patient behaviors,
- limited data describing real transport times for bedridden patients,
- Minimal research on the evacuation if any drills was not appeared in the past

In this study, people who are not fully functional are grouped as either independent patients or those who need help during evacuation. There is also a growing understanding that traditional drills are not enough. The main boundaries in research are

- Building-specific focus: The analysis is limited to the hospital's main building, excluding other facilities and locations.
- Behavioral analysis: The study does not in-depth analyze the psychological or cognitive factors influencing behavior during evacuation.
- Scope: Evacuation-only: The study focuses solely on the evacuation phase of emergency response, excluding other aspects such as fire containment and recovery.
- Simulation software: The project is limited to a single simulation tool which is Pathfinder- for evacuation modeling and does not compare it with other programs.

## 3.2 Project Objectives

This study evaluates the hospital's current evacuation capabilities:

- **Proposing Strategic Recommendations:** Developing practical recommendations and proposals to develop the hospital's evacuation strategies
- **Evacuation Results Analysis:** Analysing and comparing the results of an actual hospital evacuation setup with evacuation simulations to identify differences and find areas for improvement
- **Staff Preparedness development and enhancing the resilience of the evacuation plan**

## 3.3 Delimitations

In case project research, delimitations are the boundaries which are set by the researcher. They define what the study will include and exclude, based on the researcher's choices.

- **Limited Access to Documentation:** Even with a non-disclosure agreement (NDA), some important documents about the evacuation as security and hospital IT systems, were not available.
- **Scope of Data Collection:** The information gathered from staff surveys and other methods is voluntary, and the information may not be true
- **Time and Resource Constraints:** This project is part of a one semester-long MSc in Risk and Security Management. As a result, there is limited time and resources for analysis of the hospital's evacuation procedures.

## 4. Problem Description

This problem statement leads to important research questions designed to meet the project's goals:

- What are the weaknesses and threats in the current hospital evacuation plan?
- What is the actual level of knowledge of hospital staff regarding evacuation plan?
- How do changes in the availability of emergency routes and exits impact the evacuation?
- How can simulation tools as Pathfinder supporting the improvement and validation of evacuation plans?
- How can evacuation plans be improved to ensure safety and accessibility for patients with limited mobility and individuals requiring special care?
- How can hospital evacuation strategies be improved by using staff survey results and simulations, testing plans in various setups to prepare for different emergencies?

## 5. Methodology

### 5.1 Objectives of research

The study used staff surveys, estimated evacuation times, and computer simulations of crisis situations; The surveys show how prepared medical staff are and highlight real challenges in transport patients internally. The simulations test evacuation plans in different situations, like blocked staircases or patients who cannot move easily. By combining real observations with virtual simulations, the study supports the development of more complete hospital evacuation plans.

## 5.2 Data Collection

A chain search method is essential to find key documents about hospital emergency evacuation. The most important studies shaped the research problem. Early data showed that staff preparation, hospital design, and how people act during emergencies are important areas to study.

With this foundation, a systematic literature search was done to broaden the problem statement and find studies about emergency evacuation in hospitals. The search used the PICO model for structure[5]:

P (population): Patients, medical staff, and administrative staff.

I (interest): Human behavior during evacuation, biometric data from patients and staff, and simulation software for testing evacuation.

Co (context): Evacuations in hospitals.

These categories helped generate specific search terms such as "hospital evacuation," "human behavior in crisis," and "patient biometrics." The search used three groups, each containing synonyms and related terms, to more fully cover the literature on hospital evacuation. Systematic literature search and reports from public and private organizations helped find evacuation strategies during emergencies. The sources included evacuation procedures, plans and safety rules. These findings were used to build a theoretical framework and develop simulation models aligned with the research goals.

## 5.3 NDA and Ethical Considerations

The provisions of the confidentiality agreement (NDA) do not apply to information regarding the Hospital in Gliwice, as this information is publicly available, is published in official public sources and does not constitute confidential information within the meaning of the agreement.

## 5.4 The Survey objectives

The survey collects key information on participant demographics, evacuation knowledge, and perspectives on critical situations. This approach helps analyze human factors influencing evacuation and the dynamics of those present.

The survey utilizes a structured, quantitative interview. It focuses on collecting current information without introducing changes or interventions. This type of survey is also known as a cross-sectional survey.

Cross-sectional studies have the weakest scientific support. However, this does not mean the method is weak. It merely means that some designs are perceived as more reliable, valid, or objective. The survey design considers target groups, distribution, topic areas, question types and data collection in general. The survey is administered via a digital internal platform, accessible only to hospital staff; no one else has access to the survey. [6] The survey was conducted using Microsoft Forms, and the target group consisted of 100 individuals which is maximum capacity of the hospital building.

## 5.5 ASET and RSET

ASET is the longest amount of time people have to leave a building safely. During emergency evacuations, Available. Safe. Egress. Time. (ASET) and Required. Safe. Egress. Time. (RSET) are key measures used to assess how safe and effective evacuation plans are.

RSET is the time people actually need to get out safely, including the time to notice the emergency, leave, and move to an exit.

ASET was set at 5 minutes because of the types of materials that can catch fire. However, since many unpredictable scenarios were considered, some information is still missing. RSET, or Required Safe Egress Time, is the time needed to escape safely. It depends on four separate time periods, which are affected by how people act and move. These time factors include:

\* Detection Time: This is when a danger is first noticed either by a person or by an automatic system.

\* Pre-movement Time: The time from when the emergency is detected to when the first people start to do action. This period includes both the time it takes to recognize the emergency and to decide how to respond for the occupants.

\* Travel Time: Means the time from when people start moving until they reach a safe area.

• Walking Time: The time it takes for people to walk out of danger, to a safe place. This can be measured as the average time to reach an exit or the time it takes for the very last person to evacuate. Walking time depends on several factors, such as walking speed different for any kind of age group, distance to the exit, and any physical limits of the building or site.

• Flow Time: time during evacuation for the people to move through an exit or escape route. It depends on how many people the exit or escape route can handle at once.

Aiming a safe evacuation, ASET must be greater than RSET (ASET > RSET). If this is not the case, it shows weaknesses in evacuation plans, which means building design or safety systems need to be improved.[6] The margin of safety is shown in the following equation:

$$T_{SAFETY} = T_{ASET} - T_{RSET}$$

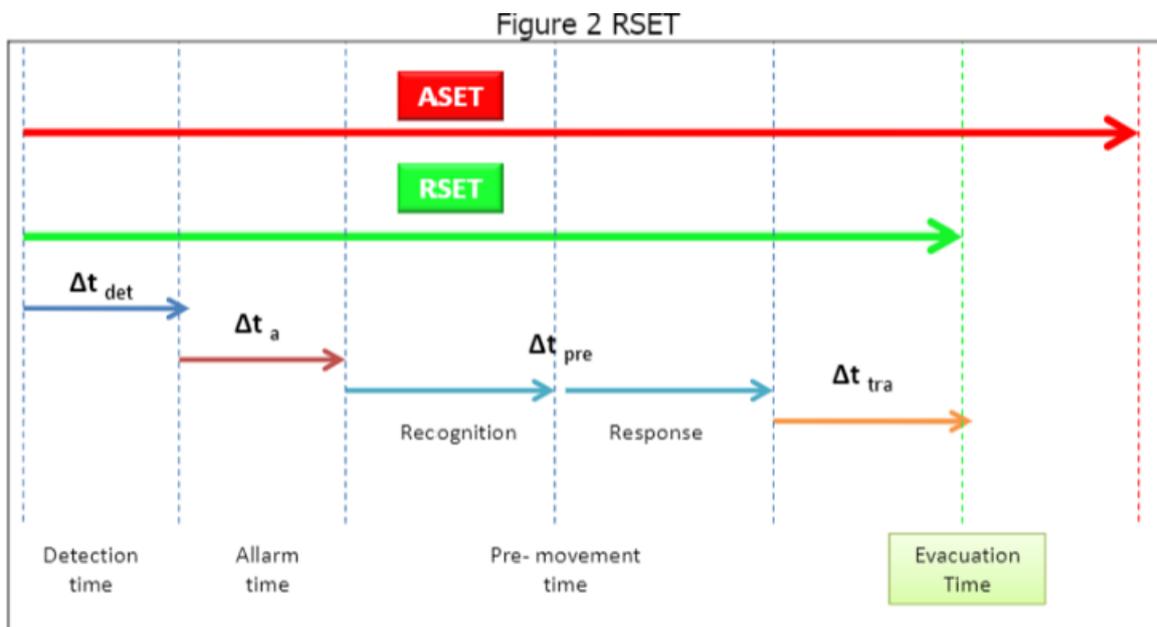


Figure 1: Available and Required Safe Egress Time with compounds

Evacuation time has two parts: pre-movement and movement. The pre-movement phase includes steps such as recognition, confirmation, assessment and finally making a decision to act.. This phase is complex and challenging in RSET because it involves the mental and emotional steps people go through before evacuating.

**Recognition:** This is the first moment when people notice a possible threat, like hearing an alarm, smelling smoke or seeing fire. The people need to decide if these signs are real. If they have experienced false alarms before or are in an unfamiliar place, it might take longer to recognize the danger and prolonging evacuation. This stage starts their awareness and prepares them for what comes next.

**Confirmation :** happens after people notice a threat. People usually try to find out if it is real. They check how serious the emergency is and whether the alarm or warning is real.

**Assessment of Options:** Once the threat is confirmed, people start to consider what they can do next. Evaluation of options comes after the threat is confirmed. This project used the average pre-evacuation time for office settings from existing research [7].

In this project, RSET is calculated using simulation. The ASET value remains at 300 seconds because of the combustible materials in the hospital and the types of people the hospital serves.

## 5.6 Pathfinder Software on this project

Developed by Thunderhead Engineering, Pathfinder is an agent-based computer program for evacuation and movement simulators. It aided in the modeling and analysis of hospital evacuation scenarios. Since Pathfinder was presented during the course, its use was strongly recommended for the project. Its features also support this choice: Pathfinder provides a complete platform for designing, simulating, and visualizing movement during emergency evacuations. This makes it useful for detailed evaluation of evacuation procedures and for identifying potential bottlenecks or areas for improvement [8]. Pathfinder has three main parts:

- Graphical User Interface (GUI): The system helps users create and edit building models, occupant profiles, and evacuation scenarios. Users can also import existing building layouts from different formats or build models directly in the software.[8]
- Simulator: This is the main engine of the program that runs evacuation simulations using the parameters and scenarios. It uses agent-based modeling techniques, so each occupant can make their own decisions important for simulation. Users watch and record how people move and see how well evacuation plans functioning. [8]

Pathfinder is an agent-based egress simulation tool that uses mathematical to model how people behave during evacuations. It has two main modes: SFPE and Steering. In SFPE mode, evacuation is modeled as a steady flow of people, with movement rates set by how populated the space is, the size of the room, and the width of the doors. People line up at exit doors and the simulation removes them based on set flow rates. This approach is common for large scenarios where people act in predictable ways.

Steering mode provides a dynamic and realistic way to simulate behaviors and individual decision-making processes. It removes the strict queuing system used in SFPE and lets occupants adjust their paths based on spatial awareness and making adaptive decisions. This mode works well in situations with bottlenecks, especially blocked exits, since system captures the unpredictable nature of evacuation.

In this project steering mode was chosen for this project because it can simulate detailed and realistic evacuation scenarios. It allows agents to move around obstacles and interact with their environment, avoid collisions and obstacles, and what's most important - change their paths in real time. For assisted evacuations, such as those involving wheelchair users, steering mode handled differences in speed and movement limits. To use steering mode effectively it's important to define simulation goals by realistic parameters from survey and existing knowledge that match the demographics and conditions of the scenario.

## 5.7 Simulation Setup

Based on the emergency floor plan, rooms, doors, stairs and elevators were created to establish the model's basic layout. The model was constructed within the software, and Pathfinder generated a 3D navigation mesh to represent all accessible spaces, including corridors, rooms, and stairwells. A range of occupant profiles from survey was defined to accurately represent the building population. Attributes such as walking speed, body size, and response behavior were assigned using data from employee surveys and established literature on evacuation behavior. Multiple evacuation scenarios were configured to assess varying conditions, including exit availability, potential obstacles, and the movement of wheelchair users requiring assistance.

The 3D Results Viewer was used to visualize occupant movements and identify congestion points, bottlenecks, and assess evacuation times. Additionally, Pathfinder's data output capabilities give output as detailed information on how quickly rooms got empty, how fast people moved through doors and individual occupant paths. The model was built in Revit software, and Pathfinder created a 3D navigation mesh to show all crucial areas, such as corridors, rooms and stairwells.

## 6. Hospital Emergency Plan Overview

Gliwice Hospital building follows a standardized approach to emergency preparedness. The building's layout features a unified design for safety functional areas, simplifying the emergency response process so that employees working in either building understand the layout and safety equipment.

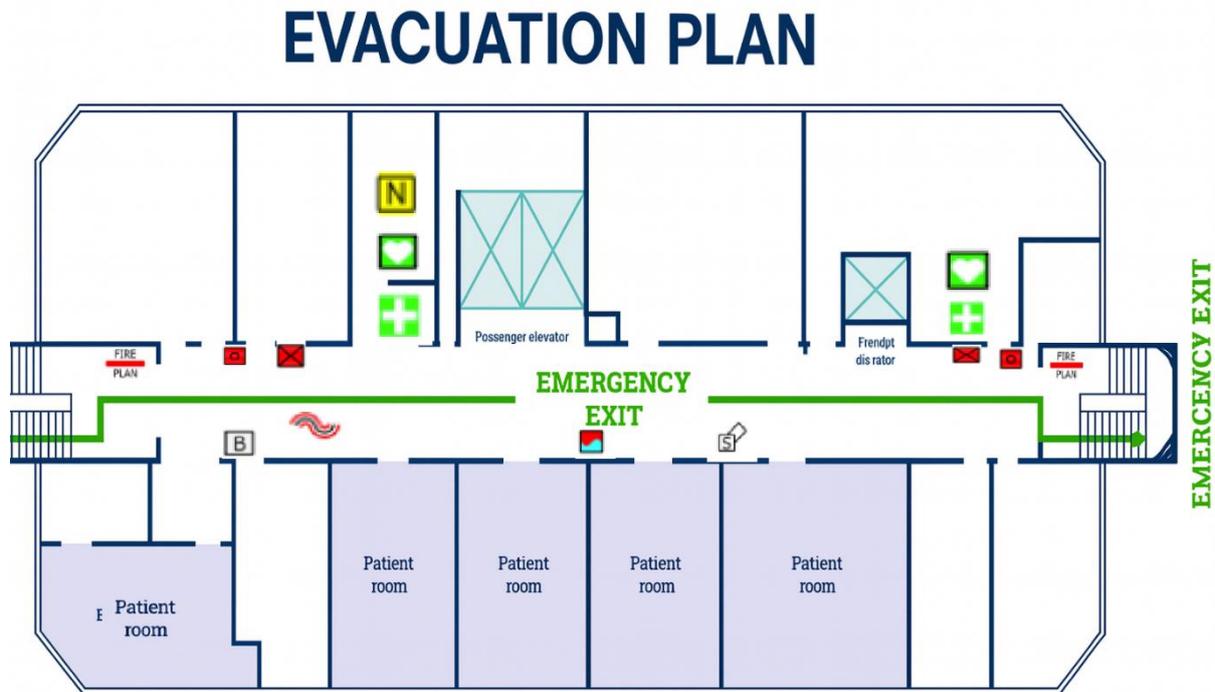


Figure 2. Evacuation Plan of the Hospital – 1<sup>st</sup> floor

### LEGEND:

	FIRE ALARM PUSH-BUTTON TRYKKNAP TIL BRANDALARM		NITROGEN ROOM SHUTDOWN NITROGEN RUMSLUKNINGSANLÆG		ESCAPE ROUTE FLUGTVEJ
	WATER EXTINGUISHER 9 L VAND SLUKKER 9 L		DRY POWDER EXTINGUISHER 2 KG PULVERSLUKKER 2 KG		ONSHORE EVACUATION TAG ONSHORE EVAKUERINGSKILT
	AUDIBLE ALARM FIRE AND GAS AKUSTISK BRAND- OG GASALARM		CO2 EXTINGUISHER 5 KG CO2 SLUKKER 5 KG		POSITION OF F&S PLAN PLACERING AF F&S PLAN
	SINGLE HYDRANT STATION BRANDHYDRANT ENKELT		FIRE BLANKET BRANDTÆPPE		
	FIRST AID KIT FØRSTEHJÆLPS KASSE				
	DEFIBRILLATOR HJERTESTARTER				

Figure 3. Legend of the Hospital Plan for all the floors

As shown in Figure 2, the map layout resembles a hospital or medical facility hallway, with many patient rooms in the lower half of the map. Along the upper hallway are utility rooms, technical rooms, and elevator. This layout is repeated without significant changes for all four floors, excluding the ground floor, where the exit locations will be configured. As shown in Figure 3, all legends are available in English and Danish. The hospital evacuation plan from figure 3 labels correspond to those in Figure 2. The evacuation plan consists of:

#### 1. Emergency Exits

- The main exit from the building in the middle

#### 2. Evacuation Route

- A green pathway marks the primary evacuation route, guiding occupants from the center and sides of the building toward the emergency exits.
- The route passes through corridor and continues toward both stairwells at the ends of the hallway exit.

#### 3. Elevators

- A passenger elevator is located near the center of the building.
- Elevators are *not* intended for use in emergencies, but are shown for orientation.

#### 4. Safety Equipment

- First-aid symbols appear near both elevator areas.
- Defibrillator/heart-health icons are located near the first-aid symbols on both sides of the corridor
- Fire equipment is positioned near each set of stairs.
- Fire plan documents are indicated at both stairwell entry points.

#### 5. Patient Rooms

- The rooms have been standardized in terms of purpose. Each room will be assigned the maximum number of people allowed to stay there. Different profiles will be assigned to specific agents, which will produce different simulation results.

The hospital has four identical floors, from the ground floor to the fourth floor. All floors have the same emergency equipment in the exact locations. That helping staff quickly locate equipment and more effectively deal with emergencies. The hospital has trained staff in every building level responsible for managing evacuations. During an evacuation everyone must follow the instructions of the evacuation officer. The officer of evacuation is responsible for directing people to leave the building quickly as possible.

## 7. Survey results and interpretations

As part of this project, a survey was conducted among hospital employees to gather insights and provide data for upcoming statistical analysis. The main goal was to collect information about their job and behaviors to improve the accuracy of the evacuation simulation. The survey also measured how well employees know the emergency evacuation plan and how prepared they feel for emergencies. The results will be used in two ways: to make the simulation models more reliable and to help better information sharing and training. Appendix A contains the full survey and all collected data. The survey included questions about personal demographics, such as age, gender, how long employees have worked in their profession. It also asked about their knowledge of emergency procedures, how they would behave during emergencies, especially awareness of the office layout and emergency equipment, and how fast they move and navigate within the hospital.

The survey used several types of questions, including multiple-choice (nominal), Likert-scale, ranking and rating, follow-up, and closed-ended questions. To avoid response bias, all questions were written to be neutral and non-leading.[9] After conducting the survey, 100 responses were collected for further analysis. These 100 people stands for 100% of the participants of the survey. The first few questions collected demographic data. Male respondents accounted for 40% (40 people), and staff were primarily in the 40–60 age group. Regarding participation in emergency exercises and satisfaction with existing procedures, 90% of staff members reported participating in trainings and being satisfied with existing methods. More than 95% of respondents stated that they can remain calm and confident when following emergency evacuation instructions and that they are familiar with the hospital's emergency alarm system.

## 8. Pathfinder Simulation

This chapter takes a closer look at the simulation software used for hospital emergency situations. The discussion is divided into sections that explain how hospital models and staff profiles are developed, how simulation results compare to real evacuation data, how emergency scenarios are planned, and how scenario performance is assessed. The model uses key variables to set essential parameters.



*Figure 4 : Gliwice Hospital in 2014 (visualisation) – 4 condignations repetitive building*

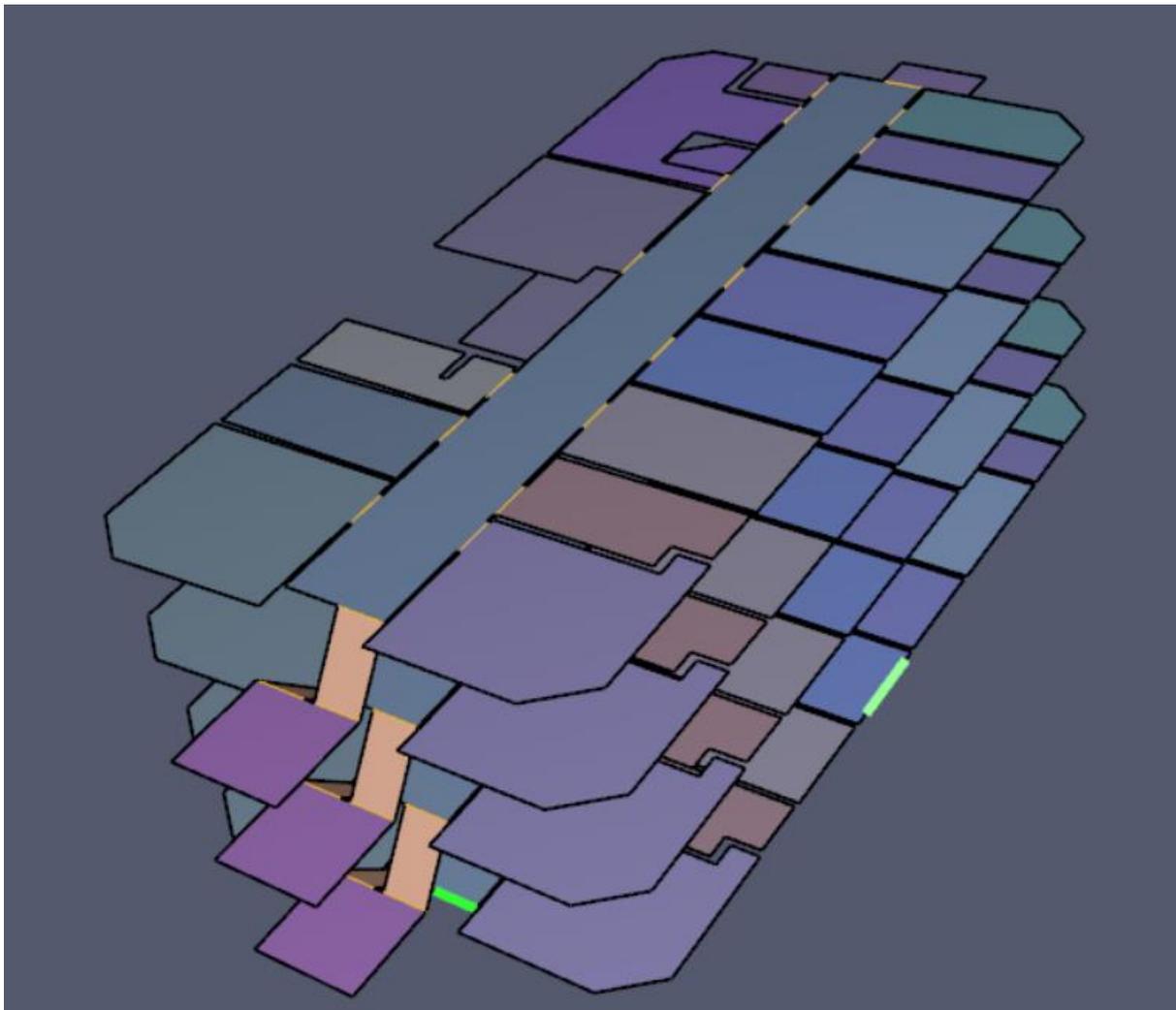
### 8.1 Pathfinder Modelling

The hospital model focuses on simulating the emergency evacuation procedure for this type of building, located in Gliwice, Poland, from 2014. To create an accurate model of a building, the fire safety plan was created from the existing plan. The measurements are accurate and have been transferred to the architecture program, Revit, to create a precise structure with exact floors, walls, stairs etc. At the same time, it is a simplified model but the maximum occupancy of people is maintained in the given

rooms, as well as their actual dimensions. The simulation must be held under five minutes under all circumstances and scenarios.

## 8.2 Model Setup and Occupancy

Evacuation staircases are placed on both sides of the corridors. These details were essential for capturing all possible evacuation routes and improving the model's accuracy.



*Figure 5 : Pathfinder Model Overview*

Each floor has a similar layout, with two elevators and a staircase inside the building. The main exit door is 2080 mm wide. The elevators, installed in 2014, can carry up to 1400 kilograms or 20 people. However, these elevators were disabled during evacuation. Participants did not choose the elevators as their first or second option for evacuation as the survey shows.

The alarm system uses the same siren sound for every type of threat. Ninety eight percent of occupants as survey find recognize the alarm sound,so this does not add unnecessary confusion.

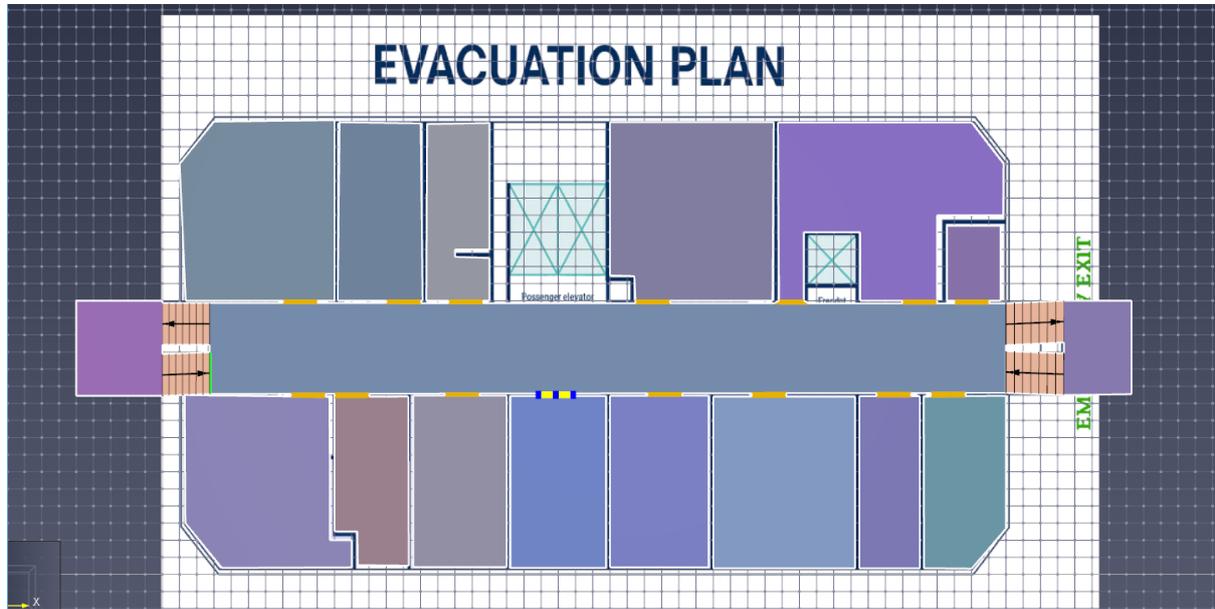


Figure 6 : Evacuation plan level 1,2,3

The fire evacuation plan and existing equipment strictly defined the hospital's layout. Exits were defined based on where patients were considered safe, i.e., where they exit the building. Defining the exit at the end of the ground floor corridor increased the realism of the simulation. Patients likely occupied beds, but during evacuation, they could be transferred to wheelchairs. Because elevators are not operational during evacuations, emergencies, or power outages, and wheelchairs are operated by staff, each patient must have their own caregiver.

A test route was chosen to reflect a typical scenario where occupants move from an entry point to a designated exit. The walking speed of each occupant was modeled based on the set parameters used in Pathfinder as default , with detailed speed settings adjusted to match the actual test conditions. The walking times were observed for both buildings using the following parameters:

- Number of test runs: 10
- Measured walking times: Mean and standard deviation for the 10 run
- Test route: Identical in both real-world and simulated environment

Observed time was : 85,0 seconds and standard deviation for 1,4 second. Exactly as in the pathfinder scenario evacuation, without any waiting time estimated.

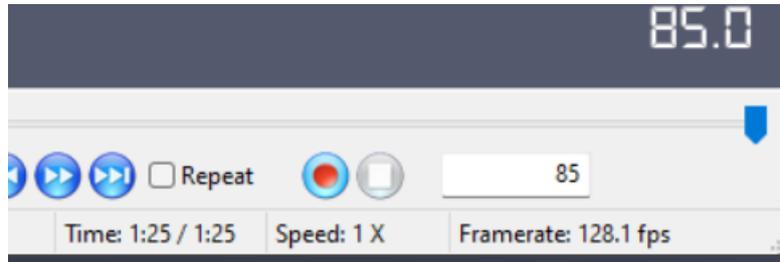


Figure 7: 1 minute and 25 seconds as result of typical scenario evacuation

These small differences in standard deviation are within an acceptable range for most egress simulations, indicating that the Pathfinder model effectively simulates walking behavior for the given test scenarios. However, it's essential to notice that evacuation must be handled below estimated 300 seconds.

After establishing the correct geometrical model, it is also important to set the correct population size and type in the model to achieve life-like scenarios. This includes setting three main aspects of the population:

1. Occupancy levels
2. Distribution of people in the building
3. Profiles and behaviors.

The number of occupants in the model was determined by the maximum possible capacity, with 100% occupancy in patient rooms and 100% of hired personnel as doctors and nurses. In the other scenarios percentage of personnel will be change to patients – the total number of people will be still 100 but their profiles will be different by amount of patients among all people in hospital. The personnel members are frequently moving between rooms - to reflect this mobility, a random allocation of occupants was implemented, but with maximal numbers on each room. This occupancy allocation was adjusted based on patient rooms, meeting rooms, the canteen or technical rooms. Numerical data on various characteristics were obtained from the hospital's internal instructions.



Figure 8 : Maximal distribution of people (hospital personnel)

### 8.3 Motion during evacuation in main scenario :

Walking speed is a key factor in figuring out evacuation times and how crowd behave. Research show data on walking speeds, age groups, and specific scenarios. Age has a strong effect on how fast people walk. Young adults usually walk the fastest, between 1.34 and 1.36 m/s (see Table 9 below). Older adults move more slowly, with speeds from 1.13 to 1.26 m/s, because of age and less physical agility. This information is important for modeling evacuations with people of different age, so the pathfinder model matches real-life situations. [10]

Age Group	Meters/Second	Miles/Hour	Kilometers/Hour
20 to 29	1.34 to 1.36	3.0 to 3.04	4.83 to 4.89
30 to 39	1.34 to 1.43	3.0 to 3.2	4.83 to 5.15
40 to 49	1.39 to 1.43	3.11 to 3.2	5.00 to 5.15
50 to 59	1.31 to 1.43	2.93 to 3.2	4.71 to 5.15
60 to 69	1.24 to 1.34	2.77 to 3.0	4.46 to 4.83
70 to 79	1.13 to 1.26	2.53 to 2.82	4.07 to 4.54
80 to 89	0.94 to 0.97	2.10 to 2.17	3.38 to 3.49

Figure 9 : Age groups and their walking speed

In emergency evacuations, walking speed is affected by psychological stress, urgency, and other constraints. Research shows that people walk about 54–60% faster on level ground and 48–50% faster when going down stairs in emergencies than in normal situations [11].

In extreme situations like overcrowding or panic, people may move more slowly, especially those using wheelchairs. Clinical staff help with horizontal evacuation by staircases to a nearby safe area. Wheelchairs are used as usual at this point. Staff make sure the patient's medical equipment is moved safely with the patient or disconnected according to protocol. Hospitals have fire and emergency codes that assign staff to move patients, prepare assistive devices, keep track of everyone, and communicate with the incident command team. When using an evacuation device, trained staff can help the patient use it safely.

- Evacuation chair (most common)
- Wheelchair assisted by one person or Bed assisted by four
- Rescue stretcher (for non-seated patients)

Moreover, it is important for staff never to push a wheelchair down stairs directly. [12] In evacuation modeling, body dimensions significantly impact crowd movement, space utilization or congestion management. The dimensions of occupants, primarily characterized by shoulder width, change based on regions and genders, as seen in the figure 10 . Gender also influences walking speed. For example, males aged 20–29 have an average walking speed of 1.36 m/s, while females of the same age as average 1.34 m/s. However, these differences become lower significant in high-density environments, where crowd dynamics way more dominate individual movement. [13]

Age Group (Years)	Gender	Shoulder Width (cm)
20-29	Male	41.4
	Female	36.9
30-39	Male	41.4
	Female	37.0
40-49	Male	41.3
	Female	36.9
50-59	Male	41.0
	Female	36.9
60-69	Male	40.5
	Female	36.4
70-79	Male	39.7
	Female	35.7
80+	Male	39.0
	Female	34.8

*Figure 10 ; Shoulder width distribution by age and gender*

Walking speed is also influenced by terrain type. While smooth, flat surfaces grant maximum speeds, slopes, stairs, and obstacles reduce mobility efficiency. In a hospital, the floor is covered with PVC, which increases the risk of slipping, but this's not considered in the calculation. The floor is flat except for the stairs, which are the primary constraint on personnel evacuation, especially patients.

## 8.4 Profiles of participants

As the questionnaire shows, data were used to set the profiles of occupants. The survey showed that the gender ratio can be assumed to be the same across different age groups. and it can be assumed as Male to Female = 40/60 adequately 1 person is 1%. The different data obtained from the literature search are utilized to set these profiles as close to reality as possible. [14]

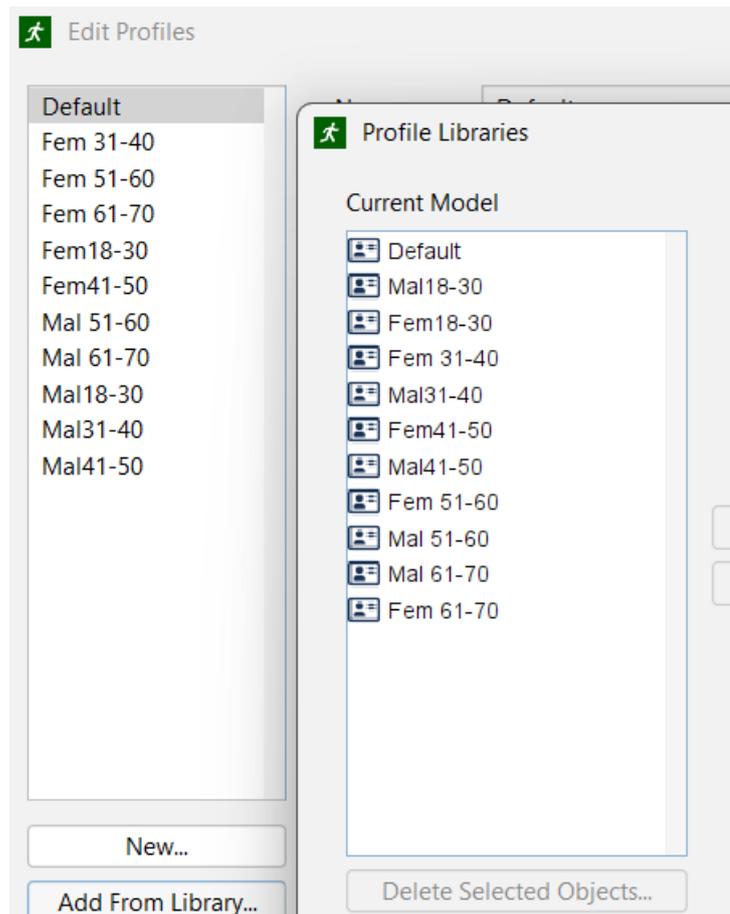


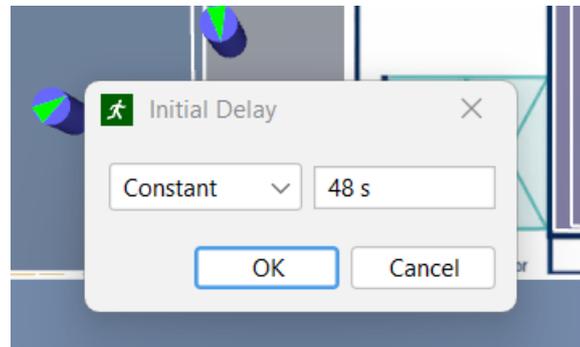
Figure 11: Age based modification trough profiles in pathfinder

The pre-evacuation time or pre-movement time is a key factor in evacuation simulation as it is considered to be the general time period during evacuations. Pre-movement time refers to the period between the moment an occupant becomes aware of an emergency situation, such as an alarm or siren, and the start of movement towards an exit.

Area	Staff		Patients		All	
	Average (sec)	Count	Average (sec)	Count	Average (sec)	Count
Pathology and Physiotherapy	52.0 [26.0-91.0]	9	37.3 [30-45]	3	48.3 [26-91]	12
Waiting Room	26.0 [16.0-43.0]	4	36.3 [34.0-40.0]	4	31.1 [16.0-43.0]	8
Treatment	45.0 [45.0-45.0]	1	59.1 [46.0-66.0]	12	58.0 [45.0-66.0]	13
All Areas	44.1 [16.0-19.0]	14	50.8 [30.0-66.0]	19	48.0 [16.0-91.0]	33

Figure 12: Table Pre-Evacuation Times within Blackheath hospital for Patients / Staff. (unified to 48 seconds as average)

At the hospital setting, despite the recommendation and training, many occupants, even after hearing the alarm still finishing their task, hesitate, gather their belongings, talking to each other. This results in a relatively long pre-movement time with wide distribution. The pre-movement time in Pathfinder has been set according to Figure 13 to 48seconds.



*Figure 13: Pre-movement time estimate in pathfinder (48s as average)*

The role of the evacuation officer who is the brand shift manager (doctor) of is to conduct a detailed inspection of the assigned part of the floors, to ensure that all occupants evacuate during an emergency. This requires setting up a different behavior in which the inspection procedure starts with a 150 s delay, which already accounts for pre-movement time and the initial period when occupants respond to the alarm signal. After the delay, assigned evacuation officers, each for the floor begin walking through the designated floor using the "Go To Waypoint" action, including bathrooms, patient rooms, the kitchen, technical rooms, as described in the figure 14. Each of the evacuation officers has similar 150 seconds delay because the setup of the floor is almost identical.

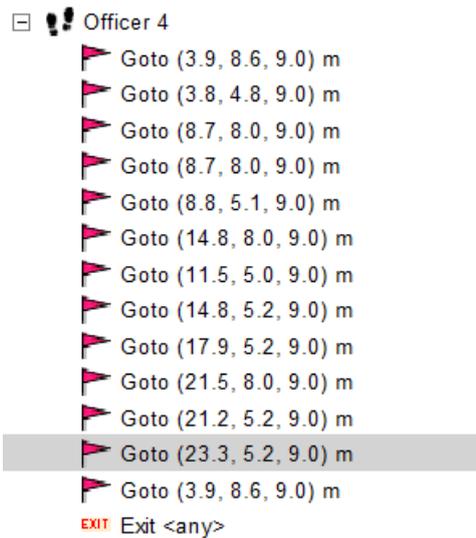


Figure 14: Evacuation officer inspection (150 seconds) at the 4th top floor

Besides important aspects in simulation is social distancing which significantly impacts movement dynamics during emergencies, influencing evacuation efficiency and crowd behavior. To accurately reflect these dynamics, simulation tools like Pathfinder can incorporate social distancing parameters, ensuring models account for the reduced proximity between individuals which is set to 30 cm as a minimum. By adjusting the spatial interaction rules within simulations, it is possible to model realistic evacuation scenarios. The exact settings can be seen in Figure 15

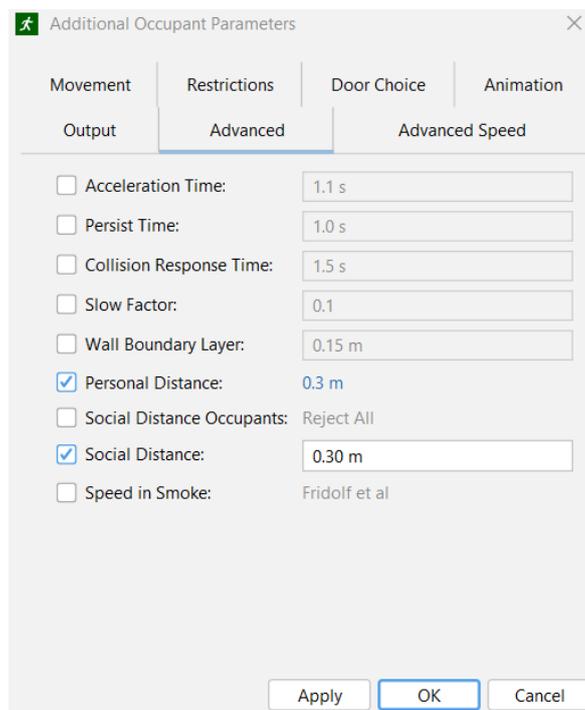


Figure 15: Social distancing setup on pathfinder

## 8.5 Simulation results in case of power outage

The evacuation in the case of a power outage is used in scenario 1 (main scenario) In this part, the elevator is not working; only the siren, emergency lightning and the central alarm lead people to evacuate because main generator is broken and generate risk of fire. To conduct evacuation by stairs was essential to ensure that the simulation accurately mirrored real-world evacuation conditions.

Firstly, the occupancy level in the simulation need to be consistent with the evacuation RSET, which is below 300 seconds (5 minutes). The hospital's occupancy information provided insights into the maximum number of people in the building at any given time, which was essential for simulating evacuation dynamics. This real-world data was used to justify the exact number of occupants within the simulation can be considered identical to the potential situation. Additionally, survey data helped to align the composition of individuals with the profiles that could be present during the power outage. This helped ensure that the factors influencing the evacuation, such as occupant behavior and movement patterns, were comparable between the real-world setup and the simulated scenario, causing consequences in figure 16.

	Negligible (No delay)	Minor (Slight delay)	Moderate (Noticeable delays)	Significant (Severe delays)	Critical (No evacuation possible)
Low	Routine drills with all exits operational. (1)	Temporary obstruction cleared quickly. (4)	Minor delays as occupants reroute to alternate exits. (7)	Moderate delays due to partial blockages in key areas. (10)	Some alternate routes remain accessible. (13)
Medium	All exits clear but with crowding due to behavior. (2)	Small areas blocked but alternative routes used efficiently. (5)	Delays caused by one major exit being inaccessible. (8)	Over-crowding as multiple exits are obstructed. (11)	Several routes blocked, leaving limited egress options. (14)
High	Minor obstruction, such as temporary maintenance. (3)	Minor blockages cause detours but do not halt evacuation. (6)	Key exits blocked, leading to panic and severe delays. (9)	Widespread blockages cause significant over-crowding. (12)	All major routes inaccessible, creating life-threatening conditions. (15)

Figure 16 : Risk Matrix consequences illustrated during the drill

After simulating under the same conditions, it was observed that the evacuation times deviated by no more than 1,5% across 100 tryouts for each scenario. This small margin of error indicates that the simulation accurately captured the dynamics of the evacuation process. This level of accuracy supports the simulation's validity as a reliable tool for future analysis.

Simulation is capable of providing more detailed data about the simulated routes of all occupants in the buildings, it can explain, what might have caused this evacuation time to occur, who were the last ones to leave the building and more. A summary of this data regarding average evacuation times and walking distances can be seen in table 15 (100 tryouts)

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
134,5s	134,5s	134,5s	265,8s

*Table 17: Results of first, main scenario with 100 attempts, where there is no disabled people.*

The options 'Go to Main Exit' and 'Go to Any Exit' shows same value, because there is only one exit where people can evacuate in this scenario. There is no disabled people and all people were escaped just a little above 2 minutes which is totally acceptable. The evacuation officer from the highest floor has been evacuated below 5 minutes (4 min 45,8 sec).

## 8.6 Testing various scenarios of evacuation

To better demonstrate the simulation process, three different categories of situations were proposed in the table below: Two Evacuation exits with 20% of patients on wheelchairs, Two Evacuation exits with 40% of patients on wheelchairs and third - Closed Staircase Wing (Left or Right) with 20 % of patients on beds.



*Figure 18: Evacuation as dependent person by wheelchair ( one assistant ) bed ( four assistants)*

### **Scenario A: Two Evacuation exits with 20% of patients on wheelchairs (during power outage, risk of fire)**

In this scenario 20% of patients meaning 20 people are disabled patients, five in the each of the floor level. Every one of them needs one assistant person who is mainly a nurse or doctor (closest person) who make evacuation happen. That means in every each of levels only 15 people are evacuating straight to the main area, the rest – 10 people are made duo – disabled person and assistant. The evacuation officer doesn't take any disabled person for evacuation – finding out if everyone has already exit the level.

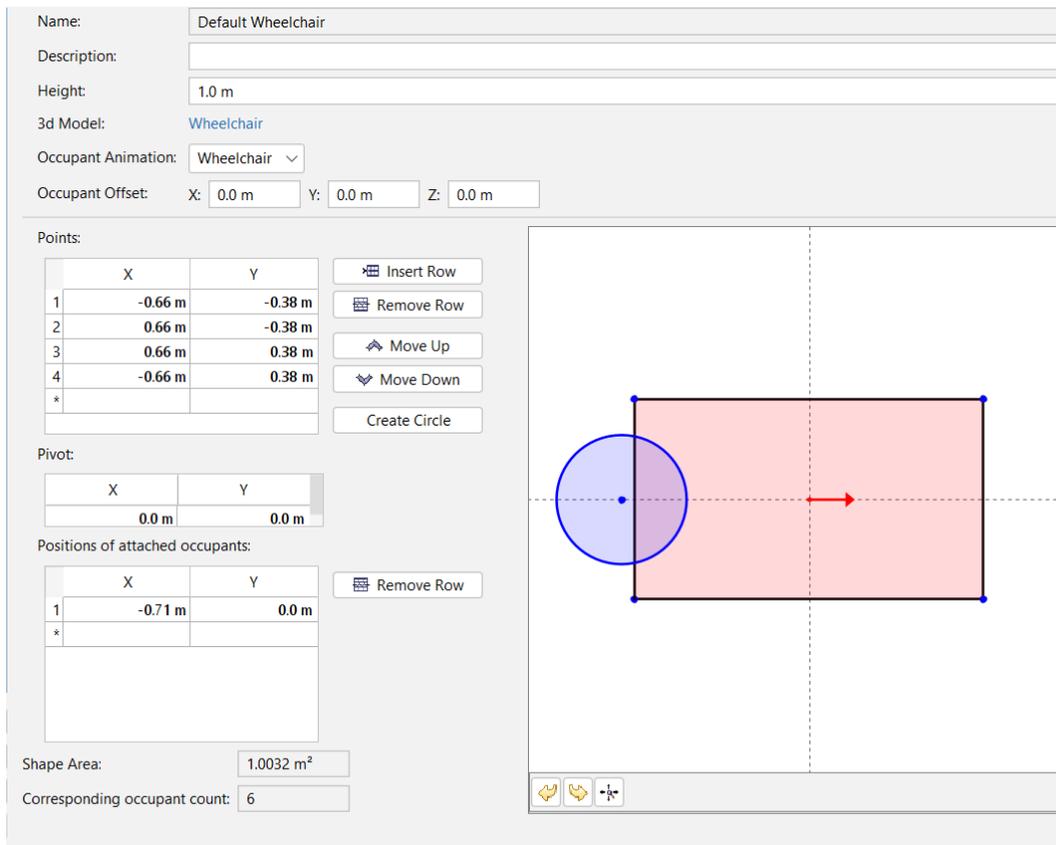


Figure 19: Default wheelchair settings in pathfinder



Figure 20: Output distribution setting in pathfinder show random distribution of people And maximum capacity in the rooms simultaneously

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
164,8s	164,8s	164,8s	265,7s

Figure 19: The results by scenario 2



Figure 21: Bottleneck in the left side of hospital

As clearly seen the appearance of the wheelchairs influenced the evacuation. During the action there was cumulated bottleneck in left wing staircases between the 80 and 110 second of evacuation. The right side is less occupied because of the room specification and setup.

**Scenario B: Two Evacuation exits with 40% of patients on wheelchairs (during power outage, risk of fire)**



Figure 22: Scenario B random distribution

In B scenario 40% of patients meaning 40 people are disabled patients on wheelchairs, ten on the each of the floor. Every one of them needs one assist person who is mainly a nurse or doctor (closest person) who make evacuation happen. That means in every each of levels only 4 people are evacuating straight to the main area, the rest – 20 people are made duo – disabled person and assistant. The evacuation officer doesn't take any disabled person for evacuation – finding out if everyone has already exit the level.

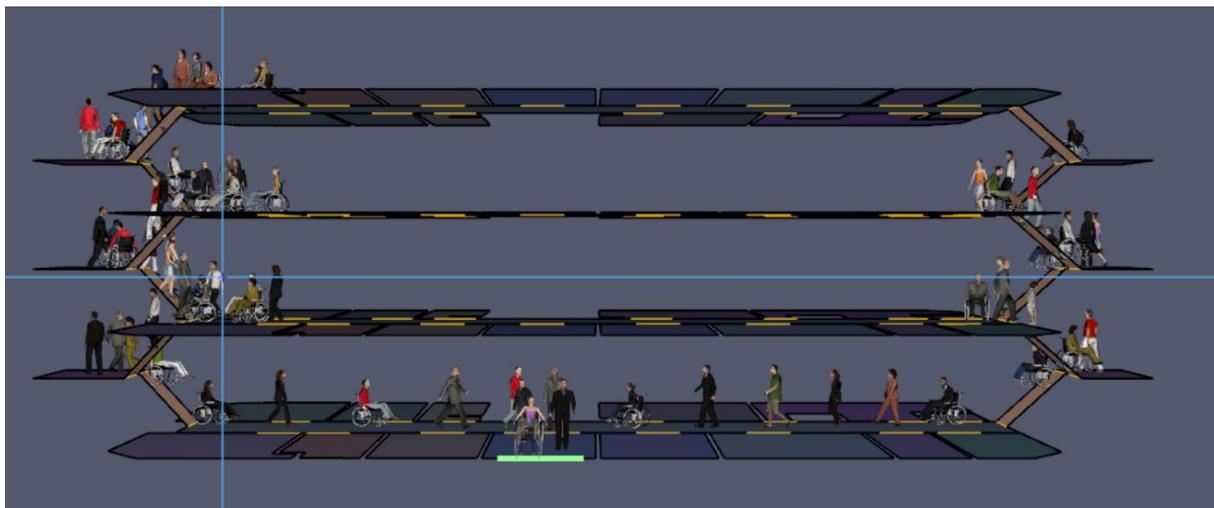


Figure 23 : Bottleneck in both of staircase wings

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
198,4s	198,4s	198,4s	265,7s

Figure 24 : Results of B setup simulation

The bottlenecks are visible in both of the staircases, but at right is rather smaller and going more smooth. The one by the left is blocked mostly between the 80 and 125 second means 45 second queue. The queue on the left is only 10 seconds providing effecting movement, blocked between 80 and 90 second from evacuation start.

**Scenario C1: Closed Staircase Wing (Left or Right) with 40 % of patients on wheelchairs (during power outage, risk of fire)**



Figure 25 : The Staircases are disabled on the left, forced people to evacuate just by right side of hospital.

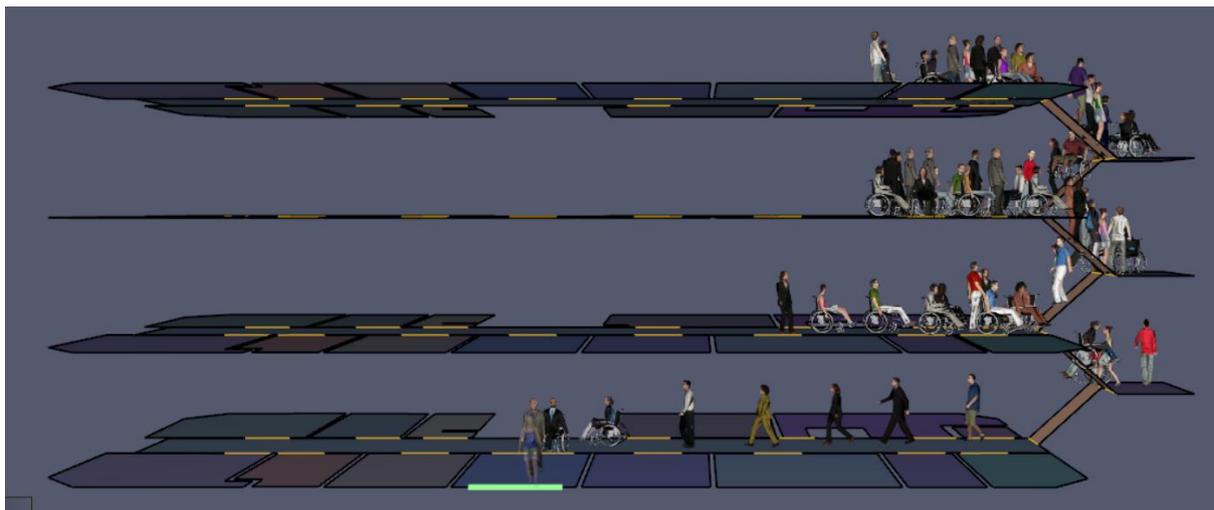


Figure 26 : Expected bottleneck in the right wing of hospital staircases

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
231,6s	231,6s	231,6s	265,7s

Figure 27 : Results of scenario C1 shows that the people on levels 1,2,3 got stuck in queues

The bottleneck is massive in only staircase the right staircase, but at right is rather smaller and going more smooth. The one by the right is blocked mostly between the 80 and 125 second means 45 second queue.

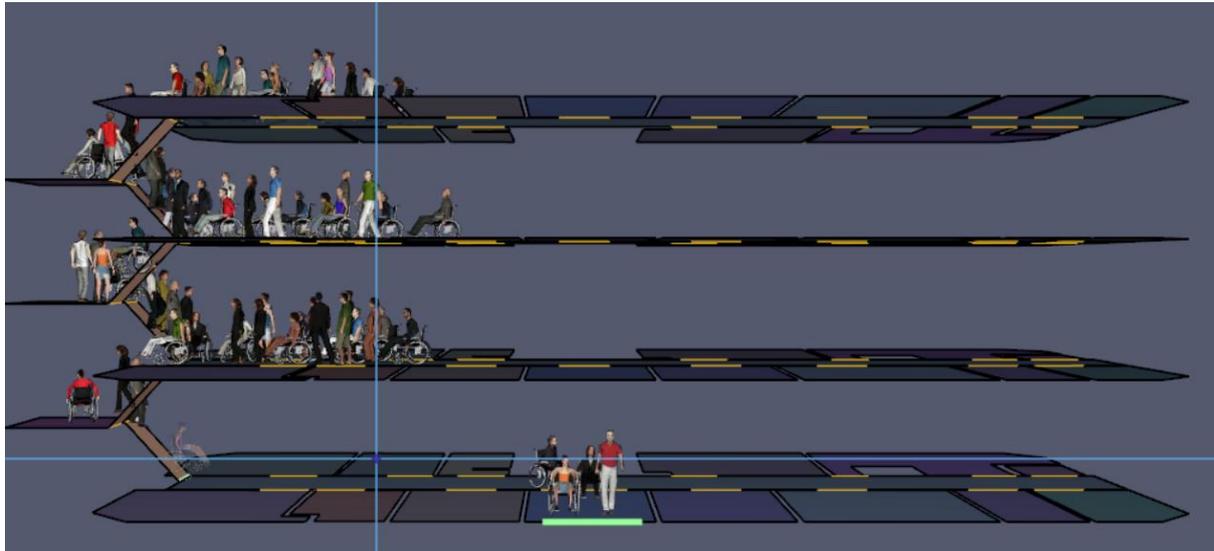


Figure 28 : Results of scenario C2 shows that the people on levels 1,2,3 got stuck in queues

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
225,8s	225,8s	225,8s	265,7s

Figure 29 : Expected bottleneck in the left wing of hospital staircases in scenario C2

By comparison of scenarios C1 and C2 with disabled left and right staircase alternately, it can be deduced that the 6 second different is insignificant as difference between these two options. The difference may be resulted by the setup of the rooms and distance to exit. The times of crowd evacuation doesn't affect evacuation officer time of leaving the building.

**Scenario D1 and D2: Closed Staircase Wing (Left or Right) with 20 % of patients on beds (during power outage, risk of fire)**



**Figure 30: Setup of D1 and D2 Scenarios with 20% of occupants are patients on beds**

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
298,8s	298,8s	298,8s	299,1s

**Table 31: D1 Scenario Left Wing Staircase is disabled**

Overall time	Go to Main Exit	Go to Any Exit	Evacuation Officer
296,9s	296,9s	296,9s	297,3s

**Table 32: D2 Scenario Right Wing Staircase is disabled**

Scenarios D1 and D2 where 20% of occupants are patients on beds shows limit values for the evacuation close to 300 seconds stands for RSET. By adding additional one bed the time of evacuation is longer for 4,3 sec (100 attempts) means it will be above 300 established time by 3,2 second. That means 20 beds is the border value for that simulation. There would be necessity for help from outside to make evacuation smooth or other solutions.

## 8.7 Scenarios Output Evaluation

The output from the program contains many different views in terms of evacuation. Pathfinder can create output data as visual diagram, CSV or JSON file especially in terms of doors or room usage. It offers velocity and density mode, the comparison of velocity vs density modes as well which may be usable for confrontation of the data to see differences or correlations. The Monte Carlo simulation also could be withdrawal as CSV file showing completion time for all occupants by 100 tryouts as in this report in attachments.

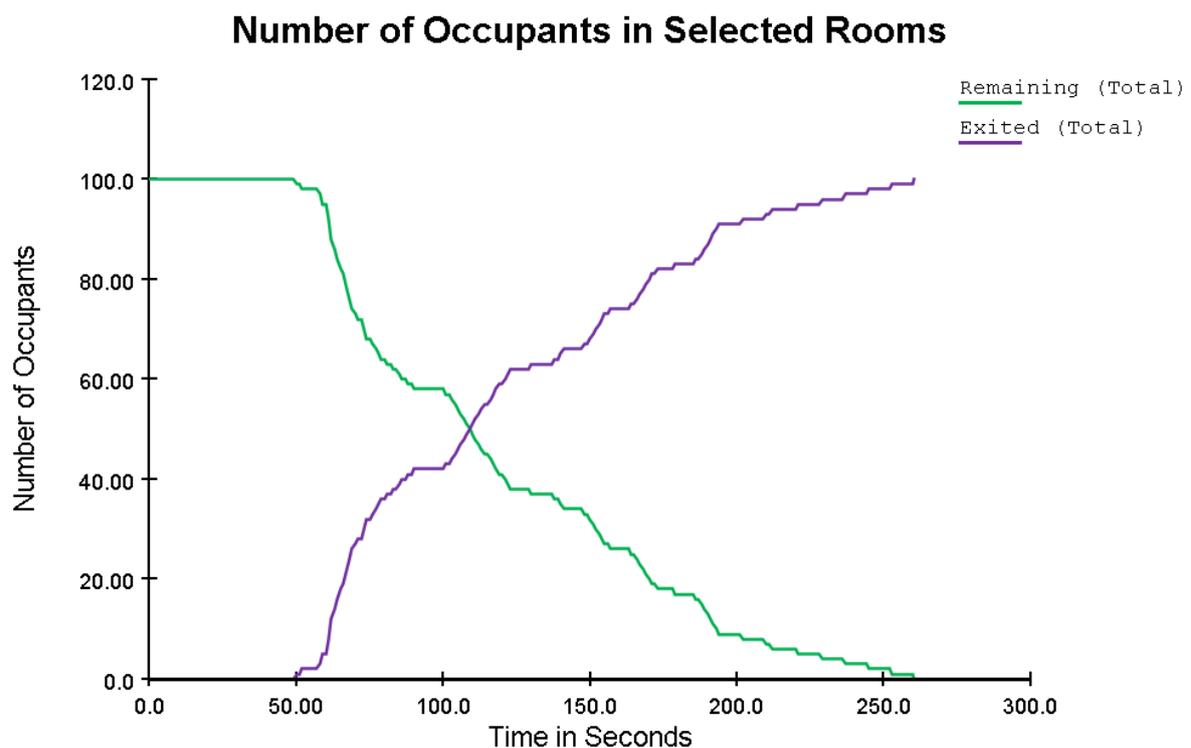


Figure 33: Number of Occupants in the building which successfully evacuate in the main scenario

By the figure 33 there is clear that almost until 50 second (48 seconds) there is pre-evacuation time where is taking place decision of the evacuation. Straight after that the people rather without many obstacles leaving the building to the time of 4 minutes, excluding evacuation officer which exits ca. 15 seconds before ASET time established for 5 minutes.

## Flow Rates for Selected Doors

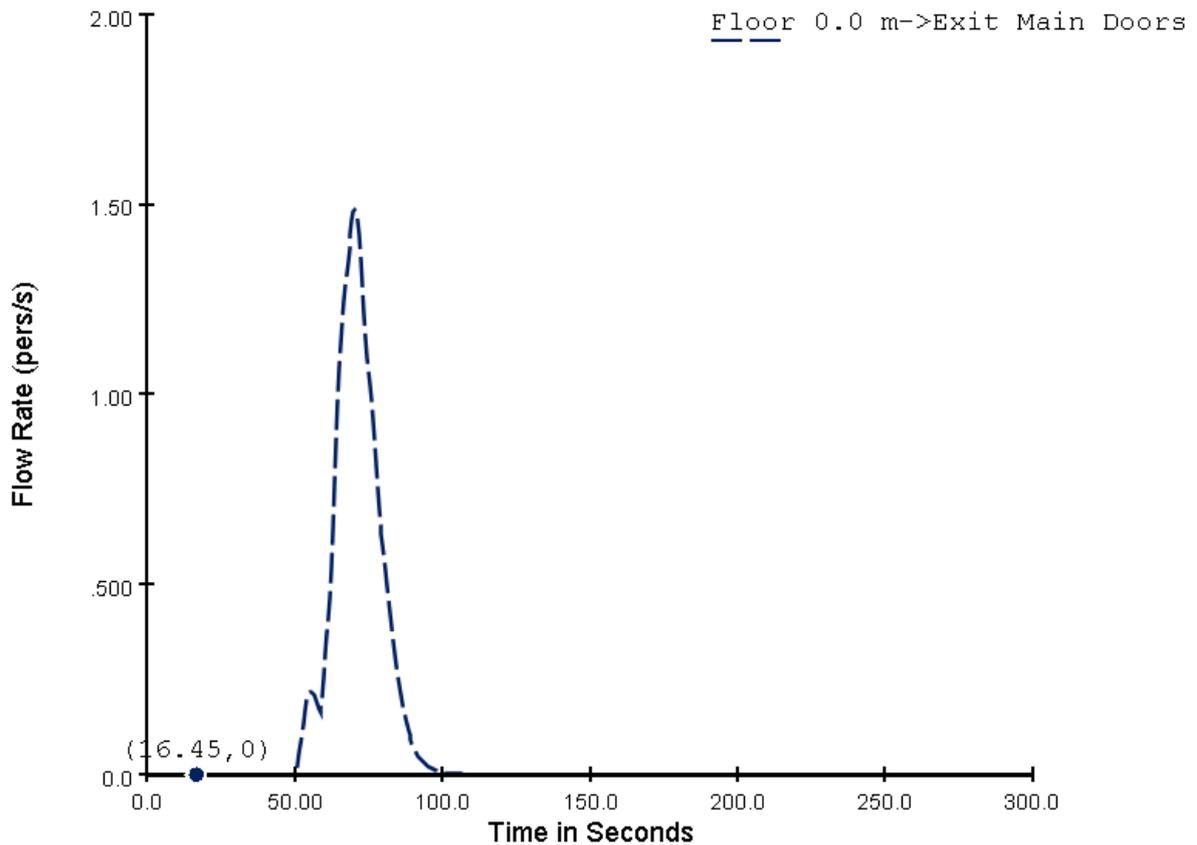


Figure 34 : Flow rate of main exit door

The figure 34 shows the main scenario traffic just between 50 and 100 seconds of evacuation at the main exit doors. It shows that in 2008 mm doors there is a possibility to go through by two people in once in case of emergency and there is a rather smooth transition by exit to the safe place. As was shown in previous simulation the border value of evacuation was additional one bed which leads to lengthen the time of evacuation above 300 seconds which is not acceptable. For this simulation, the maximum amount of wheelchair patients which are 40% of occupancy are enough for non-problematic evacuation from the hospital even below four minutes, excludes safety officer.

## 9. Discussion

The applied methods proved suitable for the purpose of this project and supported the development of hospital evacuation. The combined use of survey data and Pathfinder simulations created a great foundation for evaluating the hospital's evacuation strategy under various conditions. As intended, the survey established the necessary accent on staff familiarity with evacuation procedures and their physical data. Integrating empirical insights with the literature data ensured that the simulated scenarios reflected the unique operational conditions of a healthcare environment.

Pathfinder proved well tailored to the needs of this project and to the broader requirements of hospital evacuation analysis. Its wide functionality, particularly the ability to model wheelchair users, variable walking speeds and decision-making delays enabled the simulation of complex processes that cannot be reliably replicated during real-world actions. Simulation tools such as Pathfinder allow for visualization and analysis of scenarios that would be difficult or even impossible to conduct in real life because of unsafe environment. This capability is particularly relevant in hospitals, where certain patient groups cannot be moved independently. Models can be continuously updated as infrastructure changes occur ensuring that the actualized evacuation strategy remains aligned with the hospital's operational reality.

## 10. Conclusion

This study demonstrates the clear value of using simulation tools to enhance emergency preparedness and evacuation planning within hospital environments. By integrating staff survey results with scenario-based simulations, leads to create valid and representative model. The model setup reflects the complex behaviors, mobility limitations, and operational constraints unique to healthcare settings. The use of data gathered directly from hospital personnel, empirical data and relevant literature create accurate model population.

The hospital's existing emergency management framework shows a generally high degree of knowledge- supported by staff familiarity with alarms, evacuation routes, and roles in the case of emergency. By merging empirical staff feedback with modeled evacuation scenarios identify several critical areas for improvement. Scenarios involving the evacuation of patients with limited mobility, as well as those involving closed exit routes, clearly demonstrated the sensitivity of evacuation performance to changes in available egress paths and evacuation equipment availability.

Overall, this study strongly supports the adoption of simulation tools such as Pathfinder as an integral component of hospital emergency preparedness. Their ability to test complex conditions, evaluate the impact of infrastructural constraints makes them invaluable for real-time operational decision-making tool. Simulations enable hospitals to evaluate proposed changes, update evacuation plans as layouts to ensure that emergency strategies remain both inclusive and effective.