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Evacuation of people with physical disability in public buildings

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WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES

Master Thesis in Fire Safety Engineering

Haugesund
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Evacuation of people with functional disability in public buildings

Master thesis in Fire Safety Engineering

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Preface / Acknowledgements

This report is the result of a master's degree at the Western Norway University of Applied Sciences (HVL) in fire safety engineering.

This thesis describes evacuation and safety of disabled persons in public buildings.

I want to thank Smáralind and Harpa for the use of their premises for the evacuation exercises. In addition, I would like to thank Norðurturn for using their evacuation drill as an example in the project. I am also grateful for everyone who participated in the evacuation exercises and assisted with the work of this thesis.

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Gudrun Julia Thordardottir

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Abstract

Today, more focus is put on evacuation safety of disabled people. In this thesis, evacuation and safety of disabled persons will be investigated in buildings open for the public, such as shopping malls, conference centre and office buildings. There were performed evacuation exercises in two buildings and observation of a drill in a third building. In each building were performed three exercises, and a questionnaire was answered by the participants afterwards. In addition, an evacuation drill, that was performed in an office building, was observed to see the evacuation of a disabled person that was located in the building.

In the evacuation exercises the main obstacles discovered were staircases that the participants were unable to use to evacuate out of the buildings. The evacuation exercises also showed a lack of signage in some evacuation routes and that the refuge areas were not marked with clear and visible signs. The communication device in the refuge area should also be marked with clear and understandable signs for easy use. The participants were not familiar with the concept of refuge area.

There were also performed evacuation simulations in Pathfinder for each evacuation exercise performed. In the simulations two movement speeds were tested: 1.19 m/s and movement speed profile from SINTEF rapport. The movement speed profiles were 0.10-1.68 m/s for non-disabled occupants and 0.13-1.35 m/s for disabled occupants.

The results from the simulations showed that the disabled occupant travels a slightly longer distance than the non-disabled occupant. In addition, the non-disable occupant has on average faster movement speed than the disabled occupant. This results in shorter evacuation time for the non-disabled occupant compared to the disabled. The average evacuation time, calculated from the results from the simulations of the movement speed profile from SINTEF, have large values of standard deviation. The non-disabled occupant has on average larger standard deviation for the average evacuation time than the disabled occupant.

When the results from the evacuation exercises were compared to the results from the simulations, it showed that the movement speed of 1.19 m/s give more realistic results for the evacuation time of a disabled person rather than the use of average values from ranged movement speed profile.

Sammendrag

I dagens samfunn er det lagt mer vekt på evakuering og sikkerhet til personer med nedsatt funksjonsevne. I denne oppgaven blir evakuering og sikkerhet til personer med nedsatt funksjonsevne undersøkt i bygninger åpne for publikum, for eksemple kjøpesenter, konferansebygg og kontorbygg. Det ble gjennomført evakueringsøvelser i to bygninger. I hver bygning ble det utført tre øvelser, og hver deltaker svarte på et spørreskjema etter hver øvelse. I tillegg ble det observert en evakueringsøvelse i et kontorbygg, for å se evakueringen av en funksjonshemmede person som befant seg i bygningen.

I evakueringsøvelsene var hoved hindringen som ble oppdaget trapper som deltakerne ikke kunne evakuere videre fra og derfor kunne ikke komme seg ut av bygget på egenhånd. Det var også mangel av ledesystem i rømningsveien, og sikre sonene var ikke merket med tydelige og synlige skilt. Kommunikasjonsutstyret, som var plassert i sikre sonene, burde også merkes med tydelige og forståelige skilt for enkel bruk. Deltakerne var ikke kjent med begrepet «Sikkert sone».

Det ble også utført evakueringssimuleringer i Pathfinder for hver evakueringsøvelse som ble utført. I simuleringene ble to bevegelseshastigheter testet: 1.19 m/s og hastighetsprofil fra SINTEF rapport. Hastighetsprofilene fra SINTEF rapporten var 0.10-1.68 m/s for funksjonsfriske personer og 0.13-1.35 m/s for funksjonshemmede.

Resultatene fra simuleringene viser at funksjonshemmede bruker litt lengre avstand når de evakuerer enn den funksjonsfriske brukeren. I tillegg har den funksjonsfriske brukeren gjennomsnittlig raskere bevegelseshastighet enn den funksjonshemmede. Dette resulterer i kortere evakueringstid for den funksjonsfriske brukeren i forhold til den funksjonshemmede. Gjennomsnittlig evakueringstid beregnet fra resultatene fra simuleringene med hastighetsprofilen fra SINTEF rapporten har store standardavvik. Den funksjonsfriske brukeren har i gjennomsnitt større standardavvik for gjennomsnittlige evakueringstiden en den funksjonshemmede.

Når resultatene fra evakueringsøvelsene sammenlignes med resultatene fra simuleringene, vises det at bevegeslseshastigheten på 1.19 m/s gir mer realistisk evakueringstid for funksjonshemmede i stedet for bruk av gjennomsnittsverdier fra variert hastighetsprofil.

Western Norway University of Applied Sciences

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Definitions

Universal design	Universal design is a design of products and surroundings that can be used by all people, as much as possible without any need of customization and a special design [1]
ASET	Available safe egress time. The time from a fire starts until critical conditions occur [2]
RSET	Required safe egress time. The time from a fire starts until everyone occupying a building have evacuated safely out of the building [2]
SWGS	Safety way guidance system. It provides luminous markings and direction information for safely leading people to safety in case emergency [3]
TEK 17	Building regulation that specifies the minimum requirements for constructions in Norway [4]

1 Introduction

1.1 Background and purpose

In today's society, there is a larger focus on buildings being accessible by all people. Everyone should have the same possibility to access and use buildings and their functions, and therefore universal design is applied to most buildings. Universal design should also apply for evacuation in case of an emergency. Universal design does not cover how disabled persons can safely exit buildings in case of an emergency. It is therefore important that fire safety engineers consider evacuation of disabled people when formulating the fire design concept for buildings, to ensure the safety of all persons in the building.

This project will focus on workplaces and buildings open to the public, such as shopping malls, concert halls and office buildings. The buildings used in this project should be designed to be available and usable by all, independent of people's disabilities.

The purpose of this research is to investigate how applicable public buildings are in an emergency for people with disabilities. It is interesting to see how disabled persons react to their surroundings during an emergency and see how they evacuate. In this project the difference between real life evacuation and a simulation of an evacuation will be compared to see if there is any significant difference in their outcomes. In the simulation program a simulation of an evacuation of a disabled person and a non-disabled person will be performed to see how the evacuation of these two types of individuals will compare. It will also be investigated how accurately the simulation program is able to simulate the challenges that apply when evacuating in a wheelchair.

In the report the following thesis questions will be considered:

- How well are evacuation possibilities for disabled people thought out in existing buildings? Are there any functions or components in the evacuation route for disabled people, and how do they work in an evacuation?
- What kind of obstacles do disabled people encounter in an evacuation situation?
- Do disabled people know about the precautions and functions that are installed for their safety in buildings? What can we do to increase this knowledge?
- How do simulation programs incorporate disabled persons, and how does the simulations compare to real-life evacuation exercises?

1.2 Limitations

This report focuses on evaluating the evacuation safety of individuals with physical disabilities in wheelchairs. The participants in the evacuation exercises are therefore individuals in wheelchairs, both with and without assistants.

The evacuation exercises are performed in Iceland. The buildings that will be used to perform evacuation exercises are all public buildings, such as a shopping mall, a concert and conference center and office buildings. The buildings in this thesis are built during the period from 2001 to 2017. Therefore, some of these buildings contain refuge areas for disabled persons.

In the evacuation exercises each participant evacuates on their own. Therefore, other people will not affect the decision making for the person evacuating, and there is no influence of queues or other human factors. This is done to discover possible obstacles in the evacuation route for disabled persons, and to get a clearer picture on how they evacuate and select an evacuation route.

2 Theory

In this chapter the following evacuation and regulations regarding evacuation will be described to give sufficient understanding of the topic of this report.

2.1 Evacuation

When analysing fire safety in buildings an important component is predicting the movement of people in case of emergency. It is assumed that safe egress is achieved if the available safe egress time (ASET) is sufficiently longer than the required safe egress time (RSET) [2], see figure 1.

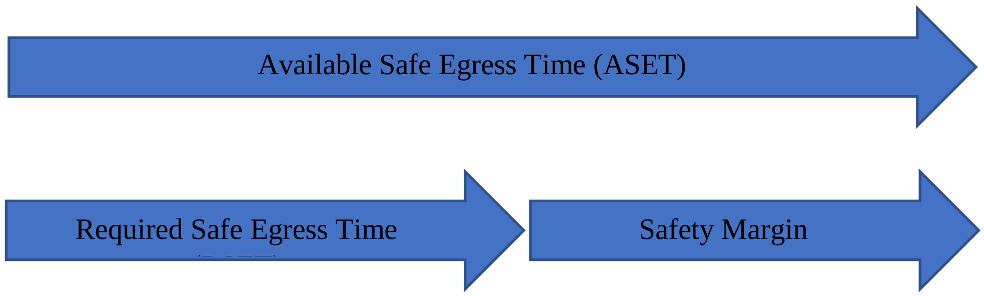


Figure 1: ASET and how it is divided into RSET and safety margin

ASET is the time from a fire starts until critical conditions occur in the building or in the room where the fire is. Critical conditions for people are based on acceptance criteria, which are limit values for critical conditions such as radiation. The acceptance criteria are based on smoke, temperature, heat radiation and gas concentrations [2]. The main determinants of ASET are hazards from toxicity and heat [5]. If the acceptance criteria are exceeded, the conditions are considered to be dangerous for people. Some examples of acceptance criteria are that the temperature in the smoke free zone should not exceed 60-80 °C, the concentration of oxygen should not be less than 15%, and CO concentration should not be more than 2000 ppm. The ASET can vary from fire to fire, and this is therefore an important parameter in assessing whether a satisfactory fire protection concept has been established [2].

RSET is the time needed to evacuate a building and reach a safe area after a fire has occurred in a building. The RSET can be divided into notification time, assessment and decision time, and movement time, as shown in figure 2.

The safety margin is the difference between the available safe egress time and the required safe egress time, as shown in figure 1. It is important that the available safe egress time in the building is significantly greater than the required egress time to ensure that people plan to evacuate the building before critical conditions occur. There is currently no statutory requirement for the size of the safety margin, but in practice a safety margin of 200-300% of the required safe egress time is generally used, which means that the required safe egress time must be multiplied by a safety factor of 2-3 [2].

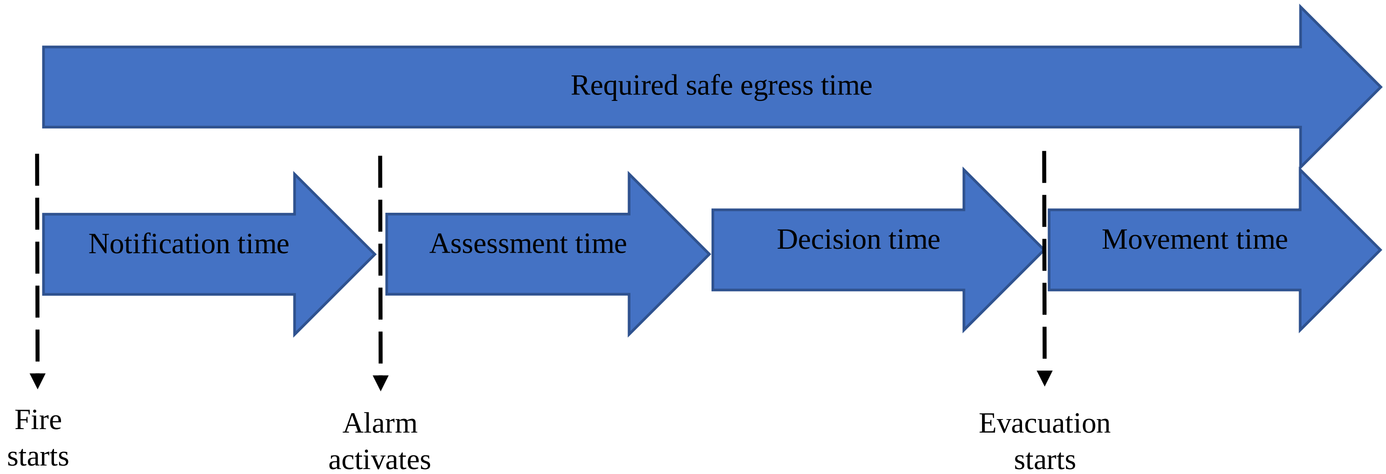


Figure 2: The different stages of evacuation within RSET

Notification time is the time from a fire starts until it is detected and the alarm is sounded. A fire can be detected either by people, smoke detectors or other types of fire detectors. Notification time is highly dependent on the time it takes for the fire to be discovered or detected, and the time it takes to alarm/alert others in the building. Assessment and decision times are the times required by persons to interpret and assess the situation and potential danger, and then decide to evacuate the building. Movement time is the time required for movement to a safe place. The movement time is dependent on the number of people in the building and person flow through the egress routes. Person flow through egress routes depends on movement rate, density and effective width of the egress routes in the building. Movement rate is the average speed of a group of people during evacuation. There will be variations in the speed of people movement due to individual differences, such as age, gender and knowledge of the building [2].

2.1.1 Human behaviour

Human behaviour during evacuation are dependent of the occupant characteristics, the building characteristics and the fire characteristics. These factors play a large role in the development and outcome of the evacuation and have an impact on the assessment time and decision time shown in figure 2. The occupant characteristics include factors such as gender, age, ability, knowledge, experience and role. Age and mobility can influence the occupant’s response to a fire and occupants with different knowledge and experience can react very differently in an emergency. For example, an employee with training reacts differently to an alarm than a customer or a visitor. Personality and role can influence the occupant’s reaction in a way that some might copy the reaction of others, for example not reacting to the alarm or pick the same evacuation route as others, while others take on a leadership role [6].

The building characteristics include factors such as occupancy, architecture, activities in the building and fire safety features. With regard to occupancy, it is not expected that occupants in a hotel will react the same way to a fire as occupants in a cinema for an example, since each building presents a specific situation. The architecture of a building can have major impact on occupant movement, for example if the evacuation routes are complex or if the familiar route is blocked, it can increase the RSET and make it harder for the occupants to find an alternate way out [6].

The fire characteristics include factors such as visual cues, olfactory cues and audible cues, such as smoke, smell of smoke and visible flames. These factors can inform the occupants of the situation. When people perceive cues from the fire, their interpretation of the situation will change rapidly and thereby influence their behaviour [6].

Figure 3 presents six individual perceptual processes that may be critical factors in the perception of a fire. Recognition occurs when an individual becomes aware of the fire, due to perceptual cues such as flames, heat and smoke. Thereafter, the individual attempts to validate the initial perception of the fire cues and obtain additional information. The definition process is the procedure where the individual attempts to relate the information concerning the fire to the perceived and contextual variables. After the definition process the process of evaluation occurs, where the individual responds to the threat and develops strategies to cope with the fire incident. In order to achieve the behavioural response strategies that were formulated in the evaluation process, the individual needs to initiate the necessary behavioural responses. The individual becomes involved in the cognitive process of reassessment and commitment if the response strategy is not completed. However, if the response results in success the anxiety and stress created by the incident are relieved. The process reassessment and overcommitment is the most stressful process for the individual because of failure to achieve the formulated response strategies to the fire incident [7].

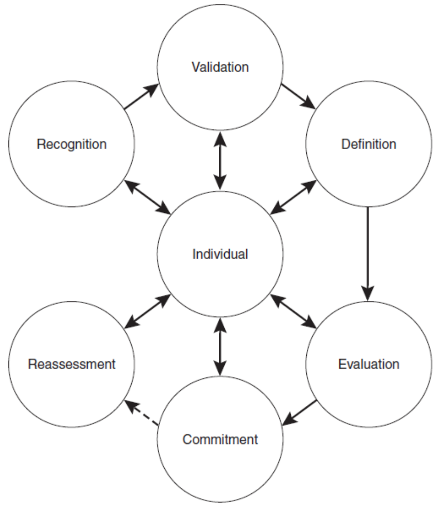


Figure 3: The decision processes of the individual in a fire [7]

2.1.2 Factors influencing evacuation

There are several factors that can affect evacuation conditions in a building. These are the buildings layout, the occupants and the organizational condition. These factors are important to evaluate/consider when assessing and calculating the required safe egress time [8].

When determining the layout of a building there are several ways to aid safe evacuation. The building shall be practically divided into fire cells. There are measures such as the placement and number of evacuation routes out of a room or a building. The layout of evacuation routes, and evacuation routes that are adapted to current occupants in the building are also important measures [8].

The people that find themselves in a building affect the evacuation, for example how familiar they are with the building and what opportunities they have for bringing themselves to safety. People who are well familiar with the building can be expected to use shorter time to evacuate. Physical features/fitness can affect movement time, and that can vary with age and possible disability [8].

In larger buildings and in special cases it is necessary to supplement the physical arrangement for evacuation with organizational measures. Such measures can be a crucial part of the fire safety in the building. They can reduce the likelihood of fire or may develop or contribute to safe evacuation. These measures include providing key personnel/guards who are trained to assist evacuation and customized information for those evacuating [8].

Building in risk classes 5 and 6 (Norway), such as shopping malls, conference centres and other commercial and public buildings must have an evacuation plan in place before the building is taken into use. The plan must contain a plan for exercises drills. Furthermore, it shall describe the tasks of the persons involved in evacuation – including who will assist persons with disabilities [8].

2.2 Evacuation strategies

When designing a fire safe environment for occupants with disabilities, there are two approaches that can be used, micro or macro approaches. The micro approach consists of finding a solution that is designed specifically for occupants with disability, and these solutions are often different from solutions for non-disabled occupants. The macro approach consists of solutions that can be used by all occupants. The most ideal solutions should facilitate the evacuation of every occupant in the building [9].

When planning the fire safety in a building a strategy is defined. The strategy takes into account fire safety requirements imposed by regulations and by occupants' limitations. When the strategy is determined, a procedure can be defined that describes the role and responsibilities of staff and occupants. From the procedure, a plan is finally devised, which consists of clear and concise instructions intended for the occupants of the building [9].

There are two options that can be chosen from when defining the strategy. The first one is "protect in place", and this option implies that some or all occupants will stay inside the building during a fire in a fire- and smoke-safe compartment. There they can wait until the situation is under control or until the fire rescue team rescues them. The second strategy is "everybody out", and this option implies immediate evacuation of the full building or floors that are affected by the fire. In this case occupants with mobility impairments can either evacuate using evacuation elevators or be carried down the stairs by other people or the fire rescue team [9].

It is important that the disabled occupants are comfortable with whatever procedure or situation being considered. A procedure is only useful if people are willing and ready to use it. It is also important that the occupants are familiar with the evacuation procedures, since it is often required in an emergency that occupants use routes that are not commonly used. People will often not think of using unfamiliar exits and might not be willing to try new routes in fear of that they will not lead them to safety. Occupants are often not willing to spend time to make themselves familiar with complicated procedures. Therefore it is important to keep the procedures clear, simple and accessible to ensure that occupants will know how to react during an emergency [9].

2.3 Components in evacuation routes

Safety way guidance system (SWGS) are one of the measures that affect the required safe egress time. They facilitate orientation in evacuation routes by making ceilings, walls, floor and doors more visible

[10]. SWGS are markings and indications in the evacuation route which show the route to a safe area. These markings and indications include not only illuminated signs, but also audible signal or touch markings, for example markings on handrails or floors. In addition, signs that guide the route to the exit with standardized icons.[11]

TEK 17 requires that buildings are designed and executed for quick and safe escape. To meet those requirements a proper SWGS must be installed in large buildings and buildings intended for a high number of persons, as well as buildings intended for activities in risk classes 5 and 6. This is also required in buildings that are accessible to the public, are under-ground, or consist of large and complex fire cells, such as larger warehouses [10].

In the Byggforsk series the main types of SWGS are described. There are marking indicator (markeringsskilt) that are placed above exits or doors that lead to an evacuation route. These marking indicators can be translucent, luminescent or illuminated [10]. Figure 4 shows an example of a marking indicator.

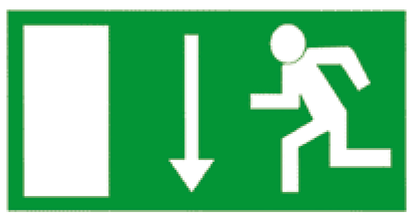


Figure 4: An example of "markeringsskilt" or marking indicator (Obtained from Byggforsk 321.038)

Then there are directional indicator (henvisningsskilt) that are used to direct people to an evacuation route that leads to a safe place. These directional indicators can be translucent, luminescent or illuminated [10]. Figure 5 shows an example of directional indicator.

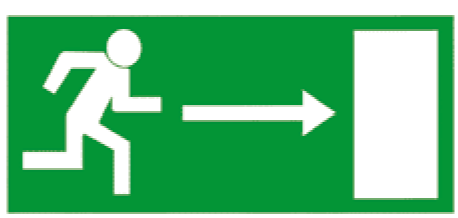


Figure 5: An example of an "henvisningsskilt" or directional indicator (Obtained from Byggforsk 321.038)

Figure 6 shows an example of a directional indicator sign that guides the evacuation route that is available for all occupants, disabled and non-disabled. This sign can be used to indicate the route leading out of the building or to a refuge area [11].

Figure 6: Example of combined sign that guides the way to safe location for disabled and non-disabled occupants [11].

To indicate that one has arrived at a refuge area, a sign could be used as shown in figure 7. "Öruggt svæði" which is written on the sign in figure 7, is Icelandic and means "Refuge area". It should be noted that the signs in figure 6 and 7 are not standardized [11].

Figure 7: Sign indication for refuge areas [11]

There are also other guidance measures that can be supplemented to the SWGS, such as voice information or alarm. In an emergency, voice information can be communicated via speakers installed in the building. The voice information can be used to ensure that the occupants immediately start the evacuation and explains how to get out using the SWGS. Research has shown that voice information results in quicker assessment and less decision time than an alarm when it comes to alarming the public and starting evacuation [10].

A refuge area is an enclosed room with fire-resisting constructions that is served directly by a safe route to an exit, evacuation lift or final exit. This constitutes a temporary safe area for disabled people, where they can wait for assistance with their evacuation. An evacuation lift can be used during emergency for the evacuation of disabled people under the direction of management or fire rescue department [12].

2.4 Factors that affect evacuation of disabled people

There are many factors that can affect the evacuation of a disabled persons. Some of the most important factors are layout and width, height differences and inclines. Disabled people need enough space to navigate through the evacuation routes. Height differences and inclines can be difficult for disabled people to navigate and often cause situations where disabled people get stuck and need assistance [13].

There are a number of measures that affect the reaction, movement and rescue of disabled people. Measures that affect reactions are technical measures such as signs and other forms of information. It is important that there are evacuation- and orientation plans available. Signs should be easy to read and guiding signs/marks with a wheelchair must be standardized to avoid confusion due to different variations. Staff that are well trained on how to react in case of emergency and how to inform and give clear information can reduce the reaction time of occupants greatly [13].

Measures that affect movement are the design and layout of evacuation routes. As mentioned before, an incline can affect movement of disabled people and therefore should ramps have a maximum slope of 1:12. In addition, doors should be easy to open, and without excessive force to ensure that everyone can open the emergency exit and prevent crowding by the doors [13].

Measures that affect rescue can be as following. When a disabled person cannot evacuate out of a building on their own, they are in need of an assistance to evacuate. Often it is the responsibility of the fire rescue team to assist the evacuation of disabled people. To increase the safety of disabled people in need of assisted evacuation, a temporary waiting place or refuge area can be installed in buildings, where they can wait for assistance to evacuate the building. Devices to be used to evacuate disabled people, are for example evacuation chairs. In high rise buildings it could be necessary to install evacuation elevator or fire elevator for the fire department to ensure transportation of extinguishing equipment and for rescue of people with disabilities [13].

2.5 Number of people with reduced mobility in Norway and on Iceland

According to Statistics Norway the population in Norway was about 5 328 212 in the fourth quarter of 2018 [14]. It is estimated that around 50 000 individuals in Norway use a wheelchair because of their reduced mobility. It is therefore estimated that about 1% of the population in Norway has reduced mobility and use a wheelchair to get around. The Norwegian Association of Disabled estimates that 15% of the population has some sort of disability, for example reduced mobility, impaired vision, hearing impairment or psychosocial disability [15]. According to this information a large part of the Norwegian population will need some kind of assistance during an emergency evacuation.

The Icelandic Parliament published an answer to an inquiry where information about the number of people with reduced mobility and people using aids was requested. According to this answer the number of people registered with reduced mobility in Iceland at the end of 2018 was 8 645 persons [16]. In September 2018 the population of Iceland was 354 152 people [17], which means that about 2.5% of the population is registered with reduced mobility in Iceland.

2.6 Universal design

According to the Norwegian Ministry of Climate and Environment, universal design is the design of products and surroundings that can be used by all people. The product or surrounding should be usable as much as possible without any need of customization or special design [1]. The main purpose of universal design is to achieve a more inclusive society, by improving accessibility for people with disabilities [18].

The biological understanding of disability as an individual problem was challenged by the importance of the environment for the individual's ability to participate in the community. This is called a social understanding of disability, claiming that it is the environment that makes people disabled, not the individuals state of health and individual prerequisites. A disabled person, such as a person in a wheelchair, is disabled by the society that is designed in a way that the person cannot participate in his or her own prerequisites. In this way, disability is understood as a social construction and a product of social and cultural conditions [18].

The objective of universal design is to create the most equal terms for all users. Everyone must be respected, no one shall be discriminated against, and the universally designed solution should be the one that is most natural to use [1]. Buildings with universal design must be equipped and arranged to be useful to all, also when it comes to egress conditions. It includes arranging active measures. For commercial and public buildings, technical and organizational measures for assisted evacuation must be included in the evacuation plan for the building [8].

Universal design is based on seven principles. The design of the building's infrastructure should not cause any inconvenience for any user groups, but be equally usable and accessible to everyone. It should serve a wide range of individual preferences and skills and be flexible in use. Usage should be easy to understand regardless of the occupants experience, knowledge, language or level of concentration. The user of the building should be provided with necessary information efficiently, independently of conditions related to the environment or the occupants ability to perceive this. The design should limit hazards, injures and adverse effects of unintentional actions, and should be effective and convenient to use with a minimal effort. There should be sufficient space available for access, operation and use, regardless of the users body size, position, range and mobility [19].

It is mentioned in a report written by SINTEF that none of these principles concern evacuation in case of fire or safety in general. The principles are of more general nature. Even in some countries, associations for people with disabilities are also unwilling to focus on fire safety because of fear that it could lead to accessibility restrictions [13].

2.7 Regulations in Iceland

In this chapter the regulations and guidelines from the Icelandic building regulation regarding evacuation will be represented.

Chapter 9 in the Icelandic building regulation focuses on fire safety and design. The following paragraphs focus on evacuation and how evacuation routes shall be designed.

Paragraph 9.5.1. explains the goals for evacuation routes in buildings. It states that evacuation routes in buildings must be organized and executed in such a way that everyone can be rescued on their own or with assistance from others during a specified evacuation time, in case of a fire or any other emergency [20].

Paragraph 9.5.2. states that when determining evacuation routes the requirements for universal design shall be considered. The guidelines for paragraph 9.5.2 refer to chapter 6 in the building regulation which focuses on universal design. It refers to paragraph 6.1.2. which has general provisions on universal design. That paragraph includes the statement that universal design shall be ensured so that people are not discriminated against with regard to access and general use of buildings on the grounds of disability, impairment or illness. In addition, they should be able to get safely in and out of buildings, even in unusual circumstances, e.g. fire. Paragraph 6.1.3 in the building regulation describes which types of buildings are required to have universal design. This includes buildings intended for the public, such as theatres, cinemas, concert halls and shopping malls [20].

Paragraph 9.5.10 states that buildings with universal design should contain two independent refuge areas available for everyone. Refuge areas shall be located on every floor, except where disabled people can get straight out of the building without any special assistance. It shall be easy for disable people to open doors to these areas. Electrical door openers on doors shall be fitted with an emergency power supply. The refuge area shall be in a special fire compartment with adequate egress routes, e.g. a staircase or a balcony. When determining the size of these areas, the number of people with disabilities in the building shall be estimated. Refuge areas should never be less than that area of at least one wheelchair, 1.5 m x 0.8 m in size. At least one of the long sides of the area shall have access to a larger area, such as staircase or a balcony. Every refuge area shall include a communication device, or include another possibility for people to communicate their location to an evacuation commander or the control center in the building. The device shall function for as long as the fire compartmention of the refuge area [20].

The Icelandic Construction Authority has published a draft of guidelines for paragraph 9.5.10 in the building regulation. In this guideline, it is stated that evacuation routes for disabled people shall generally lead directly out of the building, and refuge areas shall only be used when there is no possibility for a disabled person to evacuate directly out of a building. Generally, evacuation routes for disabled people must meet the same requirements as evacuation routes for others, and thus meet requirements in paragraph 9.5 in the building regulation. This means that there should be at least two available evacuation routes which are independent of each other, and that there are at least two refuge areas available. Safe areas should be specially marked on the evacuation plan and evacuation route. They should be discussed in the fire safety report for the building [21].

Since it is estimated that 1% of guests in risk category 2 need to use refuge areas, the distribution of the refuge areas shall be designed with this in mind. Refuge areas in buildings in risk category 5 and 6, need particular attention to the needs of people who will use the refuge areas. For example, elderly people who are led by staff and need to wait while more people are helped. In those buildings the safe area needs to be larger and adequate facilities must be provided where they can wait or sit as appropriate [21].

The guidelines give recommendations on the layout of a safe area. It must be a separate fire cell, either in the evacuation route or in connection to it. Door opening equipment must have an emergency power supply, ensuring that it is active as long as the fire cell can endure. The opening force shall not exceed 25 N in order for people with limited strength to open doors in their path. The maximum pressure or torque shall not exceed 40 N [21].

The Iceland Construction Authority recommends that communication devices in refuge areas/safe areas shall meet provision/requirements mentioned in BS 5839-9. The device shall be designed so that anyone can make the fire department aware of them and that they need to be rescued. The device shall be equipped with backup power and be active for at least 60 minutes in case of electricity loss in the building [21]. If the safe area is located on the 2nd floor with access to a window which can be opened and interact with people below, it is not considered that the safe area needs a communications device. The window should face the area where the fire department will arrive. If the safe area is located on the 3rd floor or higher, communication devices must be provided [21].

2.8 Regulations in Norway

In this chapter some of the requirements regarding evacuation from chapter 11 and 12 in the Norwegian building regulation (TEK17) will be represented. Chapter 11 in TEK 17 focuses on fire safety and design and chapter 12 focuses on the planning of buildings, including universal design.

Paragraph 11.11 states that buildings shall be designed and built for quick and safe evacuation and rescue of its inhabitants, including people with disabilities. In TEK 17 there are also guidelines (VTEK 17) following paragraph 11.11. Firstly, the time it takes to evacuate a building depends on human factors, and constructional and fire conditions. Therefore, when evacuation routes are planned and dimensioned, its not just the width and length of the evacuation route that is important for the safety of people, but also the use of the building and the users ability to get out by their own. This has provided the basis for the definition of risk categories (Risikoklasser). The risk categories shall determine the basis for the design of the evacuation conditions. The division of buildings into risk categories in Norway is presented in Appendix 1. In addition, there may be a need for special equipment to meet the requirements for a quick and safe evacuation and rescue of people with disabilities. The need for equipment will depend on the type of building, and by the internal preparedness of the building. Examples of equipment are special equipment to alarm that is fit for the users of the building and equipment to facilitate rescue via staircases [22].

Paragraph 11.12 describes measures to influence evacuation and rescue time. It mentions that in buildings where evacuation and rescue may take longer time, active measures should be installed to increase the available safe egress time. It is also required that buildings have equipment for early detection of fire, ensuring that the required safe egress time is reduced. For buildings in risk classes 5 and 6, and other public buildings and workplaces, an evacuation plan should be available for the building before the building is put in operation [22].

In chapter 12 in VTEK 17, there is a requirement that public and commercial buildings shall be universally designed as mentioned in regulations, unless the building or parts of the building functions are unsuitable for people with disabilities. If the building functions are unsuitable for people with disabilities it is because of safety reasons or that it is not practically possible for a person with disabilities to use the construction or to perform the specific work tasks. One example is a fire station which can have an administration unit that is manned by office staff. The administration unit has requirements for universal design since someone in the office staff could have disabilities, but the emergency response unit can be considered unsuitable for people with disabilities [22].

2.9 Pathfinder

Pathfinder is an agent-based egress simulation program that uses steering behaviours to model occupant motion. The program consists of three modules: a graphical user interface, the simulator and a 3D result viewer [23].

The program uses a 3D geometry model. Within the 3D geometric model there is a navigation mesh which is defined as a continuous 2D triangulated surface referred to as a “navigation mesh”. Pathfinder supports drawing or automatic generation of a navigation mesh from imported geometry. This includes Fire Dynamics Simulator files, Pyrosim files and Autodesk´s drawing Exchange Format (DXF) and DWG files. The navigation geometry is organized into rooms, and each room has a boundary that cannot be crossed. To travel between rooms, doors must be installed. Doors that do not connect two rooms, and that are located on the exterior boundary, are defined as Exit doors. There can be multiple exit doors, and when occupants enter through an exit door they are removed from the simulation [23].

Each occupant is also assigned behaviour in the user interface. Behaviour dictates a sequence of goals that the occupant must achieve in the simulation. These goals can for example be waiting or moving toward a destination [23].

In Pathfinder it is possible to simulate assisted evacuation for people with reduced mobility. When simulating an assisted evacuation, Pathfinder simulates a client, an occupant who has an associated vehicle shape which includes a wheelchair and bed, and one or more assistants who help other occupants. The clients request assistance and available assistants then proceed to help the clients. If there are more than one clients that need help in the simulation, the assistants will return and continue helping clients until they are all evacuated [24].

2.10 Previous research

There are several research studies regarding evacuation of disabled persons, some of these will be presented below.

2.10.1 Sintef Rapport – Universell utforming av byggverk og brannsikkerhet – Del 1

The main objective of this project was to provide an overview, both nationally and internationally, about how the fire safety is provided and safeguarded in a building with universal design.

Part one of this project gives information on other countries legislation and guidelines in relation to the safe escape and rescue of people with disabilities, strategies in other European countries and discuss key issues related to strategy choices, provides an overview on technical solutions and performed evacuation studies on people with disabilities. The results are based on literature searches, questionnaires, interviews with resources persons in the area and participation in seminars on evacuation for persons with disabilities [13].

It does not seem that other countries are significantly further along than Norway in getting existing buildings and new buildings universally designed in such a way that safe evacuation for everyone is ensured. The main focus has so far been the design of public buildings and workplaces. Some of the most important measures for people who cannot move down staircases on their own are automatic extinguishers, temporary waiting/escape zones, escape elevators and evacuation chairs. Some important results from previous evacuation attempts are that there are measured variations in movement rates and many doors are too heavy to open. The height of the threshold can be a critical factor, as many cannot pass threshold height over 25 mm. Ramps can be an obstacle and signs are often placed too high up on the walls. Evacuation routes should have a uniform layout and be intuitive and obvious to all users of the building [13].

2.10.2 BD 2441

This report was carried out by the Department for Communities and Local Government in London. The aim of this project was to enhance fire safety and specifically evacuation procedures for disabled people in buildings. Its objectives were to identify the effectiveness and weaknesses of existing guidance on evacuation and identify the need for further work to revise or validate existing guidance. The results in this report are found from literature review and consultation processes. The main findings are that the physical state of refuges need only minor improvements. The management of evacuation procedures, refuges and their alternatives, and the process that produces them, require a major overhaul. It is also found that disabled users do generally have a good understanding of the current arrangements and are concerned about them, and within the construction sector there are widespread gaps in the understanding of the evacuation of people with disabilities [25].

3 Buildings used in evacuation exercises

In this chapter the buildings, used in the evacuation exercises will be described. There are three buildings, Harpa, Smáralind and Norðurturn, which are all placed in Iceland.

3.1 Harpa

Harpa is a concert and conference centre in Reykjavik, the capital of Iceland. The building consists of three main halls and a large foyer surrounding the halls. Its main structural materials are concrete and steel. Construction of the building started in 2007 and Harpa was opened in 2011. Regulations and standards used for the design of the building are the Icelandic laws in fire protection 75/2000, the Icelandic building code 441/1998 and BS 9999 including others. The building is therefore designed before the current building code was published in 2012 [26].

Figure 8: Picture of Harpa in Reykjavík[1]

Harpa is used for concerts, conferences, exhibitions, banquets, and various performances [26]. There are regular events and concerts in Harpa, and it is the home of the Icelandic symphony orchestra and the

[1] Picture obtained from https://www.iav.is/starfsemi/verk/fyrri-verk/stofnanir-og-skrifstofuhus/harpa-tonlistar-og-radstefnuhus/

Icelandic opera among others. The largest concert hall in Harpa is Eldborg with an area of 1.008 m^2 and ceiling height of 19 meters. It has a seating capacity for 1800 guests and can be accessed from floor 2, 3, 4 and 5. There is also a conference hall and a recital hall that can accommodate 840 and 520 guests respectively. Harpa has also many meeting rooms with capacity for 10 to 250 guests and an auditorium with seating's for up to 195 guests. Harpa has a lot to offer with many stores and restaurants, and great view from the upper floors. The building is open every day of the week from 12:00 to 18:00 to the public [27].

3.1.1 Escape strategy

The escape strategy in Harpa, in terms of people with functional disability, is based on the possibility of horizontal evacuation routes to other fire compartments or temporary refuge area until trained staff or fire brigade arrives. Persons in wheelchair in or around the concert hall can enter the sound locks connected to the staircases. Sound locks around the rehearsal and conference hall can also be used as temporary refuge area. The locations and numbers of wheelchairs are in accordance with sizes of the sound locks (refuge areas). Communication systems are installed in all temporary refuge areas which are intended to be used by people with functional disabilities. The fire brigade can use special fire elevators to move people in wheelchairs down to the ground floor and out of the building [26].

3.1.2 Area of focus

This chapter will mainly focus on describing the locations, and later in this report the details of the evacuations will be described, for example exact location of the participant. In the evacuation exercises in Harpa the following three locations will be used: Eldborg, Kolabrautin Restaurant and Kaldalón

The first location is Eldborg, the largest concert hall in the building that is located on the 2nd floor. Figure 9 shows the overview of the evacuation routes from and around Eldborg.

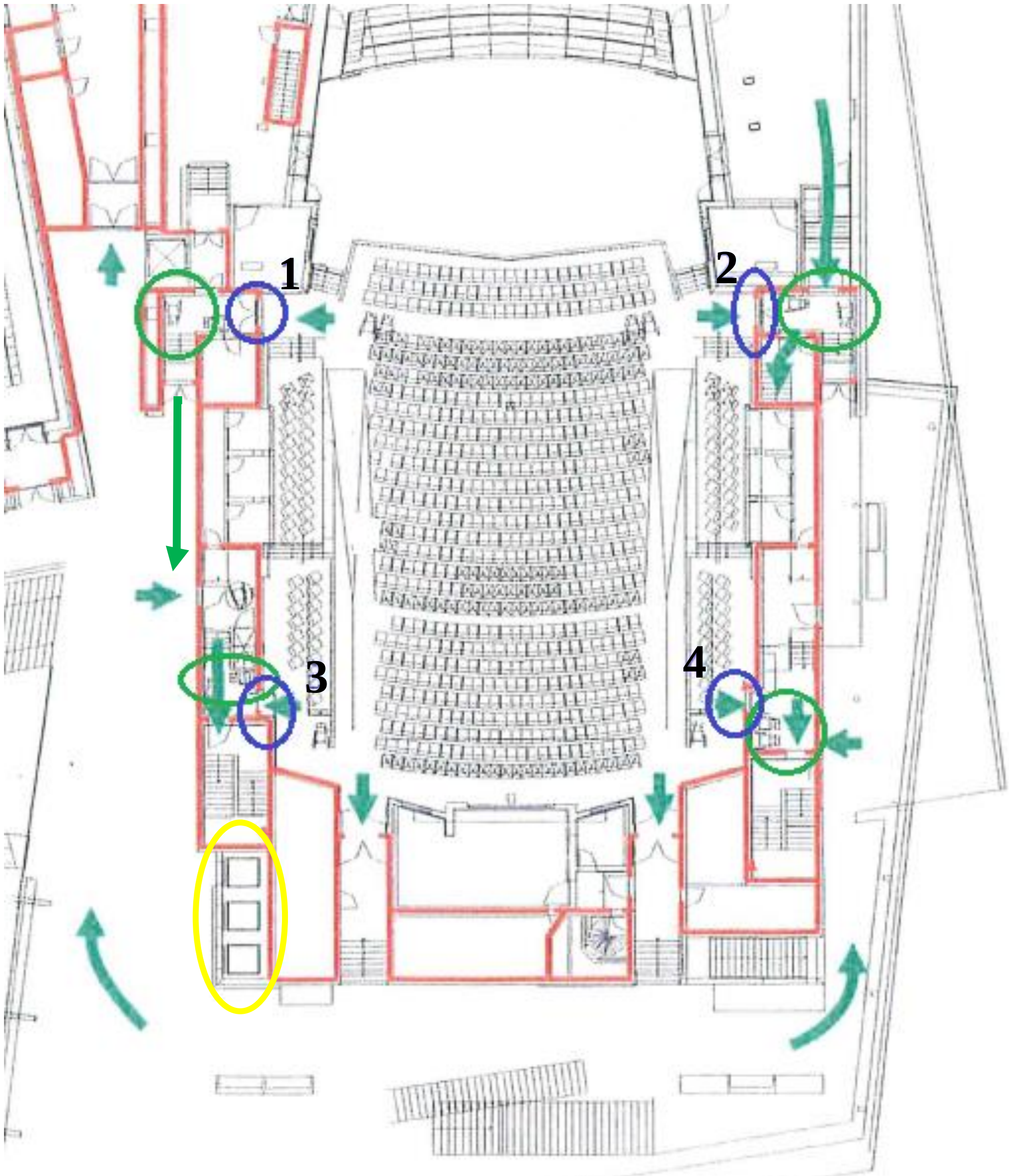


Figure 9: Overview of the evacuation routes from Eldborg

Figure 9 shows the four exits out of Eldborg, these are marked with blue circles and numbered from 1-4. The exits are in connection with refuge areas for disabled people, shown with green circles. Each of the exits lead to a staircase, except exit 1. When an individual exits Eldborg through exit 1, he or she must exit the refuge area and chose whichever route he/she thinks fittest. The staircases all lead to the 1st floor where people will eventually exit the building. Disabled individuals situated in the refuge area will be rescued by the fire rescue department. As mentioned in chapter 3.1.1 the fire rescue department will evacuate individuals in need of help through fire elevators, shown on figure 9 with a yellow circle.

The second location is Kolabrautin, a restaurant on the 4th floor in Harpa. Figure 10 shows the location of the restaurant with the letter A.

Figure 10: Overview of the evacuation routes from Kolabrautin Restaurant

People visiting the Kolabrautin Restaurant, location A, can chose between two different evacuation routes out of the restaurant through exit 1 or exit 4, see figure 10. Exit number 1 leads to a staircase, which leads further down to the ground floor, where one can exit the building. Exit number 4 leads to two possible evacuation routes. Firstly, the individual can choose to enter a staircase through the doors marked with 2 and a blue circle on figure 10. This staircase also leads to the ground floor. Secondly, one can choose to evacuate further to exit number 3, marked with a green circle. This exit is marked with a green circle is because this exit also functions as a refuge area for disabled individuals. The refuge area is marked with an X inside the green circle on figure 10. Exit number 3 has a staircase that leads to the ground floor.

The third location is Kaldalón, which is an auditorium located in the basement in Harpa. The auditorium can be accessed from both from the ground floor and from the basement. Figure 11 shows the placement of Kaldalón, marked with an A, and possible evacuation routes from the auditorium.

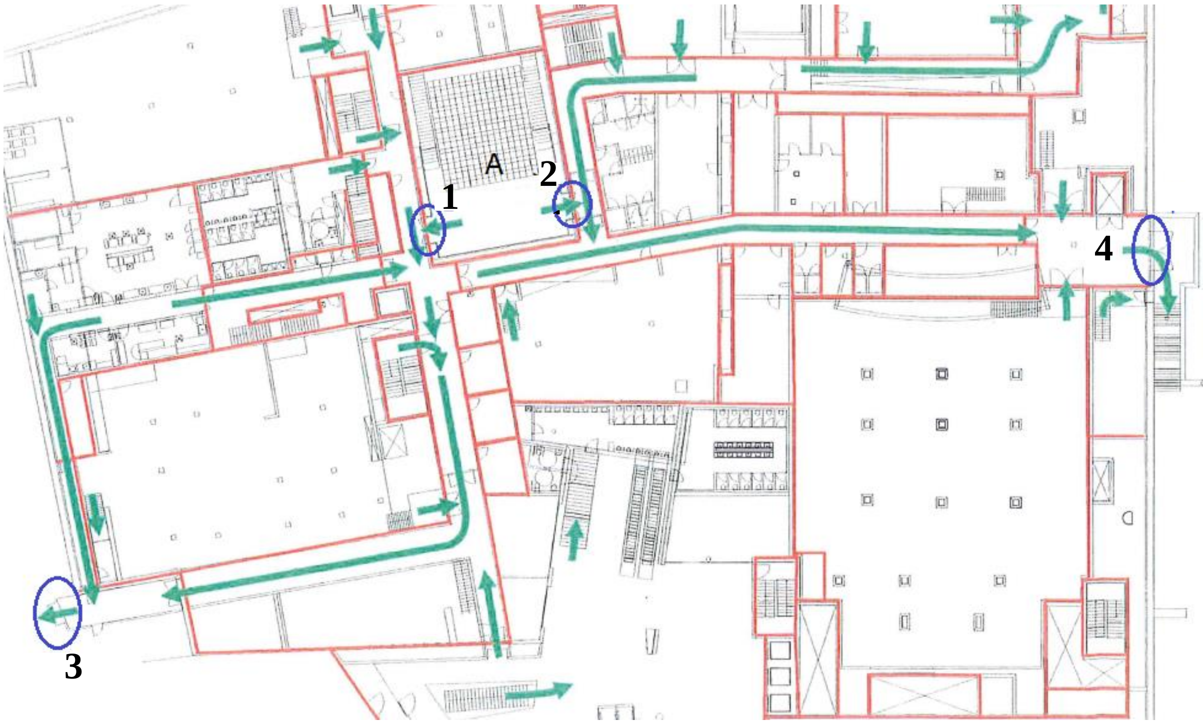


Figure 11: Overview over evacuation routes from Kaldalón auditorium in Harpa.

There are two possible evacuation routes from Kaldalón, marked 1 and 2 in figure 11. Exit 1 from Kaldalón leads to exit 3 by the SWGS in the basement. Exit 3 leads to a cell that connects the building and the parking basement. This cell has a door that leads straight out to the open but is accessed by a few steps that would stop an individual in a wheelchair. The individual is considered safe in this cell, but there is no communication device installed in that area that the individual could use to report their location. Exit 2 from Kaldalón leads to exit 3 or 4. Exit 4 leads directly out of the building, but since this floor is located partly underground, a short stair leads upwards once one is out through exit 4.

3.2 Smáralind

Smáralind is a shopping mall located in the capital region of Iceland. It is the largest shopping mall on Iceland. It was designed in 1999 and opened for the public in October 2001. The building has a total floor area of 60.000 m^2 divided in to three floors. The ground floor and 1st floor are the main shopping floors in the mall and have a floor area of respectively 26.750 m^2 and 20.220 m^2. The 2nd floor is a cinema with 5 show rooms, along with technical spaces and offices [28].

Figure 12: Picture of Smáralind[2]

3.2.1 Escape strategy

In the buildings fire strategy report it is not mentioned how people with functional disability should evacuate. On the ground floor and the 1st floor, all evacuation routes lead horizontally out of the building, but the 2nd floor does not have direct exits out of the building. People must evacuate down through a staircase to get out of the building from the 2nd floor [28].

3.2.2 Area of focus

In the evacuation exercises in Smáralind the following two locations will be examined: Smárabíó and Hagkaup. The first location is Hagkaup, which is a large compartment store located on the 1st floor. Figure 13 shows the overview over the evacuation routes from Hagkaup.

[2] Picture obtained from https://www.ask.is/is/verk/verkefni/smaralind

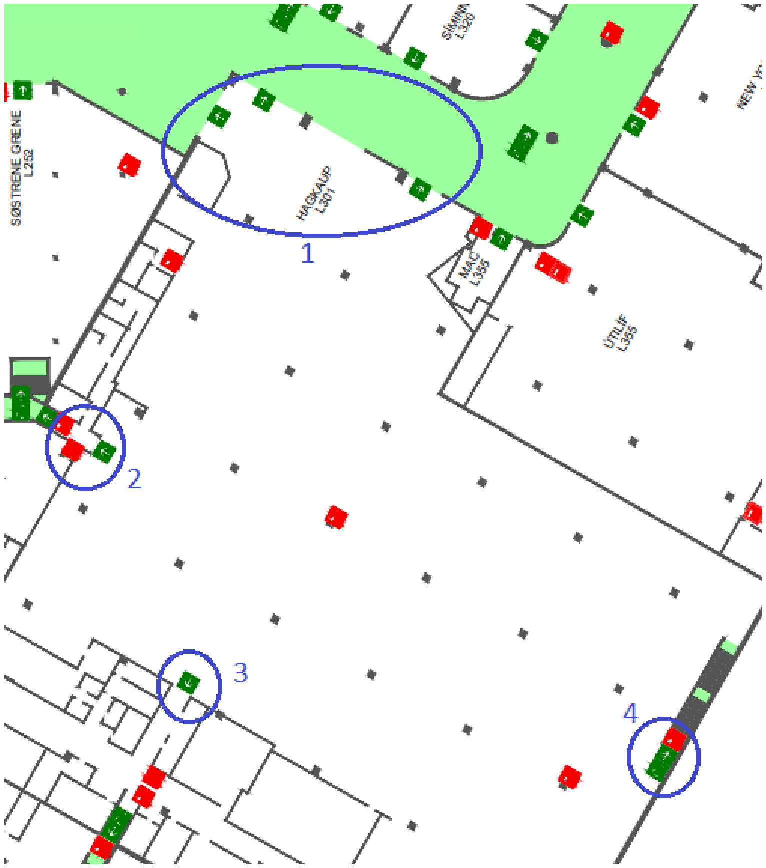


Figure 13: Overview over evacuation exits in Hagkaup

Hagkaup has a total of four exits from the store. The main exit is the entrance into Hagkaup from the main corridor, this is marked with a large blue circle and the number 1. In addition, there are three other emergency exits inside the store, marked with the number 2, 3 and 4.

The second location in these experiments in Smáralind is Smárabíó. Smárabíó is a cinema located on the 2nd floor and has 5 showrooms. Figure 14 shows possible evacuation routes from the cinema, which all lead to staircases that lead down to the 1st floor.

Figure 14: Overview over Smárabíó, the cinema in Smáralind

The entrance to the cinema is marked with the number 1 and a blue circle. From inside the cinema, the entrance is marked with SWGS signs leading people outside of the cinema. The entrance is therefore one of the evacuation routes out of the cinema. Exits 2 and 3 are other possible evacuation exits from the main floor of the cinema, available for individuals in a wheelchair. Each showroom in the cinema is marked with the letter A to E. All of these showrooms are fitted with an area for people in wheelchairs, except showroom C. All of the showrooms have two independent evacuation routes, whereas one is the entrance into the showroom and the other one is the exit where people exit the showroom when the show is over. To access the exits out of the showrooms one must walk down steps that lead to the exits, which are located at the bottom of the showroom. These exits are therefore not accessible for disabled people in wheelchairs. People in wheelchairs must use the entrance into the showrooms to exit them when shows are over and in case of emergency.

3.3 Norðurturn

Norðurturn is located in Kópavogur, Iceland. It is connected to Smáralind, the building described in chapter 3.2, although they are connected, the two buildings have separate fire alarm system and evacuation plan [29].

Norðurturn has total of 15 floors including a basement. Each floor is approximately 1000 m^2, except the 15th floor which is about 350 m^2. Apart from floor 1 and 2 which belong to risk category 2, the rest of the building is in occupation class 1. Occupation class 1 is used for office buildings, where people are familiar with evacuation routes, and occupation class 2 is used for public building/places where people are not familiar with evacuation routes [29].

It is expected that approximately 80 to 112 people are located on each floor during working hours, which makes a total of approximately 1300 people in the entire building. However, people may be in the building at all hours in connection with special events or tasks [29].

Figure 15: Picture of Norðurturn[3]

[3] Picture obtained from https://axis.is/nordurturninn/

3.3.1 Escape strategy

The evacuation routes from the upper floors lead out through the three staircases located in the building. Two of these staircases are emergency staircases, located at each end of the building, and the third staircase is located in the middle of the building near the elevators. [29]. Figure 16 shows an example of the layout of one floor in the building.

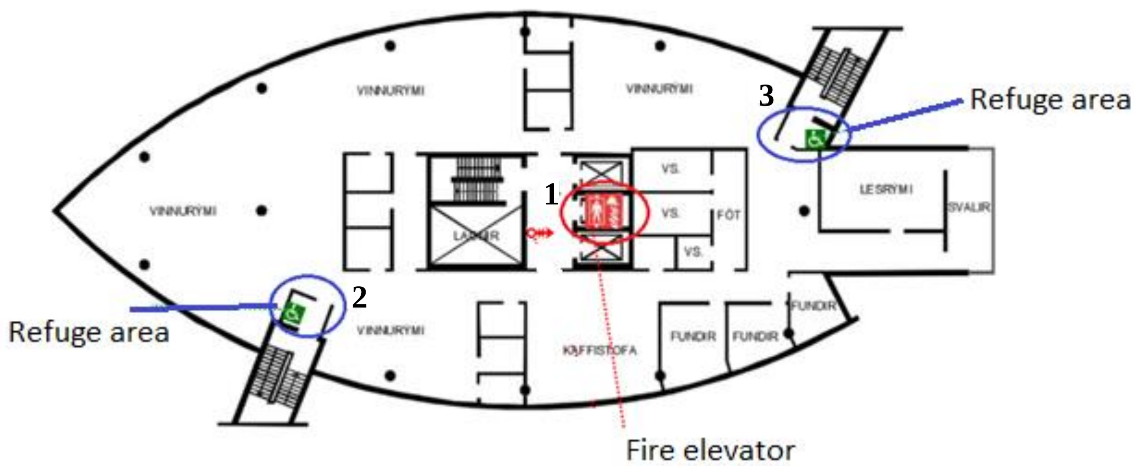


Figure 16: Example layout of one floor in Norðurturn

Norðurturn is designed to ensure the safety of people with reduced mobility and others in case of an emergency. All the floors have a secure refuge area with communication equipment. These refuge areas are located in front of the emergency staircases before one enters the staircases, and they are their own fire cells. The refuge areas are marked with number 2 and 3 and blue circles on figure 16. There is also a refuge area in front of the staircase located in the middle of the building on the 2nd floor only. One of the elevators located in the middle of the building is a special fire and rescue elevator, that the fire department can use during emergency to assist in evacuation [29]. The location of the fire elevator is marked with red circle and the number 1 on figure 16.

Figure 17 shows the communication device used in Norðurturn. The green box is the communication device. It is marked with a wheelchair, and text indicating that the device is intended for emergency calls. At the bottom of the communication device is a button which is used to call the command center and to answer the command center. Above the communication device is an information board. The information board informs about ones placement, and how to use the connected communication device. When the communication device is activated in one or more of the refuge areas, it sends a message to the control centre and the fire alarm system, indicating where the equipment was activated [29].

Figure 17: Communication device in refuge area (Picture taken in evacuation exercise)

4 Evacuation exercises

As part of the research work for this report, evacuation exercises were carried out in the buildings described in the previous chapter. In this chapter the evacuation exercises in the three buildings will be described.

4.1 Observation of emergency drill in Norðurturn

Norðurturn organized an overall evacuation exercise on the 27th of November with the capital district fire department. All the firms in the building participated in the exercise. The whole building was informed about the exercise a week in advance. Exact timing of the exercise was not given.

Before the drill it was informed that there was a disabled person in a wheelchair located on the 4th floor, which was in need of an assistance to evacuate. To observe how evacuation of a disabled person is performed in a new building like Norðurturn, it was decided to locate an observer to follow the disabled person during the evacuation. Figure 18 shows the location of the disabled person at the time when the alarm was activated with a yellow dot.

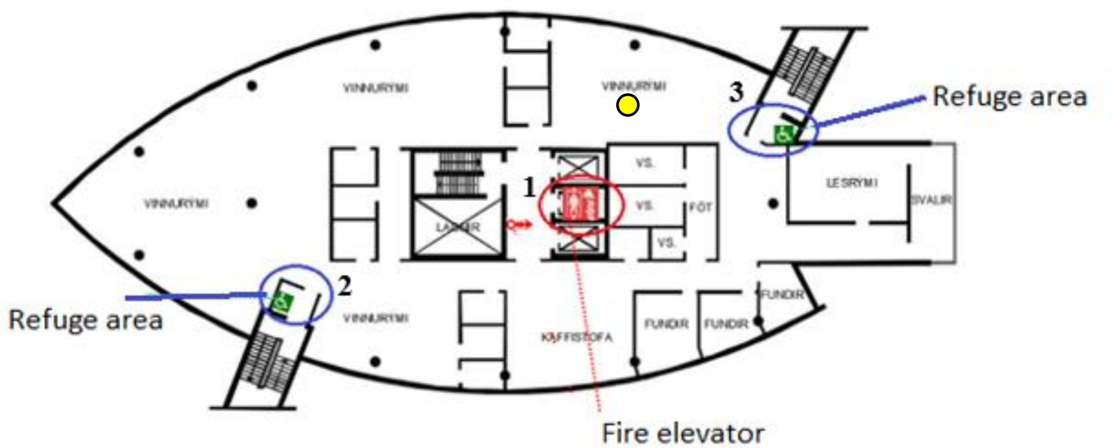


Figure 18: Location of disabled person in Norðurturn

At 14:00 on the 27th of November the alarm in Norðurturn was activated. As soon as the alarm was activated the assistant, whom was assigned to assist the disabled person, moves directly to the disabled person to assist its evacuation. The assistant is an employee from the same floor as the disabled employee, and the person is assigned this role. During an emergency, the assistant helps the disabled person to move to the refuge area, area 3 in figure 18. Once the disabled person had arrived at the refuge area, he or the assistant contacted the evacuation commander to inform their location. When the evacuation commander knew the number of and location of persons needing assistance in the evacuation, they sent the fire department to their location to rescue them.

The movement of the disabled person to the refuge area went without any obstacles. It took about 1 minute to get to the refuge area.

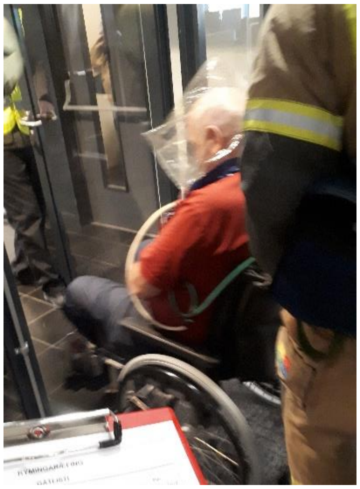


Figure 19: Disabled person during evacuation in Norðurturn

Once the fire rescue team was arrived at the refuge area, they prepared the disabled occupant for evacuation and the assistant was required to evacuate down the staircase located next to the refuge area. The fire rescue team placed an oxygen mask on the person in the wheelchair to make sure they didn't breathe in any smoke on the way out. Figure 19 shows the individual with an oxygen mask, while being helped out of the building by the fire rescue team. The fire rescue team moves the person out of the refuge area and directly to the fire rescue elevators. The disabled person was moved to the ground floor by the fire elevator with the fire rescue team, where he was further transported to an area on the ground floor where all participants were gathered.

The whole process took 10 minutes, from the alarm was activated to the disabled person was safely out of the building. The exact time that it took from the fire rescue team to be informed of the individual in need of rescue, until they arrived at the location of the individual is not known. The total evacuation time for the whole building was approximately 11 minutes.

4.2 Participants

To perform the evacuation exercises, people with functional disability were requested to take part in this project. Organizations in Iceland that work with people with disabilities were contacted in order to find participants for the exercises. Also, there were many people helpful in trying to contact people they knew. Among the organizations that were contacted was Sjálfsbjörg Landssamband hreyfihamlaðra, an association for people with reduced mobility, the Organization of rehabilitated people with spinal cord injuries, and the organization of disabled in Iceland.

4.3 Execution of exercises

The purpose of the evacuation exercises is to investigate how applicable the buildings are in an emergency situation for disabled people. Some of the buildings were designed with measures to ensure the safety of disabled people during an evacuation, such as refuge area, whilst some were designed before the requirement of universal design and refuge areas were legislated. It is therefore interesting to see how evacuations in these buildings compare, and how the disabled occupants evacuate in these buildings. In addition, it was investigated if there were any obstacles in the evacuation route for the disabled persons, and if they are familiar with measures such as refuge areas that are designed into buildings to increase their safety.

The evacuation exercises were performed in that manner that the participant was located on each location alone with an examiner and was asked to evacuate from each location as in an emergency. The examiner followed the participant and recorded the evacuation time and took notes of any noticeable deviations and how the participant evacuated. When the participant was at a location that he/she considers safe or if he/she stopped the exercise in case he didn’t find an evacuation route that he/she considers safe, the time recording was stopped and the participant answers a questionnaire, see Appendix 2 and 3. Appendix 2 includes the questionnaire in Icelandic, and Appendix 3 includes the questionnaire in English. This was repeated for each location.

4.4 Harpa

In Harpa there was performed a total of three experiment by one individual with mobile disability. There were three different locations used for the experiments. The locations in Harpa are described in chapter 3.1.2.

First location that was tested was Eldborg concert hall. Figure 20 shows the location where the participant was located to evacuate from, by a yellow dot. This location is suited for disabled guests, since few seats at the end of these rows can be removed to make space for wheelchairs. From this location, the nearest exit is marked with the number 1 and a blue circle. Beyond this exit is a refuge area for disabled persons. In the refuge area, the participant can stop and activate the communication device.

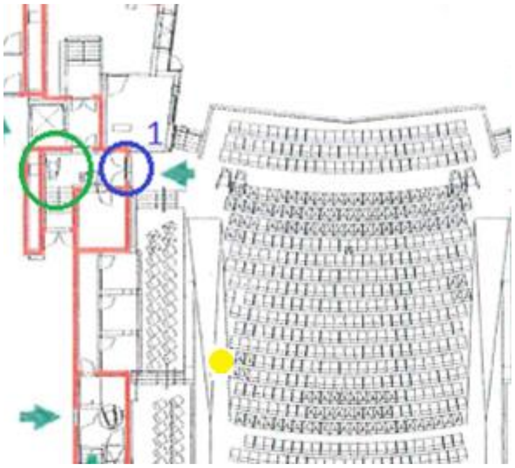


Figure 20: Location of participant in Eldborg

The second location tested was Kolabrautin Restaurant on the 4th floor. Figure 21 shows the location of the participant with a yellow dot. The participant was located outside the restaurant, where there is a sitting area. The Restaurant was closed at the time of the exercise and therefore the person was placed in the restaurants waiting area. This led to that only exit number 2 and 3, marked in figure 21, were available. Exit 3 has a refuge area with a communication device, and is shown with the x and a green circle.

Figure 21: Location of participant near Kolabrautin Restaurant

Third and last location was Kaldalón auditorium. The participant was located in the first row to the right, as can be seen with a yellow dot in figure 22. There the participant could choose from two exits, where exit 2 is closer to the participants' location in Kaldalón, see figure 22.

Figure 22: Location of participant in Kaldalón

The results from these evacuation exercises are presented in chapter 5.1.

4.5 Smáralind

In Smáralind there were performed a total of three experiment by one individual with mobile disability. Two locations were examined in the experiment, and those are described in chapter 3.2.2. The evacuation exercises were performed in the same manner as described in chapter 4.3.

The first location that was tested was Smárabíó, the cinema in Smáralind. Two showrooms were picked to perform evacuation exercises in. First the participant was located in showroom A, the placement is indicated by a yellow dot. The location is fitted for wheelchairs, see figure 23. During this exercise the doors into the showroom were kept open by magnets. Before a show starts in the showroom, the doors are kept open by the magnets and people enter the showroom. Therefore were the doors open in this scenario.

Figure 23: Location of participant in Smárabíó

The next exercise was performed in showroom D, see figure 23. The yellow dot shows the location suitable for wheelchairs. During this exercise the doors into the showroom were closed, as would be during showtime and when the alarm is activated. The doors were kept closed in this scenario to observe and compare the evacuation from scenario 1 to scenario 2.

The second location in Smáralind examined was Hagkaup, a retail shop. The participant was located inside Hagkaup, roughly in the middle of the store, near the clothing section. Figure 24 shows where the occupant was located, with a yellow dot. From this location exit number 3 and 4 were visible and marked with SWGS. The purpose for this location was to see if the participant would choose an exit that is close and visible and not the main entrance that was familiar but further away.

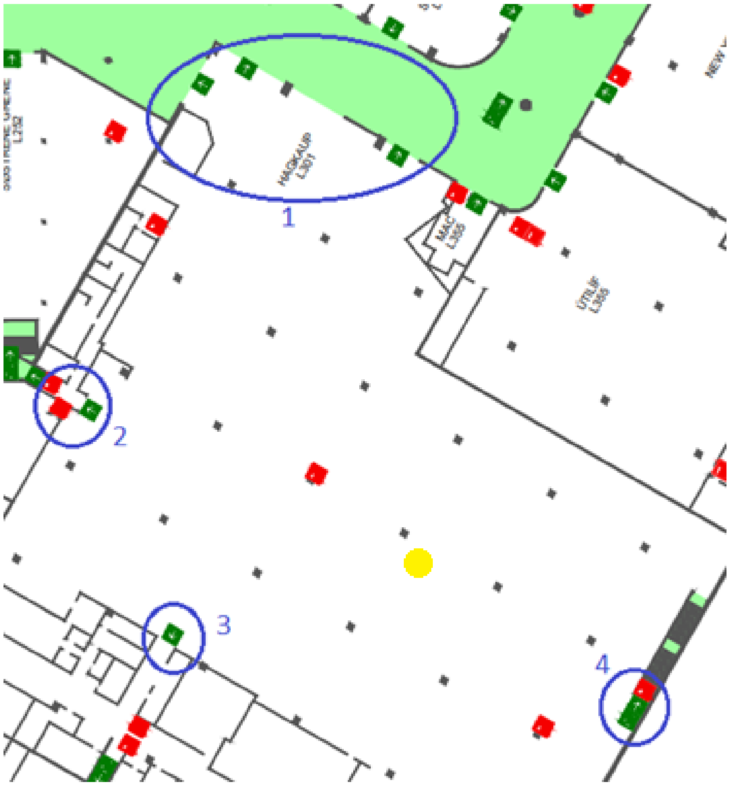


Figure 24: Location of participant in Hagkaup

The results from these evacuation exercises will be represented in chapter 5.2.

5 Results from evacuation exercises

In this chapter the results from the evacuation exercises will be represented. Section 5.1 describes the results of the experiments in Harpa, while section 5.2 contains the results from Smáralind.

5.1 Harpa evacuation routes and evacuation times

The evacuation routes and evacuation time for each scenario in Harpa will be represented in this chapter. The evacuation routes that the participant chose in each scenario are shown in figure 25, where the routes are marked with orange lines.

A B C

Figure 25: Evacuation routes chosen by the participant in Harpa. Part A) scenario 1, Part B) scenario 2 and Part C) scenario 3.

The evacuation route from scenario 1, 2 and 3 in Harpa are shown in figure 25. In scenario 1 the occupant chose the nearest exit, exit 1 placed in the top left corner, see figure 25A. This is the same exit that the participant used to enter Eldborg, which is located to the right to exit 1 and 3 on figure 25A. There the occupant entered a refuge area and stopped the evacuation. When the evacuation exercise for scenario 2 was held, the restaurant was closed, which resulted in exit route number 1 not being available, see top left corner in figure 25B. After the evacuation exercise of scenario 1 the participant was informed of the refuge area, by the housemaster of Harpa, which is located on each floor beside Eldborg concert hall. Knowing about the refuge area, the participant chose to evacuate to the refuge area, shown with a green circle in the figure 25B.

Figure 25C shows the evacuation route used in scenario 3. The participant chose the route that led to exit number 3 in the bottom left corner in figure 25C. According to figure 11 the other exit was closer.

During the evacuation exercise for each scenario the evacuation time was measured. Table 1 shows the evacuation time for each scenario. In scenario 1 the evacuation time was measures to be 12 seconds. The participant was located close to the exit, and the exit was marked with SWGS. In scenario 2 the evacuation time was measured to be 50 seconds. Lastly, in scenario 3 the evacuation time was measured to be 110 seconds.

Table 1: Evacuation time from evacuation exercises in Harpa

Scenario / Location	**Evacuation time [min]**	**Evacuation time [sec]**
Scenario 1 – Eldborg	0.2	12
Scenario 2 - Kolabrautin Restaurant	0.83	50
Scenario 3 – Kaldalón auditorium	1.83	110

5.1.1 Results from questionnaire

The participant in the evacuation exercises was a male at the age of 39. He had suffered a spinal cord injury, and therefore uses a wheelchair to get around. When entering Harpa he used the entrance from the parking floor beneath the ground floor. He is familiar with the building but usually he does not familiarize himself with evacuation plans when entering. The participant has never participated in any evacuation exercise before. He is not familiar to the term refuge area and guesses that it is a type of a waiting area.

Scenario 1 – Eldborg

In scenario 1 the participant used the nearest exit, as shown on figure 25A. This was the same exit that the participant used to enter the concert hall, in addition to being the closest exit. The participant used the SWGS and thought they were clear and visible. According to the participant it went well to find the way to the refuge area, but markings were missing, indicating that an individual has arrived at the refuge area. When the person had arrived at the refuge area, he could not get out of the area because of the steps to the exit. This was considered as the only obstacle in the evacuation route, according to the participant. The participant was not unsure where to go during the exercise and did not change his mind on where to go during the exercise. What worked well in the exercise, according to the participant, was the communication device located in the refuge area. That which did not perform as expected was the person working in the control room that was not familiar with how to operate the communication device in the control room.

Scenario 2 – Kolabrautin Restaurant

In this evacuation exercise the participant chose an evacuation route that led to a refuge area near the elevators. He chose this evacuation route because it was mentioned to him, by the housemaster of Harpa after the evacuation in scenario 1. He was informed that on each floor was a refuge area near the elevators next to Eldborg concert hall. The participant used the SWGS to find the way but noticed that the SWGS did not indicate that there was a refuge area for disabled people on this floor. Because of this, the participant thought that the SWGS was not clear and informative for disabled people. Finding the way to the refuge area could have been clearer and better indicated. There were not any obstacles in the way to the refuge area, according to the participant.

Scenario 3 – Kaldalón

In this exercise the participant used the nearest exit (exit 2 in figure 23C) in Kaldalón auditorium. When out of the auditorium, the participant followed the SWGS to find the way out. The participant noted that the SWGS was not clear enough, and that there could have been more signs available. Also, there was not specified any special evacuation route for a disabled person. It was not clear enough how to find the way to a refuge area. In the evacuation route chosen by the participant, there were boards and other furniture placed in the evacuation route, making the evacuation route narrower. Still, the evacuation route was wide enough for the participant to navigate through, however this could be an issue if other people were evacuating at the same time.

5.1.2 Observation in Harpa

The first scenario in Eldborg concert hall, the participant did not experience any obstacles on the way to the refuge area. The evacuation route was clear of any obstacles, and the door to the refuge area did not seem to be a challenge for the participant to open. Once inside the refuge area, the participant seemed unsure where to go next, since the evacuation route led further up a few steps. It took a few seconds for the participant to realize that he was located inside a refuge area, and discovered the communication device.

During scenario 2, the participant evacuated from Kolabrautin Restaurant, there was no obstacles in the evacuation route. The occupant was informed of the refuge area that was located on the floor, but on the way to the refuge area it was observed that the occupant hesitated due to lack of signs and information about the refuge areas location.

In scenario 3 it was observed that a part of the evacuation route was full of furniture and other miscellaneous objects. This did not stop the participant in the evacuation exercise, but slowed him down occasionally, since this caused that the evacuation route was narrower than it should have been.

Figure 26: Figure of the participant during evacuation exercise in scenario 3 in Harpa

Figure 26 shows the participant evacuating during scenario 3 in Harpa, through a hallway, and getting closer to an exit that leads to a compartment that separates Harpa and the parking floor in Harpa. The SWGS for the exit can be seen on figure 26. On the floor are guiding lines that lead to an exit, and at the end of the corridor is an exit with an illuminated exit sign located above the exit.

5.2 Smáralind evacuation route and evacuation time

The participant in Smáralind used a wheelchair and had an assistant that drives the wheelchair for the participant. This indicates that the assistant was in control of where the participant went and therefore decided where to evacuate in the exercises. The assistant and the participant will be referred as participants, unless otherwise is discussed.

The evacuation routes that the participants chose in the three scenarios in Smáralind are illustrated in orange in figure 27. The evacuation time from each scenario is registered in table 2.

A B C

Figure 27: Evacuation routes chosen by the participant in Smáralind. Part A) scenario 1, Part B) scenario 2 and Part C) scenario 3.

In scenario 1 the participants chose the main entrance in the cinema as an exit in the evacuation exercise. Figure 27A shows an overview of the path that the participants chose in this scenario. The participants exited the show room and headed straight to the main entrance. The evacuation exercise was stopped once the participants were out of the cinema and had stopped in front of an elevator and near the two escalators leading to the 1st floor, as shown on figure 27A. At this location, the participants were still inside Smáralind. The only way down to the 1st floor is through staircases, which is not convenient for disabled occupants. Also the participants arrived to the 2nd floor by the elevator, and therefore they might have stopped in front of the elevator, as it was in the familiar route to exit the building.

The participants chose the main entrance in the cinema as an exit in the evacuation exercise for scenario 2. Figure 27B shows an overview of the path that the participants chose in this scenario. In this scenario the participants chose the same route as in scenario 1, and stopped the evacuation at the same location as in scenario 1.

Figure 27C shows an overview of the path that the participants chose in scenario 3. In this scenario the participants chose one of the closest exits from their location, marked with a blue circle and the number 4 in figure 27C. The participants used the SWGS, but once they were at the exit, they could not open the exit and the evacuation was stopped. It was not allowed to open the exit, because it would activate the alarm system in the building.

The evacuation time measured in each scenario is displayed in table 2. In scenario 1 the participants used 0.78 minute to evacuate the chosen evacuation route, shown in figure 27A. As for scenario 2 the evacuation time was 0.98 minute through the chosen evacuation route, shown in figure 27B. In scenario 2 the difference from scenario 1 was that the doors were closed into the showroom in scenario 2. This can be a factor that influences the evacuation time. According to documented observation it took approximately 0.15 minute (9 seconds) longer to evacuate out of the showroom in scenario 2 when compared to the time it took to evacuate out of the showroom in scenario 1. This verifies that the closed doors affected the evacuation time in scenario 2. The total difference in evacuation time in scenario 1 and 2 was 0.2 minute, which makes 0.05 minute left unexplained. This difference can be the result of increased evacuation time from outside of the showroom to the chosen exit. In scenario 3 the participant used 0.5 minute to evacuate to the chosen exit.

Table 2: Evacuation time in scenario 1,2 and 3

Scenario / Location	**Evacuation time [min]**	**Evacuation time [sec]**
Scenario 1 – Showroom A	0.78	47
Scenario 2 – Showroom D	0.98	59
Scenario 3 - Hagkaup	0.5	30

The participants did not choose the closest exit in all of the scenarios. In scenario 1 and 2, there were other exits that were closer. In scenario 3 the participant chose the closest exit.

5.2.1 Results from questionnaire

The participant in the evacuation exercises in Smáralind was a male at the age of 21. He has Cerebral Palsy, which means that he has to be in a wheelchair and has an assistant with him wherever he goes. When they entered Smáralind, they used the entrance on the ground floor near Hagkaup. He and his assistant are well familiar with the building. When asked if they familiarize themselves with evacuation plans in buildings, they say that they do not do that regularly but do so if they see them. They have never participated in evacuation exercises before. According to the participants, they consider safe area to be outside the building, and are not familiar with the concept of refuge area.

Scenario 1 and 2- Smárabíó

For both scenarios 1 and 2 the participants used the main entrance into the cinema as an exit. At the end of the evacuation exercise for scenario 1 the participants mentioned that the only way down to the 1st floor was through stairs. They thought exiting the cinema through the main entrance to the cinema was the most obvious exit to use, because it is familiar. When answering the questionnaire, the participants mentioned that they used the SWGS when evacuating, and thought they were visible and clear. There was no specific way out or a refuge area that the participants could find, so they evacuated through familiar exit. There were no obstacles according to the participants during the evacuation exercises for scenario 1 and 2, and the participants never felt unsure where to go. According to the participants, everything went well in the exercises. The only comment that the participants had in the end of evacuation exercise for scenario 1 was that it is uncomfortable to be stuck and not able to exit the building safely on their own. The participants mentioned that there was not much difference in having the doors in the showroom closed compared to having them open.

Scenario 3 - Hagkaup

The participants picked the nearest exit because the SWGS led them there. Therefore, they used the SWGS, and they were visible. It was easy to find the way to the exit according to the participants. Because it was not possible to open the exit without activating the alarm system, the participant could not evacuate out of the building in this experiment.

The participants did not experience it to be difficult to find the way out and there were not any obstacles in the evacuation route. They were never unsure on which route to choose and did not change their mind. Everything worked well in the exercise, apart from it not being possible to open the chosen exit.

5.2.2 Observation in Smáralind

During the first scenario in Smárabíó there were not observed any obstacles in the way of the participants. The doors into the show room are double doors which were held in open position by magnets. When the alarm is activated the magnets release the doors, and they close. Figure 28 shows the participant where he was located in scenario 1 before the evacuation started. This location is specially designed for people in wheelchairs. From this location the evacuation route is the same route as the occupant used to enter the location, which is the entrance into the showroom. This was the evacuation route that was used in the exercise.

Figure 28: Participant in scenario 1, before starting evacuation

For the second scenario the doors into the show room were closed. It was observed that this did affect the participants, in that way that the assistant of the participant had to walk backwards to push the door open, while he was able to walk straight forward with the participant through an open door. This was the only observed obstacle in the evacuation exercise for scenario 2. Figure 29 shows the participant during evacuation in scenario 2.

Figure 29: Participant during evacuation in scenario 2.

In scenario 3 the participants did not experience any obstacles on the chosen evacuation route. The assistant of the participant was quick to start evacuating when allowed to start evacuation. He was also observed to be very certain on where to evacuate.

6 Simulations using Pathfinder

Simulations of the evacuation exercises that were executed in Harpa and Smáralind were simulated with Pathfinder. This chapter describes the setup of the models and input. The three evacuation scenarios from each of the two buildings, Harpa and Smáralind, were simulated. Each scenario was simulated with a disabled person and non-disabled person. The evacuation routes used in the evacuation exercises was used in the simulations. By using the same base, the simulations could be compared with the evacuation exercise. In addition, there were performed simulations in the Harpa model were the non-disabled and the disabled occupants evacuate out of the building through the staircases. This is done to investigate how the simulation program manages a person in a wheelchair and if the movement speed will be the same for non-disabled and disabled occupant.

6.1 Harpa model

6.1.1 Set up of model

To set up the models in Pathfinder, DXF drawings of the building were used. The DXF drawings were imported into the Pathfinder program, and the outlines from the drawings were used to create the necessary rooms that were needed to make the evacuation route according to the experiments. Figure 30 shows the model of scenario 1 in Eldborg.

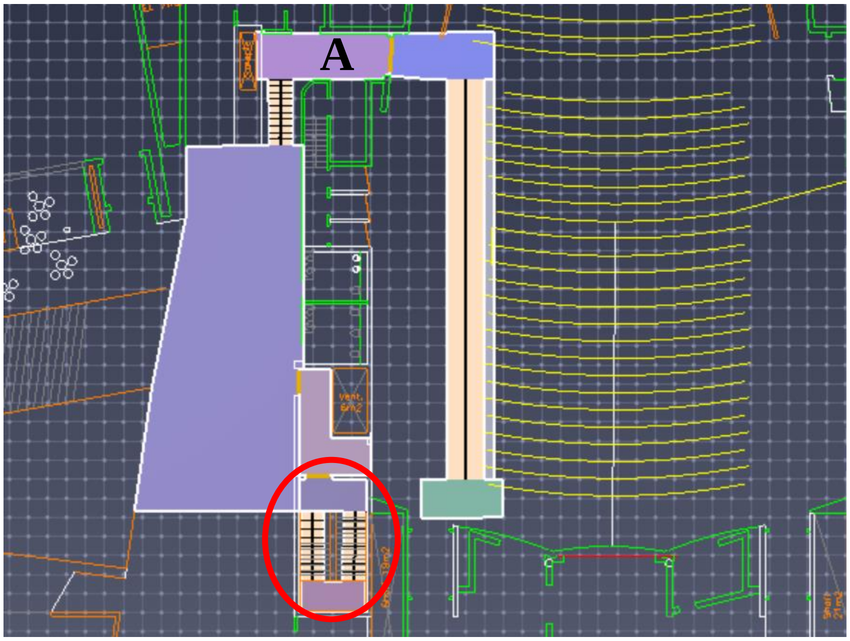


Figure 30: Model of scenario 1 in Eldborg

In Eldborg concert hall were the evacuation exercise was performed, there is an incline. This incline is located at the seat rows, shown with yellow stripes in figure 30. To simulate this incline, a ramp was created in Pathfinder, which is shown in light orange color ramp with a thick black line in the middle, next to the seat rows. To create the ramp, rooms must be located at each end where the ramp. These rooms are shown as green and blue rectangles at each end of the ramp. According to the measurements the incline is 5%. The location of the refuge area is in the room on the top to the left in figure 30, marked with the letter A. In pathfinder this room is registered as a refuge area, which will play a role in when creating a behavior profile for the disabled occupant, as to where the occupant will end the evacuation. This will be further described in chapter 6.3. If the occupant is to evacuate out of the building, the occupant will evacuate out of the refuge area up few steps that lead to a large hallway outside of Eldborg concert hall, shown on figure 30. In the middle of the hallway is a door leading to a staircase, which further leads to the ground floor where the occupant can exit the building. Figure 31 shows a part of the ground floor in Harpa, which will be simulated. The staircase in scenario 1, marked with red circle in figure 30, leads to the staircase number 1, in figure 31. On the ground floor there are six exits in the model, and they are located at the south end of the model, below staircases 1 and 2. The exits are marked as green lines at the boundary of the model in figure 31.

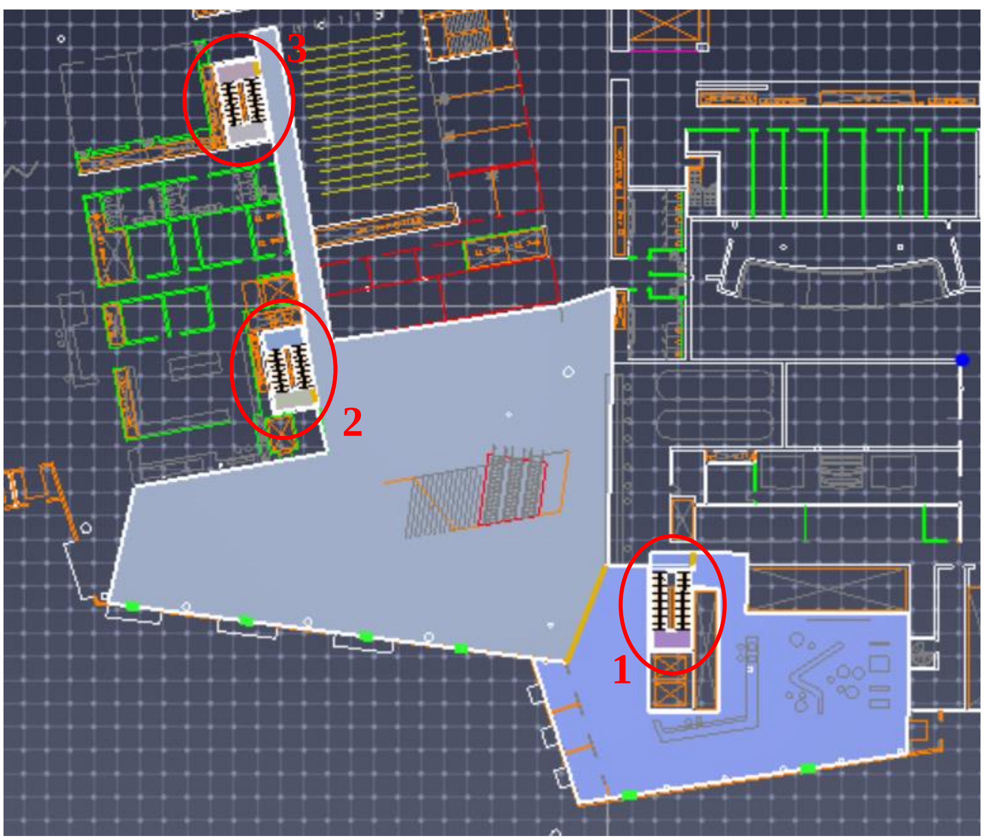


Figure 31: Model of ground floor in Harpa

Kolabrautin restaurant is marked in figure 32 with the letter A. In the model staircases were installed where the model is marked with red circles in figure 32. These staircases lead to the ground floor where the occupants can exit the building. Staircase 1 in figure 32 leads to the staircase 1 in figure 31, and staircase 2 on figure 32 leads to staircase 2 in figure 31. A refuge area is located in front of staircase 1 in figure 32.

Figure 32: Model of the 4th floor in Harpa.

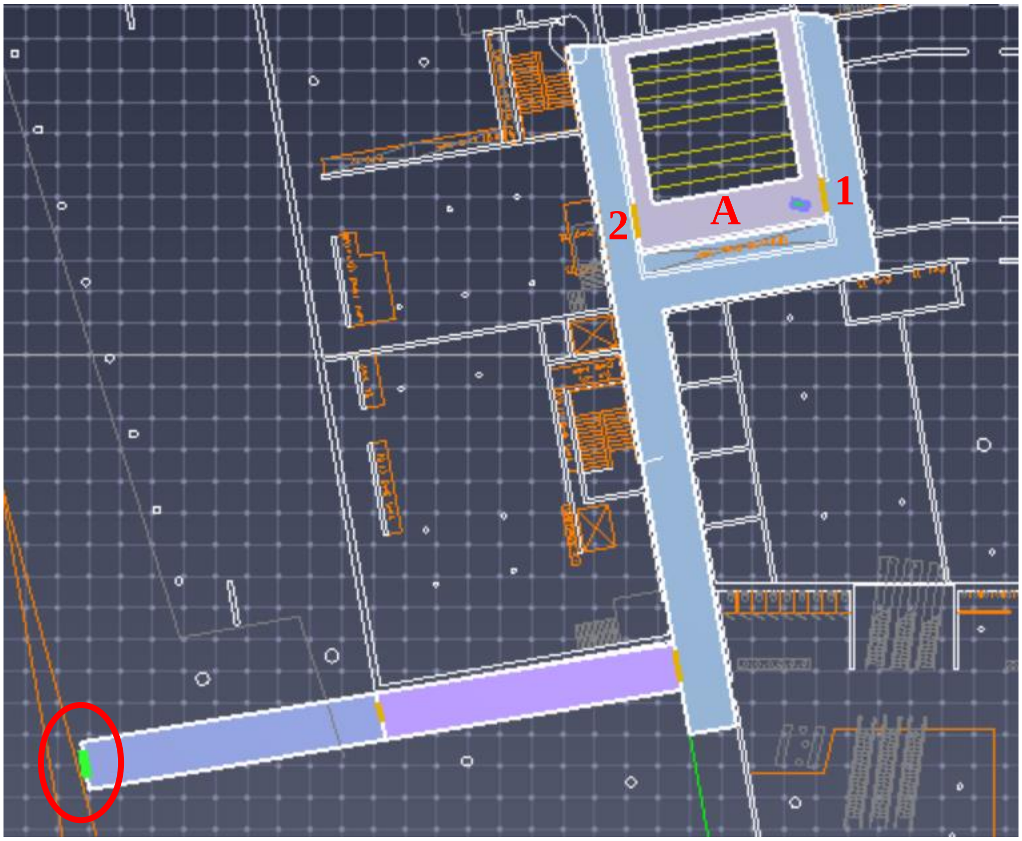


Figure 33: Model of scenario 3 in Kaldalón

Figure 33 shows the model of scenario 3 in Kaldalón. In this model, the evacuation route that was used in the evacuation exercise was modelled. Kaldalón auditorium is marked with the letter A. The auditorium can be exited from both sides, exit number 1 and number 2 as marked on figure 33. Thereafter, the evacuation route leads directly to the exit, indicated with a red circle. In the simulation exit number 1 from Kaldalón will be used, since that was the exit used in the evacuation exercise.

6.2 Smáralind model

6.2.1 Setup of model

To create the pathfinder models of Smáralind, DWG drawings of the building were used. The drawings were imported into the Pathfinder program, and the necessary rooms needed for each model were drawn by using outlines from the DWG drawings. Figure 34 shows the model of scenario 1 and 2 in Smárabíó, in Smáralind.

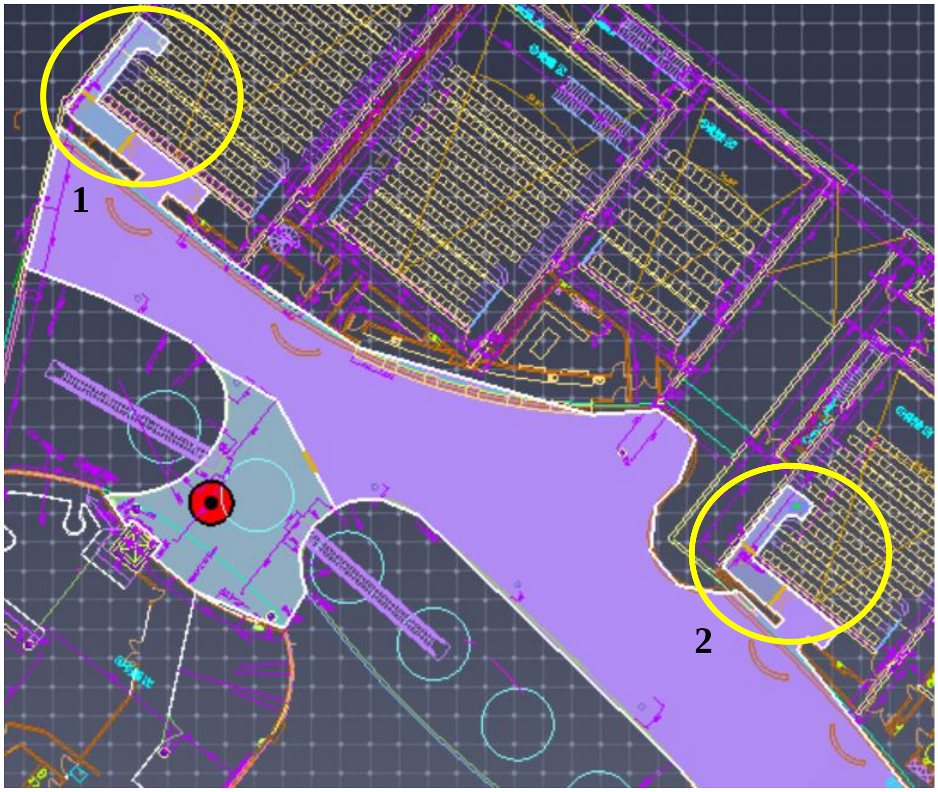


Figure 34: Model of Smárabíó, where scenario 1 and 2 will be simulated.

In Figure 34 the location of scenario 1 and 2 are shown with yellow circles. Exact location of the occupants is shown in chapter 6.3. Location for scenario 1 is indicated with a yellow circle and the number 1, and location for scenario 2 is indicated with a yellow circle and the number 2. The model is simplified in that way that only the part of each showroom which the participant will use was modelled, and therefore the seat rows in each showroom was not modelled. In the simulations for scenario 1 and 2, the occupant evacuated to the same location as the participant in the evacuation exercise. The location is indicated on Figure 34 with a red circle with a black dot in the middle. This location was created in pathfinder as a waypoint. A waypoint is a coordination in the simulation that the occupants are defined to evacuate to, and the waypoint act as an end to the simulation as the simulation ends the moment the occupant arrives at the waypoint.

Figure 35: Model of Hagkaup, where scenario 3 will be simulated

In this model scenario 3 from the real live evacuation exercise will be simulated, the model is shown in figure 35. The exit which the participant chose in the evacuation exercise is marked in Figure 35 with a yellow circle and the number 3. In addition, a scenario where the occupant chose to evacuate through the main entrance of Hagkaup and further out of the building through the exit marked with a yellow circle and the letter A was performed. This is done to investigate the evacuation time of the occupant if it would choose the most familiar evacuation route as a customer in Hagkaup, and thereafter chose the nearest exit out of the building. This model was simplified in that manner that shelves and other inventories in Hagkaup were not included in the model.

6.3 Input: People, flow and placement

In the simulations in pathfinder a non-disabled occupant and a disabled occupant was simulated. Each type of occupant has its own profile and behavior in the simulation program.

The profile for non-disabled person and disabled person differs. They have different shape and different movement speed. For non-disabled person the profile is set on default. The default setting implies that the occupant has a cylinder shape and standard size. For the disabled occupant the shape of the occupant is changed to a polygon. Polygon is used to simulate an occupant in a wheelchair and an occupant in a bed, for example a hospital patient.

Another factor in the occupant's profile is the movement speed. There were performed simulations with two sets of movement speed profiles. Firstly, there was simulations where both non-disabled and disabled occupants moved with a speed of 1.19 m/s. Based on calculations and information gathered from "Brannteknisk rømingsanalyse", 1.19 m/s is considered to be the maximum movement speed for non-disabled people when moving in corridors, on ramps and through doors [2]. This movement speed is chosen to compare the simulated evacuation time with the speed and evacuation time from the real-life evacuation exercise. Secondly, there will be performed simulation where movement speed profile given in SINTEF Rapport [13] will be used. The movement speed profiles have been gathered from various research. Table 3 shows the movement speed range that will be used in the simulations.

Table 3: Movement speed profiles used in simulations in Pathfinder [13]

Occupant	Movement speed [m/s]
Non-disabled	0.10-1.68
Disabled in a manual wheelchair	0.13-1.35

The movement speed profiles in table 3 were used to get a wide range of movement speeds and to get an overview over how the speed will affect the evacuation time in the simulations. Also, it was possible to compare the results from these simulations to the results from the evacuation exercises. For each scenario with non-disabled and disabled occupant respectively, there were performed 30 simulations with the various movement speed in table 3. This was done to get enough statistical movement speed profiles for each scenario to calculate the average movement speed and average evacuation time. In addition, the standard deviation of the evacuation time from each set of scenario simulations will be calculated.

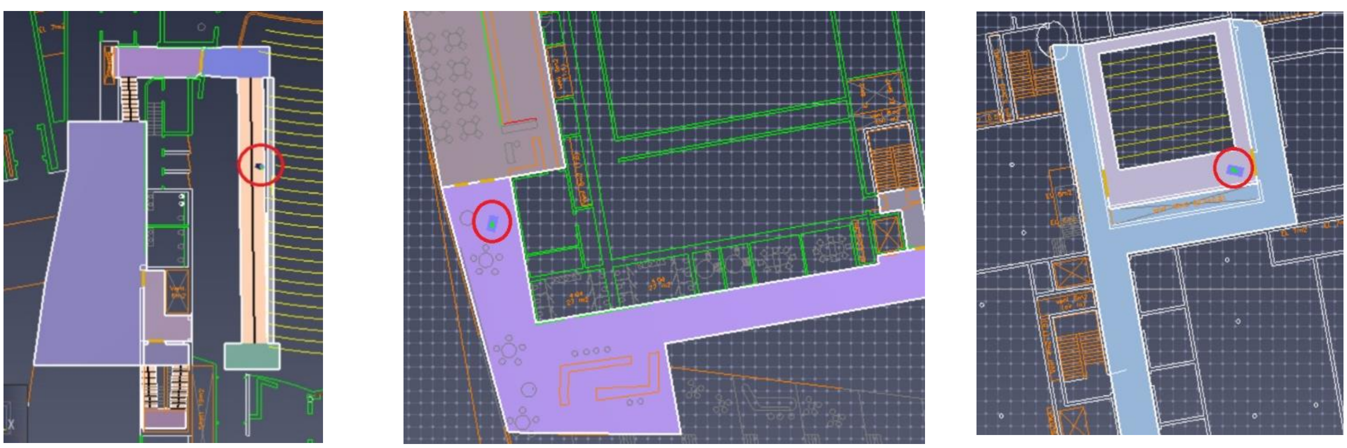
The occupants simulated in Pathfinder followed a certain behavior. The behavior affected the evacuation route and exit the occupant chose. The standard behavior in Pathfinder indicates the occupants to evacuate to the nearest exit where they will exit the building. In the simulations where the occupants are to evacuate to the nearest refuge area, a new behavior profile was created. This behavior profile indicates that the occupant shall evacuate to the nearest refuge area. The simulation ends immediately when the occupant has entered the refuge area. This behavior can only be used when the model contains a refuge area. In the simulations of scenarios 1 and 2 in Smáralind, the occupants are to evacuate to the same location as the participant in the evacuation exercise. Since the participant stopped evacuating inside Smáralind, in front of the cinema, a new behavior was created to simulate those scenarios. The behavior indicated that the occupants would evacuate to a certain waypoint located in the simulation. When the occupant arrived at the waypoint, the simulation ended. This was performed to get a simulation as close as possible to the evacuation exercise.

In the pathfinder models, doors were installed between each room and as an exit from the buildings. In order to make the models as realistic, the DXF drawings were used to measure the width of the doors, and the doors were installed into the model according to these measurements. The doors were measured to be either 1.8 meters or 1.2 meters wide. The person flow through the doors where calculated according to equations from “Brannteknisk rømningsanalyse”. Table 4 shows the person flow through the doors in the pathfinder models. Details in the calculations can be found in Appendix 4.

Table 4: Person flow [pers/s] through doors in Pathfinder models

Door width [m]	Person flow [pers/s]
1.2	1.17
1.8	1.95

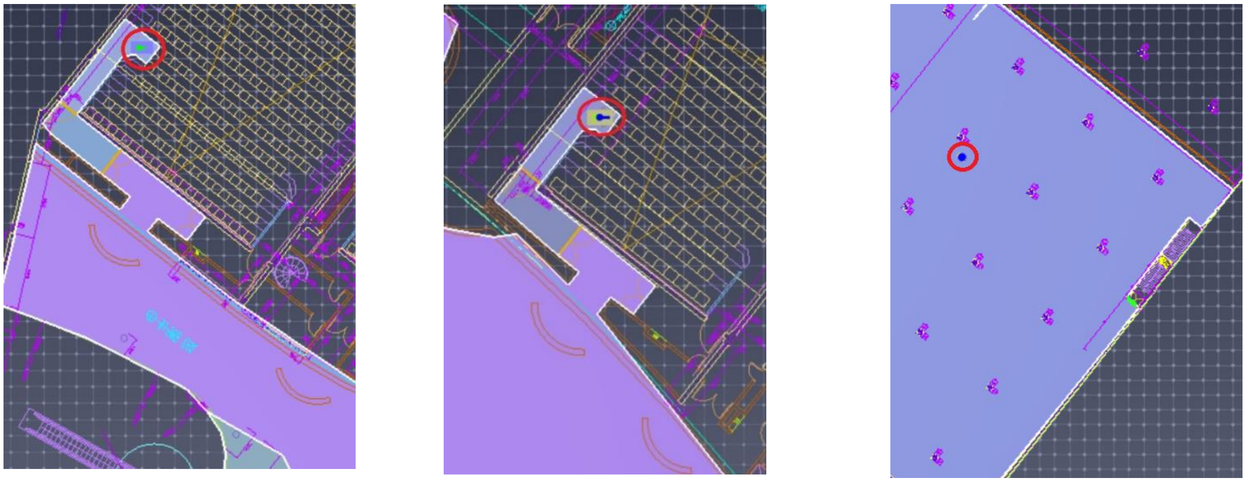
The occupant where placed in the Pathfinder models at the exact same locations as in the evacuation exercises. This was done so the results from the evacuation exercises and the simulations can be compared. Figure 36A-C shows exact location of the occupants in the simulations done in Harpa. The location of the occupants are indicated with a red circle.



A B C

Figure 36: Location of occupants in simulations of scenarios in Harpa. Part A) Eldborg, Part B) Kolabrautin restaurant and Part C) Kaldalón

A-C shows the exact location of the occupants in the simulations done in Smáralind.



A B C

Figure 37: Location of occupants in simulations of scenarios in Smáralind. Part A) Smárabíó (Sc.1), Part B) Smárabíó (Sc.2) and Part C) Hagkaup (sc. 3)

7 Results

7.1 Results from simulations in Harpa

In this chapter the results from the simulations of the scenarios in Harpa will be represented.

7.1.1 Movement distances in simulations

The movement distances which the occupants traveled in the simulations will be represented in the tables below. These movement distances for the non-disabled and the disabled occupants in each scenario can then furthermore be used to support the evaluation of the evacuation time in the forthcoming chapters.

A few movement distances from each set of simulations for each type of occupant were analyzed. This was done to see if there is any difference in the movement distance between the non-disabled occupant and the disabled occupant. In the simulations, the non-disabled and the disabled occupant start at the exact same location and end the simulation at the exact same location. These results are listed in Appendix 6. Table 5 below shows the average movement distance gathered from the simulations in scenario 1 for the different cases. The upper two values in table 5 show the movement distances when the occupants travel to the ground floor and exit the building. In this case, there is a visible difference in the distances, as the disabled occupant travels about 3.6 meter longer than the non-disabled occupant. When the occupants travel to the refuge area, there is a much less difference, only 0.1 meter.

Table 5: Average movement distances from scenario 1 in Harpa

Occupant	Average movement distance [m]
Non-disabled	82.4
Disabled	86.0
Non-disabled – Refuge area	11.8
Disabled – Refuge area	11.9

Table 6 shows the movement distances from the simulations of scenario 2. For both cases, when evacuating out of the building and to a refuge area, the non-disabled occupant travels a shorter distance than the disabled occupant. The difference is about 2.7 meters and 3 meters respectively.

Table 6: Average movement distances from scenario 2 in Harpa

Occupant	Average movement distance [m]
Non-disabled	107.3
Disabled	111.0
Non-disabled – Refuge area	78.8
Disabled – Refuge area	81.8

Table 7 shows the movement distances from the simulations of scenario 3. For scenario 3 only one evacuation route was simulated. According to table 7 the non-disabled occupant traveled a shorter distance when evacuating to the area leading out of the building, with 2 meters difference.

Table 7: Movement distances from scenario 3 in Harpa

Occupant	Average movement distance [m]
Non-disabled	76.2
Disabled	78.2

7.1.2 Evacuation time with movement speed of 1.19 m/s

The results from simulations of all scenarios with occupants with movement speed of 1.19 m/s will be represented.

The first scenario is in Eldborg concert hall. Table 8 shows the evacuation time from the simulations done in Eldborg. Table 8 shows that the disabled occupant used 0.12 minute longer to evacuate through the same evacuation route as the non-disabled occupant, evacuating to the ground floor and exit the building. When evacuating to the refuge area, the non-disabled occupant was 0.02 minute faster to evacuate.

Table 8: Evacuation time from simulation in Eldborg – movement speed 1.19 m/s

Occupant	Evacuation time [min]
Non-disabled	1.23
Disabled	1.35
Non-disabled – Refuge area	0.18
Disabled – Refuge area	0.20

The second scenario is Kolabrautin Restaurant. Table 9 shows the evacuation time from the simulations done in Kolabrautin Restaurant. The results in table 9 show that the disabled occupant takes 0.08 minute longer to evacuate out of the building compared to the non-disabled occupant. When evacuating to the refuge area the disabled occupant was 0.05 minute longer to evacuate.

Table 9: Evacuation time from simulations in Kolabrautin Restaurant – Movement speed 1,19 m/s

Occupant	Evacuation time [min]
Non-disabled	1.67
Disabled	1.75
Non-disabled – Refuge area	1.17
Disabled – Refuge area	1.12

The third scenario is in Kaldalón. In this scenario, only the evacuation route from the evacuation exercise was simulated. The evacuation time from the simulations is shown in table 10. The results in table 10 show that the non-disabled occupant had 2 seconds shorter evacuation time than the disabled occupant.

Table 10: Evacuation time from simulations in Kaldalón – Movement speed 1.19 m/s

Occupant	Evacuation time [min]
Non-disabled	1.08
Disabled	1.12

7.1.3 Evacuation time with movement speed profile from SINTEF rapport

In this chapter the results from the pathfinder simulations with the movement speed profiles from SINTEF rapport will be represented.

Figure 38 shows the evacuation time for each simulation, when simulating the evacuation of a non-disabled occupant and disabled occupant through the main exit of the building in scenario 1. The figure shows how the evacuation time varies with each of the 30 simulations. The X axis is the simulation number, and the Y axis is the evacuation time. As is shown in the figure the evacuation time varies shortest from about 1 minute up to 11 minutes for the longest, a difference of approximately 10 minutes. The yellow line presents the results for the non-disabled occupant, and the blue line presents the results for the disabled occupant. The figure shows that the disabled occupant has more simulations with higher evacuation time. The disabled occupant has 16 simulations where the evacuation time is greater than 3 minutes, while the non-disabled occupant has 8 simulations where the evacuation time is greater than 3 minutes. This could lead to disabled occupant having higher average evacuation time than the non-disabled occupant.

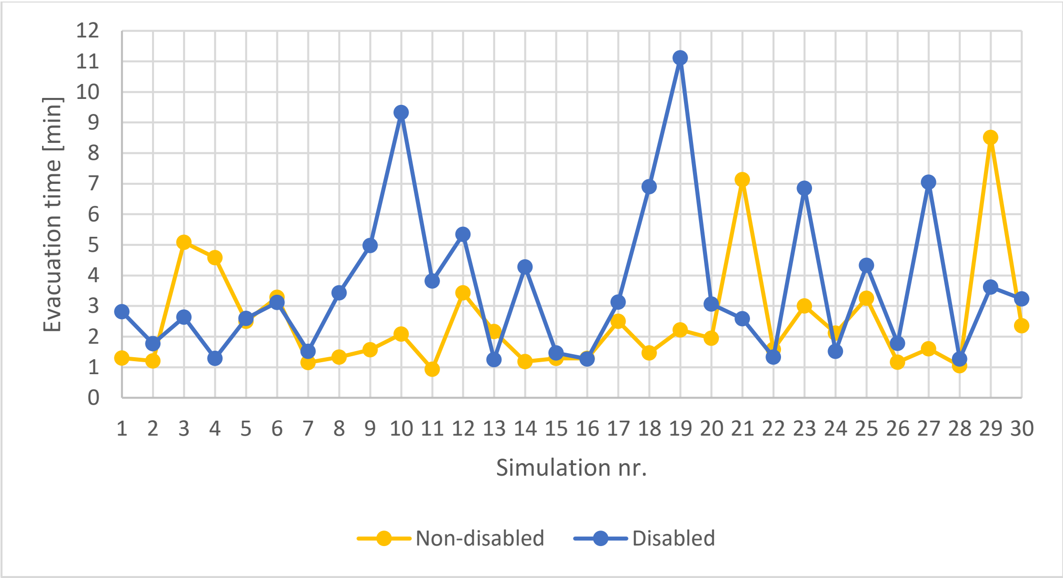


Figure 38: Evacuation time from simulations of scenario 1. Occupants evacuate out main exit.

The first scenario is in Eldborg concert hall. The results from the simulations for scenario 1 are presented in table 11. It can be seen in table 11 that the average movement speed for the disabled occupant is considerably smaller than for the non-disabled occupant. This results in greater difference in the average evacuation time for the occupants, whereas the non-disabled person has lower average evacuation time. Table 11 supports the findings from figure 38, which showed that the disabled occupant had more simulations that resulted in evacuation time greater than 3 minutes.

Table 11: Average evacuation time and movement speed – Scenario 1

Occupant	**Average movement speed [m/s]**	**Standard deviation [m/s]**	**Average evacuation time [min]**	**Standard deviation [min]**
Non-disabled	0.808	0.389	2.48	1.79
Disabled	0.627	0.391	3.62	2.49
Non-disabled – refuge area	0.893	0.446	0.34	0.26
Disabled – refuge area	0.627	0.391	0.47	0.31

The second scenario is in Kolabrautin Restaurant. Table 12 presents the results from the simulations for scenario 2. The simulations for scenario 2 resulted in higher average movement speed compared to in scenario 1. The non-disabled occupant has higher average movement speed than the disabled occupant, which also results in lower average evacuation time than for the disabled occupant.

Table 12: Average evacuation time and movement speed – Scenario 2

Occupant	Average movement speed [m/s]	Standard deviation [m/s]	Average evacuation time [min]	Standard deviation [min]
Non-disabled	0.99	0.459	3.08	3.30
Disabled	0.718	0.347	3.98	2.86
Non-disabled – refuge area	0.880	0.451	2.33	2.33
Disabled – refuge area	0.718	0.347	2.75	2.03

The third scenario is in Kaldalón auditorium. Table 13 presents the results from the simulations for scenario 3. The results in table 13 show that the non-disabled occupant had a higher average movement speed than the disabled occupant. The average evacuation time for both occupants is the same.

Table 13: Average evacuation time and movement speed from simulations in Pathfinder – Scenario 3

Occupant	Average movement speed [m/s]	Standard deviation [m/s]	Average evacuation time [min]	Standard deviation [min]
Non-disabled	0.866	0.498	2.42	2.16
Disabled	0.731	0.340	2.41	1.67

Figure 39 shows the evacuation time from simulations for scenario 3 as a function of the movement speeds. Also, the average values calculated from the results are shown. The evacuation time increases exponentially as the movement speed decreases. This causes the average value of movement speed and evacuation time to lie above the trendline that the results follow. Also, the average movement speed does not result in the average evacuation time, as figure 39 shows. The range of results for the disabled occupants is smaller due to the range in table 3, which indicates the movement speed range, is smaller than for the non-disabled occupant. The non-disabled occupant had number of simulations with movement speed between 1.3 m/s and 1.7 m/s, that the non-disabled occupant did not have, which may have caused the average movement speed to shift further to the right and become higher than for the disabled occupant. The simulation that resulted in evacuation time of nearly 10 minutes with the non-disabled occupant might have increased the average evacuation time, by increasing it.

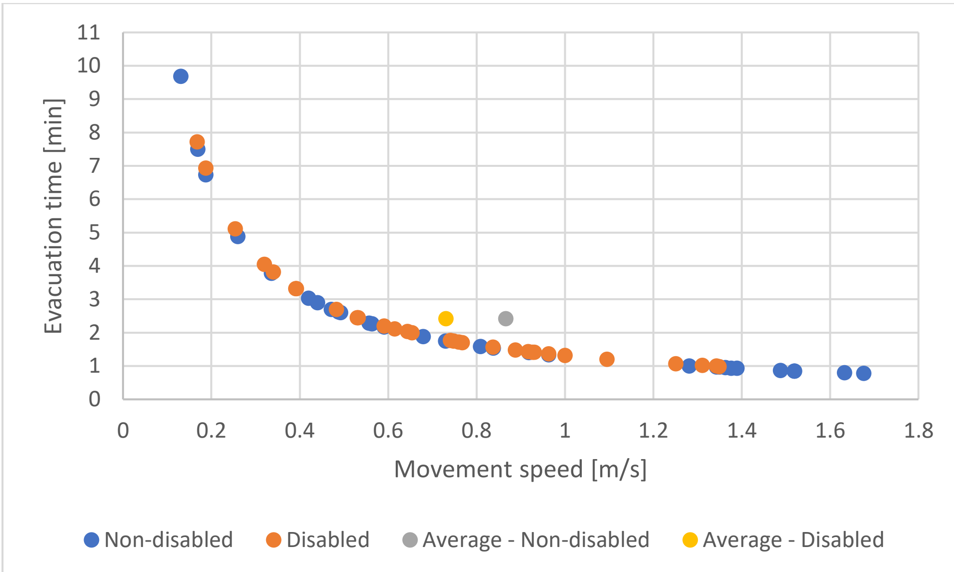


Figure 39: Evacuation time as a function of movement speed and average value

7.2 Results from simulations in Smáralind

7.2.1 Movement distances in simulations

The tables below present the movement distances from the simulations in Smáralind. The movement distances, for the non-disabled and the disabled occupants in each scenario, can then furthermore be used to support the evaluation of the evacuation time in the forthcoming chapters.

When performing the simulations, the movement distances, which the occupants traveled in the simulations, was registered. For each set of simulation for each scenario, five movement distances were collected to create an estimate on what distance the occupants were traveling. These results are listed in Appendix 6. In the tables below, the average value, calculated from the values in Appendix 6, will be presented.

Table 14 shows the average movement distances for the occupants in scenario 1 in Smáralind. According to Table 14 the non-disabled occupant travels around 1.5 meters shorter distance that the disabled occupant.

Table 14: Average movement distances from simulations of scenario 1 in Smáralind

Occupant	Average movement distance [m]
Non-disabled	44.0
Disabled	45.5

For scenario 2 in Smárabíó, Smáralind, the non-disabled occupant travels around 1.6 meters shorter distance than the disabled occupant, as shown in Table 15.

Table 15: Average movement distances from simulations of Scenario 1 in Smáralind

Occupant	Average movement distance [m]
Non-disabled	54.3
Disabled	55.9

The average movement distances for the occupants in the simulations for scenario 2 in Smáralind are shown in Table 16. According to Table 16 the non-disabled travels 0.6 meters shorter distance than the disabled occupant. If the participant would have chosen to evacuate through the main exit in Hagkaup, he would have traveled three times the longer distance than he did in the exercise.

Table 16: Average movement distances from simulations of scenario 3 in Smáralind.

Occupant	Average movement distance [m]
Non-disabled	30.5
Disabled	31.1
Non-disabled – to main exit	93.1
Disabled – to main exit	93.9

Tables 14-16, listed above, show that the non-disabled occupant travels a shorter distance in each scenario simulated in Smáralind compared to the disabled occupants.

7.2.2 Evacuation time with movement speed of 1.19 m/s

In this chapter the evacuation time which resulted from simulations of the scenarios in Smáralind will be represented. In these simulations the occupants had a movement speed of 1.19 m/s.

The evacuation time of the occupants from the simulations of scenario 1 and 2 is presented in Table 17 . In scenario 1 the disabled occupant is about 0.05 minute, or 3 seconds, longer to evacuate the same route as a non-disabled occupant. The evacuation time in scenario 2 resulted in a similar difference, where the disabled occupant had an evacuation time which was 0.03 minute, or 2 seconds, longer than for the non-disabled occupant.

Table 17: Evacuation time with movement time of 1.19 m/s in scenarios 1 and 2 in Smáralind

	Evacuation time [min]	
Scenario	**Scenario 1**	**Scenario 2**
Non-disabled	0.65	0.77
Disabled	0.70	0.80

The evacuation time of the occupants from the simulations of scenario 3 is presented in table 18. First part of the table shows the evacuation time of the occupants when they evacuate the same route as the participant from the real-life evacuation exercise. In that case, the non-disabled occupant had an evacuation time 2 seconds shorter than for the disabled occupant. For the other part of scenario 3, the occupants evacuated out of Hagkaup and further to the main exit of the building, as described in chapter 6.2.1. In that scenario the non-disabled occupant was 0.01 minute, or 1 second, faster to evacuate.

Table 18: Evacuation time with movement time of 1.19 m/s in scenario 3 in Smáralind.

	Evacuation time [min]	
Scenario	**Scenario 3 – route from exercise**	**Scenario 3 – main exit**
Non-disabled	0.43	1.32
Disabled	0.47	1.33

Tables 17 and 18 show that the non-disabled occupants use shorter time to evacuate compared with the disabled occupants in the scenarios simulated in Smáralind.

7.2.3 Evacuation time with movement speed profile from SINTEF rapport

In this chapter the average movement speed and average evacuation time, which resulted from the simulations of the scenarios in Smáralind, will be represented. The movement speed is based on a movement speed profile from SINTEF rapport, as described in chapter 6.3. The average movement speed and average evacuation time are based on 30 simulations which were performed for each scenario, see Appendix 5. In addition, the standard deviation for each average value is presented in the tables below.

Figure 40 shows the evacuation time for each simulation, when simulating the evacuation of a non-disabled occupant and disabled occupant in scenario 1. The figure shows how the evacuation time varies with each of the 30 simulations. The X axis is the simulation number, and the Y axis is the evacuation time. As is shown in the figure the evacuation time varies shortest from about 0.5 minute up to 5.5 minutes for the longest, a difference of approximately 5 minutes. The green line presents the results for the non-disabled occupant, and the orange line presents the results for the disabled occupant. The figure shows that the disabled occupant has more simulations with higher evacuation time. The disabled occupant has 18 simulations where the evacuation time is greater than 1 minute, while the non-disabled occupant has 10 simulations where the evacuation time is greater than 1 minute. This could lead to disabled occupant having higher average evacuation time than the non-disabled occupant.

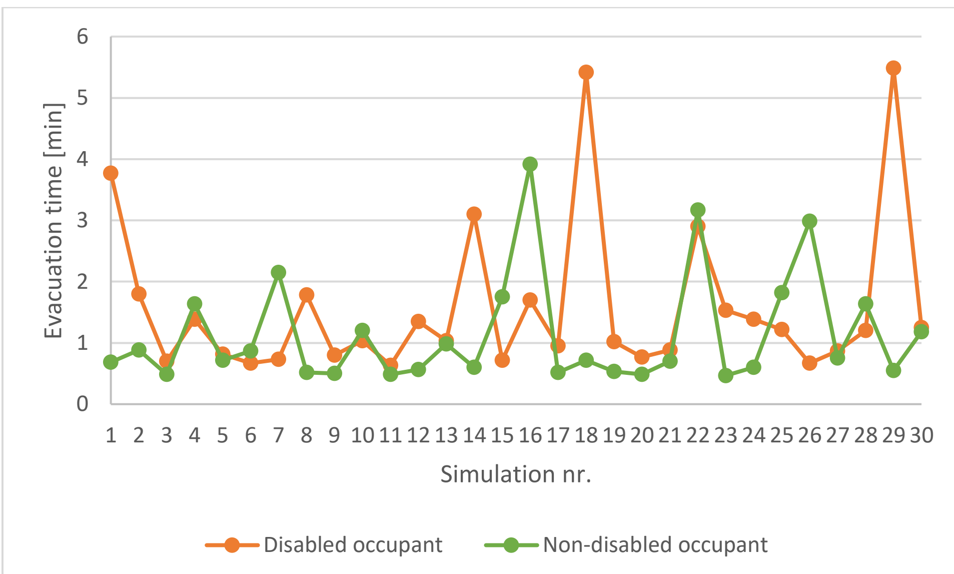


Figure 40: Evacuation time from simulations of scenario 1

Table 19 present the results from simulations of scenario 1 in Smáralind. The table shows that the non-disabled occupant has on average a faster movement speed, in this case by 0.257 m/s, and shorter average evacuation time, in this case by 0.5 minute.

Table 19: Average movement speed and average evacuation time for scenario 1 in Smáralind

Occupant	Average movement speed [m/s]	Standard deviation [m/s]	Average evacuation time [min]	Standard deviation [min]
Non-disabled	0.981	0.486	1.13	0.89
Disabled	0.724	0.350	1.59	1.29

The results from the simulations of scenario 2 in Smáralind are shown in table 20. The average movement speed for the non-disabled occupant is higher than for the disabled occupant. On the other hand, the average evacuation time for the non-disabled occupant is higher than for the disabled occupant. Figure 41 shows the results from simulations from scenario 2. It can be seen that the non-disabled occupant had a simulation that resulted in evacuation time of 8 minutes, which was about 3.5 minutes higher than the next highest evacuation time. This difference can cause the average evacuation time for the non-disabled occupant to increase.

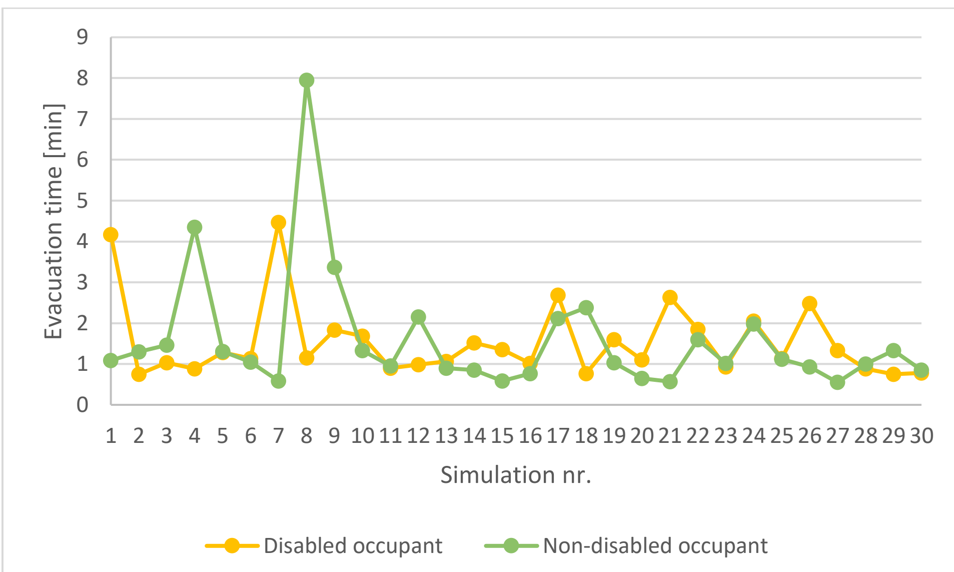


Figure 41: Evacuation time from simulations of scenario 2

When the standard deviation values for the average evacuation time is considered, it can be seen in table 20 that the standard deviation for the average evacuation time for the non-disabled occupant is much higher than for disabled occupant. The simulation mentioned before that resulted in 8-minute evacuation time, can affect the standard deviation value greatly when the difference between it and the average value is large. This simulation could have therefore affected the result greatly.

Table 20: Average movement speed and average evacuation time for scenario 2 in Smáralind

Occupant	Average movement speed [m/s]	Standard deviation [m/s]	Average evacuation time [min]	Standard deviation [min]
Non - disabled	0.859	0.427	1.57	1.47
Disabled	0.786	0.325	1.54	0.93

The average movement speed and average evacuation time for the occupants in scenario 3 is presented in table 21. As for the results from scenario 2 showed, the results from scenario 3 also show that the non-disabled occupant has higher average movement speed in both simulations sets of scenario 3 and that the non-disabled occupant has higher average evacuation time than the disabled occupant. When the average movement speed is considered, the average movement speed when the occupants move to the main exit is similar, but there is greater difference in the simulations when the occupants travel the same route as in the exercise. There the disabled occupant has on average 0.134 m/s slower movement speed. As for the average evacuation time, the non-disabled occupant has on average higher evacuation time and the standard deviation is much higher for the non-disabled occupants.

Table 21: Average movement speed and average evacuation time for scenario 3 in Smáralind

	Occupant	Average movement speed [m/s]	Standard deviation [m/s]	Average evacuation time [min]	Standard deviation [min]
Scenario 3 Route from evacuation exercise	Non-disabled	0.92	0.47	0.96	1.10
	Disabled	0.766	0.34	0.95	0.70
Scenario 3 Out through main exit	Non-disabled	0.809	0.422	2.97	2.65
	Disabled	0.794	0.384	2.84	2.24

7.3 Evacuation time from evacuation exercise compared with simulation results

Here, the results from the evacuation exercises in Harpa and Smáralind will be compared with the results from simulations in Pathfinder. This will be done to see which movement speed matches the evacuation exercises when compared to the simulation results and how the simulation program manages to approach the reality.

7.3.1 Comparison of results from Harpa

The comparison of the results from the evacuation exercise with the results from the simulations with movement speed 1.19 m/s and the average movement speed from SINTEF movement speed profile is presented in table 22. The results from the simulations with the movement speed of 1.19 m/s is similar to the results from the evacuation exercise, while the average movement speed calculated from the simulations with the SINTEF movement speed profile result in double the evacuation time in the evacuation exercise.

Table 22: Comparison of results from evacuation exercise, simulations with 1.19 m/s and average movement speed from SINTEF - Harpa

Scenario	**Evacuation exercise [min]**	**Simulation with 1.19 m/s [min]**	**Average movement speed SINTEF [min]**
Scenario 1	0.2	0.2	0.47
Scenario 2	0.83	1.12	2.75
Scenario 3	1.83	1.12	2.41

In chapter 5.1, table 1 shows the evacuation time from each scenario in the evacuation exercises in Harpa. Appendix 5 contains all the results from the simulations done in Harpa, and there the same evacuation time for the corresponding scenario will be found. This is done to compare the evacuation time from the exercises with the simulations and see which movement speed the participants in the exercise based on the simulation results. When the corresponding evacuation time is found, the movement time for that scenario is found. That will give estimation on what movement speed the participant in the evacuation exercise had.

Table 23 shows the movement speeds when the evacuation time in the evacuation exercises and simulations are compared. For scenario 1 there were two simulations that gave the evacuation time of 0.2 minutes, 1.215 m/s and 1.073 m/s. According to the simulations the movement speed of the participant in the evacuation exercise could have been on the interval of 1.215 m/s and 1.073 m/s. For scenario 2 there were no results in the simulations of that scenario that gave the evacuation time of 0.83 minutes. The closest evacuation time to 0.83 minutes in the simulations was 1.05 minutes, with movement speed of 1.325 m/s. This indicates that the movement speed of the participant in the evacuation exercise was greater than 1.325 m/s. For scenario 3 none of the simulations resulted in evacuation time of 1.83 minutes. The closest evacuation time in the simulations to the evacuation exercises was 1.76 seconds with movement speed of 0.741.

Table 23: Movement speed from simulation results compared to results from evacuation exercises in Harpa

Scenario	Evacuation time in evacuation exercise [min]	Evacuation time in simulation [min]	Movement speed from simulation [m/s]
Scenario 1	0.2	0.2	1.215 and 1.073
Scenario 2	0.83	1.05	1.325
Scenario 3	1.83	1.76	0.741

7.3.2 Comparison of results from Smáralind

The results from the evacuation exercise are compared with the results from the simulations with movement speed 1.19 m/s and the average movement speed from SINTEF movement speed profile in table 24. The results from the simulations with the movement speed of 1.19 m/s is similar to the results from the evacuation exercise, while the average movement speed calculated from the simulations with the SINTEF movement speed profile result in double the evacuation time in the evacuation exercise. The evacuation time from the simulations with movement speed of 1.19 m/s is little shorter than in the evacuation exercise.

Table 24: Comparison of results from evacuation exercise, simulations with 1.19 m/s and average movement speed from SINTEF - Smáralind

Scenario	Evacuation exercise [min]	Simulation with 1.19 m/s [min]	Average movement speed SINTEF [min]
Scenario 1	0.78	0.70	1.59
Scenario 2	0.98	0.80	1.54
Scenario 3	0.5	0.47	0.95

In chapter 5.2, table 2 shows the evacuation time from each scenario in the evacuation exercises in Smáralind. These results will be put in a table together with results from the simulation. Results from all the simulations done in Smáralind are found in Appendix 5. In the results in Appendix 5 the simulation with the same evacuation time as in the corresponding scenario is found and compared to the real-life evacuation exercise. That will give estimation on what movement speed the participant in the evacuation exercise had.

The movement speed and evacuation time from the simulations are compared with the evacuation time in the evacuation exercises in table 25. For scenario 1 there was no simulation that resulted in evacuation time of 0.78 seconds. There were simulations that resulted in evacuation time of 0.76 and 0.8 seconds, that had movement speed of 1.08 m/s and 0.99 m/s respectively. This indicates that the movement speed of the participant in the evacuation exercise could have been on the range of 0.99 and 1.08 m/s. For scenario 2 and 3 there were simulations that resulted in the same evacuation time, as shown in table 25, or 0.98 seconds and 0.5 second respectively. This indicates that the movement speed of the participant in the evacuation exercises could have been 0.99 m/s in scenario 2 and 1.09 m/s in scenario 3.

Table 25: Movement speed from simulation results compared to results from evacuation exercises in Smáralind

Scenario	**Evacuation time in evacuation exercise [min]**	**Evacuation time in simulation [min]**	**Movement speed from simulation [m/s]**
Scenario 1	0.78	0.76 and 0.8	1.08 and 0.99
Scenario 2	0.98	0.98	0.99
Scenario 3	0.5	0.5	1.09

8 Discussion

In this chapter the buildings that were used in the evacuation exercises, and results from the evacuation exercises and simulations will be discussed.

Due to lack of participants that participated in the evacuation exercises, enough results were not gathered to get clear results. Instead there were performed various simulations of the scenarios from the evacuation exercises to compare to the results and to analyse how a simulation program encounters people with disabilities.

Design of the buildings with focus on evacuation safety for disabled people

According to description of the buildings that were examined in this report, two of them are designed with a focus on evacuation for disabled people. Harpa and Norðurturn are designed with refuge areas for disabled people in case of an emergency. These two buildings are more recent built than Smáralind, and at the time, there were a larger focus on the safety of disabled people. Smáralind in designed and built before 2001, before there was not any special focus on evacuation of disabled people. However, it is important to have in mind that in Smáralind, every occupant, including disabled, have the possibility to evacuate out of the building from the ground floor and the 1st floor horizontally. These two floors have exits leading directly out of the building without any obstacles such as stairs. It is only the 2nd floor, where the cinema is located, where all evacuation routes include stairs. It would therefore be recommended to create a plan for evacuation of disabled people from the 2nd floor. Harpa and Norðurturn follow similar principles in the evacuation safety of disabled occupants. They were designed with refuge areas located on each floor. In both buildings the refuge areas have installed a communication device where the occupant can call for help and inform about their location. In Harpa and Norðurturn there is also installed fire elevators that can be operated by the fire rescue team. The fire elevators are thereby used to evacuate people in need of assisted evacuation, including disabled people.

It can be seen that in newer buildings, the evacuation of disabled people is considered and taken into account. This is a much positive direction in increasing the safety of disabled people in buildings in case of emergency. In office buildings or other buildings where people work it is more likely that disabled staff knows the measures that are in place for them, for example in Norðurturn. In public buildings where people only visit the building for short period of time it is less likely that they know about the measures that are in place for their safety, and therefore it is important with accessible and clear information, and clear marking of evacuation routes that lead to refuge areas or other safety measures.

Evacuation exercise in Norðurturn

The evacuation exercise held in Norðurturn gave a good oversight over the use of a refuge area and the response of the fire rescue team, rescuing a person in need of assisted evacuation. Since Norðurturn is mainly an office building and the greatest part of the occupants are employees, each employee is assigned an assistant that will assist the person to evacuate to a refuge area in case of emergency. This measure has a great function, as the assistant will assist the person to get to a refuge area, and eventually assist the person if there are any obstacles in the evacuation route. Once the disabled occupant arrived the refuge area, he contacted the evacuation commander through the communication device. The communication device had simple and clear instructions, informing the person on how to use the device. It is very important that the communication devise is clearly marked and have clear instructions to ensure that the person in need can effectively call for help and inform about their location. In this exercise the communication devise functioned as designed, and the disabled person could quickly inform their location. In the exercise the disabled person used the communication device, but if in need of assistance to use the communication device the assistant is to help the person.

Results from evacuation exercise in Harpa and Smáralind

According to the questionnaires from evacuation exercises in Harpa the participant commented that he does not familiarize himself with evacuation plans that show the evacuation routes in buildings when entering them. It is not given that these are accessible and visible for people entering public buildings. The participant from the evacuations performed in Smáralind, does not familiarize himself with evacuation plan regularly, but does so if he sees them. According to this it is unlikely that people familiarize themselves with the evacuation plans in public buildings, such as shopping malls and concert halls. These are buildings that people don’t stay in for a long period of time, only visit for a few hours each time. It might therefore be important to ensure that the evacuation plan for a public building is visible and accessible at a location where it can be seen easily. The evacuation plan should indicate clearly the location of refuge areas for disabled people. In addition, recorded voice alarms can be very effective in public buildings, as they could guide people the right way, especially if the occupants are not familiar with the evacuation routes in the building. The recorded voice alarm could inform the location of refuge areas and where to find them. Trained staff with specific roles during evacuation is an effective component in public buildings, as they can guide people the right and safest way.

The participants in the evacuation exercises had never participated in an evacuation exercise before. It would be considered important that disabled people participated in evacuation exercises to experience evacuation, and how refuge area function. It is effective to train their response and strategy if staying on a floor that does not have an exit that lead directly outside of the building. It could be possible to encourage owners and individuals in charge of safety management in public buildings planned evacuation exercises on regular basis and would encourage disabled people to participate. This would give the building's owner insight into how they can increase evacuation safety of disabled people in the building and discover possible obstacles and challenges in the evacuation routes and fix them. In addition, the disabled persons would gain increased understanding and preparedness on how to react in case of emergency. The disabled persons would also work on routines for how to handle an emergency situation, and how to use a communication device.

Neither of the occupants was sure what a refuge area was. One participant guessed that it was some sort of waiting area and the other participant consider a safe refuge area to be outside the building. According to these answers it is estimated that not many disabled people now about refuge areas or are not sure what they represent. Refuge areas are a relatively new concept that is not installed in all buildings. New buildings are required to have refuge areas according to building regulation in Iceland, while buildings built before the legislation of the new building regulation were not required to have refuge areas. The building regulation in Norway does not require a installation of a refuge area in buildings with universal design. It would be recommended that disabled people that need assisted evacuation are informed of measures installed in buildings. This includes refuge areas and communication devises that they can use in emergency. This could be accomplished by locating evacuation plans near all entrances where they can be easily accessible and visible, and by using voice recorded alarm that informs about refuge area and where to find them in an emergency. It is also important to inform people that these areas are designed to ensure their safety, as some people would not like to wait for assistance while watching other move by to safety. Since the refuge areas is a new concept it would be recommended that organizations that work with disabled people would cooperate with the authorities to inform disabled people about refuge areas and other measures that are installed in buildings to increase their safety. This could be done with lectures organized by the organizations and/or informative brochures created in cooperation of the organizations and the authorities.

During the evacuation in scenario 1 in Harpa, the participant evacuated to the nearest refuge area. The participant was not familiar with the refuge areas in the building before the exercise. He stopped the evacuation inside the refuge area as he could not evacuate further due to steps that led to the exit. It was not clear to the participant that he had entered a refuge area. The participant was still quick to stop the evacuation as he knew he could not evacuate further. The recording of the evacuation time stopped when he decided to stop the evacuation, which was before he tested the communication device. The communication devise located in the refuge area was not marked. The participant tested the communication devise and did not get any response from the control center. This was due to lack of knowledge with the employee, located in the control center, about the communication device. Here it would be recommended to provide clear signage that indicates that a person has entered a refuge area, and clear information on how to use the communication devise. It is also necessary that employees working in the control room, where notifications from all communication devices arrive, are informed on how to respond when it is activated. This could be accomplished by ensuring sufficient training of new employees, where they are introduces to every component in their working environment and learn how to use its components.

After the evacuation exercise (scenario 1) in Harpa the participant was informed of the refuge areas that were located on each floor in Harpa. For this reason, the participant was informed of the refuge area on the 4th floor, and therefore evacuated to that area in scenario 2. This could have affected his decision on where to evacuate, as there was a closer exit from the location that he evacuated from in scenario 2 that led to another staircase which did not include a refuge area. The participant knew roughly the location of the refuge area. Since the participant chose to evacuate to the refuge area it was discovered that there was a lack of signage that leads to the refuge area. The participant commented on the lack of signage and it was not clear where the refuge area was. For this reason, it would be recommended that refuge areas should be marked with appropriate signage on the outside, and that the evacuation route leading to the refuge area has indications leading the direction. As in scenario 1 the inside of the refuge area was not marked, and the communication devise was not made visible enough with clear signage. In this scenario the communication device was not tested, as it had been tested in the first scenario.

During the evacuation in scenario 3 in Harpa it was discovered that part of the evacuation route was used to store furniture and other items. This did not affect the evacuation exercise, however storage of items in an evacuation route decreases its width and thereby decreases its effectiveness by reducing the person flow, if many people would evacuation at once. When the evacuation route is used to store items that do not belong in the evacuation route, they act as obstacles that decrease people’s movement speed and thereby increase the RSET. Since people in wheelchairs need more space than non-disabled people this also decreases their movement speed, especially when other people are in the evacuation route, trying to get out of the building. If the individual in the wheelchair is moving slower than the other people, he also acts as an obstacle for them. It is therefore important that evacuation routes are kept clear to ensure safe evacuation.

The participant in the evacuation exercises in Smáralind had an assistant that assists the participant to move around, since the participant is not able to do so himself. For this reason, it was the assistant that chose the route to evacuate. The assistant affected the results in that manner that he chose the route to evacuate, and the disabled participant did not choose which route he would have evacuated or which route he considered best for his own safety. It is therefore the role of his assistant to be familiar with the evacuation routes in the building and choose the safest evacuation route for the disabled person. The physical strength of the assistant can also affect the evacuation time, as to how fast he moves the person in the wheelchair. It is not the participant that moves the wheelchair, but the assistant. If the assistant is strong, the movement speed would likely be faster than if the assistant is weak. The strength of the assistant in these exercises was not measured or observed, but it is a factor that can affect the movement speed of the occupant.

In the evacuation exercise for scenario 1 and 2 in Smárabíó the participants evacuated from two showrooms. In scenario 2 the doors were closed into the showroom. It was observed that the participants did not struggle to move through the closed doors, and the participant and his assistant confirmed that in the questionnaire. In this case the participant was driven by an assistant that backed through the closed doors, which means that the participant did not have to push himself through the door. It is likely that it is easier for a wheelchair user to go through closed doors when with an assistant, rather than push open the door himself/herself. According to documented observation it was observed that the participants took longer time to travel through the closed doors in scenario 2. The doors slowed down the participants, which resulted in 0.15 minute increase in evacuation time to get out of the showroom when compared to scenario 1. The doors also act as an obstacle that slows down the movement speed more than an open door. The doors into the showrooms are usually closed during showtime and are open when people enter and leave the showroom before and after showtime.

In the evacuation exercise for scenario 3 in Hagkaup, the only obstacle and limitation was that it was not possible to evacuate further through the exit that the participant had chosen. This resulted in the participant not being able to evacuate further and discover possible obstacles that could lie beyond the exit. According to drawings of the building, it was discovered that behind the exit was a staircase leding to the 1st floor and out of the building. If the participants had opened the door and seen the obstacle it could have been possible that the participants would have turned around and chosen another exit.

In the evacuation exercises the participants did not always chose the nearest exit. In scenario 1 in Harpa and scenario 3 in Smáralind the participant chose the nearest exit. Of them only scenario 1 in Harpa led the participant to a location fitted for disabled occupant. Scenario 3 in Smáralind led the participant to an exit that was not fit for a person in a wheelchair. As mentioned before the occupant was familiarized with the refuge area in scenario 2 in Harpa which influenced his decision. In scenario 3, there was no way for the participant to know which of the two routes where the shortest, but he chose the route that he felt was right. In scenario 1 and 2 in Smáralind the participants chose the familiar route, in which they entered the cinema. They did not search for any other evacuation route or consider if there were any exits closer. In these exercises the participants did not do anything unexpected. The participants did not always use the exit that they used to enter the room or building. In scenario 1 in Harpa the participant used the exit that he used to enter Eldborg concert hall. In scenario 3 in Harpa the participant exited Kaldalón auditorium through the exit that he used to enter the auditorium, but he had to evacuate further to get to a safe place and chose an unfamiliar route. That was due to the fact that he entered the basement through an elevator, and he used the SWGS to evacuate.

Results from simulations

According to the results from the simulations the non-disabled occupant traveled shorter distances in each set of simulations of the scenarios. In the simulations the starting point and the end point is exactly the same for both occupants, and therefore is there another factor that is affecting the results. This difference in travel distance could be a result of the occupant's shape in the Pathfinder model. The disabled occupant has a polygonal shape and has larger size than the non-disabled occupant. When the occupant has a larger shape is must take larger turns around corners and turns. According to the measured movement distances in the simulations it can be seen that the greater the movement distance in a specific scenario the greater the difference between the movement distance for non-disabled and disabled occupant. When the route is longer and has more corners and turns that the occupants must take, the movement distance for the disabled occupants increases. This could be a method that the program uses to simulate the difference between non-disabled and disabled occupants. The difference in movement distances could also result in different evacuation time. The results from the simulations show that the non-disabled occupant has shorter evacuation time than the disabled occupant when moving with the same movement speed.

The results from the simulation sets with various movement speed profiles show that the non-disabled occupant has on average higher movement speed than the disabled occupant. This could be caused by the movement speed profiles that were given to the occupants. For the non-disabled occupant, the range reaches to max movement speed of 1.68 m/s, as for 1.35 m/s for the disabled occupant. As a result, the non-disabled occupant is simulated with higher movement speeds than the disabled occupant. It is not given that non-disabled persons have higher movement speed than disabled persons. There are many factors that can affect the movement speed, such as the fitness of the non-disabled person that can run fast or moves slowly, and the strength of the person in a wheelchair that either moves slowly or moves fast. In addition, if the disabled person has an assistant it affects the movement speed how fast he can move the wheelchair.

There were performed 30 simulations for each set of simulations. The average movement speeds for the non-disabled and disabled occupants varied between scenarios. If there would have been performed more simulations for each set of simulations, the average movement speed for non-disabled and disabled occupants respectively would have been closer and more similar. The more simulations that are performed for each set of simulation, the more data are collected, and the average value becomes more accurate.

The average movement speed and average evacuation time do not correspond to each other. That will say, the average movement speed that is calculated for each set of simulation does not result in the average evacuation time calculated for the same simulation set. This is because when the evacuation time for the simulation set is set up as a function of the movement speed in a graph, it can be seen that the trendline is exponential. The evacuation time increases quickly as the movement speed decreases. The values for the average movement speed and the average evacuation time were within the standard deviation. The standard deviation values are large du to large range of movement speed and evacuation time. Since the evacuation time increases exponentially with decrease movement speed, it results in larger standard deviation values for the evacuation time, especially for the non-disabled occupant. This is the because the non-disabled occupant has lower value in the movement speed profile, or 0.10 m/s while the disabled occupant has 0.13 m/s.

The Pathfinder simulation program gives a good estimate on the evacuation of a disabled occupant. It has its flaws and advantages. The program takes into account the size of the occupant and has a specific occupant profile for occupants in wheelchairs. When a disabled occupant travels in the simulations it takes larger turns around corners. This resulted in larger movement distance for the disabled occupant compared to the non-disabled. The program therefore takes into account that people in wheelchairs need to travel a little longer distance than non-disabled people as a result of the space that the disabled person needs to maneuver the wheelchair. The pathfinder model does not simulate the obstacle that doors can be in the reality. It was not possible to design the doors in the model that way that they would act as an obstacle. As a result of this the evacuation time in the simulations can be shorter than in reality as people slow down when they approach and pass through a door.

In pathfinder the movement speed profile through the simulation could not be investigated. When the simulation of a scenario is finished and the results are available, the movement speed can be seen by using color profile. This was not convenient in the simulations done in this project, as is was not possible to get a precise value of the movement speed and the occupant experienced little effects by the surroundings that could slow him down if any whatsoever.

Comparison of the evacuation exercises with the results from the simulations

The results from the evacuation exercise were compared to the results from the simulations with movement speed 1.19 m/s and the average evacuation time from the simulations with the movement speed profile from SINTEF. According to that comparison it was shown that the results from the simulations with movement speed of 1.19 m/s are more compatible with the results from the evacuation exercises. The average evacuation time was double the evacuation time from the evacuation exercise. It is therefore estimated that movement speed of 1.19 m/s is much more compatible to give an estimation of the evacuation time for a disabled occupant rather than an evacuation time based on average movement speed profile.

When the results from the simulation were compared to the results from the evacuation exercise an estimate of the movement speed of the participants is found. For the scenarios in Harpa there is some variation in the comparison. For scenario 1 the movement speed is in the range of 1.073 m/s and 1.215 m/s. For scenario 2 there were no results that compared to the evacuation exercise. The fastest evacuation time was about 1.05 minutes which indicates that the participant in the exercise traveled faster than the 1.325 m/s since the participant had a shorter evacuation time of 0.83 minutes. The reason for this difference is unknown but could be due to shorter evacuation distance. It could also be possible that the participant moved faster than 1.325 m/s. For scenario 3 it is estimated that the movement speed of the participant in the evacuation exercise was 0.741 when compared to the results of the simulation. This difference in the movement speed between scenarios could be affected by many factors. The ramp in scenario 1 could have increased the movement speed of the participant, as the participant experienced acceleration downwards on the ramp, and in scenario 3 the participant could have moved slower because of the furniture and items that were stored in the evacuation route. Items that are stored in an evacuation route tend to slow people down as the evacuation route becomes narrower, since the items act as obstacles in the evacuation routes.

For the scenarios in Smáralind the comparison of the evacuation times in the evacuation exercises and in the simulations showed a similar movement speed for all of the scenarios. Scenario 1 resulted in a movement speed in the range of 0.99 m/s and 1.08 m/s, and scenario 2 resulted in movement speed of 0.99 m/s. It would be expected that in scenario 1 would result in a faster movement speed due to the doors being open in scenario 1. In scenario 3 the movement speed was estimated to be 1.09 according to the comparison. The participant had no obstacles in the way in scenario 3, so it would be expected that the movement speed would be higher than in scenario 2 where the doors were closed.

9 Conclusion

It is concluded that the evacuation safety in newer buildings have increased, due to safety measures installed for disabled people, such as refuge areas and communication devices. In older buildings that do not have installed safety measures for disabled people, it is recommended that a plan is made to increase their safety. The plan could contain a list of measures that is possible to install in the building, such as refuge area where disabled occupants can inform their location, voice alarm that informs disabled occupants where to evacuate or marking of an evacuation route suitable for disabled occupants. In addition, it would be recommended that owners of buildings would regularly plan evacuation exercises which include disabled persons to get an insight into how they can increase evacuation safety of disabled people and discover possible obstacles and challenges in the evacuation routes.

During the evacuation exercises, the main obstacles observed were stairs in the evacuation routes that the participants could not use and a lack of signage in the evacuation routes. If there are refuge areas that disabled people can use in an emergency situation it is important that these are marked with appropriate signage, and that the evacuation route that leads to the refuge area is also marked with clear SWGS. In addition, communication devises in refuge areas should be well marked and installed with clear instructions to ensure quick and easy usage of the device. In addition, it is important that the staff in the control room have been introduced to the communication device and how it works, to ensure that they are trained to operate the device once activated in an emergency.

Participants in the evacuation exercises were not familiar with the concept of refuge area. Therefore, it is important to introduce the concept of refuge area and its applications to disabled people, so that they understand its function and become familiar with it. This could be achieved in cooperation with organizations that work with disabled people and the authorities.

The pathfinder evacuation program can give a simple estimation of the evacuation time of a disabled person. The program takes into account that the disabled occupant has another shape than the non-disabled occupant. Because of its shape the disabled occupant travels longer distances compared to the non-disabled occupant. As to obstacles, such as closed doors that occupants must open to pass through, the program does not simulate its effect. The only obstacle the doors possess is the person flow through the door. Occupants move directly through the doors, without any speed reduction, when evacuating alone.

In Pathfinder were performed simulations with constant movement speed of 1.19 m/s and ranged movement speed profile from SINTEF rapport. The results from the simulations with the ranged movement speed profiles show that the non-disabled occupants have on average higher movement speed than the disabled occupants. This could be caused by the maximum movement speed that each occupant had, 1.68 m/s for the non-disabled occupant and 1.35 m/s for the disabled occupant. Since the movement speed is on average higher for non-disabled occupant and that he travels a shorter distance than the disabled occupant, the average evacuation time is shorter for the non-disabled occupant. In the results from the simulations sets for the various movement speeds there was calculated large standard deviation values for the evacuation time. This is caused by the fact that the evacuation time increases exponentially with decreased movement speed. The non-disabled occupant had in most scenarios higher standard deviation value for the evacuation time, which could be the result of lower movement speed value of 0.10 m/s in the movement speed profile, while the disabled occupant had 0.13 m/s.

From the comparison of the result from the simulation and the evacuation exercises, it is concluded that movement speed of 1.19 m/s gives more realistic results than the use of average values from ranged movement speed profile.

10 Further research

There are many possibilities and much that can be interesting to investigate and research further with focus on evacuation and safety of disabled people.

- Perform evacuation exercises with disabled individual/s in addition to people with no functional disabilities to investigate how disabled individuals affect the evacuation of other people and to investigate how other people affect the evacuation of the disabled individual.
- Perform similar simulations in other evacuation programs and compare how these evacuation programs simulate evacuation of disabled occupants.
- Perform simulation in Pathfinder and other evacuation programs with disabled occupant/s and other non-disabled occupants to investigate how the evacuation time and the movement speed is affected for both types of occupants. In addition, it could be considered which evacuation program best represents real life evacuation.

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Appendix

Appendix 1 – Construction classification in Norway and Iceland

Table A-1 presents the occupation classes according to the building regulation in Iceland.

Table A-1: Occupation classes in Iceland

Class	**Example of operation/usage**	**Slept in building**	**Occupants familiar with evacuation routes**	**Can save themselves**
1	Constructions were people work, such as commercial buildings, industrial buildings, warehouses, offices, banks and smaller shops.	No	Yes	Yes
2	Constructions were people accumulate, e.g. lecture halls, churches, cinemas, theaters, restaurants, discos, sports halls, larger shops and shopping centres.	No	No	Yes
3	Constructions were people live, such as apartments, leisure homes and individual guest rooms.	Yes	Yes	Yes
4	Constructions where accommodation is offered, e.g. hotels, leisure homes for renting and cabins for rent.	Yes	No	Yes
5	Construction such as hospitals, clinics, nurseries, apartments and institutions for the elderly or disabled, kindergartens.	Yes	No	No
6	Constructions such as prisons, closed wards in hospitals, e.g. psychiatrists and other places where people are locked inside.	Yes	No	No

Table A-2 presents the risk classes in Norway according the VTEK17. Below table A-2 are given examples of buildings in the following risk classes, see table A-3.

Table A-2: Risk classes in Norway [22].

Risk classes	Construction intended for occasional occupation	Persons in the constructions are familiar to escape conditions, including evacuation routes, and can bring themselves to safety	Constructions intended for accommodation	Intended use of construction entails little risk of fire
1	Yes	Yes	No	Yes
2	Yes/No	Yes	No	No
3	No	Yes	No	Yes
4	No	Yes	Yes	Yes
5	No	No	No	Yes
6	No	No	Yes	Yes

Table A-3: Risk classes and examples of constructions in the following risk class.

Risk class	Constructions
1	Garage and parking garage with one floor
2	Industry, Offices, Parking garage and garage with two or more floors/levels
3	Schools and pre-schools
4	Apartments, camping cabins and camping units.
5	Conference centres, sports halls, cinemas, churches, museums, shopping centres.
6	Prisons, hospitals, hotels, camp schools, Institutions for elderly and disabled.

Appendix 2 – Questionnaire from evacuation exercises (Icelandic)

Spurningalisti

Almennt:

Aldur: ________

Kyn:

- ☐ Kvenkyn
- ☐ Karlkyn
- ☐ Annað

Hvaða inngang notaðir þú þegar þú komst inn í bygginguna?

____

Hvers konar hreyfihömlun ert þú með?

____

Hversu vel þekkirðu bygginguna?

____

____

Kynnir þú þér rýmingaráætlun bygginga þegar þú kemur inn í þær?

____

____

____

Hefur þú tekið þátt í rýmingaræfingu áður?

- ☐ Já
- ☐ Nei

Ef já, hvað hefur þú lært af þessum rýmingaræfingum?

Veistu hvað öruggt svæði er?

Varðandi rýmingaræfingu:

Hvaða neyðarútgang/flóttaleið nýttir þú þér og af hverju?

Nýttirðu þér leiðarmerkingar?

- ☐ Já
- ☐ Nei

Ef já, voru leiðarmerkingar sýnilegar og skýrar?

Ef nei, af hverju ekki?

Hvernig var að finna leiðina út/á öruggt svæði?

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Voru einhverjar hindranir í vegi þínum á leiðinni?

____
____
____

Varstu einhvern tíma óviss hvaða leið þú áttir að fara?

____
____
____

Skiptir þú einhvern tíma um skoðun hvert þú áttir að fara?

- ☐ Nei
- ☐ Já, af hverju?

____
____
____

Hvað fannst þér virka vel í æfingunni?

____
____
____

Hvað fannst þér ekki virka vel í æfingunni (Hvað hefði mátt fara betur)?

____
____
____

Aðrar athugasemdir:

____
____
____

____
____
____

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Appendix 3 – Questionnaire from evacuation exercises (English)

Questionnaire

General:

Age: ________

Gender:

- ☐ Female
- ☐ Male
- ☐ Other

Which entrance did you use when you entered the building?

____

What type of functional disability do you have?

____

How well do you know this building?

____

____

Do you familiarize yourself with the evacuation plan for buildings when you enter them?

____

____

____

Have you taken part in an evacuation exercise before?

- ☐ Yes
- ☐ No

If yes, what have you learned from them?

___

___

___

Evacuation:

Which exit/evacuation route did you use and why?

___

___

___

Did you use the guidance systems during the evacuation exercise?

- ☐ Yes
- ☐ No

If yes, was the guidance system visible and of any use?

___

___

___

If no, why not?

___

___

___

How easy or difficult was it to find the way out/to a safe zone?

___

___

___

Where there any hindrances in your way during the evacuation exercise?

___

___

___

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Where you ever uncertain of which way to go?

Did you ever change your mind on where to go?

- ☐ No
- ☐ Yes. Why?

What did you think went well in the evacuation exercise?

What did you think did not work well in the exercise (What could have been better)?

Other comments?

Appendix 4 – Calculations for setup of Pathfinder models

Calculations of person flow through doors

According to DXF drawings used to create the models in Pathfinder the doors were measured to be 1.2 meters and 1.8 meters of width.

To calculate the person flow through the doors, the method from "Brannteknisk rømningsanalyse" [2] after Bjarne Chr. Hagen was used. The method is as following:

$$B_e = B - 2 \cdot B_g \tag{1}$$

Where:

B_e is the effective width of the door [m]

B is the total width of the door [m]

B_g is the boundary layer width [m]

Figure A-1 visualizes equation 1.

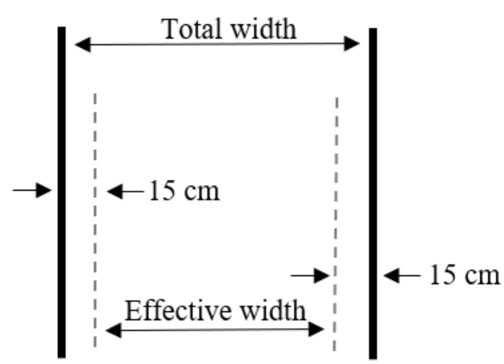

Figure A-1: Total width and effective width of an evacuation route.[4]

The boundary layer width (B_g) is, according to table 4.6 in "Brannteknisk rømningsanalyse", 0.15 m for doors.

The effective width will thereafter be used to calculate the person flow through the doors.

$$F_c = F_{sm} \cdot B_e \tag{2}$$

[4] Ámundi Fannar Sæmundsson, M.Sc. in Building Engineering.

Where:

F_c is the person flow [pers/s]

F_{sm} is the maximum specific person flow [pers/s m]

The maximum specific person flow through doors is, according to table 4.4 in”Brannteknisk rømningsanalyse”, 1.3 pers/s m.

With this information the person flow through the doors can be calculated.

Door width 1.2 meter:

Eq. 1:

$$B_e = 1.2\ m - 2 \cdot 0.15\ m = 0.9\ m$$

Eq. 2

$$F_c = \ 1.3\ \ pers/s\ m \cdot 0.9\ m = \mathbf{1.17\ pers/s}$$

Door width 2 meter:

Eq. 1:

$$B_e = 1.8\ m - 2 \cdot 0.15\ m = 1.5\ m$$

Eq. 2:

$$F_c = \ 1.3\ \ pers/s\ m \cdot 1.5\ m = \mathbf{1.95\ pers/s}$$

Appendix 5 – Evacuation time from Pathfinder

Results from simulations of scenario 1 in Eldborg, Harpa

Table A-4 presents the results from the simulations of scenario 1 for the non-disabled occupant when evacuating to the ground floor and exit the building.

Table A-4: Evacuation time for non-disabled occupant when evacuating to ground floor and exit the building, scenario 1

	Velocity [m/s]	Evacuation time [min]
	1.131	1.30
	1.237	1.20
	0.28	5.08
	0.311	4.58
	0.575	2.50
	0.435	3.28
	1.266	1.15
	1.094	1.33
	0.948	1.57
	0.693	2.08
	1.611	0.93
	0.415	3.43
	0.665	2.17
	1.248	1.18
	1.15	1.28
	1.145	1.28
	0.572	2.50
	0.987	1.47
	0.651	2.22
	0.739	1.95
	0.199	7.13
	0.916	1.58
	0.477	3.00
	0.676	2.12
	0.44	3.25
	1.271	1.17
	0.908	1.60
	1.425	1.05
	0.167	8.52
	0.613	2.35
Average	**0.808**	**2.48**
Standard deviation	**0.389**	**1.79**

Table A-5 presents the results from the simulations of scenario 1 for the disabled occupant when evacuating to the ground floor and exit the building.

Table A-5: Evacuation time for disabled occupant when evacuating to ground floor to exit the building in scenario 1

	Velocity [m/s]	**Evacuation time [min]**
	0.526	2.82
	0.859	1.77
	0.567	2.63
	1.27	1.28
	0.573	2.60
	0.474	3.12
	1.043	1.52
	0.431	3.43
	0.296	4.98
	0.157	9.33
	0.387	3.82
	0.275	5.35
	1.319	1.25
	0.347	4.28
	1.073	1.47
	1.305	1.27
	0.47	3.13
	0.213	6.90
	0.132	11.12
	0.481	3.07
	0.576	2.58
	1.215	1.33
	0.214	6.85
	1.046	1.52
	0.341	4.33
	0.852	1.78
	0.208	7.05
	1.297	1.27
	0.407	3.62
	0.455	3.23
Average	**0.627**	**3.62**
Standard deviation	**0.391**	**2.49**

Figure A-2 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 1, when evacuating to ground floor in Harpa and exit the building.

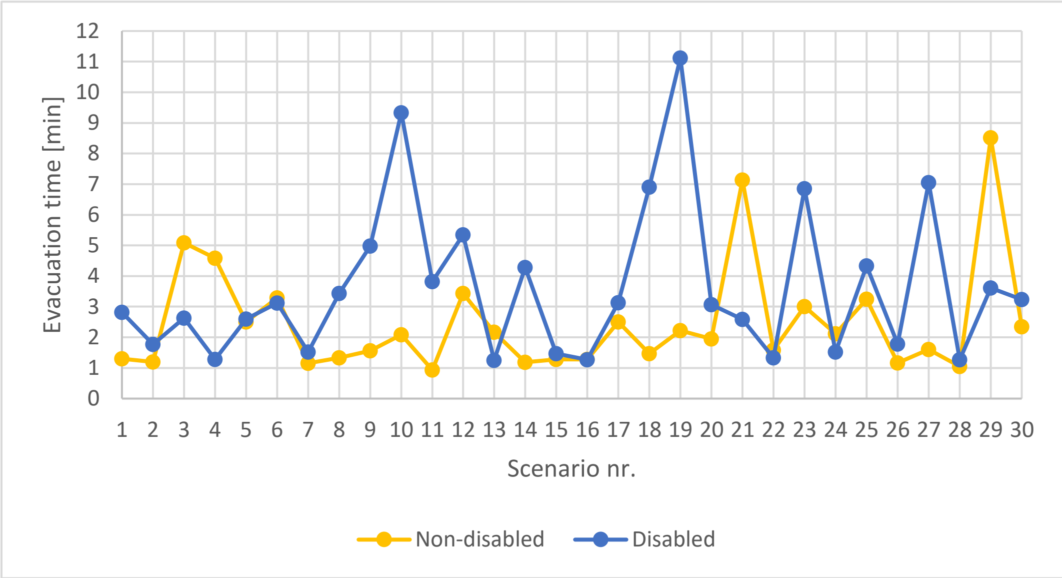

Figure A-2: Evacuation time from simulations of scenario 1, when evacuating to ground floor and exit the building.

Table A-6 presents the results from the simulations of scenario 1 for the non-disabled occupant when evacuating to refuge area.

Table A-6: Evacuation time for non-disabled occupant when evacuating to refuge area in scenario 1

	Velocity [m/s]	Evacuation time [min]
	1.05	0.20
	1.43	0.15
	0.61	0.33
	0.83	0.25
	1.3	0.17
	1	0.22
	0.59	0.33
	0.26	0.75
	1.21	0.18
	0.17	1.17
	1.35	0.17
	0.27	0.73
	0.43	0.47
	0.96	0.22
	1.62	0.13
	0.58	0.35
	1.33	0.17
	0.48	0.42
	1.38	0.15
	0.57	0.35
	0.96	0.22
	0.34	0.58
	0.91	0.23
	1.02	0.22
	0.48	0.42
	1.53	0.13
	0.2	0.95
	1.29	0.17
	1.2	0.18
	1.45	0.15
Average	**0.893**	**0.34**
Standard deviation	**0.446**	**0.26**

Table A-7 presents the results from the simulations of scenario 1 for the disabled occupant when evacuating to refuge area.

Table A-7: Evacuation time for disabled occupant when evacuating to refuge area in scenario 1

	Velocity [m/s]	Evacuation time [min]
	0.526	0.37
	0.859	0.23
	0.567	0.33
	1.27	0.18
	0.573	0.33
	0.474	0.40
	1.043	0.22
	0.431	0.43
	0.296	0.65
	0.157	1.18
	0.387	0.48
	0.275	0.70
	1.319	0.18
	0.347	0.57
	1.073	0.20
	1.305	0.18
	0.47	0.40
	0.213	0.88
	0.132	1.40
	0.481	0.38
	0.576	0.33
	1.215	0.20
	0.214	0.88
	1.046	0.22
	0.341	0.57
	0.852	0.23
	0.208	0.92
	1.297	0.18
	0.407	0.47
	0.455	0.42
Average	**0.627**	**0.47**
Standard deviation	**0.391**	**0.31**

Figure A-3 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 1, when evacuating to refuge area in Eldborg.

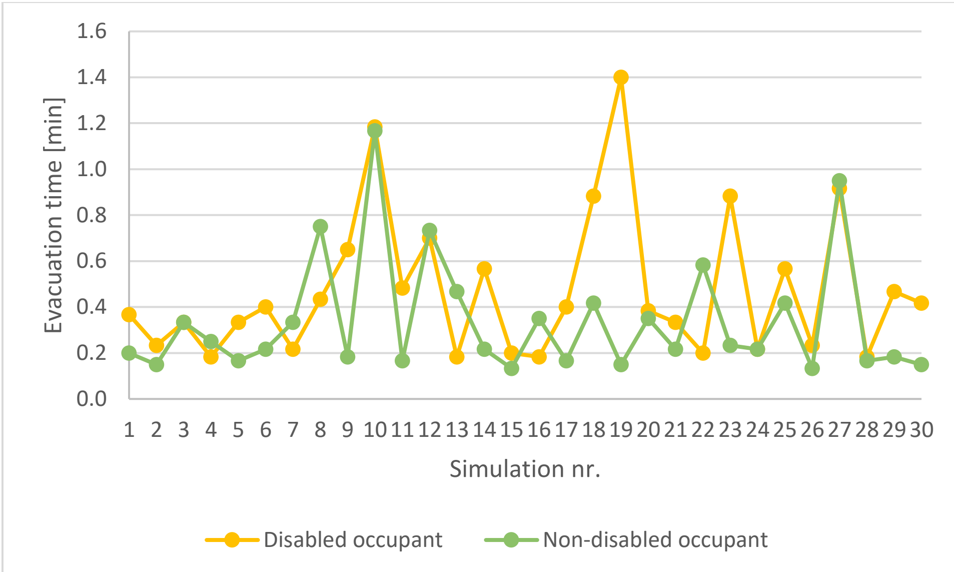

Figure A-3: Evacuation time from simulations of scenario 1, when evacuating to refuge area.

Results from simulations of scenario 2 near Kolabrautin, Harpa

Table A-7 presents the results from the simulations of scenario 2 for the non-disabled occupant when evacuating to the ground floor and exit the building.

Table A-7: Evacuation time for non-disabled occupant when evacuating to ground floor and exit the building, scenario 2

	Velocity [m/s]	**Evacuation time [s]**
	0.527	3.62
	1.087	1.80
	1.254	1.57
	1.100	1.78
	1.610	1.25
	0.357	5.32
	1.13	1.75
	1.26	1.57
	1.39	1.43
	0.35	5.43
	1.27	1.55
	0.54	3.53
	1.02	1.92
	1.17	1.68
	0.11	17.88
	1.21	1.63
	1.33	1.50
	1.63	1.23
	1.18	1.67
	1.16	1.70
	0.98	2.00
	1.64	1.23
	0.36	5.33
	0.46	4.12
	0.39	4.90
	1.65	1.22
	0.22	8.52
	1.31	1.50
	0.88	2.22
	1.13	1.73
Average	**0.990**	**3.08**
Standard deviation	**0.459**	**3.30**

Table A-8 presents the results from the simulations of scenario 2 for the disabled occupant when evacuating to the ground floor and exit the building.

Table A-8: Evacuation time for disabled occupant when evacuating to ground floor and exit the building, scenario 2

	Velocity [m/s]	Evacuation time [s]
	0.926	2.2
	0.616	3.2
	0.869	2.4
	0.61	3.3
	0.472	4.2
	1.169	1.8
	0.879	2.3
	0.214	9.2
	0.893	2.3
	1.325	1.7
	0.445	4.5
	0.977	2.1
	0.166	11.9
	0.814	2.5
	0.389	5.1
	1.222	1.8
	0.763	2.7
	0.75	2.7
	0.194	10.1
	0.333	5.9
	0.214	9.2
	0.798	2.6
	0.917	2.2
	1.153	1.8
	0.814	2.5
	0.516	3.8
	0.229	8.6
	1.287	1.7
	1.041	2.0
	0.558	3.6
Average	**0.718**	**3.98**
Standard deviation	**0.348**	**2.86**

Figure A-4 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 2, when evacuating to ground floor in Harpa and exit the building.

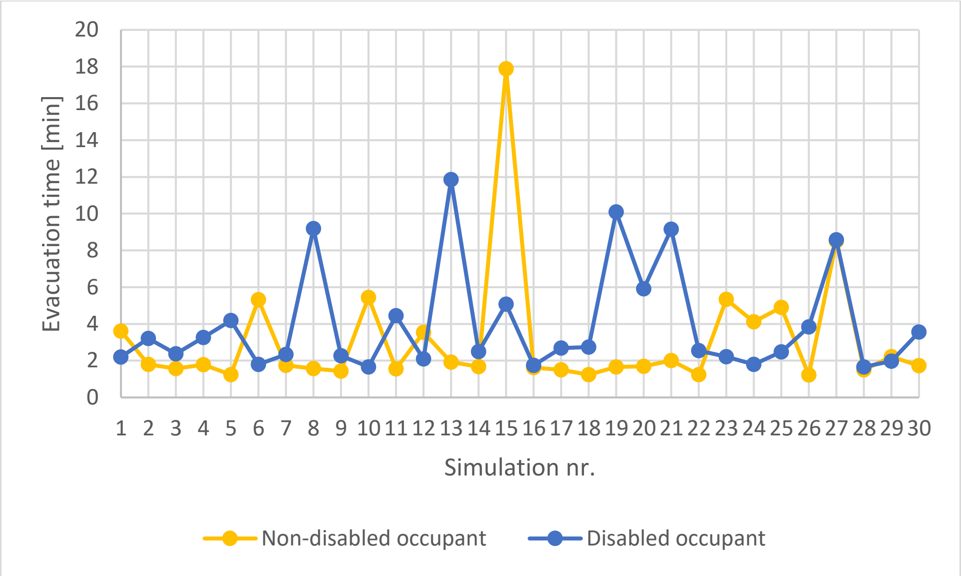

Figure A-4: Evacuation time from simulations of scenario 2, when evacuating to ground floor and exit the building.

Table A-9 presents the results from the simulations of scenario 2 for the non-disabled occupant when evacuating to refuge area.

Table A-9: Evacuation time for non-disabled occupant when evacuating to refuge area in scenario 2.

	Velocity [m/s]	Evacuation time [s]
	1.19	1.12
	1.64	0.82
	1.11	1.20
	0.1	12.55
	0.78	1.70
	0.97	1.37
	1.52	0.87
	0.61	2.15
	1.26	1.05
	0.54	2.42
	0.93	1.42
	0.69	1.92
	0.38	3.43
	0.7	1.88
	1.24	1.07
	0.81	1.63
	0.56	2.37
	1.56	0.85
	1.6	0.83
	0.22	6.02
	0.26	5.00
	1.47	0.92
	0.27	4.80
	0.6	2.20
	1.05	1.27
	0.89	1.48
	0.93	1.42
	0.41	3.20
	1.47	0.92
	0.65	2.03
Average	**0.880**	**2.33**
Standard deviation	**0.451**	**2.33**

Table A-10 presents the results from the simulations of scenario 2 for the disabled occupant when evacuating to refuge area.

Table A-10: Evacuation time for disabled occupant when evacuating to refuge area in scenario 2.

	Velocity [m/s]	Evacuation time [s]
	0.926	1.52
	0.616	2.25
	0.869	1.60
	0.61	2.27
	0.472	2.93
	1.169	1.18
	0.879	1.58
	0.214	6.43
	0.893	1.55
	1.325	1.05
	0.445	3.10
	0.977	1.42
	0.166	8.30
	0.814	1.70
	0.389	3.55
	1.222	1.13
	0.763	1.82
	0.75	1.85
	0.194	7.07
	0.333	4.13
	0.214	6.42
	0.798	1.73
	0.917	1.52
	1.153	1.20
	0.814	1.70
	0.516	2.67
	0.229	6.02
	1.287	1.08
	1.041	1.33
	0.558	2.48
Average	**0.718**	**2.75**
Standard deviation	**0.348**	**2.03**

Figure A-5 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 2, when evacuating to refuge area.

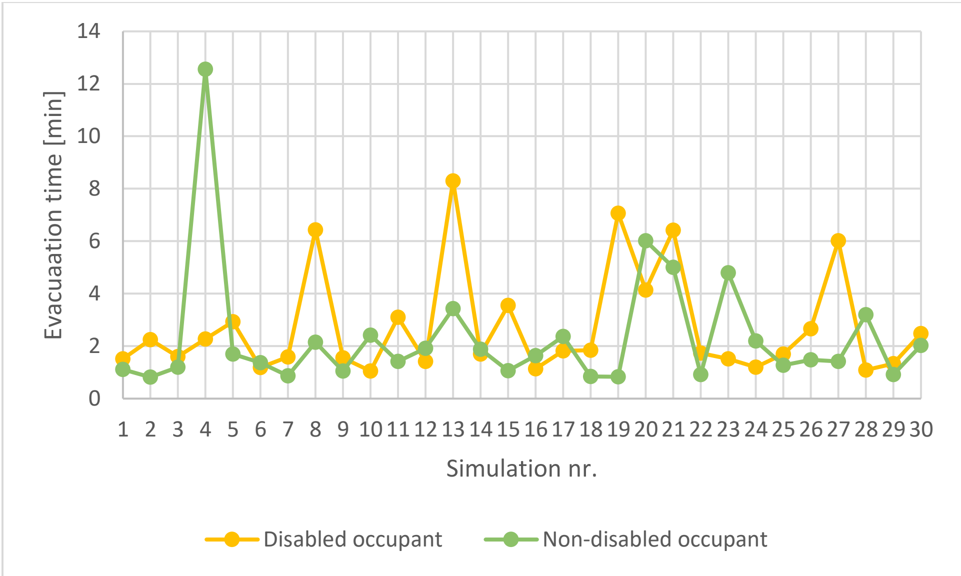

Figure A-5: Evacuation time from simulations of scenario 2, when evacuating to refuge area.

Results from simulations of scenario 3 in Kaldalón, Harpa

Table A-10 presents the results from the simulations of scenario 3 for the non-disabled occupant.

Table A-10: Evacuation time for non-disabled occupant from simulations of scenario 3.

	Velocity [m/s]	**Evacuation time [s]**
	0.838	1.53
	1.52	0.85
	1.281	1.00
	0.679	1.88
	0.563	2.27
	0.73	1.75
	0.492	2.60
	0.488	2.62
	1.343	0.97
	1.376	0.93
	1.363	0.95
	1.389	0.93
	0.187	6.73
	1.35	0.97
	0.42	3.03
	0.963	1.33
	0.471	2.70
	0.336	3.78
	0.169	7.50
	0.809	1.58
	0.918	1.40
	1.676	0.78
	0.131	9.68
	0.591	2.17
	1.519	0.85
	1.488	0.87
	0.26	4.88
	0.44	2.90
	1.633	0.80
	0.557	2.28
Average	**0.866**	**2.42**
Standard deviation	**0.498**	**2.16**

Table A-11 presents the results from the simulations of scenario 3 for the disabled occupant.

Table A-11: Evacuation time for disabled occupant in scenario 3

	Velocity [m/s]	Evacuation time [s]
	0.483	2.70
	0.917	1.43
	0.392	3.32
	1.311	1.02
	0.615	2.12
	0.748	1.75
	0.963	1.37
	0.768	1.70
	1.349	0.98
	0.391	3.32
	0.168	7.72
	0.644	2.03
	0.741	1.77
	0.76	1.72
	0.532	2.45
	0.591	2.20
	1.343	1.00
	0.654	2.00
	0.926	1.42
	0.32	4.05
	0.837	1.57
	0.34	3.82
	1	1.32
	0.888	1.48
	0.53	2.45
	0.187	6.93
	0.254	5.12
	0.931	1.42
	1.251	1.07
	1.095	1.20
Average	**0.731**	**2.41**
Standard deviation	**0.340**	**1.67**

Figure A-6 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 3.

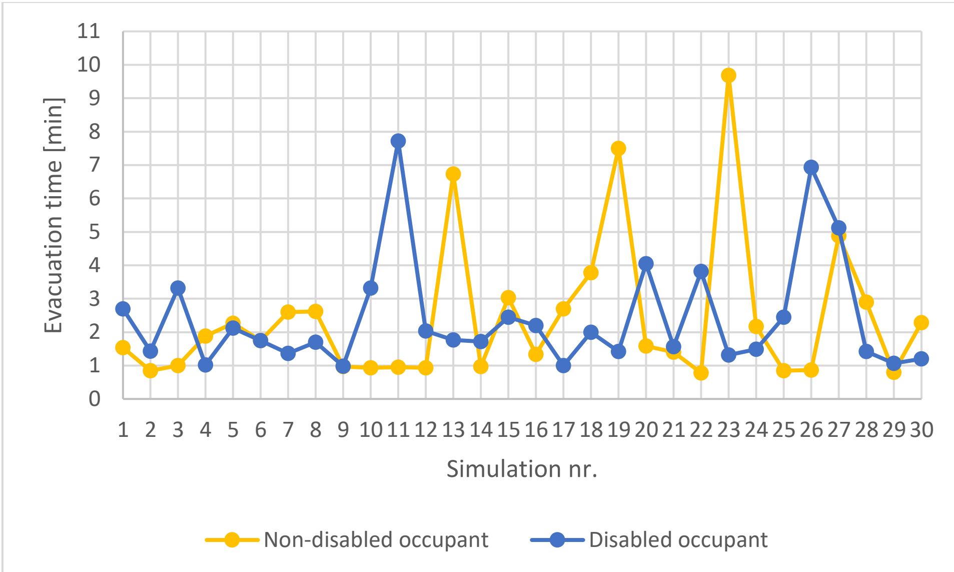

Figure A-6: Evacuation time from simulations of scenario 3.

Figure A-7 presents the evacuation time as a function of movement speed for the non-disabled and the disabled occupant from the simulations of scenario 3. In addition, the average values of evacuation time and the movement speed are presented in the figure.

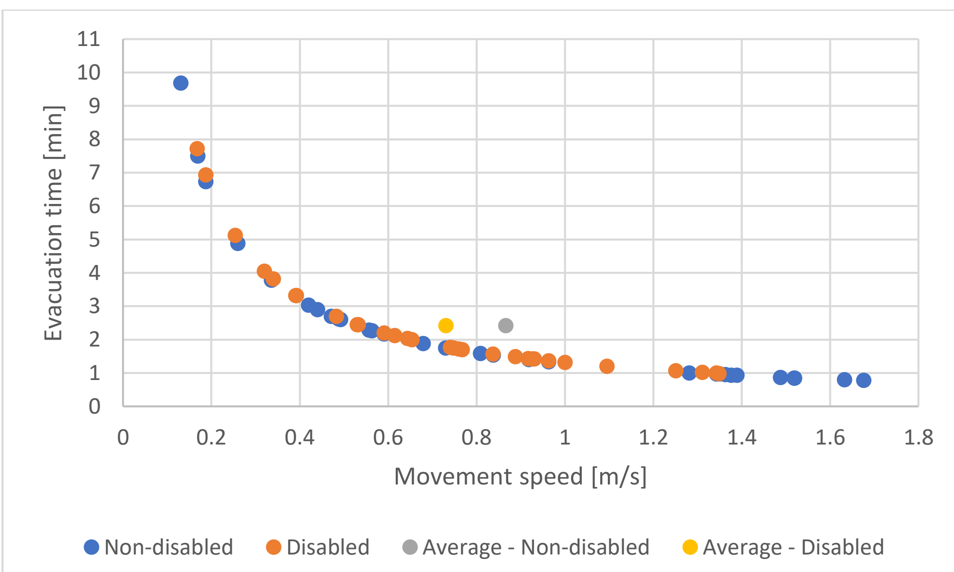

Figure A-7: Evacuation time as a function of movement speed, from simulation of scenario 3 in Harpa.

Results from simulations of scenario 1 in Smárabíó, Smáralind

Table A-11 presents the results from the simulations of scenario 1 in Smáralind for the disabled occupant.

Table A-11: Evacuation time for the disabled occupant in scenario 1in Smáralind.

	Velocity [m/s]	Evacuation time [s]
	0.2	3.77
	0.43	1.80
	1.14	0.70
	0.56	1.38
	0.98	0.82
	1.26	0.67
	1.12	0.73
	0.43	1.78
	0.99	0.80
	0.76	1.03
	1.31	0.63
	0.58	1.35
	0.77	1.03
	0.25	3.10
	1.18	0.72
	0.46	1.70
	0.84	0.95
	0.14	5.42
	0.78	1.02
	1.08	0.77
	0.91	0.88
	0.26	2.90
	0.51	1.53
	0.56	1.38
	0.64	1.22
	1.22	0.67
	0.93	0.87
	0.66	1.20
	0.14	5.48
	0.63	1.25
Average	**0.724**	**1.59**
Standard deviation	**0.350**	**1.29**

Table A-12 presents the results from the simulations of scenario 1 in Smáralind for the non-disabled occupant.

Table A-12: Evacuation time for non-disabled occupant in scenario 1, Smáralind.

	Velocity [m/s]	Evacuation time [s]
	1.12	0.68
	0.85	0.88
	1.58	0.48
	0.45	1.63
	1.07	0.72
	0.86	0.87
	0.34	2.15
	1.5	0.52
	1.55	0.50
	0.61	1.20
	1.58	0.48
	1.33	0.57
	0.76	0.98
	1.27	0.60
	0.42	1.75
	0.19	3.92
	1.5	0.52
	1.05	0.72
	1.44	0.53
	1.62	0.48
	1.07	0.70
	0.23	3.17
	1.65	0.47
	1.28	0.60
	0.4	1.82
	0.24	2.98
	1	0.75
	0.45	1.63
	1.4	0.55
	0.63	1.18
Average	**0.981**	**1.13**
Standard deviation	**0.486**	**0.89**

Figure A-8 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 1 in Smáralind.

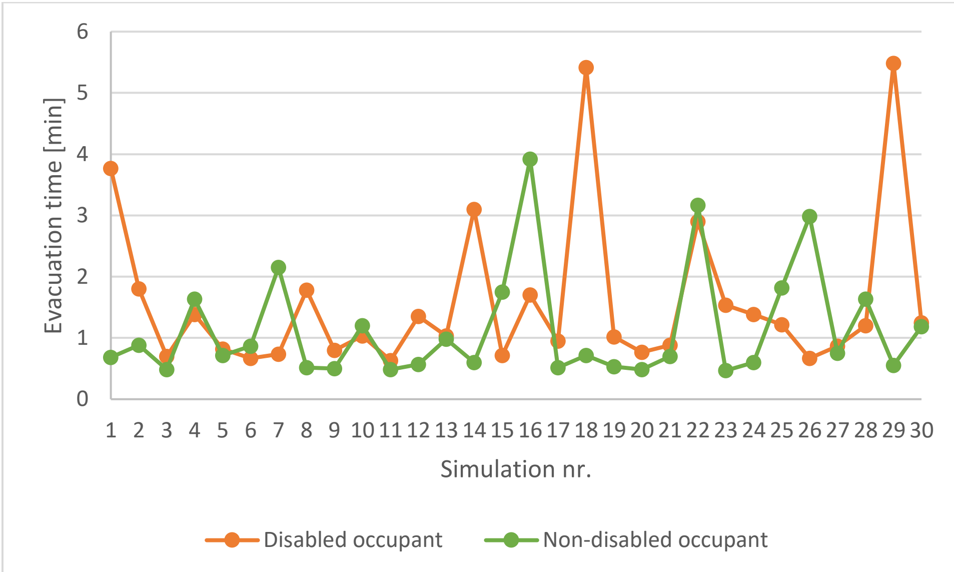

Figure A-8: Evacuation time from simulations of scenario 1 in Smáralind.

Results from simulations of scenario 2 in Smárabíó, Smáralind

Table A-13 presents the results from the simulations of scenario 2 in Smáralind for the disabled occupant.

Table A-13: Evacuation time for disabled occupant in scenario 2.

	Velocity [m/s]	Evacuation time [s]
	0.22	4.17
	1.32	0.75
	0.94	1.03
	1.09	0.88
	0.73	1.28
	0.85	1.13
	0.21	4.47
	0.83	1.15
	0.51	1.83
	0.56	1.68
	1.07	0.90
	0.99	0.98
	0.9	1.07
	0.63	1.52
	0.7	1.35
	0.95	1.02
	0.35	2.68
	1.28	0.77
	0.59	1.60
	0.88	1.10
	0.36	2.63
	0.51	1.85
	1.05	0.93
	0.46	2.05
	0.84	1.13
	0.38	2.48
	0.72	1.33
	1.11	0.88
	1.32	0.75
	1.24	0.78
Average	**0.783**	**1.54**
Standard deviation	**0.325**	**0.93**

Table A-14 presents the results from the simulations of scenario 2 in Smáralind for the non-disabled occupant.

Table A-14: Evacuation time for non-disabled occupant in scenario 2.

	Velocity [m/s]	Evacuation time [s]
	0.85	1.08
	0.7	1.30
	0.62	1.47
	0.2	4.35
	0.7	1.31
	0.9	1.05
	1.59	0.58
	0.11	7.95
	0.27	3.37
	0.68	1.33
	0.98	0.95
	0.42	2.15
	1.03	0.90
	1.08	0.85
	1.59	0.58
	1.21	0.77
	0.43	2.12
	0.38	2.38
	0.88	1.03
	1.42	0.65
	1.63	0.57
	0.57	1.60
	0.9	1.02
	0.46	1.98
	0.82	1.12
	0.99	0.93
	1.67	0.55
	0.93	1.00
	0.68	1.33
	1.09	0.85
Average	**0.859**	**1.57**
Standard deviation	**0.427**	**1.47**

Figure A-8 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 2 in Smáralind.

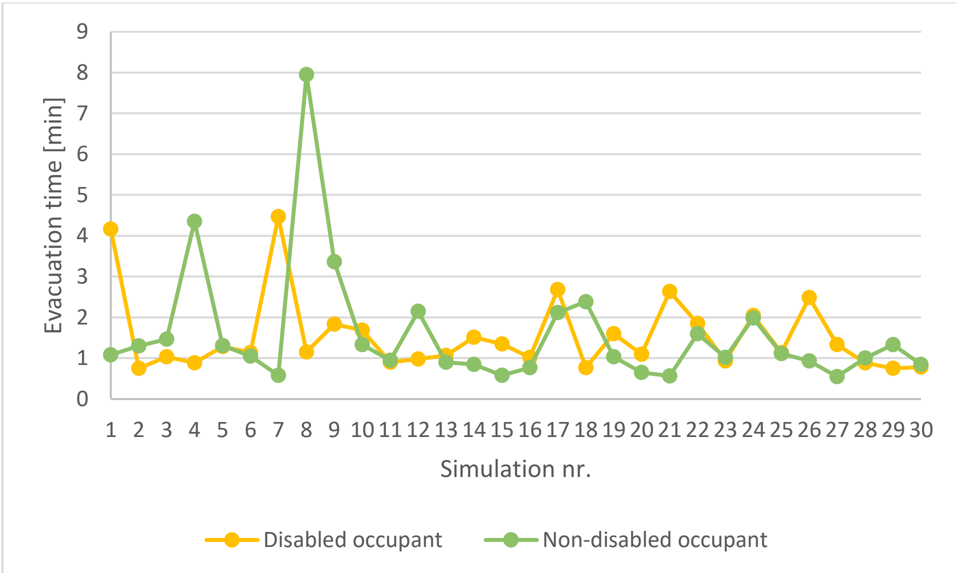

Figure A-8: Evacuation time from simulations of scenario 2 in Smáralind.

Results from simulations of scenario 3 in Hagkaup, Smáralind

Table A-15 presents the results from the simulations of scenario 3 in Smáralind for the disabled occupant, when evacuating the same route as in the evacuation exercise.

Table A-15: Evacuation time for disabled occupant in scenario 3 in Smáralind, evacuating same route as in the evacuation exercise.

	Velocity [m/s]	**Evacuation time [s]**
	1.31	0.42
	0.755	0.72
	1.21	0.45
	1.25	0.45
	0.14	3.68
	1.02	0.53
	0.56	0.95
	0.52	1.02
	0.66	0.80
	0.97	0.57
	0.83	0.65
	0.8	0.67
	1.03	0.53
	0.685	0.78
	1.25	0.45
	0.78	0.68
	0.43	1.25
	0.92	0.58
	0.42	1.27
	0.28	1.88
	0.61	0.87
	1.09	0.50
	0.91	0.60
	0.37	1.43
	0.69	0.78
	0.34	1.57
	0.56	0.95
	0.21	2.48
	1.31	0.42
	1.07	0.52
Average	**0.766**	**0.95**
Standard deviation	**0.341**	**0.70**

Table A-16 presents the results from the simulations of scenario 3 in Smáralind for the non-disabled occupant, when evacuating the same route as in the evacuation exercise.

Table A-16: Evacuation time for non-disabled occupant in scenario 3 in Smáralind, evacuating same route as in the evacuation exercise.

	Velocity [m/s]	**Evacuation time [s]**
	0.81	0.63
	1.39	0.38
	0.91	0.57
	1.64	0.32
	0.82	0.63
	0.15	3.42
	1.65	0.32
	0.78	0.67
	1.06	0.50
	0.87	0.60
	0.32	1.60
	1.55	0.33
	0.19	3.70
	1.02	0.52
	0.77	0.67
	1.27	0.42
	1.45	0.37
	1.59	0.33
	0.53	0.98
	1.48	0.35
	0.77	0.67
	0.1	5.00
	0.54	0.95
	0.63	0.82
	0.69	0.75
	0.97	0.53
	1.47	0.35
	0.4	1.25
	1.29	0.40
	0.53	0.97
Average	**0.921**	**0.96**
Standard deviation	**0.470**	**1.10**

Figure A-9 presents the evacuation time for the non-disabled and the disabled occupant from the simulations of scenario 3 in Smáralind, when evacuating the same route as in the evacuation exercise.

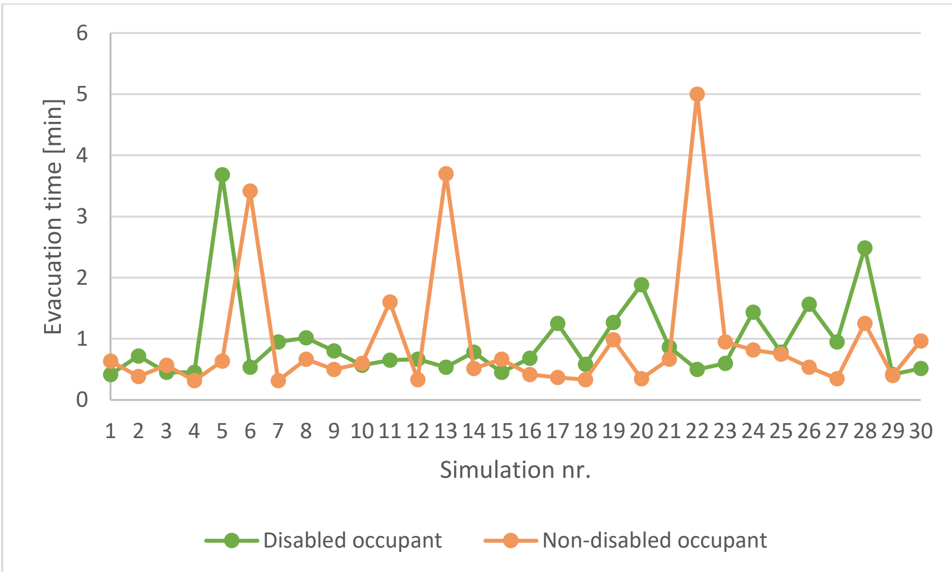

Figure A-9: Evacuation time from simulations of scenario 3 in Smáralind, when evacuating the same route as in the evacuation exercise

Table A-17 presents the results from the simulations of scenario 3 in Smáralind for the non-disabled occupant, when evacuating out of the building through the main exit in Hagkaup.

Table A-17: Evacuation time for non-disabled occupant in scenario 3, when evacuating out through the main exit.

	Velocity [m/s]	Evacuation time [s]
	0.35	4.45
	1.25	1.27
	0.8	1.97
	0.6	2.63
	0.32	4.92
	0.35	4.55
	0.31	5.05
	0.89	1.77
	1.13	1.40
	0.19	8.03
	1.23	1.28
	0.97	0.02
	1.33	1.18
	1.1	1.43
	1.03	1.53
	0.95	1.65
	1.31	1.20
	1	1.58
	0.73	2.17
	0.82	1.92
	0.54	2.92
	0.93	1.70
	1.32	1.20
	1.13	1.40
	0.22	7.18
	0.9	1.73
	0.33	4.72
	1.19	1.33
	0.43	3.63
	0.17	9.30
Average	**0.794**	**2.84**
Standard deviation	**0.384**	**2.24**

Table A-18 presents the results from the simulations of scenario 3 in Smáralind for the non-disabled occupant when evacuating out of the building through the main exit in Hagkaup.

Table A-18: Evacuation time for non-disabled occupant in scenario 3 when evacuating out through the main exit.

	Velocity [m/s]	**Evacuation time [s]**
	0.15	10.38
	0.91	1.73
	0.73	2.13
	1.16	1.35
	1.13	1.38
	0.92	1.70
	1.57	1.00
	0.4	3.85
	0.24	6.48
	1.06	1.48
	1.38	1.13
	0.23	6.88
	0.42	3.70
	1.06	1.48
	0.44	3.57
	0.99	1.58
	1.6	0.98
	0.69	2.27
	0.8	1.95
	0.52	3.02
	0.88	1.78
	1.4	1.10
	0.92	1.70
	0.45	3.50
	0.73	2.15
	1.46	1.07
	0.13	11.83
	0.41	3.75
	0.62	2.53
	0.87	1.80
Average	**0.809**	**2.97**
Standard deviation	**0.422**	**2.65**

Appendix 6 - Movement distances from Pathfinder simulations

Table A-19 to A-21 present the movement distances from simulations done for scenario 1, 2 and 3 in Harpa. In addition, the average movement distance is presented. The movement distances and the average movement distances from simulations of scenario 1, 2 and 3 in Smáralind are presented in table A-22.

Table A-19: Movement distances from simulations of scenario 1 in Harpa

	[m]	[m]	[m]	[m]	[m]	**Average distance [m]**
Non-disabled	82.5	82.4	82.4	82.3	82.5	**82.4**
Disabled	85.4	85	87.1	87.1	85.5	**86.0**
Non-disabled to refuge area	11.9	11.7	11.7	11.8	11.8	**11.8**
Disabled to refugearea	12	11.7	12	11.8	12	**11.9**

Table A-20: Movement distances from simulations of scenario 2 in Harpa

	[m]	[m]	[m]	[m]	[m]	**Average distance [m]**
Non-disabled	105.5	106.4	107.6	109	108	**107.3**
Disabled	113	111.2	111.7	109.6	109.7	**111.0**
Non-disabled refuge	78.8	79	78.7	78.7	78.6	**78.8**
Disabled refuge	81.9	81.8	81.5	82.1	81.7	**81.8**

Table A-21: Movement distances from simulations of scenario 3 in Harpa.

	[m]	[m]	[m]	[m]	[m]	**Average distance [m]**
Non-disabled	76.4	76	76.3	76	76.5	**76.2**
Disabled	78.2	77.8	78.3	78.1	78.4	**78.2**

Table A-22: Movement distances from simulations of scenario 1, 2 and 3 in Smáralind.

		[m]	[m]	[m]	[m]	[m]	**Average distance [m]**
Scenario 1	Non-disabled	43.9	43.8	43.8	44.2	44.3	**44.0**
	Disabled	45.6	45.5	45.6	45.6	45.1	**45.5**
Scenario 2	Non-disabled	54.3	54.5	54.3	54.2	54.2	**54.3**
	Disabled	56.2	55.7	55.9	55.9	56	**55.9**
Scenario 3	Non-disabled	30.3	30.5	30.5	30.5	30.5	**30.5**
	Disabled	31	31	31.1	31.3	31	**31.1**
	Non-disabled - Main exit	93	93.1	93.1	93	93.1	**93.1**
	Disabled - Main exit	93.8	93.8	93.9	93.9	93.9	**93.9**