Building Egressibility in an Ageing Society

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Abstract. This is the final report of a three-year project called Building Egressibility in an Ageing Society, sponsored by the Swedish research council for sustainable development (FORMAS). While accessibility is an established and widely used concept in building design, the evacuation of people with functional limitations is still at a stage in which several research gaps exist. In this context, this work discusses the concept of Egressibility, intended as the accessibility to means of evacuation. A categorization of populations with functional limitations in light of their egress-related abilities was performed by reviewing egress and accessibility research. The role of functional limitations on evacuation performance was investigated using the International Classification of Functioning, Disability and Health (ICF). A qualitative interview study consisting of 28 semi-structured interviews with people with functional limitations was conducted to further scrutinize Egressibility issues of older people. An Egressibility assessment instrument, the *Egress Enabler*, has been developed based on the concept of person-environment fit. A Virtual Reality (VR) experiment involving 40 participants was also conducted to demonstrate the use of VR technology to study the impact of people with functional limitations on egress. It also allowed to explore how the presence of people with functional limitations affects exit choice. Overall, Egressibility was investigated with the aim to ensure that egress planning and procedures are designed to equally consider all members of an aging society.

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Summary

Accessibility is an established domain which has brought significant advances towards achieving an inclusive built environment. Accessibility is currently seen as an important step in the design of the built environment in Sweden and worldwide. Mirroring the concept of accessibility, this project investigates *Egressibility*, intended as accessibility to means of evacuation. The increase in the average age of the population in the world often corresponds to decreased functional capacity and ability to perform daily activities such as moving around. A decreased functional capacity is here referred to as functional limitations.

The combination of a higher prevalence of functional limitations in the population along with an increased accessibility to public environments leads to potentially greater issues regarding evacuation in case of emergencies. In fact, people may be expected to perform self-evacuation in public buildings despite having an environment that may not be egressible. The *Building Egressibility in an Ageing Society* project aimed at exploring the issues associated with self-evacuation of people with functional limitations in public buildings. This was achieved making use of established concepts in the field of accessibility. The project consisted of several research activities.

The first step included the review of relevant literature in the fields of Egressibility and accessibility of public buildings with the aim of categorizing functional limitations in light of evacuation performance and identify the state-of-the-art of accessibility research. This was performed making use of the International Classification of Functioning, Disability and Health (ICF) which made it possible to identify predominant activities during access and egress and to perform a structured classification at different levels of resolution to address self-evacuation possibilities.

Key findings of the review of the egress field reported that most research is conducted for people with mobility limitations. It was suggested that it is important to distinguish the needs of people with different types of mobility impairments, i.e., those that have the limitations of upper extremities and those with limitations in lower extremities. A set of functional limitations received limited research attention. This includes the ability to smell smoke as a cue in fire emergency. Also, no dedicated studies were found on how speech impairments can affect evacuation performance. Similarly, despite the great variety of possible cognitive impairments, limited research has been found on this issue. This was overall expected given the difficulties in collecting this type of data due to ethical and practical constraints.

Key findings in the accessibility scoping review include that fitness facilities and health provider facilities are mainly addressed in cross-sectional studies, often without study participants. Moreover, this review revealed that existing research is largely concentrated around the access activities of using parking/drop-off areas, route to entrance and hygiene facilities. A variety of instruments are used, but psychometric testing is rare. Further, the articles were mainly focused on mobility and visual limitations. Further research is needed on empirical evaluation and quantification about 1) the features of buildings that cause accessibility issues; 2) access activities and how people experience the accessibility issues; and 3) which combinations of building features and functional limitations lead to accessibility issues in areas with identified knowledge gaps.

The subjective perspectives of older people with functional limitations were investigated through a dedicated qualitative interview study. This included a set of 28 semi-structured interviews with 60+ year old people having one or more self-reported functional limitations. An ad hoc self-assessment questionnaire (also based on ICF) was developed to define the sample of interviewees with the aim of describing their functional limitations. The interviews were performed remotely due to the Covid-19 pandemic in 2020. The topics discussed and associated questions in use related to the public environment, the functional limitations, evacuation, the built environment and

perception of others. The qualitative data collected were analysed using inductive reflective thematic analysis. The analysis of the interview transcripts allowed to obtain a set of three main themes. The first theme *Other people's difficulties in understanding* related to issues in making others understand the limitation and henceforth barriers. Feelings of exclusion were central in this theme. Visible limitations (such as the use of mobility aid) were perceived given more considerations from others, and that in case people wanted to give help often they did not know how. The second theme was *Strategies to cope with the limitation*. The sub-themes consisted of a set of strategies such as changes in behaviour, getting help from others, using other senses to compensate for their functional limitations, pushing through, etc. Considering the interactions with the built environment as a person-environment fit issue, these strategies mainly address the personal component, i.e., enhancing the ability to overcome barriers, rather than the interaction with the environment. The third and last theme related to the *Uncertainty of evacuation*. This theme included both uncertainties in their own behaviour as well as the ones of other people. Participants stated that they generally did not worry about evacuation.

The research project also proposed an Egressibility assessment instrument, called the *Egress Enabler*. The Egress Enabler builds upon a known and research-based tool for the assessment and analysis of accessibility issues in the built environment called the Housing Enabler. The concept of person-environment fit has been used as a starting point for the Egress Enabler development. A systematic approach was used to identify a final pool of items to be included in the environmental component of the Egress Enabler. This included an expert panel review. Sub-components were therefore identified based on evacuation elements found in buildings: Notification systems, Signage, Circulation space, Refuge areas, Occupant evacuation elevators (OEEs), Ramps, Stairs, Doors, and Outside environment. The items to be included in the personal component were then defined based on the list available in the Housing Enabler. The analysis of the interaction between the personal and environmental components enabled the quantification of severity and range of Egressibility issues. After assessing both the personal and environmental components, The *Egress Enabler* generates a score, where a higher score corresponds to a less egressible building considering the interaction between the functional limitations of the individuals in a given building and the environmental features. The instrument was then tested to evaluate its psychometric properties, using a case study of a public building (a library). Overall, the *Egress Enabler* was found useful to measure Egressibility considering that it should be seen as a person-environment fit issue. The *Egress Enabler* provides the opportunity for a comprehensive evaluation of Egressibility, considering different features of the built environment and the prevalent functional limitations in a given population.

The last research effort in this project related to understanding the impact of the presence of people with functional limitations on exit choice. This was studied performing Virtual Reality experiments. Results from 40 participants indicate that exit choice was positively influenced by other people choosing the exit, and a larger effect was found for when the other person was a wheelchair user. The design of the exit also influenced the exit choice of the participants. However, it was also found that large inter-person differences existed. Strategies reported by the participants in the subsequent questionnaire included altruistic behaviour in the form of wanting to be of help to the person in a wheelchair. This study demonstrated that VR can be a valuable tool for investigating the impact of people with functional limitations on egress.

Given the variety of methodological approaches explored, the findings obtained, and the tool developed, this project is deemed to represent a significant advancement in the field of Egressibility. It is expected that it will pave the way towards an inclusive society which considers Egressibility as an important element in the process of building design.

1. Introduction

Sweden has been at the forefront for the respect of diversity in Europe and worldwide for many years. In this context, the Swedish research council for sustainable development FORMAS has funded a 3-year project aimed at pursuing the concept of *Egressibility* [1]. Egressibility is a concept developed in parallel with accessibility for meeting the needs of people with functional limitations in case of evacuation, which until a few years ago were partially or totally neglected in the architectural design of buildings [2]. This generated several important changes in the way buildings are designed, including the development of special provisions for people with disabilities in case of emergency (e.g., areas of refuge, the possibility to use elevators for evacuation in special circumstances [3]). Today, an inclusive society should take into consideration the full range of population demographics, which includes a raising proportion of senior citizens and people with functional limitations.

This project aimed at pursuing the concept of *Egressibility* by addressing the issues associated with the egress capacity of older people. This issue has particular relevance in Sweden and worldwide, as demonstrated by the rising trend of fires in homes where older people live [4], [5] and the increasing emergency evacuation scenarios caused by terrorist attacks [6] and natural hazards linked to climate change [7].

The categorization of older people (e.g., identifying vulnerable groups) from the egress standpoint, the associated egress performance, and the identification of future research to achieve Egressibility needed investigation. This means assessing different types of functional limitations and how those can affect egress capacity in relation to building design features and a selected set of key emergency evacuation scenarios. For instance, this includes the study of the impact of functional limitations on egress performance (i.e., hearing, perceiving, understanding an emergency message, mobility issues which make people able to use a certain egress route, etc.). This was deemed to be a fundamental step to identify egress design solutions which are suitable for all, including populations with functional limitations.

Most current buildings are not designed from an egress standpoint for an aging society including people with functional limitations. In recent years, few attempts have been made to measure the impact of demographics on egress procedure effectiveness, but a limited number of studies addressed the specific issues of an aging society and how this can impact egress performance [8].

In the *Ecological Model* [9], further developed in the *Ecological Model of Aging* [10], the dynamic relationships between person and environment are described and used to highlight the balance between competence in the person and environmental demands. Too high (or too low) environmental demands might have a negative impact on the behaviour. People with lower levels of functioning may be more sensitive to the demands of the environment than people with higher levels of functioning. Overall, what needs to be considered in egress design for an aging population is the complex interaction between the person, environment and expected activities.

This project makes use of the concept of functional limitations from the Disablement Process [11], and the International Classification of Functioning, Disabilities and Health - ICF [12]. The latter provides a well-defined universal terminology. ICF describes disability as a wider term for impairments, activity limitations and participation restrictions which represent "*problems an individual may experience in involvement in life situations*" [12]. Impairment is defined as "*loss or abnormality in body structure or physiological function (including mental functions)*" [12]. The term *activity* means execution of a task or an action by an individual. Activity limitations are "*difficulties an individual may have in executing activities; an activity limitation may range from a slight to a severe deviation in terms of quality or quantity in executing the activity in a manner or to the extent that is expected of people without the health condition*" [12].

That is, for an individual to exit a building or to reach a safe place, a series of evacuation activities is needed, e.g. locating exit signs and finding architectural elements.

The findings of this project are deemed to aid the understanding of the needs of people with functional limitations in case of emergency evacuation scenarios. This will ultimately lead to an egressible public built environment. The bold focus of this project is that the changes in population demographics in Sweden and all over the world require a paradigm shift in designing egress solutions in order to achieve Egressibility.

1.1. Aim, objectives and research questions

Different areas to address the evacuation needs of an aging society were investigated and the following objectives were pursued:

1) To map the state-of-the art of research in evacuation of people with functional limitations and related accessibility research.
2) To improve the classification of people with functional limitations in the context of evacuation by adopting established methods in the accessibility field.
3) To investigate the subjective perspectives on Egressibility of older people with functional limitations, including strategies based on person-environment interactions to mitigate the issues identified.
4) To develop an Egressibility assessment instrument allowing the operationalization of the assessment of person-environment fit during emergency egress.
5) To investigating the influence of people with mobility limitations on exit choice by exploring the use of Virtual Reality.

The findings of this project represent an important step towards understanding the needs of older populations with functional limitations in case of evacuation scenarios, which will ultimately lead to improved possibilities to design egressible buildings and facilities.

As part of this project, two scoping reviews describing the research front in the areas of Egressibility and accessibility have been conducted. The reviews aim to identify the empirical studies on egress, accessibility and universal design research including older people and people with functional limitations. During the data synthesis, the aim was to link different egress and accessibility features through International Classification of Functioning, Disability and Health (ICF), and in particular to identify areas which are in need of more research.

With the help of four different research methods: scoping reviews, semi-structured interviews (SSIs), development of assessment instrument, and virtual-reality (VR) experiments, the project aims at providing answers to the following research questions:
1) In what way does the presence of functional limitations among older populations affect the interaction between human and the environment in case of evacuation?
2) How can the variability in human ability among older populations be considered in the built environment in order to ensure safe evacuation for all?

1.2. Report overview

The report is structured in the following manner. The first chapter introduces the project, its overall aim/objectives, the content of the report and project outputs. Chapter 2 presents the overall project methodology. Chapter 3 presents the scoping reviews performed (concerning evacuation and accessibility). Chapter 4 introduces the data collection. Chapter 5 presents the findings of the qualitative interview study (consisting of semi-structured interviews). Chapter 6 presents the process of development of the Egressibility assessment instrument (the Egress Enabler). Chapter 7 presents the Virtual Reality experiments. Chapter 8 presents a general discussion of the findings of the project. Finally, chapter 9 presents recommendations for future research and chapter 10 includes a set of conclusive remarks about the work conducted.

1.3. Project outputs

The project activities included a set of outputs, which are here presented. Project outputs include 6 scientific papers (at the time of report publication 5 of which have been published), 1 book chapter, 1 popular science article, 1 Licentiate thesis, and 8 presentations to conferences and events.

Scientific papers:

O. Bukvic, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, E. Ronchi (2021). *A review on the role of functional limitations on evacuation performance using the International Classification of Functioning, Disability and Health*. Fire Technology 57, pp. 507–528. Doi: 10.1007/s10694-020-01034-5

G. Carlsson, B. Slaug, S. M. Schmidt, L. Norin, E. Ronchi, G. Gefenaite (2021), *A scoping review of public building accessibility*. Disability and Health Journal. Doi. 10.1016/j.dhjo.2021.101227

E. Ronchi (2021). *Developing and validating evacuation models for fire safety engineering*. Fire Safety Journal 120, 103020. Doi: 10.1016/j.firesaf.2020.103020

E. Smedberg, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, E. Ronchi (2022). *Perspectives on Egressibility of older people with functional limitations*. Fire Safety Journal, 127, 103509. Doi: 10.1016/j.firesaf.2021.103509

E. Smedberg, B. Slaug, G. Carlsson, G. Gefenaite, S. M. Schmidt, E. Ronchi (2022). *The Egress Enabler - Development and psychometric evaluation of an instrument to measure Egressibility*. Disability and Health Journal. Doi. 10.1016/j.dhjo.2022.101396

E. Smedberg, G. De Cet, J. Wahlqvist, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, E. Ronchi (2022). *The impact of people with mobility limitations on exit choice*. Submitted to an international journal.

Book chapter:

E. Ronchi, E. Smedberg, G. Carlsson, B. Slaug (2022). The evacuation of people with functional limitations. In M. Runefors, R. Andersson, M. Delin, T. Gell (Eds.), *Residential fire safety – an interdisciplinary approach*. Springer Nature. https://doi.org/10.1007/978-3-031-06325-1_5

Popular science article

E. Smedberg, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, E. Ronchi, (2022) *Egressibility – accessible fire evacuation for all*. Fire Protection Engineering, Magazine of the Society of Fire Protection Engineering.

Licentiate thesis

E. Smedberg (2022). *Egressibility – Applying the concept of accessibility to self-evacuation of people with functional limitations*. Division of Fire Safety Engineering, Lund University, Lund, Sweden.

Presentations at conference and events

E. Ronchi, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, (2019) *Egress, Ageing and Fire Safety Engineering*. Centre for Ageing and Supportive Environment (CASE) Scientific Session.

E. Smedberg (2021), *Building Egressibility in an Ageing Society*. Arup global event (online event).

E. Smedberg, E. Ronchi, B. Slaug, G. Carlsson, S. M. Schmidt, G. Gefenaite (2021) *The Development of an Egressibility Scale*. Poster at the International Association for Fire Safety Science *(IAFSS)* Conference (online event).

E. Smedberg, E. Ronchi, G. Carlsson, B. Slaug, G. Gefenaite, S. Schmidt. (2021) *Safe Building Evacuation for all*. MIRAI 2.0 Research and Innovation Week.

E. Smedberg (2021 and 2022) *Egressibility* – Lecture in the Human Behaviour in Fire course at the Division of Fire Safety Engineering at Lund University.

E. Ronchi, E. Smedberg, B. Slaug, G. Carlsson, G. Gefenaite, S. M. Schmidt (2022) *Evacuation of People with Functional Limitations: Research Knowledge, Gaps and Modelling Implications*. Proceedings of the Fire and Evacuation Modeling Technical Conference (FEMTC) 2022, Brno (Czech Republic)

E. Ronchi (2022) *Egressibility: a paradigm shift for an inclusive building design*. CORE Webinar #2 - Designing an inclusive resilience: The full consideration of vulnerability before, during and after disasters (online event).

E. Ronchi (2022). *The evacuation of people with functional limitations*. Webinar arranged by the Swedish Fire Research board called Residential Fire Safety – An interdisciplinary approach (online event).

2. Overall project methodology

Egressibility is a highly interdisciplinary subject, which requires knowledge on a range of different subjects, e.g., population demographics, functioning and disability, architectural design and engineering. Currently, there is no agreement in the scientific community on the best data collection method to be employed for egress research [13]. Thus, this project is conducted using a mixed-method approach, using a combination of scoping reviews, semi-structured interviews (SSIs), assessment instruments, and virtual reality (VR) experiments in order to contribute to the field of Egressibility in an optimal manner.

The project aims and objectives presented in section 1 were addressed using different research methods. First, the state-of-the-art of evacuation research and accessibility in public buildings was mapped out performing scoping reviews according to the PRISMA methodology [14]. The qualitative interview study used semi-structured interviews and reflexive thematic analysis [15]. The development of an Egressibility assessment instrument was then performed, using the Housing Enabler [16] as starting point. Finally, virtual reality has been used as a tool to investigate exit choice in emergency evacuation. More detailed information into each research method is presented in the relevant report sections. Table 1 clarifies how the different research activities contribute to the project objectives.

Table 1. Links between research methods and their contribution to achieve the project objectives.

Research activities	**Contribution to project objectives**
Scoping review of accessibility literature	- Identifying access activities in relation to environmental features - Identifying gaps in current knowledge related to accessibility of public buildings - linking accessibility to predominant activities in terms of the International Classification of Functioning, Disability and Health (ICF)
Scoping review of Egressibility literature	- Identifying and assessing the clashes between human and environment - Identifying gaps in current knowledge and future needed research - Assessing the effects of functional limitations in past egress events - Aiding the identification of vulnerable groups and scenarios
Semi-structured interviews (SSIs)	- Identifying and assessing the subjective perspectives on Egressibility of older people with functional limitations, considering the person-environment interaction - Aiding the identification of key issues of people with functional limitations during egress considering their perspectives
Development of an assessment instrument	- To provide an instrument to quantify Egressibility based on the notion of person-environment fit - To facilitate the evaluation of the impact of design measures on Egressibility
Virtual reality experiments (VR)	- Explore the use of VR for evacuation research including people with functional limitations - Identifying and assessing the impact of presence of functional limitations and exit design on exit choice

3. Scoping reviews

This section presents the methods and results of two scoping reviews performed in the domain of evacuation of people with functional limitations and accessibility studies in public buildings.

3.1. Review of evacuation of people with functional limitations

The methods and findings of the scoping review related to evacuation of people with functional limitation are here presented. This work has also been published in a scientific article [17]. The idea behind this scoping review is to make use of existing research in the field of health sciences and accessibility research [18] and adopt a well-established classification, which is new in the field of fire safety, to assess the role of functional limitations on evacuation performance. To the authors' knowledge, this approach had never been used previously in evacuation studies.

A classification of functional limitations can be instrumental to distinguish the issues people may experience in performing basic activities. Previous research efforts in evacuation have focused on quantifying the ability of people with mobility limitations to perform evacuation tasks, e.g., see a recent compilation of data available in [19]. These data provide useful inputs for evacuation models and allow inclusion of quantitative variables of evacuation performance [20]. Nevertheless, a further step is needed to increase the knowledge about the various needs of people with different functional limitations in evacuation activities and subsequent evacuation performance. Detailed linkage between classified functional limitations and the predominant activities affected by them and evacuation performance has not been performed. In contrast, detailed classifications are used in the field of accessibility [18].

A key goal of this review is to provide a detailed classification of the links between evacuation activities, functional limitations and predominant activities in light of ICF.

3.1.1. Methods of the review of evacuation studies

The articles for this scoping review were primarily retrieved from the Science Direct and Scopus databases. The search was not time limited and based on a set of keywords: "egress", "evacuation", "people with disabilities", "old people", "impaired", "public buildings", "fire safety" resulting in a total of 6780 Science Direct and 427 Scopus papers. In addition, 60 papers were included based on suggestions provided by experts in the relevant field and by screening the references of the papers included.
The exact search string in use was:
"egress" OR "evacuation" AND "people with disabilities" AND "old people" OR "impaired" AND "public buildings" NOT "residential buildings" AND "fire safety"

The research work was conducted in the period from February 2019 to August 2019. Most papers were retrieved in the first two months and the search was regularly updated up to the end of the study period. For papers to be included, they had to address evacuation from public buildings with adults aged ≥60 years and/or adults aged ≥18 years with functional limitations. The choice of investigating public buildings was made to focus on buildings which are of common interest, thus possibly representing a starting point for future regulatory developments. Given the scope of the review, papers were excluded if they only focused on policy, only used/presented evacuation modelling methods, or were done in residential or nursing homes as the main focus in this work was on buildings where self-evacuation takes place. For details, see the flowchart in Figure 1.

Information about the evacuation process of people with disabilities was extracted at a behavioural level. This included reviewing evacuation activities performed depending on functional limitations and identifying the links between the situations and the activities as classified by ICF. From the selected literature, the specific evacuation activity and its relation to specific functional limitation were extracted. This means that the activities and functional limitations were not simply analysed at the basic detail level (e.g. evacuation activity – walking; functional limitation – mobility impairment) or in general. The extracted data were instead presented considering the activities potentially hard to perform and their relation to each specific functional limitation (e.g. activities such as moving on horizontal, moving on incline, opening doors; functional limitation – separating mobility impairment and upper extremities impairment). This categorization was performed along with the identification of functional limitations relevant for safe evacuation. To add an environmental dimension to this categorization, potential barriers for populations with disabilities were extracted from the body of literature.

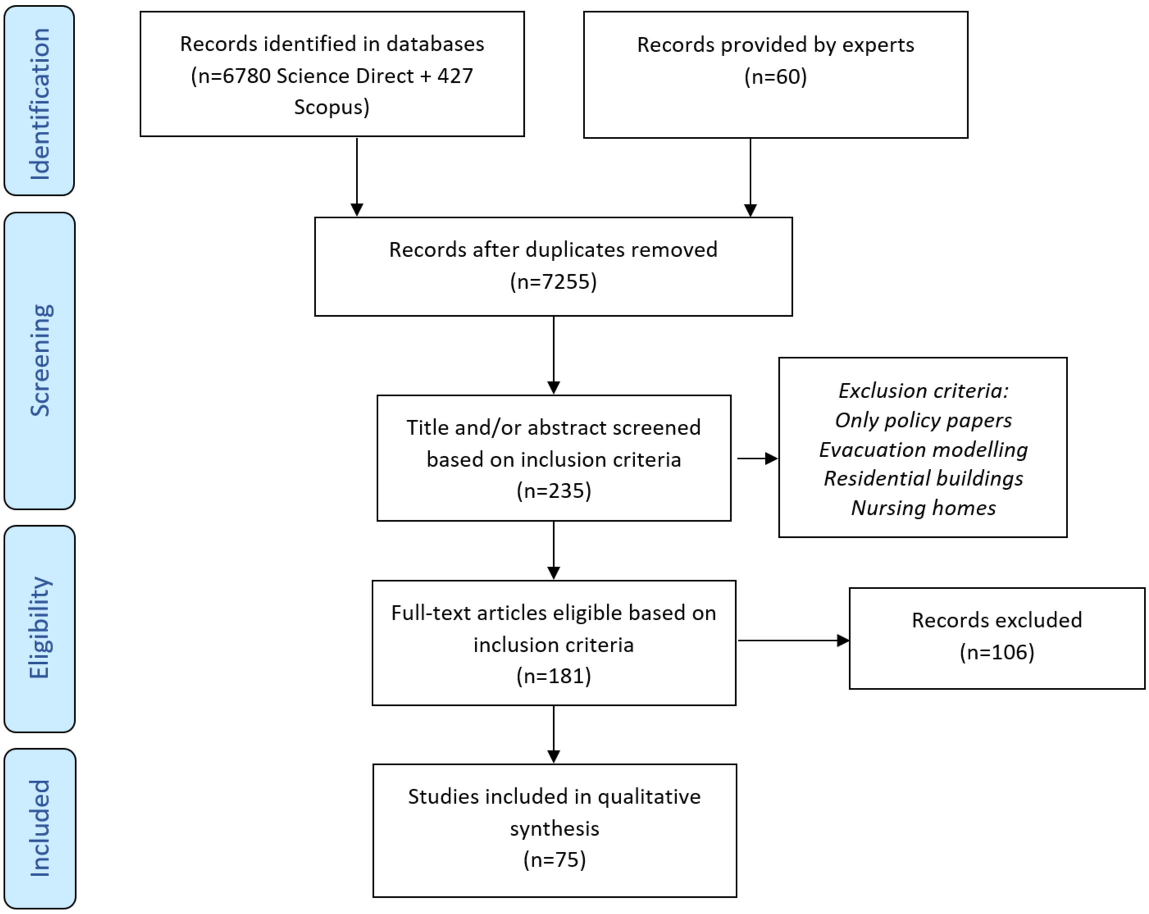

Figure 1. Flow chart of the approach adopted for the literature review.

Based on ICF, the list of activities that could be challenging for populations with disabilities during evacuation - in relation to the associated barriers - were identified. Disabilities were classified according to the type of functional limitation (e.g., cognitive, visual, mobility, etc.). Links between ICF activities and participation (i.e. ICF classification components [12]) and issues affecting evacuation performance were identified. In the ICF, activities and participation are divided into the chapters (e.g., Learning and applying knowledge, Communication, Mobility, etc.). Chapters are subdivided into "blocks", as a convenience to the user (e.g. Purposeful sensory experiences, Applying knowledge, Communicating – receiving, Communicating – producing, Changing and maintaining body position, Carrying, moving and handling objects, etc.). Within each chapter, under the ICF blocks there are two, three or four level "categories", representing the more detailed level of description of activity or participation (e.g. Watching, Listening, Solving problems, Making decisions, Conversation, Changing basic body position, Transferring oneself, etc.) [12]. A two-level classification was adopted to simplify the analysis and allow an easier evaluation of the linkage between ICF and evacuation activities. An ICF block and an ICF category were assigned to every evacuation activity found in the body of literature as potentially affected by functional limitations. This process is presented in Figure 2. Since ICF refers to normal conditions (i.e. not during a fire or other catastrophic events), specific characteristics of fire emergencies and evacuation were taken into consideration. The outcome is the linkage of evacuation activities to ICF activities and the type of functional limitation affected.

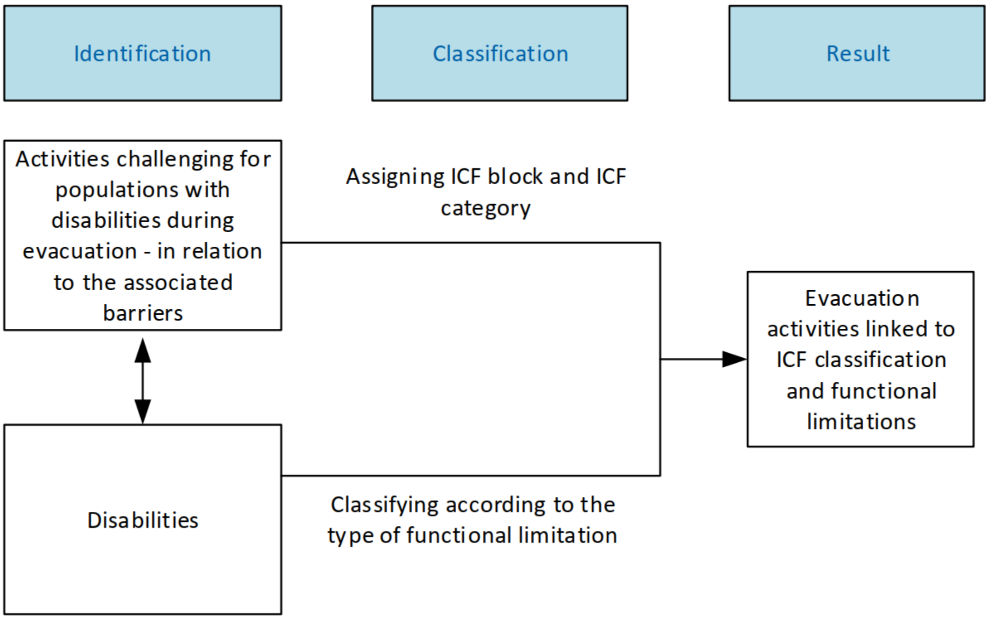

Figure 2. Flowchart of the linking process of the evacuation activities, ICF classification and functional impairments.

To provide a temporal dimension to the analysis, the engineering evacuation time-line [21] was used to build a connection between the situations people may face during an emergency and their actual functional limitations. Every evacuation activity was therefore linked with three different evacuation phases[22]. 1) The *alarm time (A)* is intended as the time from detection of the threat to the general alarm going off. 2) The *pre-evacuation time (P)* consists of the sum of the recognition and response times. 3)The *travel time (T)* therefore starts when a person has made up their mind and starts their purposive movement until they reach a safe place [22]. It should be noted that alternative terminology of the phases of the evacuation time-lines are available in the literature (e.g. the term *pre-movement* is often used instead of pre-evacuation or the term *movement time* is used instead of travel time [21]).

The link between the activities to be performed and the given evacuation phase is deemed to add a time dimension to the problem, which is a key factor for safe evacuation. In other words, it highlights not only the fact that people may or not be able to perform a task based on their functional limitation (as is currently done in accessibility research), but also how long that task would need to be performed; this implicitly considers the extent to which a functional limitation can affect evacuation performance.

3.1.2. Results of the review on evacuation studies

The selection of articles was classified in three groups: case studies, evacuation trials and Egressibility studies. Papers containing information about past evacuation events and inquiries focusing on causes of fires and fatalities in context of older adults or people with disabilities were categorized as case studies. Statistical data such as percentage of older people and people with disabilities among the total number of victims/survivals and the percentage of fires caused by them was extracted along with data on prevalence of impairments and disorders. Papers with data about human behaviour, walking speeds, testing and assessment of evacuation performance activities of target groups (through experiments and/or interviews on their experience) were classified as evacuation trials. Egressibility studies refer to papers addressing how accessible the means of egress are for older people and/or people with disabilities. This includes information about the use of assistive devices for movement and way-finding aids for populations with mobility limitations. The final number of resulting papers was 75 of which 25 were eventually used to perform the link between ICF and evacuation activities. Those included 11 qualitative studies, 8 quantitative studies and 6 studies that used both qualitative and quantitative methods.

The identified evacuation activities and their links to the phases of the evacuation timelines are provided in Table 2. A more detailed analysis of the information extracted from the papers is presented in a spreadsheet as supplementary information. Due to the complexity and variability in the emergency scenarios, evacuation activities were sometimes placed in more than one evacuation phase.

Table 2. Evacuation activities linked to ICF classification and functional limitations with listed references

Evacuation activity [Phase][1]	Predominant activity in terms of ICF - Block	Predominant activity in terms of ICF - Category	Visual limitation	Hearing limitation	Mobility limitation	Upper extremities limitation	Cognitive limitation	Other functional limitations[2]
Hearing alarm [A,P]	Purposeful sensory experiences	Listening		[23]–[26]				
Smelling emergency cues [A,P]	Purposeful sensory experiences	Other purposeful sensing[3]						Research gap[4]
Seeing emergency cues [A,P]	Purposeful sensory experiences	Watching	[27]					
Locating exit signs [P,T]	Purposeful sensory experiences Communicating - receiving	Watching Listening Other purposeful sensing[5] Communicating with– receiving – spoken messages Communicating with – receiving – non-verbal messages Communicating with – receiving – formal sign language messages Communicating with – receiving – written messages	[28]–[30]	[31]			[32] Difficulty in interpreting information [31]	
Orientation [A,P,T]	Purposeful sensory experiences Communicating - receiving	Watching Other purposeful sensing	[24], [29]				[32], [33]	

[1] In this column, [A] = alarm time, [P] = pre-evacuation time and [T] = travel time.
[2] This includes smelling impairments and speech impairments.
[3] ICF definition: "Using the body's other basic senses intentionally to experience stimuli, such as touching and feeling textures, tasting sweets or smelling flowers".
[4] A research gap is intended as a research topic which is identified as relevant in the literature, but no dedicated studies have been identified on the topic.
[5] Being able to detect tactile surfaces.

	Applying knowledge	Communicating with – receiving – non-verbal messages Communicating with – receiving – written messages Solving problems/Making decisions						
Maintaining/changing direction [A,P,T]	Purposeful sensory experiences	Purposeful sensory experiences, other specified and unspecified	[29]					
Finding architectural elements [A,P,T]	Purposeful sensory experiences Carrying, moving and handling objects	Watching Hand and arm use	[24], [29]			Research gap[4]		
Communication with others / rescue services [P]	Purposeful sensory experiences Communicating - receiving Communicating – producing Conversation and use of communication devices and techniques	Listening Communicating with - receiving - spoken messages Speaking Conversation Using communication devices and techniques Conversation and use of communication devices and techniques, other specified and unspecified		[34]			Research gap[4]	Speech impairment [35]

	Carrying, moving and handling objects	Fine hand use						
Using stairs[T]	Purposeful sensory experiences Changing and maintaining body position Walking and moving	Watching Other purposeful sensing Changing basic body position Maintaining body position Transferring oneself Moving around in different locations (including climbing stairs) Moving around (including climbing stairs) Walking Moving around using equipment	[30], [34], [36]		[24], [34], [37]–[40] Reaching and stretching [31], [41] Issues with stamina/breathing/fatigue[42]	[31], [43]		
Getting out of bed [P]	Changing and maintaining body position	Changing basic body position Maintaining a body position			[18], [44]			
Moving to wheelchair [T]	Changing and maintaining body position	Changing basic body position Maintaining a body position Transferring oneself			[41]			
Moving to escape mattress [T]	Changing and maintaining body position				[41]			
Moving to stair descent devices [T]	Changing and maintaining body position				[41]			
Moving on horizontal [T]	Walking and moving	Walking			[38], [43], [45]			

Moving on incline [T]		Moving around in different locations Moving around using equipment						
Traversing 90° bend [T]								
Using evacuation elevators [T]	Carrying, moving and handling objects Walking and moving Applying knowledge	Hand and arm use Fine hand use Moving around in different locations Moving around using equipment Solving problems Making decisions			[37], [46], [47]	[37]	Dementia of Alzheimer's type [32]	
Opening doors [A,P,T]	Carrying, moving and handling objects	Lifting and carrying object Fine hand use Hand and arm use	[24]		[31], [48]	[31], [45], [48]		
	Walking and moving	Walking Moving around in different locations						

The evacuation activities *Hearing alarm, Smelling emergency cues* and *Seeing emergency cues* are assigned both to alarm time and pre-evacuation time. An alarm can be heard as soon as it starts, and emergency cues (e.g. including seeing and smelling) maybe sensed from the moment of ignition, which qualifies these activities as alarm time (e.g. seeing/smelling smoke). On the other hand, these activities are also categorized as pre-evacuation phase since they can represent the delay time, information gathering or any activity before purposive evacuation movement [22]. *Locating exit signs* belongs to pre-evacuation time as it is defined as information gathering. This activity can be performed while following the evacuation path and therefore belongs to travel time as well. The activities *Orientation*, *Maintaining/changing direction* and *Finding architectural elements* are assigned to all three evacuation phases. Although they mostly refer to movement while being performed, this movement can occur also while gathering information (during alarm or pre-evacuation) or moving along the evacuation path (travel time). *Getting out of bed* is an activity mostly associated with trying to gather more information and is here classified within the pre-evacuation phase. The evacuation activity *Opening doors* can be performed in every stage of evacuation, and it can be linked with different purposes. Therefore, it is assumed to belong to all three evacuation phases. All remaining activities are assigned to travel time. They all refer to movement for the means of egress.

The classification of visual, hearing, mobility, upper extremities or cognitive limitation demonstrated the complexity of the evacuation process. For example, the separation of upper extremity limitations from mobility limitations is used to distinguish the ability to move in general from the ability to handle objects with hands; e.g., a person may be able to move in general but may experience difficulties in grasping the door knob or pushing the door itself. Other functional limitations refer to impairments related to speech and smelling.

The activity *Hearing alarm* refers to ICF block *Purposeful sensory experience*, category *listening*. Several issues have been identified in the literature concerning the audibility of sound alarms. People may have problems hearing specific ranges of the sound spectrum, e.g., older people may have issues hearing >2000 Hz frequencies [26]. For instance smoke alarms may not be suited for people with moderate to severe hearing impairment given the fact that they are generally emitting signals in the mid to high frequencies [23]–[26].These issues can have an impact on the human response in the alarm and pre-evacuation phase, i.e. delaying the response of people with hearing impairments.

The evacuation activity *Smelling emergency cues* belongs to ICF block *Purposeful sensory experience*. While the sense of smell is often reported in case studies [49] as clearly influencing human behaviour during the alarm and pre-evacuation phases [50], no research studies were found on how functional limitations linked to the sense of smell might affect evacuation performance.

The evacuation activity *Seeing emergency cues* also belongs to ICF block *Purposeful sensory experience*. It can represent any cue associated with the ability to see and become aware of danger during the alarm or pre-evacuation time (e.g., seeing smoke (Kuligowski, 2016), fire, observing behaviour of other people, etc.).

Further locating exit signs also refers to ICF block *Purposeful sensory experiences* and *Watching/listening/other purposeful sensing* as categories. Issues associated with this activity depend on the degree of functional limitation (mild, moderate, severe or complete [12]). The use of exit signs designed to address the needs of populations with visually and hearing impairments is widely discussed in the literature, and different way-finding systems have been suggested [18], [28]–[30], [51]. *Other purposeful sensing* refers to the ability to feel tactile surfaces [12]. For instance, tactile surfaces can make information accessible for blind and visually impaired people. Their preferred evacuation path may be along walls and tactile surfaces [30].

An additional ICF block assigned to this activity is *Communicating – receiving./-* Within this block, assigned categories are: *Communicating with – receiving – spoken messages; Communicating with – receiving – nonverbal messages; Communicating with – receiving – formal sign language messages; Communicating with – receiving – written messages.* While this activity can also refer to visual and hearing limitations, this category is associated with cognitive limitation here. Different cognitive disabilities can cause difficulties in reading, understanding and interpreting information (Boyce et al. 1999; Slaug et al. 2015) and therefore affect the ability of people to locate exit signs during emergencies.

As concluded by Passini and Proulx [29] in a way-finding experiment with blind people, maintaining and changing the walking direction as well as spatial orientation for people with visual limitations is especially hard in public places where the background sound and noise can cover informative sounds and when occupants are not familiar with the particular space. In addition, congenitally blind people are not able to visually experience and memorize space [29], which makes performing evacuation activities even harder. In a case study on how people with disabilities perceive fire safety in historical buildings, people with visual impairments state the importance of a simple building design, so they can make a mental map of space and overcome issues with orientation [24]. Cognitive limitations linked to neurodegenerative disorders (e.g. Alzheimer's disease) affect the ability to memorize space, orientation and way-finding, thus making evacuation challenging for people with these types of cognitive impairments. Being able to make a decision or plan a series of activities in order to evacuate will depend on the severity of cognitive impairment as well as on space familiarity [32], [33]. In Table 2, the evacuation activities *Orientation and Maintenance and changing direction* are classified as ICF block *Purposeful sensory experiences* and categories *Watching and Other purposeful sensing.* In addition, *Orientation* is classified as *Communicating - receiving* ICF block as well as *Communicating with – receiving – nonverbal messages* and *Communicating with – receiving – written messages* categories. In this case, it refers to people with cognitive limitations experiencing difficulties in orientation and finding the exit without reference points or easily understandable and accessible information [32]. Furthermore, the ICF block *Applying knowledge* and the categories *Solving problems and Making decisions* relate to people with cognitive impairments and their limited ability to plan and perform an evacuation effectively.

Finding architectural elements is related to and classified as ICF block *Purposeful sensory experience with Watching as category* and it refers firstly to difficulties for people with visual limitations to find the architectural elements that are a means of egress (i.e. staircase [24]) and make a decision where and how to move [29]. Secondly, this can refer to finding elements that can help occupants in orientation, which is often overlapping with the first interpretation.

Communication with rescue services in order to hear instructions to be rescued from a facility can be a relevant activity in case of a defend-in-place evacuation strategy, which is a commonly adopted strategy for impaired occupants [34], [52]. Five different blocks of predominant activities were assigned to it: *Purposeful sensory experiences* - for hearing impairment*; Communicating - Receiving* - hearing impairment and cognitive impairment*; Communicating - producing* - speaking impairment*, Conversation and use of communication devices and techniques* - speaking and cognitive impairment, *Carrying, Moving and handling objects;* upper extremities impairment in the case of need for using communication devices. In this context, the categories assigned are *Listening/ Communicating with - Receiving - Spoken messages/ Speaking, Conversation/ Using communication devices and techniques/ Conversation and use of communication devices and techniques, Other specified and unspecified*, and *Fine hand use.*

The evacuation activity *Using stairs* is a very common issue addressed in the literature for people with functional limitations. This includes both issues related to their own movement ability as well as issues for other occupants because they can represent a constraint on stair flows [36]. This activity is connected with visual, mobility and upper extremity limitations and several relevant ICF blocks and categories can be assigned to it (see Table 2). With regard to use of stairs, the ICF block *Purposeful sensory experience* includes two ICF categories: *Watching and Other purposeful sensing.* It is stated in several studies that people with visual impairments move slower on staircases due to their impairment, due to the complex shape or absence of tactile surfaces to help them navigate [30], [31], [34], [43], [53]. The key evacuation issues could be the determination of each tread/end of stairs and transferring from one flight to another [30]. In a case study on the experiences of people with disabilities in Sweden considering the evacuation of historical buildings, people with visual and mobility impairments reported the issues of assessing the shape of stairs and the lack of handrails [24]. Support from handrails is indeed mentioned as one of the most important factors for visually and mobility impaired people while using stairs [43]. In this context, visual and mobility limitations combined with upper extremity limitations (*Purposeful sensory experiences/ Other purposeful sensing*, i.e. grasping) could affect the ability of people to use stairs safely [43].

The effect of mobility limitations on the use of stairs is highly dependent on the type and degree of limitation. People with complete loss of ability to move need assistance to use stairs, and their evacuation depends on a rescue team or help from other occupants and/or descending devices [37], [39], [54]–[58]. *Using stairs* in the context of mobility limitations is defined in ICF as the block *Changing and maintaining body position including categories as/Changing basic body position/Maintaining body position/Transferring oneself and the ICF block Walking and moving including categories as Moving around different locations/Moving around/Walking/Moving around using equipment*. Mobility limitations are examined in more detail in the literature. Different health conditions may cause or significantly increase mobility limitations. Chronic conditions associated with ageing include cardiovascular diseases, diabetes, cancer, arthritis and osteoporosis, which can increase the prevalence of various disabilities [59]. Respiratory problems and obesity can be the main reasons for the need to rest during building evacuation in case evacuees need to travel longer distances [36], [38], [60], [61]. This issue is particularly associated with physical exertion [42], [62]. Obesity is common in developed countries, causing severe or complete loss of mobility [19], [38].

Getting out of bed is one of the main activities reported as causing falls in older populations [44]. Considering different degrees of mobility impairments, this can be significant for the pre-evacuation phase of occupants. The block of predominant activity assigned to this evacuation activity is *Changing and maintaining body position*. Changing basic *body position* and *Maintaining body position* are assigned as categories.

Evacuation activities *Moving to wheelchair*, *Moving to escape mattress* and *Moving to stair descent devices* (e.g. evacuation chair) refer to *Changing and maintaining body position* as block of predominant activity and *Changing basic body position/Maintaining body position/Transferring oneself* as categories. The performance of these activities is highly dependent on the assistance and preparation period, which differs from one helping device to another. For instance, the preparation times for the use of escape mattress, evacuation chairs or a wheelchair vary greatly [41].

Moving on horizontal, *moving on incline* and *traversing 90° bend* were investigated in an experiment with participants with severe loss of mobility and wheelchair users, assisted and unassisted, mainly for the purpose of defining their movement speed [38], [43], [45]. These three activities refer to ICF block *Walking and moving* and ICF categories *Walking/Moving around in different locations* (i.e. incline - ramps, stairs) and *Moving around using equipment* (meaning helping devices).

Using evacuation elevators is often a means of evacuation for people with mobility limitations because it allows for independence while using a mobility device. Nevertheless, Egressibility issues may arise for people with limitations in mobility or upper extremities if the elevator is in an enclosed lobby with heavy entrance doors [37]. For this reason, this activity is classified as a predominant activity block *Carrying, moving and handling objects* and *Hand and arm use/Fine hand use* as categories. Another block of predominant activity - *Walking and moving* – and categories *Moving around in different locations; Moving around using equipment* is also assigned to this activity since the elevators are a common means of egress for people with mobility impairments who are not able to descent the stairs independently [47]. Therefore, non-accessible evacuation elevators would represent a constraint [63]. Using elevators can be challenging for people with dementia [32]. People with dementia may be confused when using elevators and have difficulty understanding the right commands. They can also experience issues with recognizing the floor to get out of the elevator and show a certain level of nervousness while using elevators [32]. In Table 2, this is classified as cognitive limitation and as *Applying knowledge* on the block of predominant activities and *Solving problems and Making decisions* categories.

Opening doors as ICF block *Carrying, moving and handling objects and Lifting and carrying objects/Fine hand use/Hand and arm use as categories* are related to visual, mobility and upper extremity limitations. Understanding how to use opening devices is reported as an issue for some blind persons [24], and people with upper extremity impairments can experience difficulties turning door knobs (grasping, releasing, manipulating) or pushing and pulling heavy doors (manipulating) [31], [45], [48]. The ICF block *Walking and moving* and *Walking/ Moving around in different locations* as categories refer to going through a door, which means crossing door saddles and keeping the door open while manoeuvring walking devices [31], [48].

No data was found on limited ability to sense smoke, although smoke is one of the key signatures that can help to detect a fire [50], [64]. The impact of smoke on movement and behaviour has been investigated in the literature [65]–[69], but no dedicated studies were found. In Table 2, the evacuation activity *Smelling emergency cues* predominant activity *Purposeful sensory experiences* is the block assigned, and *Other purposeful sensing* as category. The lack of data on impairments causing difficulties in performance of this activity is marked as a *research gap* connected to *other impairments*.

The least explored limitation is the role of cognitive impairments due to the demanding design of experiments involving people with these impairments as well as ethical issues. While a limited body of experimental research related to cognitive limitations (with a low number of participants in the reviewed experiments) has been found [32], [33], these studies are often very general, and they do not address specific types of cognitive impairments (Boyce et al., 1999),. Furthermore, the impact of cognitive impairments on *Communication with others / rescue services* or similar activity involving understanding of information, processing and replying has not been examined, but it can be crucial in different emergency scenarios [70].

Communication is usually first associated with speaking, but no data was found connecting any kind of speech impairment to evacuation performance in fire scenarios. It would certainly affect *Communication with others/rescue services* activity and should be considered and researched in order to provide effective solutions for people with speech impairments. In Table 2, this impairment is marked as *research gap* classified as *other impairments*.

The evacuation activity *Finding architectural elements* as guidance through evacuation routes is discussed in the body of literature in terms of visual limitations (see Table 2) but could also be seen as challenging for people with upper extremities limitation (e.g. not being able to grasp the handrail of stairs or other element in order to navigate themselves or hold on to it during the evacuation). However, dedicated research on this evacuation activity-impairment scenario was not found.

3.2. Review of accessibility studies in public buildings

This section presents the methods and findings of the scoping review related to accessibility of public buildings. This work has also been published in a scientific article [71]. The overarching aim of this review was to summarize the research front in the area of accessibility to public buildings for adults with functional limitations. This was useful to set the context for the domain of Egressibility of public buildings. Specific objectives included: 1) to identify access activities in relation to environmental features of public buildings, 2) to link access activities with functional limitations and predominant activities in terms of the ICF, 3) to identify knowledge gaps with regard to accessibility issues across access activities in different public buildings.

3.2.1. Methods of the review on accessibility of public buildings

The scoping review was conducted adopting The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14] served as a guide through the process. Figure 3 presents an overview of the process of identification, screening, eligibility and included articles.

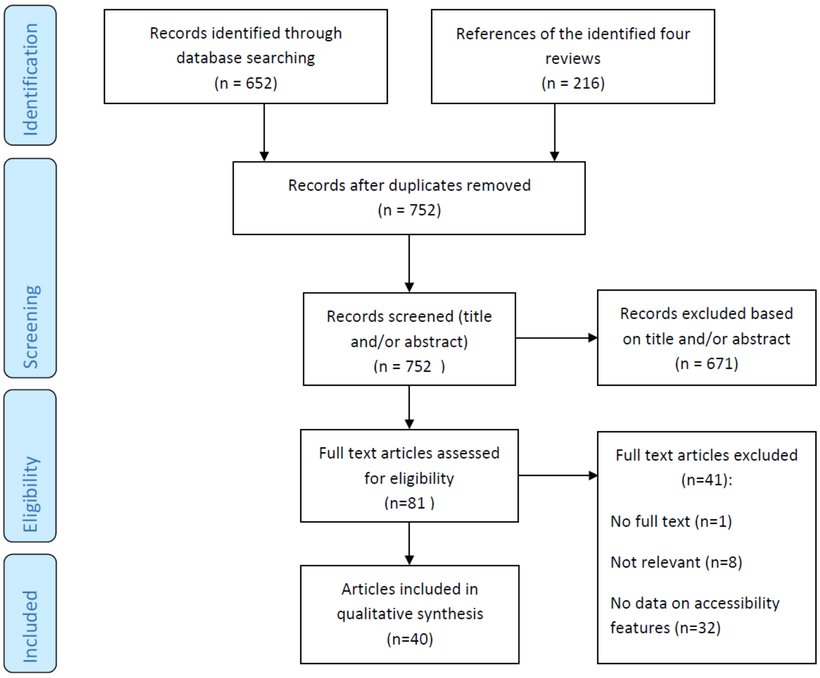

Figure 3. Data extraction and synthesis procedure of the accessibility review.

The literature search was performed in PubMed, PsycINFO, Inspec, Embase and Cochrane databases on March 25, 2019. The search terms included *built environment*, *disability* or *older age*, and *accessibility*; based on the thesaurus used by each of the databases, similar terms with some slight differences were also included. The details of the search strings for each of the databases are reported here:

PubMed
(((("Environment Design"[Mesh]) OR "Architectural Accessibility"[Mesh]) OR ("Facility Design and Construction"[Mesh])) OR ((home[Title/Abstract] OR homes[Title/Abstract] OR building[Title/Abstract] OR buildings[Title/Abstract] OR "built environment"[Title/Abstract]))) AND ("Disabled Persons"[Mesh] OR "Mobility Limitation"[Mesh] OR "Housing for the Elderly"[Mesh] OR "Frail Elderly"[Mesh] OR "Cognitive Dysfunction"[Mesh] OR "Nervous System Diseases"[Mesh:NoExp] OR "Wheelchairs"[Mesh]) AND ((accessibility[Title/Abstract]) OR usability [Title/Abstract]) AND limit: English

PsycINFO
(DE "Environmental Planning" OR DE "Environment" OR DE "Interior Design" OR DE "Urban Planning" OR DE "Architecture" OR DE "Computer Assisted Design" OR DE "Recreation Areas" OR DE "Built Environment" OR DE "Housing" OR DE "Urban Planning" OR DE "Homebound" OR DE "Human Factors Engineering" OR DE "Home Care") AND (DE "Disabilities" OR DE "Cognitive Impairment" OR DE "Brain Damage" OR DE "Brain Injuries" OR DE "Dementia" OR DE "Neurocognitive Disorders" OR DE "Health Impairments" OR DE "Physical Disorders") AND (TI (accessibility or access or availability or usability) OR AB (accessibility or access or availability or usability))
Limiters - Peer Reviewed; English

Inspec
((({building} WN CV) OR ({buildings (structures)} WN CV) OR ({civil engineering} WN CV) OR ({town and country planning} WN CV))) AND (({diseases} WN CV) OR ({medical disorders} WN CV) OR ({patient treatment} WN CV)))) OR (((disabled OR disability OR impairment) WN KY)))
Limits: journal article, English

Embase
('environmental planning'/exp OR 'environmental planning' OR 'construction work and architectural phenomena'/exp OR 'city planning'/exp OR 'furniture'/exp) AND ('disability'/exp OR 'disabled person'/exp OR 'frail elderly'/exp OR 'cognitive defect'/mj) AND ('accessibility':ti,ab OR 'usability':ti,ab) AND ([embase]/lim AND ('article'/it OR 'review'/it) AND [english]/lim)

Cochrane
("Environment Design"[Mesh] OR "Facility Design and Construction"[Mesh]) AND ("Disabled Persons"[Mesh] OR "Nervous System Diseases"[Mesh] OR "Mobility Limitation"[Mesh] OR "Frail Elderly"[Mesh])

During the search, four review articles were identified that were screened for eligible studies [72]–[75]. Articles were included in this review if they were based on original empirical studies on accessibility, were written in English, investigated the physical environment of public buildings and were relevant to or conducted with adults aged ≥60 years (commonly used to identify older people, for instance by the World Health Organization) or aged ≥ 18 years with functional limitations. Articles were excluded if they focused on residential facilities, nursing homes, hospitals, or schools, or if they were policy documents, reviews, expert opinions, commentaries, conference abstracts, or theses.

Articles were screened by titles and/or abstracts and based on the reference lists of the four reviews for eligible studies, as defined above; duplicates were removed. After finalizing the list of potentially eligible articles from the original search and the reviews, the full texts were screened for eligibility. Articles with no full text, not relevant according to eligibility, or no data on accessibility features, were excluded. Data were then extracted from the eligible articles, including a validation process of the extracted data and harmonization of the terminology.

The data extracted included the first author, publication year, study design, data collection method, instrument used, data source, geographic location of the study, type and number of public buildings, number of study participants, their age, type of functional limitations considered (i.e., mobility, vision, hearing, cognition) and environmental features addressed. For articles primarily investigating buildings, information about the functional limitations considered was extracted to the extent it was clearly described. That is, as compliance of the building design to requirements defined by the instrument at use (such as certain design of doors, pathways, stairs, etc.), considering the needs of individuals with specific functional limitations. For instance, if the instrument at use included a requirement of visual contrasts on stair treads, we interpreted this as visual limitations were considered. A procedure including several steps was adopted to present the extracted data and reveal potential knowledge gaps (see Figure 4). The environmental features were assigned and sorted into access activities (e.g., parking/drop off area, route to entrance), to provide information about the environmental context where accessibility issues were found and place them within a chain of activities performed when accessing a service. Thereafter, the extracted environmental features and functional limitations of interest were linked to the activity implied—in terms of ICF. In case more than one activity was implied, the predominant activity was identified. For instance, using stairs implies both walking and changing body position, but walking can be considered the predominant activity. The ICF level of block was used, which is the level beneath chapter. For example, *Walking and moving* and *Changing and maintaining body position* are blocks of activities, and both are in the ICF chapter on Mobility. During the process, recurrent meetings to discuss upcoming issues and to reach consensus on the extraction and synthesis of data were conducted. The data were extracted and managed in a spreadsheet format. The characteristics of the included articles were presented with descriptive statistics, using the SAS software (SAS Institute Inc., Cary, North Carolina, USA) version 9.4.

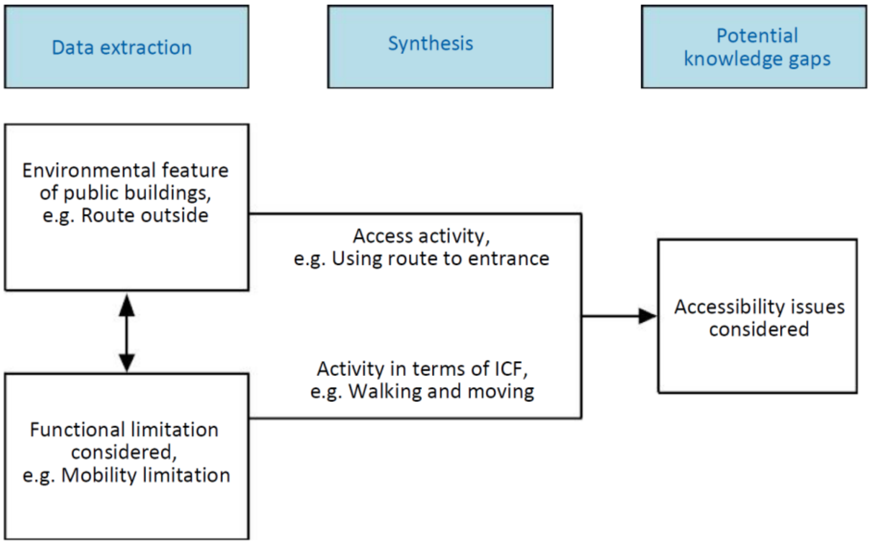

Figure 4. Process of data extraction, synthesis and identification of knowledge gaps in the accessibility review.

3.2.2. Results of the review on accessibility of public buildings

The database search resulted in 652 peer-reviewed articles, with an additional 216 references from four potentially relevant review articles, resulting in 868 records. Duplicates were removed, and then 752 articles were screened. After excluding 671 articles based on title and/or abstract, the full text screening excluded one article due to the absence of full text, eight articles lacking relevant information and 32 articles without data on accessibility components. This resulted in a selection of 40 original articles for the analysis, published between 1980 and 2018. In this section, references are numbered in accordance with their original numbering, this is reported in Table 3.

Table 3. List of included articles in the review on accessibility of public buildings.

#	Author	Year	Country	Instrument / checklist	Type of buildings	No of buildings	No of participants
29	Ahn et al [76]	1994	USA	Study specific checklist	Shopping mall/stores	250	-
30	Al-Mansoor [77]	2016	United Arab Emirates	Checklist based on country specific regulations	Mosques	*Not stated*	-
31	Alagappan, Hefferan & Parivallal [78]	2018	India	Checklist based on country specific regulations	Bus terminal	1	-
4	Andrade & Ely [79]	2012	Brazil	Assessment based on spatial accessibility (Dischinger, Bins Ely & Piardi 2009) and guided walks (Dischinger 2000)	Public buildings, unspecified	2	8
32	Arbour-Nicitopoulos & Ginis [80]	2011	Canada	AIMFREE (Rimmer et al 2004)	Fitness facilities	44	-
33	Cardinal & Spaziani [81]	2013	USA	Asesment of Physical Fitness Facilities (Figoni et al 1998)	Fitness facilities	50	-
34	Crowe, Picchiarini & Poffenroth [82]	2004	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Public buildings, unspecified	122	-
35	Dolbow & Figoni [83]	2015	USA	Asesment of Physical Fitness Facilities (Figoni et al 1998)	Fitness facilities	10	-
36	Dos Santos & Carvalho [84]	2012	Brazil	Checklist based on country specific regulations	Hotels/conference centers	17	-
37	Doshi et al [85]	2014	Brazil	Study specific checklist	Hotels/conference centers	36	-
38	Evcil [86]	2009	Turkey	McClain and Todd questionnaire (1990)	Public buildings, unspecified	26	-
39	Figoni et al [87]	1998	USA	Asesment of Physical Fitness Facilities (Figoni et al, 1998), developed from the McClain and Todd	Fitness facilities	34	-

				questionnaire (1990)			
40	Graham & Mann [88]	2008	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Health provider facilities	68	-
41	Gray et al [89]	2014	USA	Mobility Device User Work Survey (MWS)	Work environments, offices	*Not stated*	132
42	Hamzat & Dada [90]	2005	Nigeria	ADA Accessibility Guidelines Checklist for Buildings and facilities (1992) / prior recommendations from American National Standards Institute (1980)	Public buildings, unspecified	38	-
43	Iezzoni et al [91]	2010	USA	Study specific checklist	Health provider facilities	*Not stated*	20
44	Kim, Lee, Kwon & Chung [92]	2014	South Korea	Study specific checklist	Public buildings, unspecified /Ramps	15	30
45	King et al [93]	2011	Canada	Study specific checklist	Public buildings, unspecified	1	1
46	Leal Rocha et al [94]	2015	Brazil	Study specific checklist	Health provider facilities	89	204
47	Martin [95]	1987	USA	Study specific checklist	Public buildings, unspecified	13	-
48	McClain [96]	2000	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Shopping mall/stores	3	-
21	McClain & Todd [97]	1990	USA	McClain and Todd questionnaire (1990)	Grocery/convenience stores	40	-
49	McClain et al [98]	1999	USA	ADA Accessibility Guidelines Checklist for Buildings and	Shopping mall/stores	1	-

				Facilities (1992) / prior recommendations from American National Standards Institute (1980)			
50	McClain et al [99]	1993	USA	McClain and Todd questionnaire (1990)	Restaurants	120	-
51	Meyers et al [100]	2002	USA	Study specific checklist	Public buildings, unspecified	*Not stated*	28
52	Mojtahedi et al [101]	2008	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Grocery/convenience stores	82	-
53	Moyo et al [102]	2000	Zimbabwe	McClain and Todd questionnaire (1990)	Public buildings, unspecified	20	-
54	Mudrick et al [103]	2012	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Health provider facilities	2389	-
55	Mulazadeh & Al-Harbi [104]	2016	South Africa	ADA Accessibility Guidelines Checklist for Buildings and facilities (1992) / prior recommendations from American National Standards Institute (1980)	Public buildings, unspecified	13	-
56	Nary, Froehlich & White [105]	2000	USA	McClain and Todd questionnaire (1990)	Fitness facilities	8	-
57	Reich [106]	1980	USA	Study specific checklist	Shopping mall/stores	*Not stated*	297

19	Rimmer et al [107]	2004	USA	AIMFREE (Rimmer et al 2004)	Fitness facilities	35	-
58	Rimmer et al [108]	2017	USA	AIMFREE (Rimmer et al 2004)	Fitness facilities	227	-
59	Rivano-Fischer [109]	2004	United Arab Emirates	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Public buildings, unspecified	17	-
60	Sá et al [110]	2012	Portugal	Study specific checklist	Public buildings, unspecified	11	24
61	Saigal & Narayan [111]	2014	India	Study specific checklist	Work environments, offices	*Not stated*	50
62	Sanchez et al [112]	2000	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Health provider facilities	40	-
63	Seliger [113]	1981	USA	Study specific checklist	Health provider facilities	402	-
64	Useh, Moyo & Munyonga [114]	2001	Zimbabwe	McClain and Todd questionnaire (1990)	Public buildings, unspecified	20	-
65	Zissermann & Tumiel [115]	1989	USA	ADA Accessibility Guidelines Checklist for Buildings and Facilities (1992) / prior recommendations from American National Standards Institute (1980)	Public buildings, unspecified	274	-

Note: All 40 articles reported non-intervention studies of cross-sectional design.

In 14 of the included articles, the type of public buildings were unspecified; seven articles focused on fitness facilities; and six articles focused on health provider facilities (health care centers, dental care facilities etc.). Two thirds (n=2,988) of the total of 4,518 buildings studied were health provider facilities. For further details, see Table 4.

Table 4. Public buildings considered in the review of accessibility studies.

Article	**Type of buildings**	**No of articles**	**No of buildings studied (%)**
Alagappan et al (2018)	Bus terminal	1	1 (<0.1)
Arbour-Nicitopoulos et al (2011), Cardinal & Spaziani (2003), Dolbow & Figoni (2015), Figoni et al (1998), Nary, Froehlich & White (2000), Rimmer et al (2004), Rimmer et al (2017)	Fitness facilities	7	408 (9.0)
McClain & Todd (1990), Mojtahedi et al (2008)	Grocery/convenience stores	2	122 (2.7)
Graham & Mann (2008), Iezzoni et al (2010), Leal Rocha et al (2015), Mudrick et al (2012), Sanchez et al (2000), Seliger (1981)	Health provider facilities	6 [a]	2,988 (66.1)
Dos Santos & Carvalho (2012), Doshi et al (2014)	Hotels/conference facilities	2	53 (1.2)
Al-Mansoor (2016)	Mosques	1	*Not stated*
Andrade & Ely (2012), Crowe et al (2004), Evcil (2009), Hamzat & Dada (2005), Kim et al (2014), King et al (2011), Martin (1987), Meyers et al (2002), Moyo et al (2000), Mulazadeh & Al-Harbi (2016), Rivano-Fischer (2004), Sá et al (2012), Useh, Moyo & Munyonga (2001), Zissermann & Tumiel (1989)	Public buildings, unspecified [c]	14 [d]	572 (12.7)
McClain et al (1990)	Restaurants	1	120 (2.7)
Ahn et al (1994), McClain (2000), McClain et al (1990), Reich (1980)	Stores, shopping malls	4 [d]	254 (5.6)
Gray et al (2014), Saigal & Narayan (2014)	Work environments, offices	2	*Not stated*
	Total	40	4,518 (100.0)

[a] Public buildings are defined as buildings that the public has access to (SFS 2010:900). [b] No of buildings stated in 5 of 6 articles. [c] In one article (Kim et al, 2014), only ramps to 15 buildings were assessed. [d] No of buildings stated in 13 of 14 articles. [e] No of buildings stated in 3 of 4 articles.

Thirty articles examined buildings using only instruments/checklists to assess accessibility, while the remaining ten involved study participants (see Table 5). All of the 40 articles concerned mobility and 14 of them also addressed visual limitations, while few addressed cognitive or hearing limitations. Consequently, all of the ten articles with study participants also focused on mobility limitations. Additionally, three of them addressed visual limitations, one hearing limitations and one cognitive limitations. Four were from North America, two from South America, three from Asia and one from Europe. Taken together, there were 794 participants, and based on the available data from seven of these articles, the participants were mainly in the age range of 16 to 64 years.

Table 5. Study participants and functional limitations considered in the review of accessibility studies.

				Functional limitation			
Article [a]	**Country**	**No of study participants**	**Age Mean (SD)**	**Visual**	**Hearing**	**Mobility**	**Cognitive**
Andrade & Ely (2012)	Brazil	8	*No info*	X	X	X	X
Gray et al (2014)	USA	132	46.3 (10.8)	-	-	X	-
Iezzoni et al (2010)	USA	20	*No info*	-	-	X	-
Kim et al (2014)	South Korea	30	25.4 (2.1)	-	-	X	-
King et al (2011)	Canada	1	25	-	-	X	-
Leal Rocha et al (2015)	Brazil	204	39.8 (22.7)	X	-	X	-
Meyers et al (2002)	USA	28	47.0 (14.7)	-	-	X	-
Reich (1980)	United Arab Emirates	297	Range 16-64 [b]	-	-	X	-
Sá et al (2012)	Portugal	24	*No info*	-	-	X	-
Saigal & Narayan (2014)	India	50	Range 25-60 [b]	X	-	X	-
Total		794		3	1	10	1

[a] 30 articles did not have study participants, only examined public buildings in relation to instruments / checklists. [b] Only information provided.

Instruments used

A mix of instruments was used to assess accessibility issues. In six of the articles, an instrument originally focusing on food store accessibility was used [97], but in some instances, modified versions of the same instrument were employed for other types of facilities. Moreover, the Assessment of Physical Fitness Facilities developed by Figoni et al [87] was essentially based on the McClain and Todd [97] instrument. The Assessment of Physical Fitness Facilities was also used in a study by Cardinal and Spaziani [81] and later by Dolbow and Figoni [83] with some further additions. Three articles [80], [107], [108] utilized the Accessibility Instruments Measuring Fitness and Recreation Environments (AIMFREE) developed by Rimmer et al [107]. These instruments all referred to guidelines of the Americans with Disabilities Act (ADA) [116] at the time and reported psychometric testing. AIMFREE is the one that has undergone most tests such as unidimensionality of constructs, which showed adequate to good fit to the Rasch model, internal consistency (0.70–0.90), test-retest reliability (0.70–0.97) [107] and inter-rater reliability (0.83–0.92) [108]. Another eleven articles reported studies where data was collected with instruments that in some way were based on the ADA or on recommendations from the American National Standards Institute before ADA was launched. Furthermore, 15 articles referred to study specific checklists, and 12 of them did not refer to any country-specific regulation. Accessibility issues were also assessed by means of the Mobility Device User Work Survey in one article [89]. Finally, guided walks developed by Dischinger [117] were used in one article [79].

Access activities and environmental features

Ten main access activities were identified among the accessibility issues described. They were: *Using parking/drop-off area, Using route to entrance, Entering building, Using inside pathways, Using elevator, Using stairs inside, Using service desk, Using service, Using hygiene facilities* and *Exiting building.* In total, a large number of environmental features were addressed on a detailed level but were summarized into 31 main environmental features that may be encountered when accessing a service, such as using a fitness facility or buying food in a shop, from the parking/drop-off area to services inside, and to emergency exit. Environmental features addressed in most articles concerned parking/drop-off area (32 articles), entrance area (27 articles) and restroom/toilet (32 articles). For further details, see Table 6.

Functional limitations and predominant activities
Most of the accessibility issues identified were related to mobility limitations, and all 40 articles addressed such issues. There were also 14 articles addressing issues related to visual limitations. The predominant activities in terms of ICF that were identified were: *Walking and moving*, *Changing and maintaining body position*, *Purposeful sensory experienc*e and *Applying knowledge*. Of the access activities identified, all included issues related to *Walking and moving*, except *Using hygiene facilities* (considering *Changing and maintaining body position* and *Purposeful sensory experiences*). Issues related to *Purposeful sensory experiences* were identified in all ten of the access activities, and issues related to *Applying knowledge* were found in four of the access activities (i.e., *Using route to entrance*, *Using elevator*, *Using service inside* and *Exiting building*).

Table 6. Access activities identified in the review of accessibility studies.

Access activity	**Environmental feature**	**Public building**	**Predominant activity in terms of ICF** [b]	**Number of papers considering related issues** [a] **Functional limitation: Visual**	**Hearing**	**Mobility**	**Cognitive**
Using parking/drop-off area	Parking/drop-off area	Fitness facilities, Grocery/convenience stores, Health provider facilities Hotels/conference facilities, Mosques, Public buildings/unspecified, Restaurants, Stores/shopping malls, Work environments/offices	Walking and moving			31	
Using route to entrance	Route outside	Bus terminal, Fitness facilities, Grocery/convenience stores. Health provider facilities, Hotels/conference facilities, Mosques, Public buildings/unspecified, Stores/shopping malls	Walking and moving Purposeful sensory experiences Applying knowledge	2	1	16	1
	Entrance area outside	Fitness facilities, Grocery/convenience stores, Health provider facilities, Hotels/conference facilities, Mosques, Public buildings/unspecified Stores/shopping malls	Walking and moving Purposeful sensory experiences Applying knowledge	3	1	27	1
	Ramp outside	Bus terminal, Fitness facilities, Grocery/convenience stores, Health provider facilities, Public buildings/unspecified, Restaurants,	Walking and moving Purposeful sensory experiences	1		24	

		Stores/shopping malls					
Entering building	Entrance door	Bus terminal, Grocery/convenience stores, Health provider facilities, Mosques, Public buildings/unspecified, Stores/shopping malls	Changing and maintaining body position Walking and moving Purposeful sensory experiences	1		13	
Using inside pathways	Ramp inside	Health provider facilities	Walking and moving			1	
	Route inside	Bus terminal, Fitness facilities, Grocery/convenience stores, Health provider facilities, Public buildings/unspecified, Ramps, Restaurants	Walking and moving Purposeful sensory experiences	4		17	
	Floor surface	Hotels/conference facilities, Mosques, Public buildings/unspecified, Work environments/offices	Walking and moving Purposeful sensory experiences	1		4	
	Orientation/ information signage	Fitness facilities, Health provider facilities, Hotels/conference facilities, Mosques, Work environments/offices	Walking and moving Purposeful sensory experiences	7		3	
Using elevator	Elevator	Bus terminal, Fitness facilities, Health provider facilities, Public buildings/unspecified, Restaurants, Stores/shopping malls, Work environments/offices	Walking and moving Purposeful sensory experiences Applying knowledge	7	5	23	1
Using stairs inside	Stairs inside	Bus terminal, Health provider facilities, Hotels/conference facilities, Public buildings/unspecified	Walking and moving Purposeful sensory experiences	3		7	
Using service desk	Service desk	Fitness facilities, Grocery/convenience stores, Hotels/conference facilities, Public buildings/unspecified, Stores/shopping malls	Walking and moving Purposeful sensory experiences	1		9	
Using service inside	Acoustics inside	Hotels/conference facilities	Purposeful sensory experiences		1		
	Dining area	Restaurants, Public buildings/unspecified, Stores/shopping malls, Work environments/offices	Walking and moving Purposeful sensory experiences	1		5	
	Dressing room	Public buildings/unspecified, Stores/shopping malls	Changing and maintaining body position			4	

Drinking fountains	Fitness facilities, Health provider facilities, Public buildings/unspecified, Stores/shopping malls	Walking and moving Changing and maintaining body position			11	
Exercise and safety equipment	Fitness facilities, Health provider facilities, Public buildings/unspecified	Walking and moving Purposeful sensory experiences	2	1	10	
General interior environment	Health provider facilities, Hotels/conference facilities, Public buildings/unspecified, Stores/shopping malls, Work environments/offices	Walking and moving Purposeful sensory experiences Applying knowledge	4	2	10	1
Health care service room	Health provider facilities	Walking and moving Changing and maintaining body position			4	
Hotel room	Hotels/conference facilities, Public buildings/unspecified	Walking and moving Purposeful sensory experiences	1		1	
Induction/hearing loop	Hotels/conference facilities	Purposeful sensory experiences		1		
Lighting inside	Hotels/conference facilities	Purposeful sensory experiences	1			
Locker room	Fitness facilities, Public buildings/unspecified	Changing and maintaining body position	1		8	
Office computer	Work environments/offices	Walking and moving Purposeful sensory experiences	1		1	
Seats inside	Health provider facilities, Mosques, Public buildings/unspecified	Changing and maintaining body position			3	
Shopping basket	Grocery/convenience stores	Walking and moving			1	
Swimming pool, showers and sauna	Fitness facilities, Public buildings/unspecified	Walking and moving			5	
Telephone	Fitness facilities, Grocery/convenience stores, Health provider facilities, Hotels/conference facilities, Public buildings/unspecified, Stores/shopping malls	Walking and moving Purposeful sensory experiences		3	17	

	Waiting and other rooms inside	Fitness facilities, Health provider facilities, Hotels/conference facilities, Public buildings/unspecified, Stores/shopping malls, Work environments/offices	Walking and moving Purposeful sensory experiences	1		7	
Using hygiene facilities	Restroom/Toilet	Bus terminal, Fitness facilities, Grocery/convenience stores, Health provider facilities, Hotels/conference facilities, Mosques, Public buildings/unspecified, Restaurants, Stores/shopping malls, Work environments/offices	Purposeful sensory experiences Changing and maintaining body position	3		32	
Exiting building	Emergency exit	Health provider facilities, Public buildings/unspecified, Work environments/offices	Walking and moving Purposeful sensory experiences Applying knowledge	2	2	2	1

[a] Total number of papers included is 40, the same paper can consider more than one issue. [b] The International Classification of Functioning, Disability and Health (ICF).[9] Linking to ICF at block level.

4. Data collection

This section reports a set of key information concerning the data collected during the project. This includes information about the research participants that were recruited, ethical considerations and data handling.

4.1. Research participants

Two studies (the SSIs and the VR experiments) included research participants.

In the SSIs, research participants were included in the study upon meeting the following inclusion and exclusion criteria.
Inclusion criteria (SSIs):

- Having one or more functional limitations according to the ICF classification
- Being able to give an informed consent
- Being able to communicate in Swedish
- Being ≥ 60 years old

Exclusion criteria (SSIs):

- Being confined to a bed
- Having cognitive impairments which require constant help from another person

In the VR experiments, research participants were included in the study upon meeting the following inclusion and exclusion criteria.
Inclusion criteria (VR):

- Being able to give an informed consent
- Being able to communicate in Swedish
- The minimum age allowed was 18 years old.

Exclusion criteria (VR):

- Experience any functional limitation
- Experiencing epilepsy

The recruitment of participants for the SSIs aimed towards acquiring a wide range in type and extent of functional limitations. The participants were informed about the inclusion and exclusion criteria listed above and had to declare that they comply with these before being allowed to participate. The declaration is done when the participants give their informed consent on the day of the SSIs or VR experiment.

Participants were recruited on a voluntary basis through advertisement in one of the following channels:

- Through the email list and social media by the Centre for Ageing and Supportive Environment (CASE)
- Lund University webpage
- Website for research participant recruitment
- Pensioner organizations
- Posters at university campus
- Online-search for relevant contacts
- Associations of people with specific disabilities of interest
- Face-to-face recruitment

The final number of participants recruited was 28 persons for the SSIs and 40 persons for the VR-experiments.

An expert panel was recruited for the development of the Egress Enabler. This consisted of five senior researchers and/or practitioners working in the domain of egress, accessibility and psychology. The expert panel was informed about the scope of the project and agreed to take part in the study and have their name mentioned.

4.2. Ethical considerations

The SSIs and the VR experiments followed the principles outlined in the Declaration of Helsinki [118], and an ethical approval was given by the Swedish Ethical Review Authority prior to initiating the study (application number 2019-06334 for the SSIs and application numbers 2019–06334 and 2022-02635-02 for the VR experiments). All participants were informed of the purpose of the study and the amount of time required for participation. In the SSIs, informed consent was sent to the participants through regular post. The forms were completed and sent back to the research group prior to the SSIs. Participants were assured that their personal information and interview responses would remain confidential, and they could withdraw from the study at any time without giving any explanation. All participants in the SSIs and VR experiments were offered compensation equivalent of 100 SEK (approx. 10 EUR).

Risks associated with the SSIs include feelings of discomfort when discussing evacuation scenarios. The researchers considered this issue and were clear with the research participants that it is okay to terminate the SSI at any point. If the research participant wanted to do so, the researchers did not ask for an explanation as to why this was wished. While conducting the SSIs, the research participants were not covered by any other insurance than their own.

The experiments in VR may lead to discomfort, and the research participants were able to terminate the experiment at any point without having to explain why. During the VR-experiments, a researcher was always present to closely monitoring the participant and terminating the experiment if needed. VR may cause "motion sickness" leading to nausea and/or loss of balance. This may come as a consequence of the VR-environments inability to fully represent the participants motion in real life. The presence of "motion sickness" depends both on the participant and the VR-environment. The participants were informed about this risk and that if feelings of nausea or loss of balance occurs, take off the headset and close their eyes. Note that this risk was not limited to this experiment, but is present in all VR-experiences. The research participants were insured by the a personal injury protection insurance during the experiments.

The VR-experiments were conducted in a controlled environment, and in a setting in which the participants were aware that they were taking part in an experiment. This was deemed to limit the risks. A first-aid-kit and water were always present when the experiments were conducted. The experiments may have benefited the participants by providing a setting in which they could prepare for a similar, potentially life-threatening, situation in real life. The results from the study will also inform future design in a way that is beneficial for them. It is deemed that the potential benefits outweighed the risks associated with participating in the SSIs and VR experiments.

4.3. Data handling

The data collected in this project is summarized in the list below:

- Place of recruitment
- Background data: gender, age, occupation, preferred hand
- Self-assessment of functional limitations
- Written informed consent (only document containing name)
- Recorded audio from the SSIs
- Researcher notes from the SSIs

- Chosen exits by the participants during the VR experiment
- Questionnaire answers during the VR experiment

Audio recordings were transcribed shortly after they were collected and thereafter the audio recording was deleted. Audio recording is to be considered as personal data and by transcribing it, it is made non-personal.

All data that could be pseudonymized were pseudonymized with the help of personal identifiers. Thereafter, the data is to be considered as non-personal data when separated from the key of personal identifiers. Non-personal data from the interviews and experiments were kept at network based, password protected storage services. Personal data (informed consent and key of personal identifiers) were stored in a locked safe at the Division of Fire Safety Engineering at Lund University, either as hard copies or on a hard drive. The informed consent forms will be saved for a maximum of 10 years. The key containing personal identifiers was deleted once all the data from each research activity were collected. Any contact information (email, phone, address) was saved until the data collection for each research activity were completed, and thereafter deleted. The contact information was saved in case the researcher needed to contact the participants after the SSIs/VR-experiments.

5. Subjective perspectives on Egressibility

The aim of this qualitative interview study was to explore how older people with functional limitations reason about Egressibility from public buildings such as movie theatres, concert halls, shopping malls, etc. It was anticipated that most potential participants (and the population in general) had limited experience of real evacuations. In addition, among those that had experienced an evacuation, they may have not done so in their current functional capacity. Therefore, this study focused on Egressibility rather than evacuation, incorporating aspects of accessibility and interactions with the public environment in general, while the analysis sets this in relation to evacuation. It is also argued that Egressibility, which is the scope of this study, concerns accessible exit from buildings in general and thereby is not strictly relevant only to evacuation. As a result, we explored the following research questions:

1. How do older people with functional limitations consider Egressibility when they are in public buildings?
2. How do the interactions between older people with functional limitations and the public environment cause issues relevant to Egressibility, and how do they mitigate those situations?

This study was published in a scientific article [119].

5.1. Methods & sample

To best capture the thoughts, perceptions and experiences of older people with functional limitations, a qualitative interview study was deemed appropriate. Qualitative research focuses on categorizing, structuring and giving meaning to non-numerical data gathered from participants [120]. The perspective of older individuals with functional limitations on Egressibility was studied using semi-structured interviews performed remotely. To characterize the sample, a self-assessment questionnaire on functional limitations was developed and used (see Appendix 1). After an initial contact between the researcher and the participant was established by phone and/or e-mail, the participant received the self-assessment questionnaire and was asked to fill it in. When returned, a time for the interview was booked.

5.1.1. Sampling procedure

Participants were recruited through non-probability convenience sampling [121]. Information was sent to organisations, such as senior citizen organisations and interest organisations for people with functional limitations in Sweden, and people interested in participating could ask for more information. There were three inclusion criteria: participants should be older. The age of 60+ years old was chosen as criterion considering availability of participants and prevalence of functional limitations. Additionally, 60+ years old is often used to characterize older people for example by the World Health Organization [122]). Participants also needed to have one or more self-reported functional limitations, and be able to communicate in Swedish. People confined to a bed and people experiencing severe cognitive limitations were excluded from the study. Efforts were made to recruit a sample that was as diverse as possible when it came to functional limitations. The variation in the types of functional limitations in the population was ensured by contacting organizations with different interests (e.g. organizations linked to people with certain functional limitations, e.g., people with visual impairments, etc.) rather than selecting participants within the people who applied. No effort was made to recruit people with previous experience of evacuations. The reason for this was to keep the sample as representative as possible in relation to the research questions posed. The research revolved around thoughts and concerns rather than actual experiences. As the research focused on public buildings and elderly people retired from work, no screening was made for living arrangements and/or work arrangements. The recruitment of participants and the contacting of organizations were performed in parallel to conducting the interviews. The researchers contacted people who had reported interest to participate in the order in which they had done so. It was during this first contact that the researcher determined whether the person met the inclusion or exclusion criteria. As such, participants were included in the study solely based on the time by which they reported their interest, and whether or not they met the criteria specified above. In some instances, participants decided not to participate in an interview after the researcher had registered their interest and checked for eligibility.

The concept of saturation was used to determine the sample size. Although the concept of saturation in qualitative research has been the object of some debates [24,25], the definition of saturation in this study was that new data does not lead to the construction of new themes. In other words, the constructed themes were iteratively compared with the research questions in relation to the scope of the analysis. Once the research questions were satisfactorily addressed, the recruitment of participants was discontinued. This definition was established prior to initiating the interviews to allow for systematic evaluation of saturation. The resulting sample size was 28 participants. Comparing this to a mean of 31 participants from 560 previous studies [125], our sample size seems reasonable for this type of study. Based on these premises, the results obtained in this study are deemed not to have been impeded by the number of participants. Nevertheless, readers should consider this approach when considering generalizability of findings to the population.

5.1.2. Self-assessment questionnaire: Functional limitations

To characterize the sample based on functional limitations, the participants were asked to fill in a study-specific self-assessment questionnaire (see appendix 1), describing their functional limitations. As an overall framework, the International Classification of Functioning, Disability and Health (ICF) [126] was used to describe the functioning, health, and disability of individuals, irrespective of underlying causes or health conditions. ICF is a biopsychosocial model of functioning and disability, integrating the social and medical model of disability. The questionnaire was developed by the authors based on the personal component of the Housing Enabler (HE) instrument [16], thus including impairments as well as some activity limitations in the concept of functional limitations. Since the HE is developed for accessibility applications, the questionnaire used in this study was complemented to better reflect functions relevant to evacuation (e.g. the ability to smell smoke). Some components from the HE were also excluded because of the scope of this study (e.g., components related to cognitive limitations). To achieve content validity, the questionnaire was discussed and reviewed through multiple iterations with intermittent research group meetings. The research group were deemed apt to evaluate the content validity of the self-assessment questionnaire due to the expertise found within the research group. The questionnaire was developed in Swedish, but the categories are presented here in English.

The questionnaire consisted of 22 items, covering a wide variety of functional limitations and the response alternatives were given on a 7-point scale from *no limitation* to *extensive limitation*. The answers were then categorised in four different categories: *None* (0)*, Low* (1-2)*, Moderate* (2-4)*, Severe* (5-6). The 22 items covered 12 categories of functional limitations, presented in Table 7. Certain functional limitations had more than one item to capture their complexity and variation. This was a necessary step in order to better characterize the sample, as some categories could not be captured by a single item. The self-assessment questionnaire is provided in appendix 1.

Table 7. Categories of functional limitations covered by the self-assessment questionnaire.

Category	# of items per category
Seeing	3
Hearing	3
Mobility – Head	1
Mobility – Spinal column and/or lower extremities	3
Dependency on mobility aids	2
Dependency on wheelchair	2
Balance	1
Stamina	2
Coordination	1
Mobility – Upper extremities	2
Fine hand use	1
Smell	1

In cases where the participants had trouble answering certain questions, missed answering a question, or simply were unable to fill in the form due to their functional limitation, the researcher helped them complete the questionnaire prior to the interview. This was performed on an as-needed basis answering any questions the participants had about filling in the questionnaire.

5.1.3. Participants' characteristics

The age of the participants ranged from 61 to 88 years old (Median=78). Forty-three percent of the participants identified as men, 54% identified as women, and 4% identified themselves with another gender not specified. All but one participant were retired. The distribution of categories of functional limitations among the participants is visualised in Figure 5.

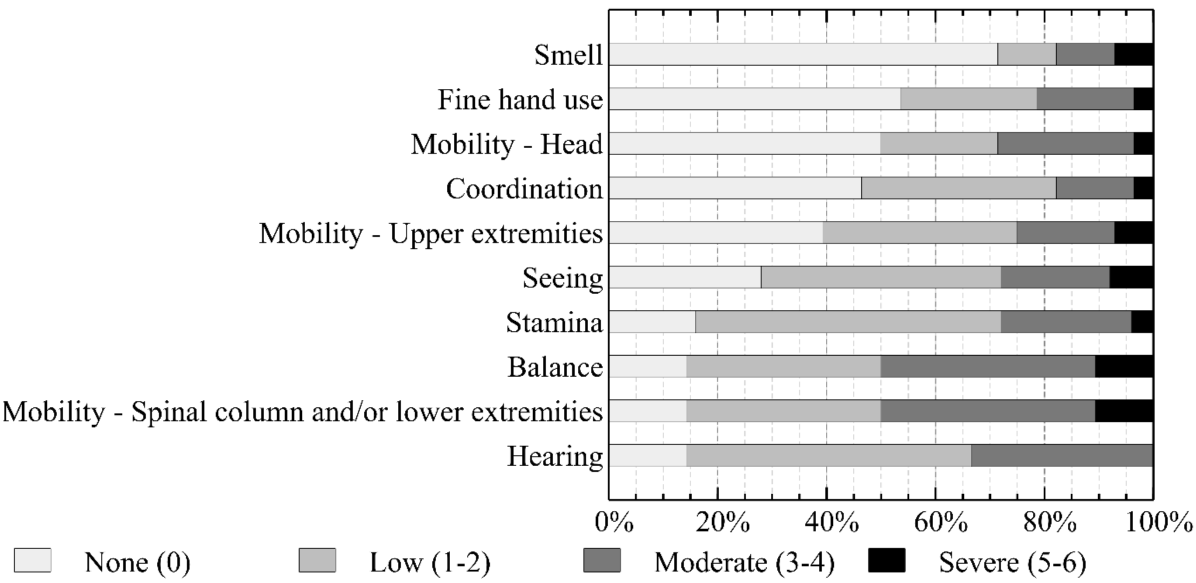

Figure 5. Frequency of participants with different levels and categories of functional limitations (N=28).

The most frequent functional limitation in the study sample was balance and lower body mobility limitations, where 50% (n=14) of the participants stated that they had moderate to severe difficulties. The least frequent was smell, where only 18% (n=5) stated that they had moderate to severe difficulties in recognizing the smell of smoke. The number of functional limitations where the participants stated they had moderate to severe limitations is presented in Figure 6. Sixty-four percent of the participants (n=18) stated that they had moderate to severe limitations in more than one functional limitation category, and 32% (n=9) stated that they had moderate to severe limitations in more than three functional limitation categories. It is anticipated that, as a person experiences more than one functional limitation, their interactions with the environment during egress and other activities are made more complex.

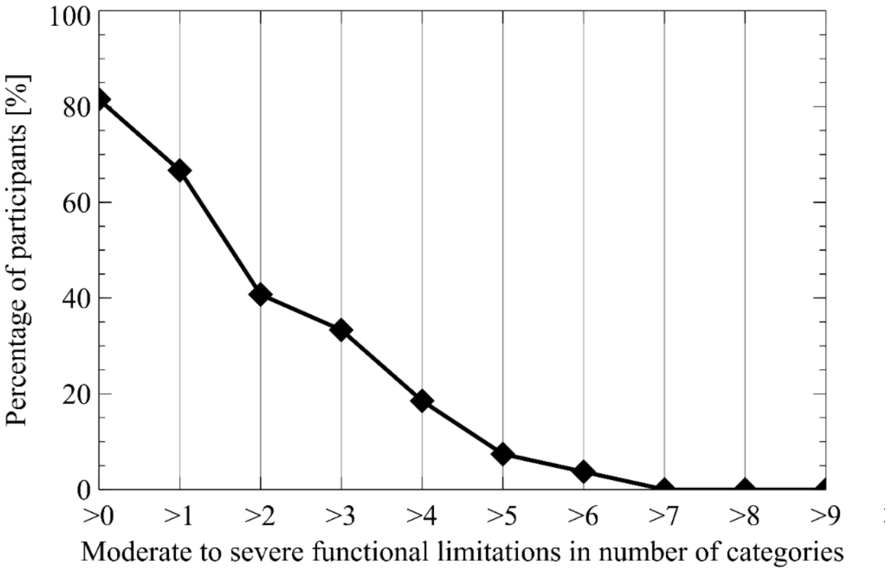

Figure 6. Number of moderate to severe functional limitations.

Participants were also asked about their dependence on mobility aids. Twenty-one percent (n=6) of the participants stated that they were dependent (fully or partially) on some mobility aid other than wheelchair indoors (outdoors; 36%, n=10), and 7% (n=2) stated that they were dependent (fully or partially) on the use of a wheelchair indoors (outdoors; 11%, n=3). While 29% of the participants stated that they used some mobility aid indoors (outdoors; 46%, n=13), slightly more participants stated that they had moderate to severe limitations in lower body or spine column mobility (50%, n = 14). It is possible that the participants in this study chose not to use a mobility aid even though they had limitations, but this was not investigated to a greater extent in this study.

5.1.4. Semi-structured interviews

The interviews were performed remotely due to the Covid-19 pandemic in 2020. The interviews were conducted in Swedish by phone between May 2020 and October 2020. The first five interviews were conducted jointly with two researchers present representing different disciplinary backgrounds (engineering and health science) to establish a consistent manner of conducting the interviews ensuring important aspects of Egressibility and functional limitations were captured. The rest were conducted only by the first author. Interviews were audio recorded with permission from the interviewees and later transcribed verbatim. The interviews lasted between 25 and 90 minutes. One of the interviews was conducted via email as the participant had a hearing limitation (self-rated as four on the 7-point scale) which made an oral interview inaccessible for him/her.

An interview guide (see Appendix 2) was developed based on the literature reviews conducted in the project and professional expertise of the authors. The guide covered aspects related to Egressibility and functional limitations and contained prompting questions to initiate the conversation, followed by probing questions to deepen the content. However, the interview was conversational and organic in nature rather than fixed. The interview guide was designed to encourage reflections on specific subjects, and not to gather quantitative data. In other words, the analysis relies on how the participants argued and formulated their perspectives, rather than if they answered yes or no to specific questions. This method of analysis conducted in this work allows to reflect upon how the participants formulated themselves, and the sole purpose of the questions has been to motivate the participants to reflect on the topic. This is in line with the reflexive approach adopted in this study. The topics under consideration and associated prompting questions in use are presented below (here translated from Swedish to English):

- **The public environment:** About the participants' use and perception of the public environment in everyday life. E.g. *Could you please tell me which places you normally visit during weekdays and weekends?; Are there some places that you visit less often?*
- **The functional limitations:** About the participants' experience and perception of his/her own functional limitation(s). E.g. *Which aspects of your functional limitation affect you the most when you are in a public environment?; Do you think you have any advantages because of your functional limitation when you are in a public environment or during an eventual evacuation?*
- **Evacuation:** The participants' experience, thoughts and concerns about evacuation. E.g. *Have you experienced a real evacuation? If so, please tell me what happened; How do you experience situations that resemble evacuation, such as leaving a concert, lecture, sports event, train station or similar?; Are you in any way worried about being in an evacuation situation?; How would you describe your own ability to evacuate?; Do you use any precautionary measures to compensate for your functional ability?*
- **The built environment:** Specific aspects of the built environment experienced to be of particular help, or to cause problems, in relation to Egressibility. E.g. *Are there aspects of the built environment that you think are especially useful for you when it comes to evacuation?; Are there aspects of the built environment that you think are more difficult to interact with when it comes to evacuation?*
- **About others:** The participants' experience, thoughts and concerns about others with regards to evacuation. E.g. *Which group of people with a specific functional limitation do you consider to be the most vulnerable when it comes to evacuation?; Do you think you would receive help from others during an evacuation?*

5.1.5. Qualitative data-analysis

As there is limited knowledge in the area of Egressibility in relation to older people with functional limitations, inductive reflexive thematic analysis [15] was deemed most appropriate in this study, given its exploratory nature and focus on participants' perspectives.

Thematic analysis can be described using six phases, and is here used as a structure to describe this study:

1. <u>Familiarizing yourself with the data</u>
   After the interviews were completed, they were transcribed. To facilitate data analysis, they were imported into the software NVivo 12 [127]. The first author read through the transcripts to become familiar with the data.
2. <u>Generating initial codes</u>
   The first author coded the transcripts. Codes are used to label parts of the data in a meaningful way in relation to the aim of the study. A pre-constructed coding book was not used in this study due to the inductive approach. Instead, the coding was a dynamic process. This dynamic process also led to the decision to not include multiple coders, but instead discuss the coding process intermittingly within the research group. The transcripts were coded using the technique of descriptive or semantic coding [15]. Because inter-rater reliability is not compatible with reflexive thematic analysis [128], it was not evaluated as part of this study.
3. <u>Searching for themes</u>
   After the transcripts had been coded once, the first author started searching for themes in the data. A theme is described by Braun and Clarke [129] as capturing "something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set". Codes that were similar or shared a common pattern were constructed into sub-themes. These sub-themes were themselves also constructed into themes at a higher level of abstraction. After conducting nine

interviews, a preliminary analysis was undertaken, and sub-themes and themes were formulated. By doing this, the analysis of the forthcoming interviews was conducted more efficiently as this first cycle of coding informed the authors on what seemed to be recurrent and relevant to the research questions. However, the authors were still open for new findings and patterns to be constructed. For further information concerning the process of constructing themes, please refer to Braun and Clarke [129].

4. Reviewing potential themes
   This phase consisted of an iterative discussion where all authors reviewed the primary themes and related sub-themes and codes proposed by the first author. Most of the themes were altered to some extent at this phase. As changes were proposed by the other authors, the first author went back to the transcripts and the codes generated to see if the theme could be reformulated or reworked. This phase deals largely with improving the reliability and validity of the analysis.
5. Defining and naming themes
   The naming of themes is essential in thematic analysis. This phase consisted of careful considerations involving all authors. Theme names should be clear, focused and unique. Themes and theme names should convey a patterned meaning or response and should not be merely a summary of everything that was said related to a specific topic.
6. Producing the report
   This final phase is writing the actual report. In qualitative analysis such as this, the analysis is largely interconnected with the process of writing up the results. Therefore, this manuscript has been a working document since before the first interview was conducted.

Important for all scientific studies is that the results presented should be trustworthy. Two of the more established criteria for trustworthiness of qualitative research are credibility and transferability [47–49]. Credibility in qualitative research resembles what is known as internal validity in quantitative research, meaning that the findings presented are plausible interpretations of the original data, i.e. the transcripts. Interpretation by just one person may be biased, so to strengthen credibility in this study, the interpretation of the data by the first author, i.e. the codes generated and applied to the data and the themes generated from those, was iteratively discussed and reviewed until the final coding and theme construction was agreed upon.

Transferability on the other hand resembles what is known as external validity or generalizability in quantitative research. Transferability is facilitated by a "thick description of the participants and the research process" [131]. To support transferability of results of the current study, such descriptions have been presented previously in this section. This description enables the reader to decide if the findings presented here are transferable to other contexts.

5.2. Results of the interviews

The participants were asked what public buildings they frequently visit. Examples of answers to those questions are shopping malls, grocery stores, libraries, gyms, churches, communication centres, etc. While conducting the interviews, it was noted that the participant often drew parallels to accessibility rather than discussing evacuation. As anticipated, many participants stated that they could not recall that they had ever experienced a real evacuation, and only a few stated that they recalled having taken part in an evacuation drill. Additionally, these experiences were often from a long time ago, when the participants did not experience the functional limitations at the time of the interview. However, the participants gladly shared their thoughts on related topics, such as accessibility, crowding, availability of information, etc. When asked with specific questions about evacuation, the answer was typically in the form of "I don't know how I/others would behave". This indicates that evacuation is something very unfamiliar to most people, and that it is therefore a hard topic to discuss and relate to own experiences. The results presented here are related to Egressibility, but less so to first-hand experiences of evacuation.

The analysis of the interviews resulted in the construction of three themes and thirteen sub-themes, as shown in Table 8.

Table 8. Themes and sub themes constructed from the perspectives of older people with functional limitations, as well as examples of codes.

Theme	Sub-theme	Code example
Other people's difficulties in understanding	People find it difficult to understand my problems	Others have a hard time knowing how limited I am
		Hard to make people understand that I cannot hear
	People do not know how to help me	Others harm instead of help
		Those who try to help become vulnerable
	Limitations that are more clearly visible are shown more consideration	People show more consideration when they see that I am in a wheelchair
		If people see that I have problems, maybe I'll get help
Strategies to cope with the limitation	Adjusting behaviour	I must look around more due to vision loss
		I try to ensure that I have enough time available to compensate for my limitation
	Avoiding inaccessible environments	I don't visit places with stairs
		I avoid rush-hour
	Using others to compensate for functional limitation	If I can't hear, I can ask
		I ask others when I cannot see what it [e.g. the sign] says
	Using the other senses	I can see instead of hearing
		I use smells to help with orientation
	Accepting my limitation	I have to accept my limitations and take the same route as everyone else
		Sometimes I forget about my limitation
	Pushing through	I can push through if it is needed
		I would use the escalator if I had to
Uncertainty of evacuation	I do not know how I would react or behave in an evacuation	Difficult to know how I would react in an evacuation
		My reaction would be dependent on the situation
	I do not think that I can rely on help from other people in an emergency	Difficult to know if other people would help me
		People only care about themselves in an emergency
	I can rely on help from other people in everyday situations	People are helpful in everyday situations
		People are happy to help
	I do not worry about evacuation	I don't worry about evacuation situations
		I don't avoid environments due to evacuation safety

The following sections aim to visualize and describe the constructed themes. Note that since some participants decided not to participate in the interview study after being registered by the researcher, one participant is being referred to as participant 31A despite the sample size being 28.

5.2.1. Other people's difficulties in understanding

Being able to understand struggles faced by individuals with a different ability than oneself might be difficult because of the lack of personal experience and inability to put oneself in someone else's position. Therefore, helping or communicating with someone with different needs than one's own may also be problematic, as explained by one of the participants experiencing a hearing difficulty:

Participant 5A: Yes, for example that you have problems with the social and... when you meet a lot of people and such and... if I meet more than two or three persons then you are put aside and such when we are discussing. So like that... It's to get people to... to really understand it, what problems you have. So you avoid initiating certain conversations and such.

The fact that people do not understand the struggles one is facing does not only lead to a feeling of exclusion, as highlighted in the above excerpt. It may also lead to issues when someone else is trying to be nice and tries to help. It could be that the good intention from others instead leads to more issues, as explained by one participant sitting in a wheelchair when asked which group of individuals is most vulnerable when it comes to evacuation:

Participant 7A: The most vulnerable group is others who have to evacuate at the same time and try to show consideration, and then run away, want to run away but in fact run in the way. […] strangers can cause problems, but... I do not know how to... You cannot educate other people to be perfect...

Interviewer If I understand you correctly, do you mean that they have an intention to help but it will be that they are in the way instead?

Participant 7A: Yes, that's what I mean. It has happened on a few occasions, I was going to open a gate, and then there was a man who thought that the gate might not be fully open and ran back and would correct the gate but in fact stood in the way when I arrived. But it was the good will and stuff.

In a similar way, people that do not understand one's limitation or struggles may also be reluctant to help. This was explained by one participant with total loss of sight.

Participant 10A: Ignorance too. I think that maybe sighted people would need to practice a bit too actually. And, how to help someone who needs help getting out. 'Cause that's what I think, if I grab someone, that someone in a panic can feel, "My God, how can I help her, she can't do anything basically. She is blind". There are some people who react in the same way in other situations. And do not understand that there may be certain things you can say, or in some ways you can help, and then it can work. Even pretty good. It is very important what words you use to give information to someone who does not see. And I notice a huge difference in how people manage to explain if I ask in the city, for example, that, "now I have lost myself, where am I?" There is a huge difference in how people say what they want to say. And some information is straight... Yes, to no use at all or even confusing. While other may consider more what they need to say.

Interviewer: It is probably situation-dependent as well, but can you give an example of good or bad communication then that you can get when you ask for help or so?

Participant 10A: Yes, a very... It is if someone says that "it's over there".

Interviewer: Yeah, it is a common reflex many people have maybe, just to say that.

Participant 10A: Yes, and point or so. Or "to the right". That is also difficult when you don't see anything. And it is of course impossible for another human being to understand how much or how little a visually impaired person sees. And if he or she sees at all...

It was often reported by the participants that they perceived others to be helpful and kind, but a pattern emerged depending on the visibility of the limitation. Some limitations are clearly visible to others, such as the use of mobility aid, while others are more hidden, such as hearing or balance difficulties. This was explained most vividly by a participant who had progressed from using no mobility aid, to using a cane, and later also a mobility scooter:

> *Participant 7A: But, two examples. When I started walking with a cane, I noticed that it was much easier to get out into the traffic, cars and cyclists [showed] a consideration I had never received before. When I started riding a scooter it was the same step with greater consideration.*

Being old (or looking old) also led to more consideration from others, as explained by the following participant experiencing a non-visible limitation in shoulder movement:

> *Interviewer: I wonder... how do you think yourself... when you go up a flight of stairs; do you think that others see that you need to use the handrail?*
>
> *Participant 9A: No, not always. I am quite light and free in the body and so that... it is not visible because it is a shoulder so... I am quite unobstructed in the legs even though I am not as strong as when I was younger so. I do not think it is visible, but they see that I'm a little older. So that's probably what makes them move away easily.*

In many evacuation situations, a person can be more or less dependent on the help from others, irrespective of functional ability. The awareness by others that someone needs help, and that they also have the skills or ability to provide the appropriate help, is therefore of importance.

The theme *Other people's difficulties in understanding* covers aspects such as issues in making others understand the limitation and henceforth barriers. Communication and feelings of exclusion are central in this theme. It was noted that visible limitations (such as the use of mobility aid) were perceived given more considerations from others, and that issues occurred when others tried to help but not knowing how. This link between the visibility of the limitation and level of consideration can be linked to the representativeness heuristic [133]. This heuristic can be used to infer how likely it is that something or someone is part of a "class", in this case people with disabilities. If people see someone using a mobility aid or similar, according to the heuristic, they are more likely to see this person as disabled since they more closely represent our "mental model" of a disabled person. This might then lead to showing more consideration to this person and highlights that society's attitudes and overall understanding of disability has importance also for evacuation.

This theme relates largely to the experience of others in interacting with people with functional limitations. The theme highlights that the perspectives of the participants in this study were that experiences in helping people with functional limitations are to a large part lacking. This may in turn affect an evacuation situation.

5.2.2. Strategies to cope with the limitation

Experiencing a limitation means that it is part of everyday life, and that one needs to cope with it somehow. Understanding the different coping strategies used is necessary in order to make sense of and predict their actions in emergencies. The participants mentioned a variety of ways in which they try to cope with their limitation. For example, behavioural changes were often mentioned as one type of strategy, as can be seen in the following excerpt:

> *Interviewer: Do you think that you think more about how you could get out of a building, compared to a person who has no functional limitations?*

Participant 12A: Oh yes, I think so. Both to get in and out, I'm probably much more observant. I notice that among my friends. Most of my friends are walking and are mobile, so when I say, "what does it look like for me?", "Yes we did not think of that", they say. They do not, because they do not have to.

Here, the participant highlighted that there is a lot more planning required for her because some environments are inaccessible for her. This uncertainty could also lead to a reluctance to try to access unfamiliar environments.

Participant 12A: […] I do not travel as much at all, and I hardly go to Denmark anymore. So... no I think I limit... I no longer expose myself in the same way. I am much more at home and move around in the local environment and so on. And that's probably because I do not want to expose myself simply. I cannot take it. It's probably more than I can bear.

Relating to evacuation, one does not expect to be asked to evacuate when visiting a public building, and it is not possible to avoid such a situation if it were to occur. This means that this strategy has limited applicability to evacuation, and a person may be forced to do something is not comfortable with. This is one of the main differences between accessibility and Egressibility. If encountered with an accessibility issue, a person may, in some cases, decide not to participate. This is not always a viable option when it comes to evacuation. Instead, people are forced to use other strategies to cope. One such strategy is by using the other senses, as expressed by this participant experiencing a loss of hearing:

Interviewer: Would you say that there are environments that you avoid because of that you would feel worried about your own safety if it were to be… or connected to evacuation?

Participant 6A: uh ... hard to say. I have my vision, so if there was an evacuation, I would see what everyone else did. Then I would do the same thing I guess, even if you did not hear that they sounded the alarm for example.

For evacuation design, it is important to acknowledge these kinds of strategies in order to facilitate them. These strategies were mostly mentioned in relation to seeing and hearing but could of course be relevant for other functional limitations as well. As can be seen in the excerpt, an alternative stimulus could be the actions of others. In cases where this is impossible, another visual stimulus, such as light beacons, could be used. In some instances, participants stated that they simply had to accept their own limitation by ignoring it.

Interviewer: Can you come up with a situation where you think you would need help?

Participant 9A: Yes, it can be to open doors. It can be going down stairs. Yes... I try to think of the places where I usually am... I often feel that it is very nice if most people go out, so I can get out at my own pace. But it does not always work that you can adapt. You have to follow the flow. I don't really know…

This sense that one cannot always adapt the situation to one's own needs could also lead to other coping strategies being required. In some instances, a person may be forced to go beyond his/her own ability. This was acknowledged by some participants, and some also stated that they had a potential to "push through" in such situations. This means that they perceived themselves to have an increased capability in case of emergency.

Participant 19A: […] and should it be in a situation where you have to rush out and cannot bring the crutches with you, you must try to cope with that bit also, if it is not too far. It's kind of like imagining a candle, before it goes out it burns up properly and lights up before it goes out. And it is the same, if you *were in such a situation, you would have to take all your strength to cope, if it becomes such a serious situation. And I think that... In general, humans can do much much more than they think they can.*

This ability to push through could be seen as some sort of last resort when everything else fails. It is nevertheless interesting to note that some participants, including participant 19A in the excerpt above, would be comfortable in doing so. There is however a risk that this strategy is relied upon too heavily, and that the decline in functional capacity would not be considered carefully enough. This could mean that people, unconsciously, put themselves in situations which they cannot handle.

Considering the interactions with the built environment as a person-environment fit, these strategies mainly address the personal component, i.e. enhancing the ability to overcome barriers. Recognizing these different strategies allows for enhancing Egressibility for older people by facilitating their adoption. For example, recognizing that people tend to make use of other unimpaired senses highlights the importance of offering different kinds of stimuli to become aware of a potentially dangerous situation, such as complementing auditory alarms with visual alarms.

One suggestion brought up by the participants was the use of directional sound for the visually impaired to aid orientation. This issue has been investigated before in the fire safety domain mainly with the scope of studying human behaviour in smoke-filled conditions [134], [135]. The studies concerning the use of directional sounds showed a reduction in evacuation times even in perfect visibility and without the presence of visual impairments. Even the use of conventional loudspeakers has been shown to have some effect on improving orientation in a smoke-filled environment [66], [136]. Hence, it is deemed that auditory systems for wayfinding could be of value for the visually impaired, and others alike. This also underscores that designing for the permanently impaired is not only beneficial for the aforementioned, but that during an evacuation situation, we may all become impaired due to situational circumstances (such as smoke) and might benefit from such design considerations. Similarly, solutions could be adopted for people with other kinds of functional limitations (e.g. alternative fire alarms for people with hearing impairments [137], [138]).

The strategy to use other senses was most evident when it came to seeing and hearing, but some participants also mentioned that they may ask for help (i.e. using speech) if they were not able to negotiate the environment due to physical constraints. Participants who were blind reported that they used both memory, smell and sound to orient themselves in both familiar and unfamiliar environments. It should be noted that some of these strategies, i.e. accepting the limitation and pushing through, might lead to adverse outcomes when it comes to evacuation. Participants stating that they would have the ability to push through did so while recognizing that it may lead to increased discomfort. This relates to a common bias when it comes to decision-making under uncertainty, namely *Illusion of control* [38,39] stating that people tend to think that they can influence or control situations out of their control. In other words, this sub-theme should not be seen as a support for a systematic "pushing through" approach to address the needs of people with functional limitations. The effect of "pushing through" is indeed difficult to quantify and unreliable.

5.2.3. Uncertainty of evacuation

Evacuation is an issue people in general do not deal with on a regular basis, and most participants stated that they had never experienced a real evacuation. This lack of experience means that there is a lot of uncertainty surrounding evacuation situations. One issue is the uncertainty in one's own behaviour as explained by a participant with multiple moderate functional limitations:

Interviewer: Would you say that you are in any way worried about how you could affect other people in an evacuation situation? I then think of situations where there are a lot of people and so on.

[…]

14A: I do not think I can answer that question because how I behave in such an extreme situation, depends on like my... yes, my attitude and so on... If there are a lot of people who are young around me, it may not be necessary for me to intervene. Should there be someone sitting in a wheelchair or whatever, I can hope I would help.

It is difficult to know why this participant did not think about having full control over her own actions in an evacuation situation. It is clear that her wish is to be of help, but that she is uncertain about her actions. It should also be noted that she had no clear explanation of what her actions would depend upon, but that it may have something to do with her attitude. This kind of uncertainty was not only found in discussions about one's own behaviour, but also regarding the actions of others in such situations.

Interviewer: […] I also thought in connection to evacuation situation and the like, and other people then. Do you think you would get help from other people in an evacuation situation if you needed it?

Participant 31A: [sighs] It's probably not so much up to me actually as the people around me, what their attitude is maybe. How... how much you interpret so to speak "here it is a matter of saving yourself" huh. So that... but in a... so... in general, I probably think that people are quite accommodating and so. And helpful with most things. But, I think like you have... I have… if we ignore the medical conditions themselves and things like that, so just that you have become a little older, there are quite a few who give space for you at the bus, and then in the beginning you almost got pissed and thought "I'm not that old" [laughs]. Now I accept it with joy, so it's all right. But... No, I mean... I actually still experience most of the people around me as friendly and helpful. And if they can maintain that kindness and helpfulness in a stressful situation, I cannot answer that.

In this excerpt, the participant explicitly mentions that people are considerate and helpful in other situations, but it is uncertain if that would be the case in an evacuation. However, this pattern was not found among all participants. Some participants stated that they thought others would help in emergencies, but the uncertainty was still there. Interestingly, most participants perceived others to be helpful in everyday situations, even though the opinions differed when it came to emergencies. This excerpt is from another participant where the discussion was about help in everyday situations.

Interviewer: How do you think people in general are when it comes to showing consideration?

Participant 12A: Well, I think people are good at that. I think most people do. But there I think the situation can change quickly if there is... yes fire or evacuation and so on. But in ordinary everyday life, people show consideration, I think.

The participant makes a clear distinction between the actions of others in normal everyday situations, and those anticipated in an emergency. The element of uncertainty is also present in this excerpt. As exemplified in the excerpts, uncertainty about evacuation is common. However, this uncertainty seems not to be dealt with by the participants. Most participants stated that they did not worry about evacuation.

Interviewer: yes or if you think that other people may not think as much about how to get out, or how they can get out, compared to how much you think about it?

Participant 10A: I have not thought about it too much, so I think it... It's probably the same as for many others I think. It may have more to do with attitude. If you are anxious or if you... I think if I would have *been in an evacuation situation like this before, then of course I would have considered, or found out more, I think. Made myself more aware.*

As can be seen in the excerpt, for the participants, worrying seems to be related more to individual attitudes and experience, and not so much related to being vulnerable or experiencing functional limitations. This was reported by numerous participants, i.e., being not the worrying kind, they would not worry about evacuation either. This should be read in context with that many participants, albeit not all, reported that they saw themselves as more vulnerable when it came to evacuation.

This theme incorporates uncertainties in the behaviour of others, as well as one's own behaviour. It also incorporates how participants stated that they generally did not worry about evacuation. It is not concluded whether or not "not worrying" about evacuation is connected to experiencing functional limitations, or if it is a general issue. Indeed, evacuations from public buildings are rare events and the experience of such events is therefore limited in the general population. When asked if they worried about evacuation, most participants stated that they did not, and that they were not the kind of person who was worried, indicating that worrying about evacuation was seen as something more connected to the proneness of worrying in general. This theme is closely connected to risk perception. A previous study conducted in the residential setting showed that risk perception was low among the older participants, and that they felt confident in their ability to act in such a situation [141]. Similar findings emerged in this study related to the themes *Strategies to cope with the limitation* and *Uncertainty of evacuation*.

It should be noted that some participants stated that they perceived that the risk of experiencing adverse effects in an emergency was higher for them than for others not experiencing functional limitations, indicating a higher perceived vulnerability [142]. This together with the fact that participants stated that they generally did not worry about evacuation, indicates that anchoring bias (that people tend to rely too much on previous experiences) [139] has some influence. It has been shown in previous investigations that experience and preparedness is a success factor when it comes to evacuation [40,41]. Whether or not they would receive help in emergencies was illustrated with many uncertainties. Many participants stated that they perceived others to be helpful in everyday life, but they were uncertain if that would be the case in an emergency. This was frequently attributed to the concept of panic, and a belief that people who panic do not think of anyone other than themselves and exhibit some kind of anti-social behaviour. It should be noted that the need to investigate such complicated and rare phenomena is of limited scientific interest, since even large groups of people usually move in a quite orderly and cooperative manner [144] (and buildings are generally designed to avoid extremely congested scenarios).

As previous research has shown [42,43], panic is a concept surrounded by a lot of misconceptions, and these misconceptions were found in this data set as well. The idea that people in such situations exhibit anti-social behaviour is one such misconception [44,45]. The participants frequently stated that they would help others in an emergency if they could. Some participants stated that this was because they had a greater understanding of the different functional limitations people might experience, and they therefore knew that they might be vulnerable.

6. The Egress Enabler

In the accessibility domain, several assessment instruments have been developed [71], [108], [149]. These instruments have been shown to be useful in both identifying, quantifying, and addressing accessibility issues [150], [151]. As the population ages and many buildings are designed for people without functional limitations, especially in relation to egress opportunities, similar instruments are needed for Egressibility. Existing instruments to measure levels of Egressibility or evacuation safety for people with functional limitations cover aspects such as relative time delays [152], binary assessments of ADA [116] compliance within evacuation routes [153], and assessments of the need for assistance during evacuation [154]. While these instruments are recognized as valuable, this work in contrast defines Egressibility as a person-environment fit issue. This is not always measurable in time delays, but still quantifiable, resulting in the need for a new instrument that measures Egressibility accordingly. The aim of this part of the project was therefore 1) to describe the development of the *Egress Enabler,* a new instrument for evaluating public building Egressibility, 2) to investigate its construct validity, and 3) to evaluate inter-rater reliability through a psychometric evaluation.

6.1. Methods for the development of the Egress Enabler

The *Egress Enabler* was developed in several pre-defined steps consistent with the Housing Enabler methodology [16]. First, the two components (personal and environmental) were defined based on the Housing Enabler and literature reviews. The necessary data in the Egress Enabler were collected by means of checklists containing items that should be evaluated. Items in the personal component referred to the presence of aspects of functional capacity. The personal component was represented in the Egress Enabler using the same functional limitations as descriptors of functional capacity as used in the Housing Enabler [16]. Items in the environmental component were checklist formulations aimed towards identifying the presence of environmental barriers. The environmental component of the Egress Enabler covered physical aspects of evacuation from the temporal point of threat detection to the relocation to a safe assembly area outside the building (or equivalent). This included typical evacuation elements considered in evacuation design such as notification systems, signage, stairs, doors, circulation spaces, etc. [155], [156]. Items for the environmental component were therefore identified based on relevance inside these boundaries and categorized into relevant sub-components. To identify items for the environmental component, a literature review was undertaken in two different domains, egress and accessibility. This allowed the identification of existing and established assessment instruments, checklists, guidance documents and similar in both domains.

After the environmental barriers were identified in the two domains, consensus discussions were undertaken to construct a final list of items. The items were then reviewed and sometimes reformulated or adjusted to ensure readability and comprehensiveness in capturing potential barriers for egress. Egressibility issues were identified by juxtaposing the personal and environmental component, and severity and range of issues were established. A schematic representation of the Egress Enabler is provided in Figure 7.

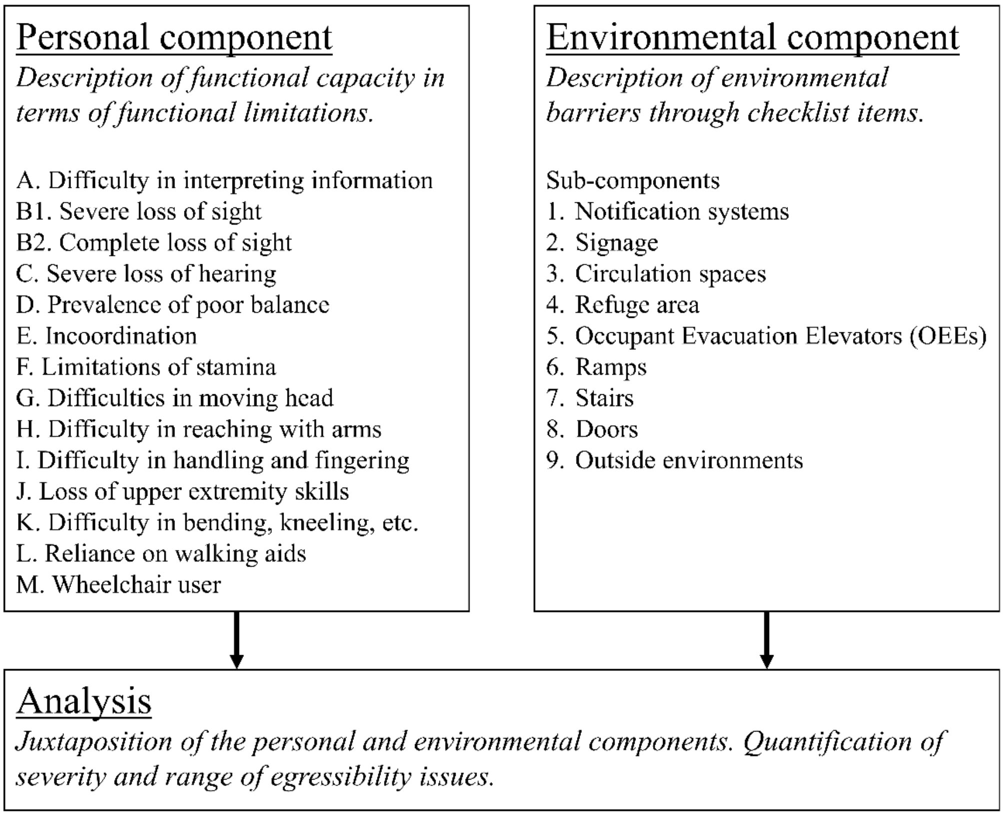

Figure 7. Schematic representation of the Egress Enabler, including the personal component, the environmental component, and the analysis.

6.1.1. Assessing content validity and feasibility through an expert panel

Content validity of the items in the environmental component was assessed by an expert panel, which consisted of five senior researchers and/or practitioners working in the domain of egress (n=2), accessibility (n=2) and psychology (n=1). Two of the participants in the expert panel were part of the project group and were not involved in the selection of the items in the previous stage. The two experts in accessibility had previous experience with developing similar assessment instruments in the accessibility domain. The expert panel participants were asked to rate all identified environmental barrier items based on *relevance* (1 = not relevant, 2 = somewhat relevant, 3 = quite relevant, 4 = very relevant) for Egressibility, such as "Is there an evacuation alarm with auditory signals?" (rated as very relevant by all experts). Experts were given the option to declare that they did not know how to assess relevance. In those cases, their non-rating was not considered in the calculation of content validity. For example, if two out of five experts decided not to rate relevance, content validity was based on the rating of the three other experts instead. After the individual review, an online workshop was held where a summary of the expert panel review was presented, and any disagreements were discussed. The workshop did not alter the relevance scores. The relevance scores were used to calculate content validity indices (CVI) [157]: Scale Content Validity Index/Universal Agreement (S-CVI/UA); Scale Content Validity Index/Average Agreement (S-CVI/Average); and Average Relevance Rating. The S-CVI/UA should be interpreted as the proportion of items in which the experts universally agreed that the item was relevant (rated 3 or 4). The S-CVI/Average should be interpreted as the average of all Item Content Validity Index (I-CVI) (the proportion of experts rating the item as relevant (rated 3 or 4)). Average Relevance Rating is simply the average of all relevance ratings. Items that scored low on relevance were considered for removal or reformulation.

In conjunction with the approach to assess content validity described above, an effort was made to assess the feasibility of the items, using the same expert panel. This was achieved by asking the expert panel participants to rate all items on *ease to assess* (1 = not easy, 2 = somewhat easy, 3 = quite easy, 4 = very easy). These assessments were used to calculate the project specific measure of *Feasibility Index* (FI). The calculation of FI is identical to that of CVI, with the exception that *ease to assess* ratings are used as input. *Ease to assess* ratings were also discussed during the workshop, and items that scored low on *ease to assess* were considered for removal or reformulation.

6.1.2. Developing the scoring system

Buildings are modular, meaning that some evacuation elements are found more than once. It is also argued that two units of the same element may not afford the same level of Egressibility, e.g., there may be more than one type of door. The developed Egress Enabler includes a system to address this issue. Also, there is a system to deal with the fact that, for some buildings, evacuation elements are missing. While scores are calculated by juxtaposing individual environmental barriers with individual functional limitations, the Egress Enabler also generates aggregate scores. Aggregation takes place so that it is possible to evaluate the building as a whole or by evacuation element type and considering all functional limitations or only one. The scores are then comparable for different buildings, meaning that a building that is bigger and holds more occupants should not be consistently given a higher score than a smaller building.

6.1.3. Classifying Egressibility issues

Egressibility issue scores are calculated by combining the presence of environmental barriers with the presence of functional limitations. Each environmental barrier has 14 Egressibility issue scores associated with it. Each of these 14 scores represents the anticipated issue for a person with functional limitation X when faced with environmental barrier Y. These scores were assigned on a scale from 0-4 (0 = no issues, 1 = potential issues, 2 = issues, 3 = severe issues, 4 = impossibility) based on the procedure adopted in the Housing Enabler methodology [16]. This way of defining the severity of issues makes it possible to differentiate the anticipated issues depending on what functional limitation is considered (e.g., a person with hearing limitations would have issues associated with auditory alarms, but not visual alarms).

The typology of person-environment fit issues by Slaug et al. [158] were used to classify Egressibility issues. For each environmental barrier, the activities involved (purposeful sensory experiences, applying knowledge, walking and moving, etc.), and to some extent, the environmental context were considered (stairs, doors etc.). This information was then matched to one of the 48 constellations of the typology. If no constellation was deemed entirely appropriate, the closest fit was altered to better reflect expected Egressibility issues. Consensus discussion followed to establish the final classification. During this phase, some items were merged or divided to better reflect the various Egressibility issues associated with them.

6.1.4. Assessing inter-rater reliability and construct validity through a case study

To demonstrate the use of the Egress Enabler and to evaluate its inter-rater reliability and construct validity, a case study was conducted. The case study consisted of the evaluation of a purposefully selected building using the developed Egress Enabler instrument. Due to the ongoing Covid-19 pandemic, the case study was conducted virtually. A university library in Sweden was used as a basis for the case study. This building was chosen as it represents a typical public building, and it offered an adequate degree of complexity. The floor plan of the building is shown in Figure 8.

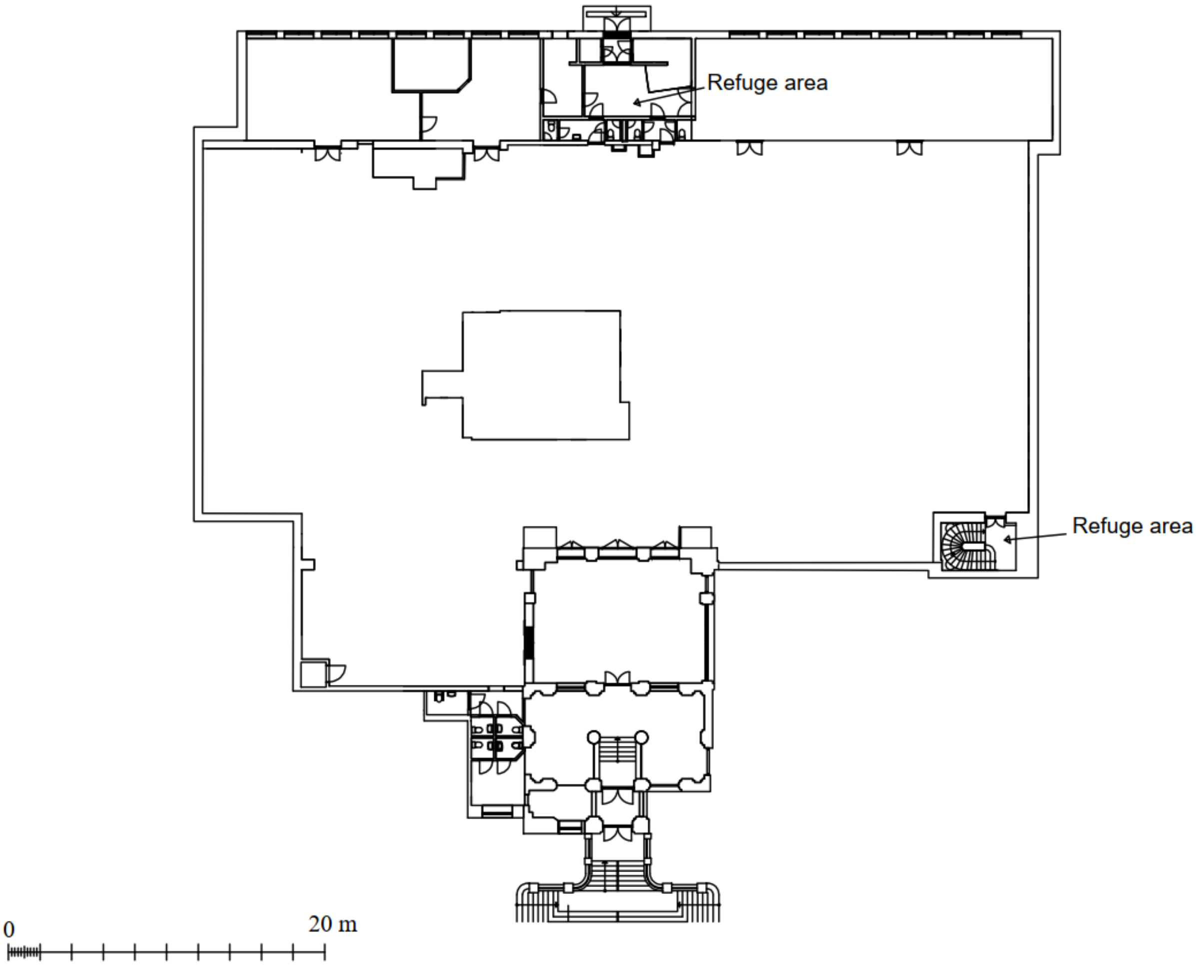

Figure 8. Entry level floor plan of the fictitious building used in the case study. Note that there was one additional emergency exit located on the floor below that can be reached through the stair in the lower right part of the figure. The third refuge area is located on the floor below as well.

The building contained three emergency exits. All emergency exits could only be reached via stairs. Three refuge areas were located near two of the emergency exits, but none were close to the main entrance. No ramp or occupant evacuation elevator was installed.

To demonstrate the flexibility of the Egress Enabler, and to make the case study more transparent through limiting the scope, only the frequently visited public parts of the building were evaluated. This includes the floor presented in Figure 8. The building was reconstructed using 360-degree pictures, which were then incorporated in an application designed specifically for the purpose of the case study. The building was assessed with the Egress Enabler by three rater pairs, with two of the authors in each pair. The rater pairs were able to go around in the environment by clicking on different "hotspots" containing a 360-degree picture of that location. Items that could not be evaluated through the application (e.g., opening forces, door widths, notification system, etc.) were indicated on an annotated floor plan.

To investigate inter-rater reliability the assessments by the three rater pairs were compared. The pairs conducted the assessment independently and were asked to record the time it took them to conduct the assessment. Inter-rater reliability was investigated through single rater, absolute-agreement, two-way random effects model intraclass correlation coefficient (ICC), as well as single rater, consistency, two-way random effects model ICC [159]. The reason for computing both the 'agreement' and 'consistency' ICC measures was because they highlight two different aspects of reliability. The interpretation of the results was based on the bounds of the 95% confidence interval. An ICC value less than 0.5 was considered “poor”, 0.5 < ICC < 0.75 = “moderate”, 0.75 < ICC < 0.9 = “good”, and 0.9 < ICC < 1 = “excellent” [159]. Statistical calculations were performed using R [160], and the psych package [161].

The case study was also used to evaluate two aspects of construct validity: namely convergent and discriminant aspects. The convergent aspect tests whether the scale measures the theoretically abstract construct of Egressibility. This was assessed qualitatively by the authors by considering the personal and environmental component, and reviewing the score computed through the Egress Enabler. Discriminant construct validity on the other hand tests whether the scale can discriminate given different inputs. For the case study, this was evaluated based on examining the score differences between the different functional limitations, as well as through making fictitious alterations to the building design. A total of five fictitious changes were made.

6.2. The personal and environmental component of the Egress Enabler

The personal component of the Egress Enabler consisted of 14 variables describing the presence/non-presence of 14 functional limitations and use of mobility aid, each with a unique identifier (A, B1, B2, C, … , M). The functional limitations are given in Figure 9.

In the application of the Egress Enabler, the 14 functional limitations were used as a classification of Egressibility issues. That is, as different functional limitations affected the functional capacity of individuals differently, the anticipated Egressibility issues also differed.

The items for the environmental component were identified from two different domains: egress and access. The egress items were identified from four different publications based on the literature review:

- *Emergency evacuation planning guide for people with disabilities* by NFPA [162],
- *Fire safety law: the evacuation of disabled people from buildings* [163],
- *Risk assessment checklist* in the context of *safe egress for all* [164], and
- The Swedish building regulation related to fire safety [155].

The accessibility items were identified from three different publications based on the literature review:

- The *Housing Enabler* [16],
- *AIMFREE* [107] and
- The *ADA checklist* [165].

It should be noted that the literature identified in the access domain were previously developed checklist instruments, making the identification of items to include in the environmental component easier. Items were also added and/or altered based on the expertise of the authors. In many cases, items from the accessibility domain and Egressibility domain were similar and were therefore merged. After several iterative consensus discussions, 139 unique items were identified. The process of identifying and selecting items for the environmental components is presented in Figure 9.

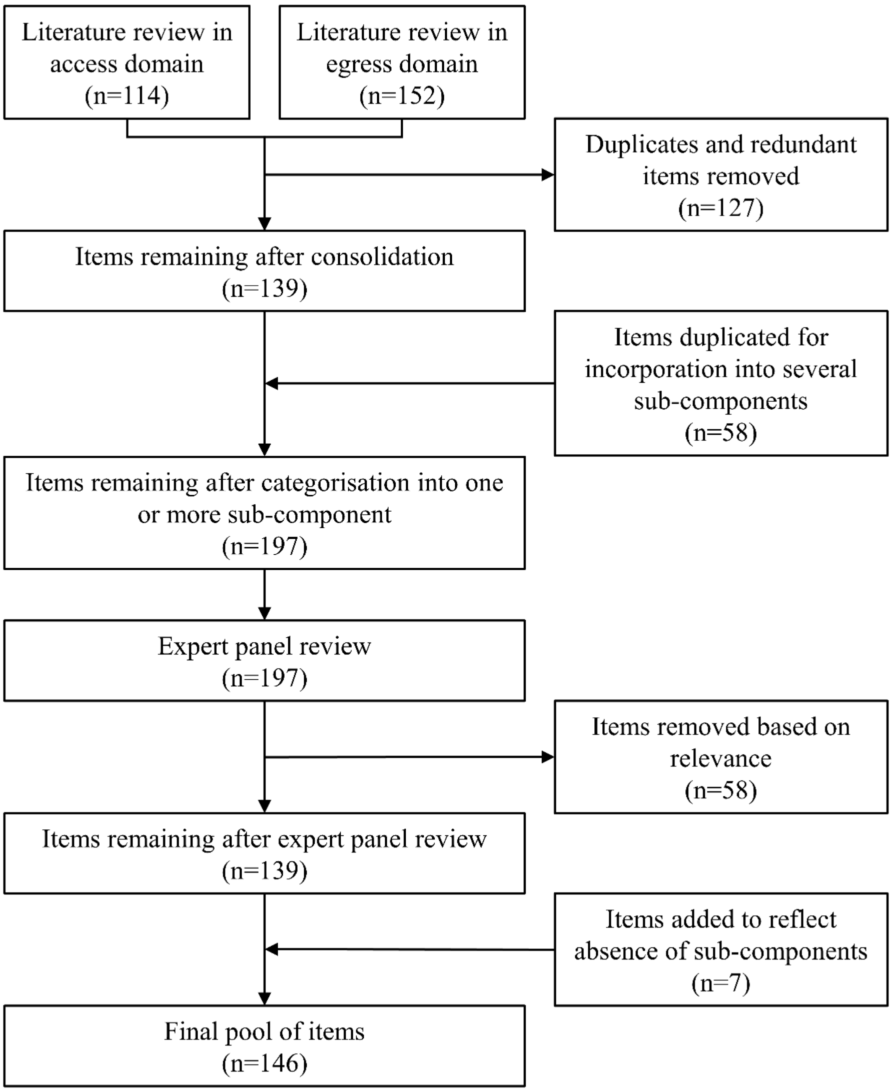

Figure 9. Flowchart depicting the identification and selection of items for the environmental component.

To facilitate a flexible tool, the Egress Enabler is modular consisting of several sub-components with items. These sub-components were identified based on the expertise of the authors and cover aspects of evacuation from the temporal point of threat detection to the relocation to a safe environment outside the building. Sub-components were therefore identified based on evacuation elements found in buildings. Nine sub-components were identified: *Notification systems, Signage, Circulation space, Refuge areas, Occupant evacuation elevators (OEEs), Ramps, Stairs, Doors*, and *Outside environment*. After all items had been classified into one or more sub-components (depending on relevance) through iterative consensus discussions, the total number of items in the scale was 197.

6.3. Content validity of the environmental component

Utilizing the expert panel approach consisting of five experts in relevant fields, the S-CVI/UA was calculated to be 0.73. S-CVI/Average was calculated to be 0.91. The average relevance rating was 3.61 (range 0 to 4). Utilizing the same expert panel, the feasibility was also assessed. The S-FI/UA was calculated to be 0.16, and the S-FI/Average was calculated to be 0.65. The average feasibility rating was 2.97 out of 4. After reviewing the results of the expert panel review, some items were removed, combined, or reformulated. As a result, the number of items were decreased from 197 to 139, a reduction of 58 items. Note that it was pure coincidence that the number of items was decreased to 139, the same number that was identified from the literature review (see Appendix 3 for the full list of items).

6.4. Scoring system of the Egress Enabler

The Egress Enabler was built upon the aggregation of scores, and a higher score corresponded to a less egressible building. In addition to the items identified, the environmental component also contained scores to be added to the total score in case of total absence of an evacuation element. For example, if a building of two or more stories lacks an occupant evacuation elevator and/or refuge areas, a score needs to be added to the total score to reflect the lack of that feature. For this first version of the Egress Enabler, the decision was made to equal the effect of the absence of an item to the presence of a fully non-compliant feature. This resulted in seven additional items, bringing the grand total to 146 items in the final pool of items. The final number of items in the nine sub-components is given in Table 9.

Table 9. Sub-components constructed. Each sub-component corresponds to a different evacuation element.

Sub-component	**# of items**	**Description**
Notification systems	7	Systems in place to notify occupants of imminent threats.
Signage	12	Wayfinding signage and systems to direct occupants to safety.
Circulation spaces	22	Horizontals spaces in the building (rooms etc.).
Refuge areas	13	Safe areas in the building where occupants can wait for further assistance.
Occupant evacuation elevators (OEEs)	20	Elevators that are safe to use in case of emergency.
Ramps	19	Sloping flat surfaces for vertical transportation.
Stairs	25	Stairs that are meant to be use during egress.
Doors	16	Exit doors that are meant to be used during egress.
Outside environments	12	The route from the exit to the point of assembly.
Total	*146*	

Before initiating the evaluation of a building, the user must construct the Egress Enabler by incorporating the appropriate number of sub-components, depending on the number of evacuation elements in place. For example, if a building has five different doors, five door sub-components need to be incorporated. Similarly, if a building has more than one unique notification system, e.g., in two different compartments, two notification system sub-components need to be incorporated.

To make the evaluation of different buildings and evaluations of different levels of detail comparable, the result from the incorporated sub-components needs to be weighted together. The weights should be applied so that each sub-component is counted only once. Consider a building using two door sub-components; those sub-components should be weighted so that the sum of them equals to one. As buildings are different, thus making it difficult if not impossible to provide general recommendations on how this should be done, this is to a large extent up to the judgement of the evaluator. However, some general recommendations can be made:

- If a building has more than one instance of the sub-components circulation spaces, signage, and notification systems, they should be weighted according to the size of the compartment which they cover. Evacuation elements that are part of the main evacuation strategy (areas in which evacuees need to pass through, irrespective of initial location) should be weighted according to twice their size.

- Doors, stairs, ramps, OEE's, refuge areas and outside environments that are part of the familiar entrances should be weighted with a higher weight to reflect that many occupants tend to move towards familiar places during evacuation according to the theory of affiliation [166].

The readers can refer also to the user manual of the Egress Enabler supplied in Appendix 4.

When a building-specific scale has been constructed and evaluated, the Egress Enabler Score (EES) can be calculated using the identified scoring pattern for each evaluated item. The EES is calculated individually for all functional limitations (indicated as A, B1, B2, …, M). To calculate the EES, the score in the scoring pattern corresponding to the specific functional limitation is added to the EES if the environmental barrier/item has been identified as non-compliant. This is repeated for all environmental barriers/items within all sub-components. To calculate the Total Egress Enabler Score (TEES), all EES are summated. To facilitate interpretation, a star rating system has been developed. A (T)EES of zero yields four stars. A (T)EES of 0-25% of the maximum (T)EES yields three stars, 25-50% yields two stars, 50-75% yields one star, and a (T)EES score of more than 75% of the maximum (T)EES yields no stars. Star ratings are presented for each functional limitation individually, as well as for all combined.

6.5. Classification of Egressibility issues

The items were classified according to a pre-existing typology from the field of accessibility [158]. The typology consists of 48 different scoring patterns each representing a typical environmental barrier in relation to accessibility. In the end, none of the scoring patterns were used as is. The typology was nevertheless useful as a way for the authors to determine how to define the scoring patterns.

The face validity of the scoring patterns (intended here as the degree to which the Egress Enabler appears effective in terms of its stated aims) was assessed through iterative consensus discussions among all the authors until agreement were met. During this phase, some items were merged or divided to better reflect the various Egressibility issues associated with them. These additions have been incorporated into the final number of items. Examples of environmental barrier items are given in Table 10. In the scoring patterns presented, the order of the score in the scoring pattern (from left to right) corresponds to the list of functional limitations. The values of the scores represent the anticipated severity of Egressibility issues associated with the environmental barrier. For example, the environmental barrier "Visual contrast is provided on evacuation routes to minimize falling risks" yields a score of 3 corresponding to "severe issues" for the functional limitation "severe loss of sight", while a score of 1 ("potential issue") is yielded for the functional limitation "difficulty in interpreting information". Note that sometimes the answer option "yes" and sometimes "no" increase the total score. In Appendix 4, the answer option yielding the score is highlighted in grey.

Table 10. Examples of environmental barrier items and scoring patterns.

Environmental barrier item	**Functional limitation**													
	A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
Visual contrast is provided on evacuation routes to minimize falling risks.	1	3	0	0	0	0	0	0	0	0	0	0	0	0
There are obstructions (e.g., furniture, equipment, protruding objects) on the evacuation paths.	0	2	3	0	1	1	0	0	0	0	0	0	2	3
Does the door have hardware that is operable with one hand?	0	0	0	0	0	1	0	0	0	1	4		2	3

After all scoring patterns had been determined, the maximum Egress Enabler score could be calculated to [A:81, B1:141, B2:162, C:28, D:130, E:115, F:82, G:14, H:20, I:27, J:35, K:40, L:209, M:230]. Each position in the vector represented a different functional limitation. The overall maximum score was 1314, and the maximum scores by each of the functional limitations vary from 14 to 230.

6.6. Inter-rater reliability and construct validity in the case study

The three rater pairs conducted the assessment of the case study in approximately two and a half hours. The resulting Egress Enabler scores by functional limitation are presented in Table 11, and by sub-component in Table 12.

Table 11. Egress Enabler scores by functional limitation for the three rater pairs used in the reliability analysis.

Functional limitation	**Egress Enabler scores**			
	Pair 1	Pair 2	Pair 3	**Mean (SD)**
A. Difficulty in interpreting information	32	45	35	**37 (6)**
B1. Severe loss of sight	61	81	69	**70 (8)**
B2. Complete loss of sight	83	108	97	**96 (10)**
C. Severe loss of hearing	15	15	15	**15 (0)**
D. Prevalence of poor balance	72	88	70	**77 (8)**
E. Incoordination	59	75	59	**64 (8)**
F. Limitations of stamina	44	50	38	**44 (5)**
G. Difficulties in moving head	4	5	4	**4 (0)**
H. Difficulty in reaching with arms	11	13	10	**11 (1)**
I. Difficulty in handling and fingering	12	14	13	**13 (1)**
J. Loss of upper extremity skills	15	21	12	**16 (4)**
K. Difficulty in bending, kneeling, etc.	8	16	9	**11 (4)**
L. Reliance on walking aids	110	136	118	**121 (11)**
M. Wheelchair user	117	141	128	**129 (10)**
Total	***642***	***802***	***677***	**707 (69)**

Table 12. Egress Enabler scores by sub-component for the three rater pairs used in the reliability analysis. Not applicable refers to evacuation elements that were not present in the case study building.

Environmental sub-component	**Egress Enabler scores**			
	Pair 1	Pair 2	Pair 3	**Mean (SD)**
Notification systems	3	3	3	**3 (0)**
Signage	29	33	25	**29 (3)**
Circulation spaces	386	450	381	**406 (31)**
Refuge areas	36	55	47	**46 (8)**
Occupant evacuation elevators (OEEs)	Not applicable	Not applicable	Not applicable	**Not applicable**
Ramps	Not applicable	Not applicable	Not applicable	**Not applicable**
Stairs	88	153	119	**120 (27)**
Doors	57	59	72	**63 (7)**
Outside environments	43	49	31	**41 (7)**
Total	***642***	***802***	***677***	**707 (69)**

Inter-rater reliability results are shown in Table 13. The calculations were based on the EES values presented in Table 12.

After conducting the case study, some items were reformulated for reliability and validity reasons. These changes were made by one author and presented to the other authors, who went back and checked their initial evaluations. These alterations have then been incorporated in the calculations.

Table 13. ICC agreement and consistency estimates and confidence intervals (CI) for the reliability analysis based on sub-component. Not applicable refers to evacuation elements that were not present in the case study building.

Environmental sub-component	**ICC (Agreement)**	**95% CI (Agreement)**	**ICC (Consistency)**	**95% CI (Consistency)**
Notification systems	1		1	
Signage	0.936	0.854-0.977	0.94	0.862-0.979
Circulation spaces	0.977	0.905-0.993	0.988	0.97-0.996
Refuge areas	0.87	0.683-0.954	0.901	0.779-0.964
Occupant evacuation elevators (OEEs)	Not applicable	Not applicable	Not applicable	Not applicable
Ramps	Not applicable	Not applicable	Not applicable	Not applicable
Stairs	0.856	0.548-0.954	0.919	0.815-0.971
Doors	0.901	0.779-0.964	0.908	0.793-0.967
Outside environments	0.814	0.612-0.93	0.833	0.647-0.937
Total	*0.968*	*0.825-0.991*	*0.987*	*0.967-0.995*

Convergent construct validity was evaluated through scrutinizing the results from the case study. The results from the evaluation of rater pair 1 presented in Table 12 were used as a basis. In this rating "difficulty in bending, kneeling, etc.", "difficulty in reaching with arms", and "difficulties in moving head" yielded the lowest Egress Enabler scores. "Reliance on walking aids" and "Wheelchair users" yielded the highest scores in the Egress Enabler.

To evaluate the discriminant construct validity (i.e., to demonstrate its sensitivity to changes in design configurations) of the Egress Enabler, the score from pair 1 presented in table 3 was used as a baseline on which to base the qualitative comparison. Five fictitious changes were made to the case study and the Egress Enabler evaluation was changed accordingly. The five changes are presented in Table 14.

Table 14. Fictitious changes used to evaluate construct validity.

Scenario	**Change in environment**
S1	A compliant ramp is added near the main exit
S2	A compliant OEE is added near the main exit
S3	Door opening forces, thresholds, opening direction and opening procedures are altered to be compliant
S4	Compliant communication possibilities and information are added in all refuge areas
S5	The refuge areas are removed

In Figure 10, the change in Egress Enabler score by the 14 functional limitations as a result of the fictitious changes is presented.

Figure 10 shows that all but one of the fictitious changes resulted in an increase in Egressibility. The removal of refuge areas resulted in decreased Egressibility, primarily for people using a mobility aid or wheelchair and for people with difficulty in interpreting information. The most significant increase in Egressibility was found when a compliant ramp was added near the main entrance.

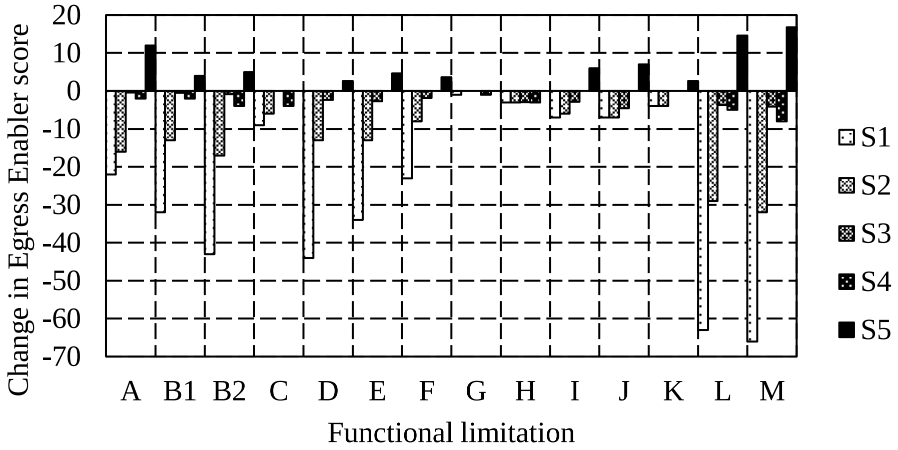

Figure 10. Change in Egress Enabler score based on fictitious changes to the environment. S1: A compliant ramp is added near the main exit, S2: A compliant OEE is added near the main exit, S3: Door opening forces, thresholds, opening direction and opening procedures are altered to be compliant, S4: Compliant communication possibilities and information are added in all refuge areas, S5: The refuge areas are removed.

7. The impact of people with functional limitations on exit choice using Virtual Reality Experiments

This section presents the virtual reality (VR) experiments performed during the project. The purpose of this work was dual, namely 1) to investigate the influence of people with mobility limitations on exit choice in relation to the design of emergency exits in terms of accessibility and 2) to explore the potential of using VR for the investigation of issues related to the presence of people with functional limitations during evacuation. The results aim towards facilitating efforts in modelling evacuations including for people with mobility impairments.

The decision to investigate exit choice was taken since during the process of evacuating a building, this aspect can have a significant influence on the evacuation performance [167]. Ideally, the evacuees would use the available exits to optimize evacuation time. However, research studies [166], [168] have revealed that this is not often the case, and that evacuee exit choice is influenced by many factors not always strictly related to increased evacuation efficiency.

Exit choice during evacuation scenarios in the general population is a topic that has received significant scientific attention. Studies revealed that people tend following the crowd (social influence) [169], [170], avoiding congestion [171], choosing familiar exits (place affiliation) [166], going with people they are aware of (person affiliation) [166], and that the design of the exit itself influences exit choice [172], [173]. The impact of signage has also been investigated to a large extent [174]–[177].

As exit choice is influenced by social aspects, presumably it could be influenced by the characteristics of the neighbouring evacuees. In recent years, demographical studies have shown that populations are getting increasingly older, and that functional limitations related to old age increase in prevalence [178]. This trend, along with increased accessibility to public buildings, implies that the evacuating crowds today and in the future may be more heterogeneous in terms of functional capacity. However, exit choice related to people with functional limitations (FL) has not received the same amount of scientific interest as other influencing factors. One previous study including 47 participants (of which 12 had functional limitations; 11 visual and 1 mobility) showed that exit choice was influenced by the presence of people with FL at the exit [179]. It is suggested that people with FL tend to follow others with FL, while people without FL may choose another exit [179]. It is hypothesized that the type of functional limitation and its visibility may have an effect on neighbouring evacuees exit choice based on the results of a recent interview study [119].

Furthermore, the design of the exit can influence exit choice [180]. Nilsson [167] has investigated how exit choice can be influenced by their design by using Gibson's theory of affordances [181]. In evacuation design, it is common to direct the evacuees to different exits, e.g. aiming at optimizing flows and based on the functional capacity of the evacuees. For example, people using wheelchairs may need to be directed to evacuation routes without level differences or exits leading to areas of refuge. Also, the exit door needs to be accessible to the person who is intended to use it. This has an impact on several design features such as the door width, type of handle and signage.

Exit choice studies are common in the field of human behaviour in fire [182]. Methods employed include non-immersive stated preference [183]–[185], field studies/drills [179], [186], and more recently, virtual reality (VR) [187], [188].

7.1. Methods for the VR experiments

The type of method employed to study exit choice affects the ecological validity, with field studies, drills, etc., performed in real environments often reported to have the highest [189]. Nevertheless, Virtual Reality (VR) has become a popular method due to its ability to produce repeatable scenarios with less resources and high experimental control [189]. Furthermore, exit choice studies have come to include areas of econometrics [190], [191] to investigate the behaviours of the participants. Specifically, discrete choice modelling has been used with success looking at variables such as smoke, presence of non-player characters (NPCs), distance to exits, crowding, etc., [168], [184], [185], [188], [192]–[196]. Discrete choice modelling relies on estimating the 'utility' a person receives from discrete alternatives in order to model the choice probabilities. The benefits of discrete choice modelling includes that the combination of different independent variables can be estimated, the interactions between those, and that the variation in preferences between participants can be modelled [191]. Given these premises, it was decided to conduct this study using Virtual Reality and then perform an analysis of the results obtained using discrete choice modelling.

7.1.1. VR participants' sampling procedure

Participants were recruited on a university campus through posters, through a participant recruitment webpage (accindi.se), and through snowball sampling. The experiments were conducted in 2022 in Sweden, thus participants were required to speak Swedish. Participants recruited were without any functional limitations. In total, 40 participants took part in the study (24 males and 16 females). The age of the participants ranged from 18-64 (mean = 28.5, standard deviation = 10.4). Most of the participants were students (n = 26).

7.1.2. VR experimental design

The study was designed as a discrete choice experiment where the participants were asked to choose one of two exits out of a room. These two exits are defined as discrete choices and were characterized by two attributes. These two attributes are defined as the independent variables, the exit choice being the dependent. The two attributes can take on different 'values', named as levels. The attributes, number of levels, and description of these levels were:

- Characteristics of simulated agent. *3 levels. No agent/Wheelchair user (WU)/Non-wheelchair user (NWU).*
- Design of exit. *2 levels. Narrow door with a handle resembling the EN 179 standard* [197]*/Wider door with a handle resembling the EN 1125 standard* [198].

A full factorial design was used to generate the scenarios to be tested. This resulted in a total of $(3 \times 2 =) \ 6$ possible exit configurations. Given that there were two exit options in each choice set, there were $\binom{6}{2} = \frac{6*5}{2} = 15$ possible combinations. To eliminate potential bias for left or right exit, these 15 combinations were duplicated and mirrored, resulting in a total of 30 test trials. The trials are presented in Table 15. To eliminate the influence of any learning effects given that each participant performs multiple trials, five training trials were introduced at the beginning of the experiment which were not considered in the subsequent analysis.

To investigate the validity of the study, validity trials were introduced along with the actual test trials. The validity trials were similar to the test trials in that they contained two exit choices. However, in the validity trials, one of the exits was clearly identified as unsuitable for evacuation. This was accomplished by identifying the exits as a toilet by use of a sign. The design of the toilet door is shown in Figure 11. Hence, if the participants choose the WC option, data may be invalid. Validity trials are presented repeatedly after the initial training trials and then intermittently after 10 test trials. The trial sequence then looks as follows: *5 training trials – 1 validity trial - 10 test trials – 1 validity trial – 10 test trials – 1 validity trial – 10 test trials.*

Table 15. Description of the 30 test trials conducted by each participant. Trial numbers in brackets refer to the same configuration but mirrored left and right. WU = wheelchair user, NWU = non-wheelchair user.

Trial	Total number of agents	Exit Choice 1		Exit Choice 2	
		Agent	Door	Agent	Door
1 *(16)*	0	--	Narrow	--	Wide
2 *(17)*	1	--	Narrow	NWU	Narrow
3 *(18)*	1	--	Narrow	NWU	Wide
4 *(19)*	1	NWU	Narrow	--	Wide
5 *(20)*	1	--	Wide	NWU	Wide
6 *(21)*	1	--	Narrow	WU	Narrow
7 *(22)*	1	--	Narrow	WU	Wide
8 *(23)*	1	WU	Narrow	--	Wide
9 *(24)*	1	--	Wide	WU	Wide
10 *(25)*	2	NWU	Wide	WU	Wide
11 *(26)*	2	NWU	Narrow	WU	Wide
12 *(27)*	2	NWU	Narrow	WU	Narrow
13 *(28)*	2	WU	Narrow	NWU	Wide
14 *(29)*	2	WU	Narrow	WU	Wide
15 *(30)*	2	NWU	Narrow	NWU	Wide

7.1.3. VR apparatus

The study was performed in VR through a Head Mounted Display (HMD) (Oculus Quest, first generation). The participants performed the experiment sitting down on a swivel chair. The participants were asked to choose an exit by selecting it with a ray cast (a 'laser pointer') from the hand controllers. No other hand interactions or physical movement were required. The virtual environment was generated using Unity (version 2021.1.19f1) and the built-in 3D modelling package ProBuilder (version 5.0.4). In the virtual environment, a virtual nose was rendered to reduce the potential for 'motion-sickness' [199].

7.1.4. Virtual environment

The design of the virtual environment is presented in Figure 12. The virtual environment consisted of a virtual room with sides 7.7 m × 7.7 m. The height of the ceiling was three meters. On one of the sides, two doors were present. The doors were placed at an equal distance from the room's centreline, one to the left and one to the right. The room was kept as simple as possible to avoid any confounding factors. The participant starting position was placed near the opposite wall at an equal distance from both doors. The two possible agents were placed close to the participant, one to the left and one to the right. The agents were either sitting in their wheelchairs or sitting on a chair at the start of the trial. The starting position of the agents did not determine their exit choice, i.e., they were randomly assigned to one of the two exits. The doors are presented as either of the three configurations presented in Figure 11.

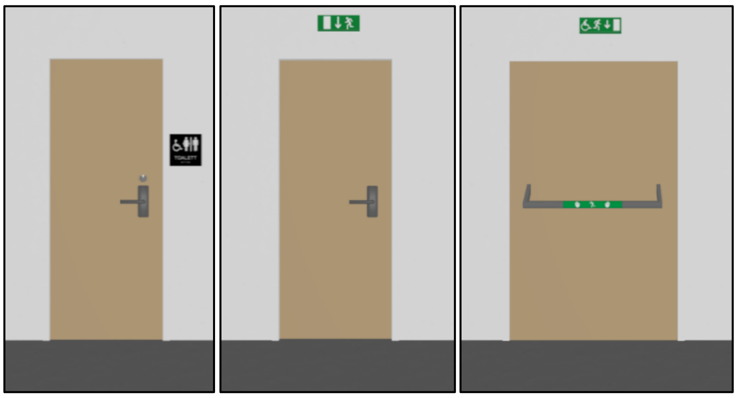

Figure 11. Left: Validity test door: toilet. Middle: Door configuration 1: Door width=0.8 m, 'EN 179' handle. Right: Door configuration 2: Door width=1.2 m, 'EN 1125' handle.

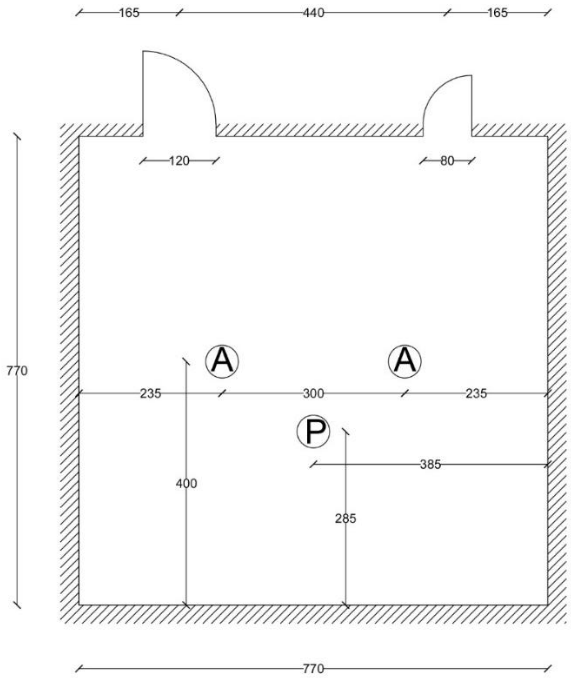

Figure 12. Floorplan of the virtual environment at the time the trial would start (dimensions are in centimetres). The circles with the letter 'A' represent the positions in which the agents are generated; the circle with the letter 'P' is the position of the participant.

The agents (i.e., their visual representation) were randomized from a pool of similar agents of the same gender (male) to avoid gender bias. A screenshot from the virtual environment is presented in Figure 13. The camera position is at the participant starting position.

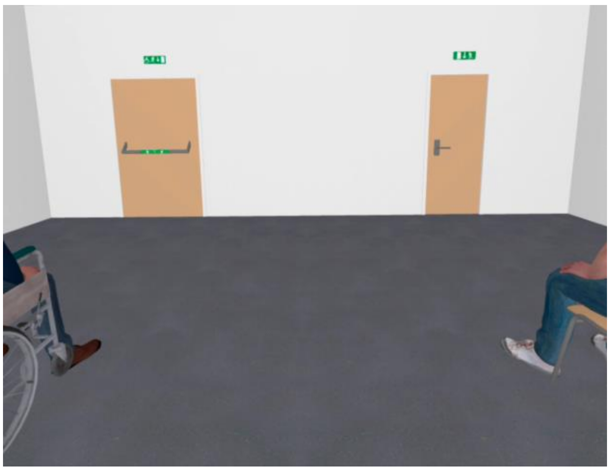

Figure 13. Screenshot of the virtual environment as seen from the participant starting position.

7.1.5. Procedure

Each participant performed 30 repeated trials. The participants started each trial within the room behind none, one, or two agents, with or without wheelchairs. Then the alarm started (represented by a 2 second bell sound), and the trial began. The agents chose one exit (not the same if there were two agents present). The movement speeds of the agents were 1 m/s when not a wheelchair user, and 0.8 m/s when a wheelchair user. After a couple of seconds, it was evident which exit the agents had chosen, and the participant was allowed to make their choice of exit. After the choice had been made, the screen faded to black, and the next trial began. Hence, the participants were not allowed to change their choice of exit.

Before the experiment started, the participants were informed about their aim according to the below formulations (this was originally in Swedish, here there is the English translation).

> "In the scenarios, you will be located in a room. In the room, you will see two doors and maybe some other people. A sound ('ring') indicates that there is an emergency, and you are asked to evacuate the building. Hence, you are asked to choose one of the two doors for your evacuation. Bear in mind that there is not necessarily a correct choice but try to respond as you would in a real emergency!"

The application included an option to pause the experiment at any time, which the participants were informed about.

7.1.6. Post VR experiment survey

In addition to collecting data on the choice of exit, the participants were asked to answer to a questionnaire covering factors influencing exit choice (4 point Likert scale). The questions are presented in Table 16.

Table 16. Questionnaire on factors stated to have influenced the participants' exit choice. Answered on a 4-point Likert scale ranging from 'disagree completely' to 'agree completely'.

1.	*I choose the exit because it seemed closer*
2..	*I choose the exit because it was wider*
3.	*I choose the exit because it was easier to see*
4.	*I choose the exit because it was the first one I saw*
5.	*I choose the exit because I followed the person without a wheelchair*
6.	*I choose the exit because I followed the person with a wheelchair*
7.	*I choose the exit because I avoided following the person without a wheelchair*
8.	*I choose the exit because I avoided following the person with a wheelchair*
9.	*I choose an exit at random*
10.	*I choose the exit because it seemed more accessible*
11.	*I choose the exit because it seemed to have a better handle*
12.	*I choose the exit which I thought would take me quickest to safety*
13.	*I choose to follow the person that I identified most with*
14.	*I felt that I would want to be of assistance to the person without a wheelchair*
15.	*I felt that I would want to be of assistance to the person with a wheelchair*
16.	*I felt that I wouldn't want to be in the way for the person without a wheelchair*
17.	*I felt that I wouldn't want to be in the way for the person with a wheelchair*
18.	*I felt that the person without a wheelchair could have delayed my own evacuation*
19.	*I felt that the person with a wheelchair could have delayed my own evacuation*

Apart from the questions stated in Table 16, the participants were also asked about their preference to choose the right or left exit. They were also asked if they ever choose the toilet door used in the validity trials and their reasoning for doing so.

To investigate the feelings of 'presence' induced by the virtual scenario, the Slater-Usoh-Steed (SUS) [200] questionnaire was used. Furthermore, the participants were asked to rate the extent that they perceived six feelings: *insecurity*, *stress*, *fear*, *orientation issues*, *physical discomfort – nausea*, and *physical discomfort – irritated eyes*. This is in line with previous VR studies investigating evacuation [201], [202].

7.1.7. Data analysis

To interpret the findings of this study, a mixed logit model was fitted to the data. In discrete choice models such as mixed logit, the assumptions made is that the participants will choose the alternative (exit door) for which they perceive maximizes their utility [191]. The participants were prompted to evacuate the rooms after the alarm sounded, so it is assumed that the participants choose the exit that they perceived would grant them the quickest and most certain escape route. No observations were made on the utility perceived by the participants, but the variables observed were used to model utility.

Due to the design of the experiment in which each participant is faced with more than one choice situation, a mixed logit model was estimated instead of for example a conditional logit model. Furthermore, a mixed logit model is described as a *"highly flexible model that can approximate any random utility model"* [203]. The disadvantage of the mixed logit model is that its choice probabilities are not in closed form, rendering the process of estimation computationally expensive. The mixed logit model also allows for the estimation of random coefficients, meaning that variation in preference between decision makers can be modelled. The utility (*U*) observed by participant *n* for choice *i* at time *t* is specified in Equation 1.

$$U_{nit} = \beta'_n x_{nit} + \varepsilon_{nit} \qquad \text{[Equation 1]}$$

Where x_{nit} is a vector of observed variables for alternative *i*, β_n is a vector of coefficients of these variables for decision maker *n*, and ε is a random term that is an independent and identically distributed extreme value. The coefficients vary over decision makers in the population with density $f(\beta)$. The probability (*P*) that participant *n* chooses alternative *c* is given by equation 2.

$$P_{nc}(\beta) = \int \prod_{t=1}^{T} \frac{e^{\beta'_n x_{nct}}}{\sum_{j=1}^{J} e^{\beta'_n x_{njt}}} f(\beta) d\beta \qquad \text{[Equation 2]}$$

For a more detailed description on mixed logit modelling, see [191]. Statistical calculations were performed in *Python* using the packages *xlogit* [204] for estimating mixed logit and conditional models, and *scipy* [205] for performing the likelihood ratio tests.

7.2. Results of VR experiments

The results of the VR experiments are presented here in terms of descriptive statistics, mixed logit modelling and responses to the questionnaires.

7.2.1. Descriptive statistics of exit choices

As each participant conducted 30 trials each, a total of 1200 choice results were obtained. Out of the 30 trials conducted by each participant, 16 contained choices were there was only one agent present. In those trials, the participants followed the agent in 58.9% of the trials. Out of those 16, 8 were with a person not in a wheelchair, which was followed by the participants in 57.8% of trials. Respectively, for the remaining 8 trials where the agent was a wheelchair user, the participants followed the agent in 60.0% of the trials. In 8 trials there was both a wheelchair agent and a non-wheelchair agent, and the participants followed the wheelchair agent in 61.5% of the trials. In 18 of the 30 trials conducted by each participant, there were two different doors, one 1.2 meter wide with the EN 1125 handle, and one 0.8 meter wide with the EN 179 handle. In those trials the participants choose the wider door in 60.1% of the trials.

Four participants choose the toilet door in the validity trials on at least one occasion. Most participants (n=3) stated in the subsequent questionnaire that this was because they wanted to make sure that no person was still in the toilet, perhaps needing help evacuating. The other participant stated that they did not see the sign in the first of the three validity trials. For this reason, these participants were not excluded in the analysis.

7.2.2. Mixed logit modelling

Mixed logit models were fitted to the data to give insights to the participants preferences. Different models were fitted with a varying number of variables considered. Models that do not include random effects are not mixed logit models, but instead conditional logit models [191]. Mixed logit models used the participant identifier as panel data to account for taste variation. As suggested by Hensher et al. [190], the mixed logit models were estimated over a large number of Halton draws (500-40000 draws) to confirm the stability of the estimates. It was found that the estimates were stable after 5000 Halton draws, so 5000 Halton draws were used to simulate the random distribution of the parameters [191]. The random coefficients were assumed to be normally distributed.

Likelihood-ratio tests [191] were performed to see how model fit was affected by including less variables. The description of all fitted models, their log-likelihood, and likelihood-ratio test statistics are displayed in Table 17.

Table 17. Comparison of mixed logit and conditional logit models with different attributes. LL = Log-likelihood; χ^2-statistics refer to model comparisons; df = degrees of freedom.

Fixed coefficients	Random coefficients	LL	χ^2	df	p-value
Design × (WU + NWU) + Direction	Design × (WU + NWU) + Direction	-480.9	-	-	-
Design × (WU + NWU)	Design × (WU + NWU)	-488.6	15.36	2	<0.001
Design × (WU + NWU) + Direction	Design + WU + NWU	-508.0	54.11	3	<0.001
Design × (WU + NWU)	Design + WU + NWU	-508.4	54.96	4	<0.001
Design + WU + NWU	Design + WU + NWU	-509.4	57.01	6	<0.001
Design + WU + NWU	-	-799.4	636.92	9	<0.001
WU + NWU	-	-814.6	667.47	10	<0.001
Design	-	-816.9	671.94	11	<0.001

As seen in Table 17, removing attributes from the most complete model resulted in significantly worse model fit according to the likelihood-ratio test in all cases. The attribute estimates of the most complete model are displayed in Table 18.

Table 18. Estimates, standard errors, and p-values of the coefficients in the best fitting mixed logit model.

Attribute	Estimate	Standard error	p-value
Design	1.31	0.28	<0.001*
WU	2.92	0.39	<0.001*
NWU	0.80	0.26	0.007*
Design×WU	-0.56	0.40	0.301
Design×NWU	-0.42	0.37	0.422
Direction	-0.09	0.12	0.615
sd.Design	3.08	0.37	<0.001*
sd.WU	7.77	0.68	<0.001*
sd.NWU	3.31	0.40	<0.001*
sd.Design*WU	3.81	0.47	<0.001*
sd.Design*NWU	0.32	0.56	0.678
sd.Direction	0.65	0.18	<0.001*

Eight out of the 12 estimated attributes were significantly different than zero (*p=0.05*). The attribute that was most influential, on average, was the case of a wheelchair agent choosing the exit, meaning that participants saw an increase in utility of the exit when a wheelchair agent choose it. The same effect relating to non-wheelchair agent was significantly smaller.

Notably, the standard deviation estimates (i.e., *'sd.Design'*, *'sd.WU'*, etc.) are of significant magnitude meaning that large inter-person differences (or taste variation) existed in the data set. The estimates of the standard deviations provide further insight into the participants behaviour. The distribution of the random coefficients was in this study modelled as normal, meaning that for the attribute *'Design'*, two thirds of the participants saw an increase in utility when the door was wider, with a better handle, and with an accessible signage (*N(1.31, 3.08)*). This also means that one third of the participants saw a decrease in utility from this attribute. The attribute of a wheelchair using NPC choosing the exit was the attribute with most taste variation among the participants. For this attribute, 65% saw an increase in utility to follow the wheelchair using NPC, and 35% saw a decrease in utility (*N(2.92, 7.77)*).

Three attributes returned non-significant mean estimates. This may have two reasons. Either the estimate is very close to null, or the standard error of the estimate is large. In the case of preference for left or right (attribute 'Direction'), the estimate is very close to null (participants find almost no utility in this attribute) which explain why it is non-significant. For the interaction terms (*'Design*WU'* and *'Design*NWU'*) the estimates are slightly higher, but still lower than for the other attributes.

7.2.3. Reasons for exit choice

The participants were asked after the experiment the reasoning behind their behaviour by answering a post-experiment questionnaire. The results are displayed in Figure 14.

As seen in Figure 14, the reported reasoning behind the participants' choice varied between participants in line with the results of observed exit choice. Interesting to note is that participants more often reported that they wanted to be of help to the wheelchair agent rather than the non-wheelchair agent (questions 14 and 15), and more participants reported that they perceived that the wheelchair agent could delay their own evacuation than what was reported relating to the non-wheelchair agent (questions 18 and 19).

The relationship between a participant's tendency to follow the wheelchair agent and their stated strategy of doing so (question 6) was assessed. A Kendall's tau-b correlation test showed a significant strong positive relationship (tau-b = 0.696, $p < 0.001$). Interestingly, performing the same test relating to participants' tendency to follow the non-wheelchair agent and their answers to question 5 revealed no significant relationship (tau-b = -0.002, p = 0.99). This perhaps indicates that participants had a conscious strategy to follow the wheelchair agent but were at the same time unconsciously influenced to follow the non-wheelchair user. Furthermore, the relationship between a participant's tendency to follow the wheelchair user and their answer to question 15 about wanting to be of help to the wheelchair agent was assessed. A Kendall's tau-b correlation test showed a significant strong positive relationship (tau-b = 0.513, $p < 0.001$). Significant medium to strong positive relationships were also found relating to participants' tendency to choose the wider exit and their answers to questions 2 (tau-b = 0.404, p = 0.001), 10 (tau-b = 0.325, p = 0.01), and 11 (tau-b = 0.396, p = 0.002).

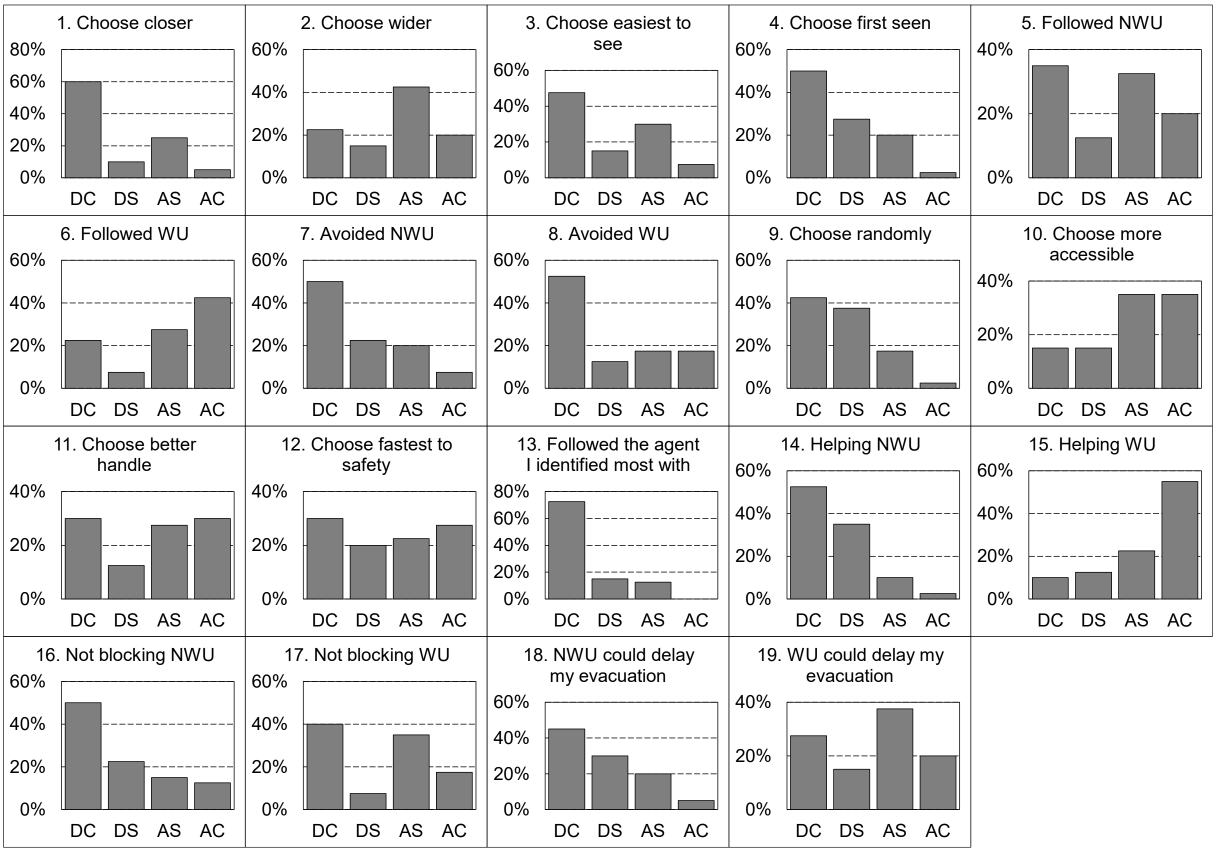

Figure 14. Reported strategies for exit choice according to the questionnaire responses. DC = disagree completely; DS = disagree somewhat; AS = agree somewhat; AC = agree completely; WU= wheelchair agent, NWU= non-wheelchair agent.

To gauge the VR experience in terms of enforcing a feeling of presence, the Slater-Usoh-Steed questionnaire [200] was used. The results are displayed in Table 19.

Table 19. Results from the Slater-Usoh-Steed questionnaire. Mean and standard deviation. Min = 1; Max =7.

	Q1	Q2	Q3	Q4	Q5	Q6
Mean (SD)	4.28 ± 1.40	2.90 ± 1.67	3.65 ± 1.92	5.33 ± 1.29	4.53 ± 1.73	3.70 ± 1.66

Overall, people reported medium to high levels of presence. The mean of all question is 4.1, which is in line with previous studies in the field of evacuation [206].

Furthermore, the participants were asked about the feelings they perceived during the experiment. The results in terms of mean and standard deviations are displayed in Table 20.

Table 20. Feelings reported by the participants. Mean and standard deviation. Min = 1; Max = 7.

	Insecurity	Stress	Fear	Orientation issues	Physical discomfort - Nausea	Physical discomfort – Eye irritation
Mean (SD)	3.40 ± 1.67	2.10 ± 1.26	1.43 ± 0.77	1.78 ± 1.17	1.08 ± 0.35	1.43 ± 1.05

Overall, the participants reported feeling low levels of the feelings asked. The mean for 'insecurity', 'stress', and 'orientation issues' is slightly higher, presumably relating to the choice situation itself and not the use of the equipment.

8. Discussion

This section discusses each individual study of the project, including the two reviews on evacuation and accessibility, the subjective perspectives on Egressibility, the Egress Enabler and the study concerning the impact of people with functional limitations on exit choice using Virtual Reality experiments.

From the review of evacuation studies, it appeared evident that there have been a few attempts in recent years to meet the needs of people with functional limitations in evacuation scenarios. They have included the pre-evacuation and movement phases, assisted evacuation and self-evacuation, as well as the relationship between reception, perception and realisation of evacuation tasks [59], [207]. Nevertheless, a universal classification of functional limitations in the context of fire safety and evacuation has not yet been made. Following a review of existing literature, this project presents a detailed categorization of six functional limitations based on the state-of-the-art method adopted in health sciences and accessibility research. Using ICF [12], the functional limitations were linked to predominant activities during the evacuation phases.

This work allowed the identification of a set of issues. First of all, it is important to distinguish the needs of people with different types of mobility impairments, i.e. those with limitations in upper extremities and those with limitations in lower extremities. People who have difficulties in activities such as grasping, holding, and pushing, might have problems when interacting with egress components in certain facilities. Limitations in lower extremities, referred to as mobility impairments in the current study, refers to people with reduced spine or lower extremity function, wheelchair users and people walking with mobility devices such as sticks, rollators, etc. This classification is deemed to better inform designers in assessing the needs of these two groups, as these functional limitations are associated with different evacuation activities. The review also highlighted a set of functional limitations that has not been largely investigated. For instance, despite knowing that the ability to smell smoke is a cue in fire emergency scenarios [49], no research has been found related to this functional limitation. Despite the fact that speaking is one of the main means of communication, there are no dedicated studies investigating how speech impairments affect evacuation performance (e.g. communication with rescue services or other occupants). Similarly, given the great variety of conditions and disorders causing cognitive impairments, which may impact the ability to get orientated and communicate with others, limited research has been found on this issue [24].

Although the role of mobility impairments on evacuation activities is the most investigated issue (e.g. activities *using stairs*, *getting out of bed*, *moving to wheelchair*, *moving to escape mattress*, etc.), a better understanding of the needs of people with different levels of functional capacity would require the study of a larger variety of specific mobility impairments. While both engineering and medical research address *limitations of stamina*, [18], [36], [38], [42], [60], [61], [208] and *difficulty in reaching with arms and stretching* [18], [41], [48], [208], data concerning limitations linked to *poor balance*, *lack of coordination*, *difficulties in moving head*, *difficulty in bending, kneeling, etc.*, *loss of upper extremity skills* [18] are found only in medical studies. Dedicated fire safety engineering research should consider mobility impairments at a more detailed level linked to different evacuation activities.

The interaction between specific functional limitations and the environment can be perceived as an existing barrier for every evacuation activity [12], which represents the static dimension of this relationship. The dynamic dimension instead relates to the temporal scale of performing such activities. For example, in the literature, the ability of people with functional limitations to negotiate doors, i.e. *turn the doorknob, cross door saddle, keep the door opened* has been analysed [28], [43] but with limited sample sizes, which may not be considered representative of the great variety of actual limitations affecting this evacuation activity. *Turning the doorknob, crossing door saddle, keeping the door* *opened* are the environmental barriers for evacuation activity *Opening doors*. The level of activity performance depends on the interaction between the person with functional limitations and the specific environmental demands, i.e. if the environmental demands become barriers or the individuals manage to deal with them. The importance of including the concept of barriers in future research is also reflected in addressing the variety and complexity of functional limitations. For the activity *Opening doors*, in relation to the barrier *turn the doorknob,* the third level of ICF can be assigned, e.g. *Grasping* for the ICF category *Fine hand use*, and *Pulling or Pushing* for *Hand and arm use*. This way, the barriers help perceiving certain activity performance linked to specific functional limitation on even more detailed level, which can help better understanding the needs of vulnerable groups.

The scoping review on accessibility to public buildings for older people and people with functional limitations revealed that existing research was largely concentrated around the following access activities: using parking/drop-off area, route to entrance and pathways inside the building. A limited body of research concerned the use of different kinds of service desks inside the building and using emergency exits. Moreover, the articles were mainly focused on mobility and visual limitations and the predominant ICF activities of *Walking and moving*, *Changing and maintaining body position* and *Purposeful sensory experiences*. Research on accessibility issues in public buildings related to cognitive limitations and the predominant ICF activity of *Applying knowledge* was also scarce. Most of the articles reviewed consisted of the assessment of buildings with instruments in order to check the fulfilment of requirements for accessibility without including the target population groups. This suggests there is a need to develop and use scientifically robust instruments that are easy to administer. All articles that included study participants used study-specific checklists and often had the aim of evaluating whether certain facilities were accessible for specific groups, such as people using mobility devices. This scoping review demonstrated that there is a need for further instrument development and psychometric testing. In addition, studies should focus on enabling empirical evaluation and quantification of issued caused by different combinations of building features and functional limitations. Intervention studies with a before and after analysis are also lacking, which could give guidance on the impact of typical measures to improve accessibility. A variety of public buildings were examined, but health care and fitness facilities predominated. The type of buildings under investigation may be associated with a given incident or social debate at the time they were conducted. The most common environmental features studied were the parking/drop-off areas, entrance areas and hygiene facilities. All of the included articles considered mobility and several visual limitations, a few articles addressed cognitive limitations, and only one was about hearing limitations. In terms of the ICF, *Walking and moving* was the predominant activity that was most reported in the articles included in the current review, followed by *Purposeful sensory experiences* and *Changing and maintaining body position*. A methodological challenge is to address accessibility problems at the right level. When for example stairs and ramps were addressed in the articles included, environmental details such as handrails were not always discussed in depth. The environmental features that cause accessibility issues may differ depending on which functional limitations a person experiences. There is a large diversity in people's capacity to overcome different barriers and what they perceive as obstacles, while accessibility is just about the compliance with legislation, which means that accessibility of facilities does not per se guarantee that a person finds the facility usable. With solid evidence, accessibility can be addressed at societal level and may increase the possibilities for participation by all people regardless of their age, ability or disability.

The qualitative interview study allowed to explore the subjective perspectives on Egressibility of older people experiencing a wide variety of functional limitations. The aim was achieved using the qualitative analysis method of inductive reflexive thematic analysis on a set of 28 transcripts of semi-structured interviews, resulting in three themes: *Other people's difficulties in understanding, Strategies to cope with the limitation*, and *Uncertainty of evacuation*. The use of a qualitative approach - compared to quantitative approaches investigating physiological characteristics such as walking speed etc. [209] - allows for a nuanced and complex understanding of the perspectives and concerns related to Egressibility of older people with functional limitations. The results highlight aspects such as perceived risk and vulnerability, coping strategies, uncertainties about evacuation, etc. which may benefit from more in-depth studies. Main findings are that the themes and sub-themes largely reflect uncertainties or a lack of reliance on the physical environment and other people to be supportive in evacuation situations. To mitigate evacuation situations the participants were instead mostly considering changing their own behaviour, using other senses to compensate for functional limitations or avoiding visiting buildings where issues may occur. It should be noted that these findings are based on the responses of the participants in this study and hence do not present a comprehensive view on the issue of Egressibility, but rather the views of a relevant group (a sample of 60+ years old people with functional limitations from Sweden). Furthermore, we argue that measuring the physiological abilities of people with functional limitations is not sufficient in itself to guide the community in increasing the fire safety for this increasing portion of the population. Therefore, the research presented here provides valuable complementary guidance in doing so.

In the qualitative interview study, to characterize the sample in terms of their functional limitations, a self-assessment questionnaire was used. To ensure the questionnaire validly captures perceived functional limitations, it was developed through an extensive process involving multiple iteration. The responses to the questionnaire provided a nuanced picture of the functional limitations experienced by the individuals and demonstrated that a diversity of functional limitations was represented in the participants. It should be noted though that the reliability of the self-assessment questionnaire needs further testing, and a test-retest study would be recommended to support further use. It should be noted though that the self-assessment questionnaire is largely based on both the International Classification of Functioning, Disability and Health [126], as well as the Housing Enabler [16]. Those are widely used and established methods in their respective field and have been used to develop the questionnaire used in this study. While its further testing and analysis would be beneficial, this questionnaire still represents an accurate method for self-reporting functional limitations. An effort was made to recruit a diverse sample in terms of functional limitations. However, due to the qualitative nature of the current study it is not possible to compare the prevalence of the functional limitations in our sample to that found in other older population-based studies or population statistics. The way in which functional limitations are defined may differ across studies, depending on the ways of assessment (e.g. self-report versus professional assessment) as well as measurement instruments (i.e., types of questions or questionnaires) used. Nevertheless, functional limitations related to hearing were frequent in the sample, and are frequent in the Swedish population as a whole [210]. Based on Statistics Sweden [210], it is also indicated that visual impairments, mobility impairments and multiple functional limitations were more frequent in our sample than in the Swedish population of older adults.

The qualitative interview study highlighted the perspectives of the participants with various functional limitations in relation to Egressibility. The context of the discussions were wide, involving different environments and actions related to evacuation. This is in contrast to previous qualitative studies in the area, looking specifically at participants' perspectives on evacuation methods for mobility impaired [211], [212] or investigating evacuation issues in the specific context of historical buildings [213]. Compared to studies of historical buildings [213], the participants in the current study did not emphasize the importance of organizational aspects to a large extent. This may stem from the fact that public environments are different, and that in some, organization plays a bigger role in evacuation safety. Another possible explanation is that in the present study the participants did not emphasize their experience with fire drills or real fire scenarios. The results from the qualitative interview study should be seen as informative for identifying a set of key issues that may benefit from more in-depth studies.

The project also involved the development of a new tool, the Egress Enabler, to measure Egressibility, and the evaluation of its psychometric properties. The personal component of the Egress Enabler was directly adopted from the Housing Enabler assessing accessibility [16]. It was found through the development process that the description of functional capacity worked well also in the context of egress. Arguably, dichotomising functional capacity has its limitations. Not all people who use wheelchairs have the same functional capacity, and neither do people who experience difficulties with balance. This applies to all functional limitations [214].

Since the field of Egressibility is in its beginning, with only a few research studies regarding environmental barriers, the current work relies partly on scientific studies on accessibility. Specifically, the environmental component of the Egress Enabler was primarily based on two recent literature reviews in the domains of egress [215] and access [71]. Items were identified based on existing norms, standards and knowledge (e.g. [16], [155], [162], [165]). The review of environmental barriers as described in section 6.2 was undertaken mostly in the context of Swedish legislation and public buildings.

While the identification of items to include in the environmental component was challenging, requiring a lengthy iterative process, the evaluation of content validity through the expert panel approach yielded promising results. The results related to content validity were in line with previous efforts to develop similar tools in the accessibility domain [216]. The experts had difficulty rating 21% of the items, which further highlights the need for a checklist-based tool like the Egress Enabler as it is difficult for a single person (or even for a team of people in a given discipline) to obtain the required expertise in all domains covered by the Egress Enabler.

The environmental component was structured into nine different sub-components covering different evacuation elements found in public buildings. A challenge has been to determine the process by which scores are aggregated. One such issue lies in how the absence of an egress feature should be evaluated, something that was highlighted in the 2010 revision of the Housing enabler as well [16]. Each item of the environmental component could be given the maximum score of four on severity, representing 'impossible'. The sub-components incorporate between 7 and 25 items each. Hence, a building without the necessary features would receive a lower total score than the same building with the features present (albeit less accessible).

The application of weights to consider together multiple instances of the same sub-components in the Egress Enabler (e.g., multiple doors) introduced a set of issues. The rationale for including weights was to make comparison of different buildings possible. Nonetheless, some buildings are inherently less egressible due to an abundance of evacuation elements such as doors for example. However, a single occupant will likely not make use of all the doors in a building during an evacuation, and hence it would be misleading to add the scores for all doors.

As the scores generated by the tool indicate the possible extent of Egressibility issues, a higher maximum score for a certain functional limitation should be interpreted as more potential issues regarding evacuation for people with that functional limitation. Based on the scoring pattern, people relying on a mobility aid and wheelchair users had the highest possible maximum scores (209 and 230 respectively), whereas difficulties in moving head were associated with the lowest maximum score (14). This is not surprising, since building evacuation research shows that people relying on walking aids and wheelchair users are faced with many issues in regard to evacuation [143]. This may also explain why people with those specific limitations have been the subject of a higher number of studies [209], [215]. It can be argued that moving the head easily is not a crucial activity during evacuation, explaining the low level of potential issues for people with this functional limitation. For some functional limitations, it is currently not known how to eliminate environmental barriers to facilitate egress without relying on assisted evacuation. The limited identification of barriers might therefore lead to a lower maximum score. In other words, the scoring patterns aim to represent the current understanding of Egressibility.

In the case study applying the Egress Enabler, inter-rater reliability was considered "good" to "excellent" in relation to agreement by evaluation through single rater, absolute-agreement, two-way random effects model ICC [159]. In relation to only consistency, the reliability was estimated as "excellent". Reliability was lowest for the sub-components *Refuge areas*, *Stairs*, and *Outside environments*. The reason for the lower reliability found for the sub-components *Refuge areas* and *Stairs* was possibly because in the case study these features appeared more than once, and the instances were somewhat different. Therefore, the way they were weighted together had a great impact on the results. It was assessed by the authors that the *Outside environment* scored lower on reliability as it was the least defined sub-component. The outside environment covered a large area in the case study as it included three different paths from exits to the area of relocation. The fact that consistency was evaluated as higher than agreement might have been linked to the systematic differences between the rater pairs that accounted for some variation.

From the Egress Enabler case study presented, it can be seen that most Egressibility issues were found for people using a walking aid or wheelchair. This was expected since this group has been highlighted many times as particularly vulnerable with regards to evacuation [209], [211]. The case study included inaccessible vertical evacuation, explaining parts of the resulting high scores. The least Egressibility issues were found for people with difficulties in moving head, difficulties in reaching with arms, and difficulties in bending, kneeling, which could be because these activities are not as often performed during an evacuation. To be able to draw stronger conclusions, it would be beneficial to apply the Egress Enabler to several buildings and evaluate how they differ both in terms of Egress Enabler score and in building design.

Evaluation of discriminant aspects of construct validity of the Egress Enabler through five fictitious changes in building design (*adding a compliant ramp near the main exit; adding a compliant OEE near the main exit; altering door opening forces, thresholds, opening direction and opening procedures to be compliant; adding compliant communication possibilities and information in all refuge areas; removing the refuge areas*) revealed that four of the five changes increased the level of Egressibility. The removal of refuge areas decreased the level of Egressibility. The most significant negative change in relation to removing the refuge areas were found for the functional limitations "difficulty in interpreting information", "reliance on walking aid", and "wheelchair user". The fact that the level of Egressibility decreased for people relying on walking aid or wheelchair is perhaps obvious, but the fact that for other functional limitations the change was negative as well relates to the fact that the absence of a feature was considered equal to the presence of a fully non-compliant feature. Some features of a refuge area (e.g., the presence of communication possibilities for people who are deaf or hard of hearing) do not directly affect a wheelchair user, even though a wheelchair user will most likely use the refuge area. This aspect of the Egress Enabler is both positive and negative. It is negative as the Egress Enabler yields scores for features that may not be used by people with certain functional limitations, but it is at the same time positive since a person in a wheelchair can be deaf or hard of hearing at the same time. Adding a compliant ramp next to the main entrance was shown to have the most positive effect among the fictitious changes made. The smallest positive effect can be found for functional limitations related to upper body movement and people with difficulties in bending, kneeling, etc. The most positive effects were found for people with lower body movement limitations as well as people with sensory and interpretation limitations. It makes sense that adding a ramp had such a positive effect since it provides an opportunity for people who cannot evacuate via the stair.

The Egress Enabler is assuming self-evacuation. In evacuation situations, assistance in various ways is often used as a measure to mitigate Egressibility issues for people with functional limitations [154]. Assistance from others can often 'hide' environmental demands so that people with functional limitations do not experience the activity restrictions that would otherwise be associated with such an environmental barrier [217], [218]. For example, a heavy door is not a barrier for someone with limited muscle strength if it is held open by someone else. Nonetheless, assistance is not negative when it comes to the evacuation safety of people with functional limitations, but it is not included in this study. It is also known that in younger ages, the capacity to adapt to the environmental demands is greater than in older ages [214], meaning that Egressibility issues due to person-environment fit issues might be more recognized by older people. This highlights that it is difficult to validate a tool like this based on people's perceptions, as there is vast inter-person variation anticipated with respect to reported Egressibility issues experienced. Nonetheless, future studies should aim towards validating the Egress Enabler by surveying people with functional limitations. Preferably, real-life experiences should be sought, even though they may be difficult to find [119].

Due to the definition adopted for Egressibility, the Egress Enabler will always yield a score of zero when evaluating a building against a person without functional limitations. This highlights an important distinction between evacuation safety and Egressibility. There are two aspects of evacuation safety that are relevant in this context: the restriction of harm and suffering and equal provisions of safety. The Egress Enabler deals primarily with the latter and assumes that the restriction of harm and suffering is already fulfilled for persons without functional limitations.

During egress, time is of outmost importance. Egress is often measured in terms of time and presented as required safe egress time (RSET) during performance-based fire engineering design [219]. However, while a time-delay based approach may be appealing, it is currently unfeasible given the scarcity of current data and the vast variation in environmental design and functional capacity. Some aspects of Egressibility and accessibility are also difficult to measure in terms of time [220]. Although some environmental barriers may delay evacuation and could hence be possible to measure in terms of time, others may not cause delays, or delays that are hard to quantify, such as causing unnecessary harm and discomfort. Therefore, it was decided to not design the Egress Enabler to measure time delays for people with functional limitations. Nonetheless, Egressibility is only one aspect of evacuation safety, and assessments of time delays need to complement assessments of Egressibility.

The VR experiments focussed on a discrete choice in which participants were asked to choose an exit among two discrete alternatives. The alternatives were characterized by the door configuration and the characteristics of the simulated agent choosing the exit. The choices were then analysed by means of mixed logit and the strategies used by the participants were investigated through a questionnaire. Overall, the results show that the participants were affected by the variables introduced. These results also to some degree confirm previous findings in this field relating to social influence [168], [169], [188] and the theory of affordances [167].

The primary contribution of this VR experimental work was that the social influence guiding exit choice was influenced by the characteristics by the simulated agent. It was found that, on average, there was a stronger tendency among the participants to follow a simulated agent in a wheelchair than a simulated agent without a wheelchair. It is also evident that large variations in preference among the participants existed. The design of the exit door had an influence on the exit choices made by the participants. It was hypothesised that this effect would be small given that both exits were accessible to the participants of this study not experiencing functional limitations. This was found to be true when comparing to the influence of a simulated agent with a wheelchair choosing the same exit.

The findings of the VR study are in contrast to a previous study showing that people without functional limitations tended to avoid exits occupied by others with functional limitations [179]. When comparing the studies, two discrepancies can be found which may explain the differences in behaviour. First, the simulated agents with functional limitations were in this study represented by wheelchair as compared to mainly people with visual impairments in the study by Gaire et al. [179]. In a recent interview study including older people with functional limitations, one of the findings were that the interviewees considered the visibility of their limitation potentially influencing the altruistic behaviours of others around them [119]. Hence, this difference could have had an influence on the results. In the sub-sequent questionnaire, 31 participants stated that they wanted to be of help to the simulated agent in a wheelchair, influencing their choice of exit. Secondly, the number of other people or simulated agents present in the choice situation was fewer in this study compared to the study conducted by Gaire et al. [179]. Possibly, this could also influence the altruistic behaviour of the participants. A crowd could have had an effect in that 'responsibility' is distributed among a larger number of people, leading to a bystander effect [221] and therefore showing less positive influence to follow the simulated agent on a wheelchair.

In the VR study, a mixed logit model was estimated in contrast to conditional logit models. The main benefit was that taste variation between participants could be estimated. From a modelling perspective, this approach is beneficial in that it allows for modelling not only mean effects, but also variations within the population. Hence, using the results from a conditional logit model implies that all evacuees behave the same under identical circumstances. In reality, this is known to be incorrect and variations in preference exist and should be included in any modelling efforts.

Compared to other studies [184], [185], more Halton draws were needed in this study for the estimates to convergence. Although the reason for this cannot be concluded, one hypothesis is that the large taste variations observed in this study mean that a wider distribution had to be sampled, leading to more draws from the distribution needed.

Although the VR study proposes a choice model based on the results from the trials, its implementation into evacuation models should be done in a careful manner. The reason being that the present study presents a very specific environmental and social context, in which evacuee decision making should not be generalized to another context. Nevertheless, tendencies reported here can be used to inform the user of evacuation models on appropriate assumptions.

All in all, the project made use of a wide set of methods and approaches to investigate different aspects related to Egressibility and the impact of functional limitations on egress. This is deemed to be one of the largest studies on this subject encompassing a variety a research methods and approaches. It is desirable that this study will pave the way towards a new stream of research in the domain of Egressibility.

9. Future research

The current research project as a whole and its different parts (e.g. reviews, qualitative interview study, development of an assessment instrument and VR experiments) highlighted the need for several new studies in the domain of Egressibility, some of which are brought up here.

Depending on the degree of mobility loss, people with mobility limitations may need to use assistive devices for evacuation. Different studies (evacuation drills, experiments, Egressibility studies) have been conducted on the types of assistive devices for assisted and non-assisted evacuation [41], [43], [46], [55]–[58], [222], [223]. These studies provide data about the amount of time needed to prepare assistance, velocities of the assistive devices, total evacuation time depending on the type of device, their size and weight, physical demands on supporters and optimal number of people to manage devices during the evacuation. However, there are limited data on the activities that people with functional limitations need to perform to prepare for this type of evacuation. They will differ on several factors such as whether the evacuation is assisted or not or the experience of the person(s) giving assistance [224], causing frequent delays in the evacuation [225]. Additionally, the type of functional limitations will affect the activity performance and the type of assistive device that is most efficient for a given impairment. Further research should therefore be conducted to investigate the relationship between these variables.

Besides the static analysis of the evacuation activities in relation to functional limitations conducted in the present work, future research should include dynamic analyses to account for the variability present in different emergency egress situations. This could include the time required to go through an egress component or interpret and use a means of escape. For example, in contrast to the accessibility domain, during an evacuation, conditions affecting the accessibility of the means of egress may vary substantially over time both in terms of the population (e.g. using medications, substance abuse, assisted vs. self-evacuation) as well as the environment (e.g. lighting, presence of smoke/heat) [226], [227]. In particular, substance/medication use has been scarcely investigated in terms of its impact on evacuation, even though the impact of substances has been identified as an issue in the evacuation domain [228], [229]. This is also an issue because groups of older people with functional limitations making use of medication are a high risk group in fire scenarios [230]. In this context, the ICF can facilitate the evaluation in dynamic conditions and expand the knowledge on the subject.

Another issue identified is that most studies look at the impact of a given impairment in isolation. In contrast, people may have multiple impairments, and public buildings can often be very crowded, thus adding another layer of complexity to the specific evacuation needs of people with functional limitations. In crowded places, the evacuation performance of heterogeneous groups, including people with several functional limitations and able-bodied populations, will highly depend on the interactions between these groups and the space they are surrounded by [226], [231]. In a study on the movement of heterogeneous groups trough bottlenecks, it is shown that the higher mixing ratios of wheelchair users and pedestrians affect the moving efficiency and increase congestion. No specific studies were found concerning people with a stroller. The degree of this impact is also depending on the design (i.e. the angle) of the bottleneck [232]. In general, the underlying dynamics of social groups can indeed have a significant impact in emergency scenarios [233], [234].

This project indicated a scarcity of information on the role of cognitive impairments on evacuation activities (as well as in the accessibility domain). This was expected given the difficulties in collecting such data due to ethical and practical constraints. Therefore, future studies should ideally look into such limitations.

Future research could focus on predicting the activities which are potentially harder to perform and which may have a greater impact on evacuation performance. This can depend on the nature of the population and the environment. Such work would rely on an accurate assessment of the functional limitations. Therefore, a potential direction for future research is the systematic development and testing of a self-assessment questionnaire of functional limitations (possibly based on the instrument proposed in this work) specific to the context of egress and Egressibility. This could include the identification of more specific anchor points in the questionnaire that relate to the activities required during egress.

The participants included in the qualitative interview study lived in Sweden and the case study for the Egress Enabler was also conducted in Sweden. Previous research has suggested that culture affects the evacuation behaviour of people [235]. Therefore, a further generalization of the findings would require performing the study with a wide variety of populations from different cultures. As norms and standards can differ substantially between regions, it is anticipated that some work is needed to fully adopt the Egress Enabler to other regions. The same applies if the Egress Enabler is to be adapted to another environmental arena. It is also anticipated that for the Egress Enabler to continue to be relevant, it needs to be continually updated as norms, standards, and knowledge may change. Examples of how tools like the Egress Enabler can be adapted to other contexts can be found in the field of accessibility evaluation instruments [216], [236]. One key aspect of culture that is thought to have a large influence is the view of older people and people with disability in the society [237] (along with having repercussions on regulatory policies).

One of the findings in the qualitative interview study was that others tended to respect the needs of people that could easily be identified as vulnerable. In a society where there is more or less respect for the vulnerable, the findings may therefore have been different. Future research in the area of Egressibility relating to older citizens should investigate the role of cultural and social factors. Considering the definition adopted for Egressibility [238], it becomes evident that the built environment influences Egressibility to a large extent. It is therefore important to note that the findings from this kind of study may be different if it is conducted in a setting with the built environment being generally different. This includes for example a significantly higher proportion of high-rise buildings, the provision of refuge areas, the design of wayfinding systems, etc.

One indication is that the participants generally had limited experience of evacuation, and that they therefore had issues imagining such a situation. However, the participants are familiar with issues of accessibility encountered in everyday life and could easily draw parallels to other situations. Utilizing other methods for data collection, such as ethnographic go-alongs [239] where the participants are provided a fictitious evacuation scenario, may help in addressing these issues. Similarly, virtual reality [201] has shown great potential and therefore could be used to investigate the relation between degree of visibility of functional limitation versus proneness of others to help. In this context, it would be interesting to use the same study design adopted in VR but with different sample of participants (e.g., with mobility limitations or a different cultural background). Given the high experimental control, several additional variables related to the personal component (e.g. sample of the VR experiments) or environmental component (e.g. configuration of the exits and the space) could be explored in VR.

Future work on the Egress Enabler should also focus on improving its score system. A decision was made to equate the absence of a feature to the presence of a fully non-compliant feature. This means that the absence of a feature did not necessarily reflect the Egressibility issues associated, but this way the comparison of different buildings was made more consistent. While this approach proved useful at this stage, future studies might investigate other potential ways to aggregate the scores. For example, the maximum points for each egress feature, and the absence of such features, could be established through a Delphi study [240]. The items identified in the present study could then be used and weighted by the results of the Delphi study. More empirical data linked to the application of the Egress Enabler in different contexts would also be beneficial.

10. Conclusion

This is the final report of the project "Building Egressibility in an ageing society" funded by the Swedish Council for Sustainable Development FORMAS. The project adopted a multi-method approach to investigate different aspects related to Egressibility. This included mapping out the field of evacuation of people with functional limitations and related accessibility research in public buildings, perform a qualitative interview study on the perspectives of people with functional limitations, developing an Egressibility assessment instrument (the Egress Enabler) and demonstrate the use of Virtual Reality experiments to investigate the impact of functional limitations on evacuation.

This project highlighted the benefits and limitations of different research methods for the investigation of evacuation of people with functional limitations and shed light on several aspects related to Egressibility. This included improving our understanding on the perspectives of people with functional limitations on egress, providing a novel tool for the assessment of Egressibility in existing and future buildings, and enabling a better understanding of exit choice in presence of people on wheelchairs.

In conclusion, this project represents one of the largest research efforts at the time this work was conducted in the domain of Egressibility and it is deemed to pave the way towards a new stream of research in this area. Its bold premise and intended key message is that evacuation safety should be provided in an equal manner to every member of our society.

Appendix 1

Self-assessment of functional limitations

In this questionnaire, we ask you to grade your own functional ability. After each question, we ask you to grade your functional ability on a scale that follows each question. When you fill in the scale, imagine that zero represents no limitation, one represents least impaired, and six represents extensive limitation. Do not hesitate to ask if you are uncertain about anything.

1.1. Do you use glasses? Please mark one alternative for each category below:
At home: □ No □ Sometimes □ Always
In public places: □ No □ Sometimes □ Always

1.2. Do you have trouble seeing?
N.B.! If you have answered that you use glasses sometimes or always in public places, please grade your functional ability when you use glasses.

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

2.1. Do you use hearing aid? Please mark on alternative for each category below:
At home: □ No □ Sometimes □ Always
In public places: □ No □ Sometimes □ Always

2.2. Do you have trouble hearing normal sounds?
N.B.! If you have answered that you use hearing aid sometimes or always in public places, please grade your functional ability when you use hearing aid.

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

3. Do you have limited ability to turn the head to look up or down or to either side?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

4. Do you have reduced ability to move in your back, or do you have poor strength in your back, which makes it difficult for you to sit down/get up, kneel, bend or turn the body or to perform activities such as to walk? (Include also in your answer if you feel limited by bandage, corset or amputation)

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

5. Do you have reduced ability to move in your hip, or do you have poor strength in your hip, which makes it difficult for you to sit down/get up, kneel, bend or turn the body or to perform activities such as to walk? (Include also in your answer if you feel limited by bandage, corset or amputation).

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

6. Do you have reduced ability to move in <u>your knees,</u> or do you have poor strength in <u>your knees</u>, which makes it difficult for you to sit down/get up, kneel, bend or turn the body or to perform activities such as to walk? (Include also in your answer if you feel limited by bandage, corset or amputation).

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

7. Are you fully or partly dependent on walking aid to <u>walk indoors</u>? (Does not apply to prosthesis or a white cane due to visual impairment)

□ Fully □ Partially □ No

- □ Stick
- □ Crutches
- □ Rollator
- □ Other (specify): ______________________________

8. Are you fully or partly dependent on walking aid to <u>walk outdoors</u>? (Does not apply to prosthesis or a white cane due to visual impairment)

□ Fully □ Partially □ No

- □ Stick
- □ Crutches
- □ Rollator
- □ Other (specify): ______________________________

9. Are you fully or partly dependent on a <u>wheelchair indoors</u>?

□ Fully □ Partially □ No

- □ Manual wheelchair
- □ Electric wheelchair
- □ Electric-scooter (3- or 4-wheeler)
- □ Other (specify): ______________________________

10. Are you fully or partly dependent on a <u>wheelchair outdoors</u>?

□ Fully □ Partially □ No

- □ Manual wheelchair
- □ Electric wheelchair
- □ Electric-scooter (3- or 4-wheeler)
- □ Other (specify): ______________________________

11. Do you have problems with <u>balance</u> or do you get light-headed?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

12. Do you have problems with stamina when walking in stairs at normal pace (shortness of breath, pounding and pressure in chest)?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

13. Do you have problems with stamina (shortness of breath, pounding and pressure in chest) when walking on horizontal surfaces (floors, sidewalk or similar) at normal pace?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

14. Do you have difficulty in controlling, placing or steering arms and legs in a coordinated and effective manner?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

15. Do you have limited ability to move one or both arms or experience stiffness, reduced sense of touch, pain or tremor in one or both arms or wrists? Please grade your functional ability on the following scale, and mark which arm(s) are affected.

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

□ right arm, □ left arm, □ both arms

16. Do you have difficulty grasping or performing well-balanced movements with one or both hands, such as writing or fastening buttons, or do you have tremor that causes problems? Please grade your functional ability on the following scale, and mark which hand(s) are affected.

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

□ right hand, □ left hand, □ both hands

17. Do you lack functional ability in one or both arms, i.e. are you paralyzed, amputated, or do you have other similar limitation that leads to reduced functioning in one or both arms? (Answer No if you only have reduced functioning in the hands or if you have a prosthesis that compensates you functional limitation well)

□ Yes (specify): ____ □ No

18. Do you have reduced ability to feel the smell of smoke?

	□	□	□	□	□	□	□	
No limitation	0	1	2	3	4	5	6	Extensive limitation

Appendix 2. Interview Guide (in Swedish)

Intervjuguide

Syfte:

- Att undersöka hur personer med funktionella begränsningar tänker kring utrymning och hur de skulle beskriva sin egen förmåga att utrymma.
- Att identifiera ifall det finns vissa kritiska aspekter i den byggda miljön som kan vara till hjälp eller skapa problem för personer med funktionella begränsningar.
- Att identifiera grupper av personer som är särskilt sårbara med hänsyn till utrymning.

Introduktion:
I detta projekt är vi intresserade i att undersöka hur personer med funktionella begränsningar tänker kring utrymning och hur de upplever sin egen förmåga att utrymma. När vi pratar om utrymning menar vi när man i rask takt behöver ta sig ut ur en byggnad vid en nödsituation. I detta möte är det dina tankar och synpunkter som är viktiga. Jag kommer att ställa frågor, men det finns inga svar som är rätt eller fel. Min uppgift idag är att lyssna på vad du har att säga.

Öppningsfråga:
Var vänlig och förklara varför du är intresserad av att delta i den här studien.

Teman att diskutera:
Temana berör i huvudsak interaktionen med miljön i ett utrymningsscenario.

1. **Den publika miljön**
   Detta tema berör individens användning av och uppfattning av den publika miljön.
   Startfrågor
   - Kan du berätta om vart du vart du vanligtvis går under vardagar och på helger?
   - Finns det publika miljöer som du besöker mer sällan och som du tycker är svåra att besöka? Varför är dessa miljöer svårare att besöka? Finns det miljöer du undviker för att du är orolig för din egen säkerhet kopplat till utrymning?
2. **Funktionella begränsningen**
   Berör individens uppfattning om den egna funktionella begränsningen.
   Startfrågor
   - Vilka aspekter av din funktionella begränsning tycker du skapar mest problem när du befinner dig i en publik miljö?
   - Har du någon fördel av din funktionella begränsning när du befinner dig i en publik miljö eller vid en eventuell utrymningssituation?
3. **Utrymning**
   Berör individens tankar, synpunkter och erfarenheter av utrymning.
   Startfrågor
   - Har du upplevt en utrymningssituation? Ifall du gjort det, var vänlig och berätta vad som hände.
   - Hur upplever du situationer som liknar en utrymningssituation, exempelvis att ta dig ut efter en konsert, föreläsning, sportevenemang, tågstation eller liknande?
   - Oroar du dig för att du ska konfronteras med en utrymningssituation?
   - Hur skulle du beskriva din egen förmåga att utrymma?
   - Använder du dig av några försiktighetsåtgärder för att kompensera för din funktionella begränsning?

- Tror du att du tänker mer på hur du kan ta dig ut jämfört med en person som inte har några funktionella begränsningar?

4. Den byggda miljön

Berör interaktionen och perceptionen av den byggda miljön och speciella aspekter av den.

Startfrågor

- Finns det saker i den byggda miljön som du tycker är svårare att interagera med koppling till utrymning?
- Finns det saker i den byggda miljön som är speciellt användbara för dig med koppling till utrymning?

5. Om andra?

Detta tema används för att diskutera andra personers förmåga och hur andra kan påverka eller bli påverkade av individens funktionella begränsning.

Startfrågor

- Vilken grupp av personer med en specifik funktionell begränsning är att se som den mest sårbara gruppen med hänsyn till utrymning?
- Tror du att du skulle få hjälp av andra i en utrymningssituation?
- Oroar du dig för att du skulle påverka andra i en utrymningssituation?

Appendix 3. Environmental component of the Egress Enabler

Notification systems

Item #	Item	Yes	No	Scoring pattern													
				A	**B1**	**B2**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
101	Is there an evacuation alarm with auditory signals?			1	3	3											
102	Does the audible alarm include sounds at lower frequencies (i.e. not only 2500 Hz or more)?						2										
103	The sound pressure level of the evacuation alarm is less than 70dBA or less than 10dBA above ambient sound (measured at the maximum distance from alarm), or louder than 110dBA (measured at the minimum distance from alarm).			2			4										
104	Is there an evacuation alarm with visual signals that can be seen throughout the area that the sub-component refers to?			1			2										
105	IF NO TO #104: Is there complimentary visual signals in spaces where a person might be alone, e.g. in accessible bathrooms?			1			4										
106	Visual signals are presented 180 cm or higher from the floor.				2												
107	If people are expected to be sleeping in the area: 1) is the alarm complemented with a low-frequency alarm (approx. 520 Hz) OR 2) is the bed or similar equipped with a vibrating device (bed-shaker or pillow-shaker)?						3										

Signage

Item #	Item	Yes	No	Scoring pattern													
				A	**B1**	**B2**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
201	Signs are posted and arranged along circulation paths to adequately show how to get to the nearest exit and are clearly visible and not blocked by other objects. Notice the difference between this item and item 210.			2	2												
202	Signs are posted and arranged along circulation paths to adequately show how to get to the nearest exit and are in tactile text or in braille.					1											
203	Emergency exits are clearly marked with appropriate signage.			2	2												
204	Are the evacuation signs internally illuminated?				3												
205	Pictorial symbols are included on evacuation signs.			2	3												
206	If there are evacuation paths involving stairs, evacuation paths not involving stairs are indicated as accessible via signage.															3	3
207	If an exit or path involves stairs, the direction to the closest exit or path without stairs is given.															3	4
208	Are evacuation signage involving text that are located within reach complemented with tactile information?				1	1											
209	Is the height of evacuation signage greater than (viewing distance (m) / constant)? The constant is 200 for internally illuminated signs, and 100 for other signs.			1	3												

210	There are brightly lit signs, displays, or other lit objects in or near the line of vision that obstruct exits signs or distract attention from them. Examples include advertisement banners and other information displays. Notice the difference between this item and item 201.			1	3												
211	Are there audio instructions (directional sound system or similar) to aid orientation?			1	2	3											
212	Are there tactile maps/evacuation plans near the main entrance, and is there a tactile path leading to them?				1	2											

Circulation space

Item #	Item	Yes	No	Scoring pattern													
				A	**B1**	**B2**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
301	Is the circulation path sufficiently wide? (at least 150 cm at all places)															3	4
302	Is the clear height at least 200 cm?				1	3		1	1		2				3	1	
303	There are obstructions (e.g. furniture, equipment, protruding objects) on the evacuation paths.				2	3		1	1							2	3
304	The walking distance to the nearest emergency exit exceeds 60 meters.					1				4						2	3
305	Are there steep gradients in the circulation path's walking direction (more than 1:20), or is there a steep cross slope (more than 1:48)?							3	3	3						3	4
306	Are there thresholds higher than 15 mm? 30 mm thresholds are allowed if there are sloped edges.				2	3		3	3							3	4
307	Is it possible to rest during the evacuation without hindering others? Required at least every six meters (travel distance).							2	2	3						3	3
308	Are the escape routes used in general circulation?			3	2	4											
309	The escape route is illogical and/or complicated. Examples include routes with many turns and/or doors.			3	1	3										1	1
310	Visual contrast is provided on evacuation routes to minimize falling risks.			1	3												
311	Are there sufficient tactile cues of abrupt level changes/other hazards?				2	3											
312	Is the surface regular/even (without joins, sloping sections, cracks, and holes larger than 5 mm in the direction of travel), and slip-free?				2	3		1	1						1	3	3
313	If there is carpeting, does it make wheelchair travel difficult?															3	4
314	Excessive queuing is expected on horizontal egress components.					1		3	2	3	1					3	3
315	Is lighting sufficient, non-blinding and without sharp reflexes? Refers to situations where there is a power outage.			1	2			1	2								
316	Evacuation is expected to occur through windows.				1	2		3	3			2		4	3	4	4
317	Is it possible to relocate to a safe place outside the building without using stairs, ramp or OEE from the circulation space? A refuge area is not considered a safe place outside the building.																
	Note: the forthcoming items should only be considered once per isolated circulation space. That is, if there are two circulation spaces that connects horizontally without level differences, these items should only be considered for one of them.																

318	IF NO TO #317: Is it possible to relocate horizontally to a safer place (another fire compartment) to avoid using the stairs? A refuge area is an example of a safer place, but it could also be another fire compartment.					1		1	1	3					2	3	4
319	IF NO TO #317: is a ramp, OEE or area of refuge available in close connection to stairs to allow for relocation to a safe place outside the building?							2	2	3					2	3	4
320	IF NO TO #317: Is there a ramp available to egress from the circulation space to a safe place outside the building? (IF YES: evaluate the ramp and the stair; IF NO: evaluate stair) The scores in the scoring pattern reflects the presence of a fully non-compliant ramp.			6	19	26	3	#	#	#	1		1			#	#
321	IF NO TO #320: Is there a refuge area available to egress from the circulation space? (IF YES: evaluate all refuge areas) The scores in the scoring pattern reflects the presence of a fully non-compliant refuge area.			#	6	9	4	3	5	4	1	3	6	7	3	#	#
322	IF NO TO #320: Is there an OEE available to egress from the circulation space to a safe place outside the building? (IF YES: evaluate all OEE's) The scores in the scoring pattern reflects the presence of a fully non-compliant OEE.			#	13	17	6	#	#	5		3	6	7	2	#	#

Refuge areas

Item #	Item	Yes	No	Scoring pattern													
				A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
401	Is there sufficient maneuvering spaces where turning is necessary? (at least 1,3 x 1,3 m)															3	4
402	Are there at least two independent refuge areas where necessary?							2	2	3					2	3	4
403	The refuge area is large enough to accommodate the needed number of occupants (70*130 cm * Total occupancy * 0,01; minimum 70*130 cm).							1	1	1					1	3	4
404	Is there information in the refuge area that the refuge area is a safe environment in case of fire?			3												3	4
405	Are signs in the refuge area equipped with appropriate size letters?			1	1												
406	Are signs in the refuge area equipped with tactile letters or braille letters?				2	3											
407	If there are controls in the refuge area, are the controls illogically designed? Examples include too many controls, or improper signage. Examples of controls include communication device controls.			4	2	3											
408	Does the refuge area have controls that require complex maneuvers and good precision?			2	1	2			2				3	3		1	
409	Does the refuge area have controls that require use of hands?												3	4		1	
410	Are there communication possibilities in the refuge area?			2												3	4
411	IF yes to #410: is there only one-way communication?			2												3	4
412	Is there a dedicated way for a person with a hearing or speech impairment to communicate from the refuge area?						4										
413	Are the emergency communication device located 80 cm (+- 10 cm) from the floor?					1					1	3				2	4

Occupant Evacuation Elevators (OEE's)

Item #	Item	Yes	No	Scoring pattern

				A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
501	The OEE is clearly indicated as such (i.e. safe to use for evacuation).			3												2	3
502	Are signs inside and outside the OEE printed with proper contrast?				3												
503	Is there audio information/signal indicating OEE arrival?			1	2	4											
504	Is there visual information/signal located 180 cm or more from the floor indicating OEE arrival?						2										1
505	Do OEE signals indicate the direction of the lift?			1													
506	Is the OEE door power operated, remains open for at least 20 seconds when activated, and reopens automatically when obstructed by an object or person?							3	3							3	4
507	Can the OEE be used without assistance from others (staff or similar)?															2	3
508	Is there a communication system by the OEE?			3												1	2
509	Is there a dedicated way for a person with a hearing or speech impairment to communicate by the OEE?						4										
510	Is there sufficient space in the OEE (at least 200*140 cm)?							1	1							3	4
511	Does the OEE stop at the same level as the building floor, and is the gap between the OEE and the building floor less than 3 cm?			1	1	2		2	2						1	3	4
512	Are there handrails in the OEE?					1		3	3	3						3	
513	Is there a seat in the OEE?							1	1	2					1	3	
514	Is there enough of clear space for a person to approach and reach the controls and use the OEE? (at least 80*120 cm)?															2	3
515	There are illogically designed controls inside and/or outside the OEE.			4	2	3											
516	Are controls inside and/or outside the OEE placed within height 0.9-1.0 m?					1						3				2	4
517	Does the OEE have controls inside and/or outside the OEE that require complex maneuvers and good precision?			2	1	2		1					3	3		1	
518	Does the OEE have controls inside and/or outside the OEE that require use of hands?								1				3	4		1	
519	Are the control buttons inside and/or outside the OEE equipped with tactile characters or braille?				2	4											
520	Do floor buttons inside the OEE have visual indicators to show each floor destination?			1	2												

Ramps

Item #	Item	Yes	No	Scoring pattern													
				A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
601	Is the clear width at least 90 cm?															3	4
602	There are obstructions (e.g. furniture, equipment, protruding object) on the ramp.				2	3		1	1							2	3
603	Is there a level landing where the ramp changes direction that is at least 150 x 150 cm?							1	1							3	4
604	Is it possible to rest during the evacuation without hindering others? Resting places are required every six meters (travel distance).							3	3	3						3	3
605	Is the ramp steeper than 1:20 in the travel direction?							3	3	3						3	4
606	Is there a steep cross slope (more than 1:48)?							3	3	3						3	4

607	Are there sufficient tactile cues of abrupt level changes/other hazards?				2	4												
608	The route to the ramp is illogical and/or complicated. Examples include routes with many turns or if it is hidden.			3	1	3												
609	Is there protection (4 cm or higher) against slipping off?				1	3		1									3	3
610	Does the surface of the ramp extend at least 30 cm beyond the inside face of the handrail?				1	3		1									2	3
611	Visual contrast is provided on the ramp and handrails to minimize falling risks.			1	3			2										
612	Excessive queuing is expected.						3	3	3								3	3
613	Is lighting sufficient, non-blinding and without sharp reflexes? This refers to situations where there is a power outage.			1	2			2										
614	Are there handrails on both sides?				1	3		2	2	3							2	
615	Do handrails have at least 30 cm extensions at both top and bottom?				1	2		2	2	1							2	
616	Are handrails placed at 85-95 cm of height?				1	1		1	1	1							1	
617	Is the handrail gripping surface continuous, obstructed along the top or sides, and easy to grip with one hand (i.e. not too big or small)?				1	1		1	1	1			1				1	
618	Ramp includes see-through material. Examples include grated steel.			1	1			3			1							
619	Is the ramp's surface regular/even (without joins, cracks, and holes larger than 5 mm in the direction of travel) and slip-free?				2	3		2	1								3	3

Stairs

Item #	Item	Yes	No	Scoring pattern														
				A	**B1**	**B2**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**
701	Are there tactile cues to stairway in the circulation path?				1	4												
702	Is the clear width at least 120 cm at all places?														1	3	4
703	Is the clear height at least 200 cm?				1	3		1			2				3		
704	Are there obstructions (e.g. furniture, equipment, protruding objects) on the evacuation paths?				2	3		1	1							2	3
705	The stair is used in general circulation.			4	3	4											
706	The vertical distance of the stair exceeds 15 m.					1				4					4	4	4
707	Is it possible to rest during the evacuation without hindering others? Resting places are required at least every six meters (diagonal distance).							3	3	3					3	3	3
708	Is there a resting area in front of the stair (max 1:50, at least 150*150 cm)?							3	3	3					2	3	3
709	Is it a spiral stair?				1	2		3	3	3	1				2	4	4
710	A stair-descent device is provided.															2	3
711	The provided stair-descent device requires transfer from wheelchair or other mobility aid.															2	3
712	Are there trained staff available to aid with the use of the stair-descent device?															2	3
713	Excessive queuing is expected.				1	2		3	2	3	1					3	3
714	Visual contrast is provided on handrails.			1	3			2									
715	Are there visual patterns on the surface of stair treads that make edges of treads distinct?			1	3												

716	Is lighting sufficient, non-blinding and without sharp reflexes? This refers to situations where there is a power outage.			1	2			2									
717	Stairs include see-through material. Examples include grated steel.			1	1			3			1						
718	Are the steps with projecting nosing?			1	2	3		2	3								
719	Are there tactile cues on the first and last step?				1	3											
720	Are stair treads regular and with at least 26 cm depth, and are the stair risers regular and of 15-17 cm height?				3	3		3	3	3					2		
721	Are the stair treads even (without joins, sloping sections, cracks, and holes larger than 5 mm) and slip-free?				2	3		1	1						1	3	
722	Are there handrails on both sides?				2	3		3	2	3						3	
723	Do handrails have at least 30 cm extensions at both top and bottom?				1	3		3	2	1						3	
724	Are handrails placed at 85-95 cm of height?				1	1		1	1	1						1	
725	Is the handrail gripping surface continuous, obstructed along the top or sides, and easy to grip with one hand (i.e. not too big or small)?				1	1		1	1	1			1			1	

Doors

Item #	Item	Yes	No	Scoring pattern													
				A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
801	Does the door opening have at least 80 cm clearance?															3	4
802	Is the clear height of the door at least 200 cm?				1	3		1	1		2				3		
803	Is there sufficient maneuvering space in front of the door? (at least 1,5 x 1,5m and 70 cm on the opening side)							1	1	1						3	4
804	The evacuation door is easily detected as such (e.g. through signage or contrasting color).			2	3												
805	Is the door opened in the evacuation direction?			1		1		1	1			1		1		2	3
806	Are operable parts of the door hardware within 80-120 cm from the floor?					2						2				2	3
807	Does the door have a complicated or illogical opening procedure?			4	2	4							1				
808	Does the door have hardware that is operable with one hand?								1				1	4		2	3
809	Does the door have hardware that require tight grasping, pinching or twisting of the wrist?								1				4			1	1
810	The vertical force required to open the door is more than 25N.							2	2	2		3	2	4		2	2
811	The horizontal force required to open the door is more than 25N.							2	2	2		3	2	4		3	3
812	Does the door open automatically through the use of a sensor, electronic device or push button, and is the automatic opening operable during an emergency?			1				2	2	1		3	3	4		2	2
813	Does the door stay in open position or stay open sufficient time to get through comfortably? (Minimum 20 seconds)				1	2		3	3	2						3	3
814	Are there thresholds higher than 15 mm? 30 mm is allowed if there are sloped edges.				3	3		3	3							3	4
815	Does the door have a glass section without contrasts?				2												
816	If there are two consecutive doors, e.g. vestibule, is the distance between the doors at least 120 cm plus the width of the doors when swinging into the space?								1							2	3

Outside Environment

Item #	Item	Yes	No	Scoring pattern													
				A	B1	B2	C	D	E	F	G	H	I	J	K	L	M
901	Is the path to the assembly point at least 150 cm wide?															3	3
902	The clear height of the path to the assembly point is at least 200 cm.				1	3		1	1		2				3		
903	Are there obstructions, e.g. furniture, plants and/or equipment on the path to the assembly point?				2	3		1	1							2	3
904	Are there steep gradients on the path to the assembly point? (more than 1:20)							3	3	3						3	4
905	Are there sufficient tactile cues of abrupt level changes/other hazards?				2	4											
906	Is there a steep cross slope? (more than 1:48)							3	3	3						3	4
907	Are there high curbs or steps on the path to the assembly point? (more than 4 cm)				2	3		3	3							3	4
908	The path to the assembly point is illogical and/or complicated. Examples include routes with many turns or routes that are hidden.			3	1	3											
909	Visual contrast is provided on the path to the assembly point to minimize falling risks			1	3												
910	Is the surface regular/even surface (without joins, sloping sections, cracks, and holes larger than 5 mm in the direction of travel) and slip-free? Consider also the conditions in case of moderate rainfall.				2	3		2	2							3	3
911	Is lighting sufficient, non-blinding and without sharp reflexes? Refers to both daytime and nighttime.			1	2			1	1								
912	Signs are posted and arranged along the path to the assembly point to adequately show how to get there and are clearly visible.			1	2												

Appendix 4. Egress Enabler - User Guide

The Egress Enabler tool and the user guide can be found in this repository:
https://zenodo.org/record/7075501

Disclaimer

The developers of the Egress Enabler makes no warranty, expressed or implied, to users of the tool, and accepts no responsibility for its use and/or content. Users of the Egress Enabler assume sole responsibility for determining the appropriateness of its use in any particular application; for any conclusions drawn from the results of its use; and for any actions taken or not taken as a result of analysis performed using the Egress Enabler.

Users are warned that the Egress Enabler is intended for use only by those competent in the fields of human behaviour in fire, fire safety, human functioning and accessibility, and is intended only to supplement the informed judgment of the qualified user. Lack of accurate predictions by the Egress Enabler could lead to erroneous conclusions with regard to fire safety. All results should be evaluated by an informed user.

Background

This document serves as a user guide to the Egress Enabler, an evaluation tool for Egressibility developed as a joint effort between the division of fire safety engineering, and the Center for Ageing and Supportive Environments (CASE), both at Lund University.

Components

The Egress Enabler consists of two components, the environmental and the personal, which serves as the basis for the evaluation of Egressibility in the analysis phase.

Environmental component

The environmental component contains description of the environmental barriers present in the context under evaluation. These barriers are interpreted as barriers for people with functional limitations to make use of the egress components present in the environment. Ultimately, these barriers may hinder a person to evacuate in a safe and timely manner. In the Egress Enabler, these environmental barriers consist of checklist items that are to be evaluated on a dichotomous scale (yes/no).

Personal component

The personal component describes functional limitations in 14 different domains. These 14 functional limitations are given in Table A.

Table A. Functional limitations in the Egress Enabler.

Functional limitation
A. Difficulty in interpreting information
B1. Severe loss of sight
B2. Complete loss of sight
C. Severe loss of hearing
D. Prevalence of poor balance
E. Incoordination
F. Limitations of stamina
G. Difficulties in moving head
H. Difficulty in reaching with arms
I. Difficulty in handling and fingering
J. Loss of upper extremity skills
K. Difficulty in bending, kneeling, etc.

L. Reliance on walking aids
M. Wheelchair user

Analysis

With the use of the two above mentioned components, an analysis of Egressibility is undertaken. Associated with each environmental barrier is a scoring pattern that contains severity ratings for each of the 14 functional limitations. The severity ratings are on a scale from zero to four. The interpretation of each severity rating is given in Table B.

Table B. Severity ratings and interpretation.

Severity rating	Interpretation
0	No issues
1	Potential issue
2	Issue
3	Severe issue
4	Impossibility

Note that the severity ratings are put in relation to a person without any functional limitations. That is, if an item is equally difficult for a person without functional limitations, and a person with functional limitation X, the severity rating is 0.

Applying sub-components

In order to make the Egress Enabler flexible to use and applicable for a variety of building designs, a flexible structure is adopted. This involves structuring all items in nine different sub-components, each representing a different egress component. The sub-components need to be applied to evaluate the building. As some egress components are often found more than once in a building's evacuation strategy, the Egress Enabler employs a weighting strategy to make evaluation of different buildings, with different numbers of egress components, comparable. This essentially means that each sub-component should only be counted once, so that the maximum Egress Enabler score will be the same irrespective of the building being evaluated (apart from buildings that do or do not require vertical evacuation).

This section contains a description of the sub-components, when to apply them, how to weight them, and things to consider when applying them.

Notification systems

The purpose of the notification system is to notify the occupants of the imminent threat. Preferably, the system should do so reliably irrespective of the presence of functional limitations.

The scale should be applied once to every unique notification system. Common is that the notification system is the same throughout a building, and the sub-component can then be applied only once. If there are more than one sub-component applied, they should be weighted according to the number of occupants that is expected to be served by the notification system.

Signage

Signage is used to direct occupants to the emergency exits, as well as provide other information that is useful in the event of an evacuation. This information should reach all occupants of the building.

The scale should be applied once to every unique signage. Common is that the signage is designed similarly throughout a building, and the sub-component can then be applied only once. If there are more than one sub-component applied, they should be weighted according to the number of occupants that is expected to be served by the signage.

Circulation spaces
A circulation space is the horizontal space that makes up the building. Each circulation space is then connected to doors, refuge areas, stairs, refuge areas and/or occupant evacuation elevators.

A circulation space sub-component should be applied at least once per floor (separated by vertical egress components). If two or more circulation spaces are substantially different within a floor, apply more than one sub-component per floor.

The sub-component circulation space contains additional items at the end, items #318-322. These items should only be accounted for once per floor, even though there may be more than one circulation space sub-component per floor.

To weigh the sub-component together, the same principle applies as for notification system and signage. That is, the circulation space sub-components should be weighted according to their expected usage counted in number of occupants.

Refuge areas
The purpose of a refuge area is to provide a safe place for people who cannot evacuate otherwise to stay and wait for help from the fire and rescue services or similar.

Apply one sub-component per refuge area and weigh them together according to their expected usage.

Occupant evacuation elevators
Occupant evacuation elevators are supplied as a means of vertical evacuation. Important to note is that occupant evacuation elevators are specifically designed to be used during evacuations and are hence not to be confused with regular non-emergency elevators.

Apply one sub-component per occupant evacuation elevator and weigh them together according to their expected usage.

Ramps
Ramps are supplied as a means of vertical evacuation. Only ramps that are used in the evacuation strategy should be evaluated.

Apply one sub-component per ramp and weigh them together according to their expected usage.

Stairs
Stairs are supplied as a means of vertical evacuation. The distinction between a stair and a step is that a stair has more than one step, or a step of at least 10 cm height. Only stairs that are used in the evacuation strategy should be evaluated.

Apply one sub-component per stair and weigh them together according to their expected usage.

Doors
Doors are means of evacuating from one room to another, or from one room to the outside environment. Only doors that are used in the evacuation strategy should be evaluated.

Apply one sub-component per door and weigh them together according to their expected usage.

Outside Environment

The outside environment refers to the area from outside the emergency exit connecting to the outside and to the area of relocation. Buildings typically have stairs or ramps connecting the entrances and exits to the outside. These should be regarded as stairs or ramps in the evaluation and not part of the outside environment under certain circumstances. If it is possible for a person to relocate to a safe distance from the building without using the stair or ramp, the stair or ramp should not be evaluated as stair or ramp. Instead, they should be a part of the outside environment evaluation.

Apply one sub-component per uniquely designed path from exits to the area of relocation and weigh them together according to their expected usage.

Analysing results

The results from an evaluation using the Egress Enabler can be visualized in different ways. First, there are two different ways to visualize the yielded score: Egress Enabler score (EES), and a star rating. Secondly, there is an option to present the results as an average of all functional limitations, or individually for all functional limitations.

Egress Enabler score

The Egress enabler score presents the sum of all individual scores associated with the environmental barriers that are present. The maximum score is 1314 for all functional limitations combined. The maximum score for each functional limitation is given by the following scoring pattern: [A:81, B1:141, B2:162, C:28, D:130, E:115, F:82, G:14, H:20, I:27, J:35, K:40, L:209, M:230]. A higher score means that more Egressibility issues were found. The Egress Enabler score is divided by all functional limitations to make it easier to identify where Egressibility issues exists. A simple example of how the Egress Enabler scores should be aggregated is provided in Table C. On the last row, the aggregated score for each functional limitation (A-M) is presented. In the rightmost column on the last row, the total Egress Enabler score is presented. Note that it is only the scoring patterns of those items that have been evaluated (marked with an x) in the grey cells that are used in the calculation of the score. The grey cell represents the non-compliant answer.

Table C. Example of aggregating Egress Enabler scores.

	Yes	No	A	B1	B2	C	D	E	F	G	H	I	J	K	L	M	
Item 1	x		1	2	1			2	2		1		2		1	3	
Item 2		x		3		2	2		1	1		2	3	1			
Item 3		x	2		2		1	1		2	2			1	2		
Results			*1+2*	*2*	*1+2*	*0*	*1*	*2+1*	*2*	*2*	*1+2*	*0*	*2*	*1*	*1+2*	*3*	*∑28*

Star rating

The Egress Enabler score is used to calculate a star rating from zero to four stars. More stars mean the building is more 'egressible', when compared to the norms, regulations and knowledge that constitutes the environmental component of the Egress Enabler. A star rating of four is given to buildings in which no environmental barriers were found. Three-star ratings is given to buildings where 0-25% of the potential Egressibility issues were found. Two-star ratings for buildings where 25-50% of the potential Egressibility issues were found. One-star rating for buildings where 50-75% of the potential Egressibility issues were found No stars are given to buildings where 75-100% of the potential Egressibility issues were found.

References

[1] K. M. Christensen, S. D. Collins, J. M. Holt, and C. N. Phillips, 'The relationship between the design of the built environment and the ability to egress of individuals with disabilities', *Rev. Disabil. Stud. Int. J.*, vol. 2, no. 3, 2014.

[2] E. Carattin, R. Lovreglio, E. Ronchi, and D. Nilsson, 'Affordance-based evaluation of signage design for areas of refuge', in *14th International Conference and Exhibition on Fire Science and Engineering*, Royal Holloway College, University of London, UK, 2016.

[3] E. Ronchi and D. Nilsson, 'Fire evacuation in high-rise buildings: a review of human behaviour and modelling research', *Fire Sci. Rev.*, vol. 2, no. 1, p. 7, 2013, doi: 10.1186/2193-0414-2-7.

[4] A. Jonsson, C. Bonander, F. Nilson, and F. Huss, 'The state of the residential fire fatality problem in Sweden: Epidemiology, risk factors, and event typologies', *J. Safety Res.*, vol. 62, pp. 89–100, Sep. 2017, doi: 10.1016/j.jsr.2017.06.008.

[5] A. P. Harpur, K. E. Boyce, and N. C. McConnell, 'An investigation into the circumstances surrounding fatal dwelling fires involving very young children', *Fire Saf. J.*, vol. 61, pp. 72–82, Oktober 2013, doi: 10.1016/j.firesaf.2013.08.008.

[6] E. Ronchi, 'Disaster management: Design buildings for rapid evacuation', *Nature*, vol. 528, no. 7582, pp. 333–333, Dec. 2015, doi: 10.1038/528333b.

[7] W. M. Jolly *et al.*, 'Climate-induced variations in global wildfire danger from 1979 to 2013', *Nat. Commun.*, vol. 6, 2015.

[8] P. Thompson, D. Nilsson, K. Boyce, and D. McGrath, 'Evacuation models are running out of time', *Fire Saf. J.*, vol. 78, pp. 251–261, Nov. 2015, doi: 10.1016/j.firesaf.2015.09.004.

[9] M. P. Lawton and L. Nahemow, 'Ecology and the aging process.', 1973.

[10] R. J. Scheidt and C. Norris-Baker, 'The general ecological model revisited: Evolution, current status, and continuing challenges', *Annu. Rev. Gerontol. Geriatr.*, vol. 23, no. 1, pp. 34–58, 2003.

[11] L. M. Verbrugge and A. M. Jette, 'The disablement process', 1994.

[12] World Health Organization, Ed., *International classification of functioning, disability and health: ICF*. Geneva: World Health Organization, 2001.

[13] S. M. V. Gwynne, 'Improving the Collection and Use of Human Egress Data', *Fire Technol.*, vol. 49, no. 1, pp. 83–99, 2013, doi: 10.1007/s10694-010-0210-9.

[14] A. C. Tricco *et al.*, 'PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation', *Ann. Intern. Med.*, vol. 169, no. 7, pp. 467–473, 2018.

[15] V. Braun and V. Clarke, 'Thematic analysis.', in *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological.*, Washington, DC, US: American Psychological Association, 2012, pp. 57–71. doi: 10.1037/13620-004.

[16] S. Iwarsson and B. Slaug, *Housing Enabler — A method for rating/screening and analysing accessibility problems in housing. Manual for the complete instrument and screening tool.* Veten & Skapen HB & Slaug Data Management., 2010.

[17] O. Bukvic, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, and E. Ronchi, 'A review on the role of functional limitations on evacuation performance using the International Classification of Functioning, Disability and Health', *Fire Technol.*, Sep. 2020, doi: 10.1007/s10694-020-01034-5.

[18] B. Slaug, O. Schilling, S. Iwarsson, and G. Carlsson, 'Typology of person-environment fit constellations: a platform addressing accessibility problems in the built environment

for people with functional limitations', *BMC Public Health*, vol. 15, no. 1, p. 834, Dec. 2015, doi: 10.1186/s12889-015-2185-4.

[19] P. Geoerg, F. Berchtold, S. Gwynne, K. Boyce, S. Holl, and A. Hofmann, 'Engineering egress data considering pedestrians with reduced mobility', *Fire Mater.*, p. fam.2736, Aug. 2019, doi: 10.1002/fam.2736.

[20] S. Gwynne and K. E. Boyce, 'Engineering Data', in *SFPE Handbook of Fire Protection Engineering*, M. J. Hurley, D. T. Gottuk, J. R. Hall, K. Harada, E. D. Kuligowski, M. Puchovsky, J. L. Torero, J. M. Watts, and C. J. Wieczorek, Eds. New York, NY: Springer New York, 2016, pp. 2429–2551. Accessed: Feb. 18, 2016. [Online]. Available: http://link.springer.com/10.1007/978-1-4939-2565-0_64

[21] D. A. Purser and M. Bensilum, 'Quantification of behaviour for engineering design standards and escape time calculations', *Saf. Sci.*, vol. 38, no. 2, pp. 157–182, Jul. 2001, doi: 10.1016/S0925-7535(00)00066-7.

[22] E. Ronchi and D. Nilsson, 'Basic Concepts and Modelling Methods', in *Evacuation Modeling Trends*, A. Cuesta, O. Abreu, and D. Alvear, Eds. Cham: Springer International Publishing, 2016, pp. 1–23. doi: 10.1007/978-3-319-20708-7_1.

[23] R. W. Huey, D. S. Buckley, and N. D. Lerner, 'Audible performance of smoke alarm sounds', *Int. J. Ind. Ergon.*, vol. 18, no. 1, pp. 61–69, 1996.

[24] L. Kecklund, K. Andrée, S. Bengston, S. Willander, and E. Siré, 'How Do People with Disabilities Consider Fire Safety and Evacuation Possibilities in Historical Buildings?—A Swedish Case Study', *Fire Technol.*, vol. 48, no. 1, pp. 27–41, Jan. 2012, doi: 10.1007/s10694-010-0199-0.

[25] K. A. M. Moinuddin, D. Bruck, and L. Shi, 'An experimental study on timely activation of smoke alarms and their effective notification in typical residential buildings', *Fire Saf. J.*, vol. 93, pp. 1–11, Oct. 2017, doi: 10.1016/j.firesaf.2017.07.003.

[26] G. Proulx, *Evacuation planning for occupants with disability*. Fire Risk Management Program, Institute for Research in Construction …, 2002.

[27] E. D. Kuligowski, 'Human Behavior in Fire', in *SFPE Handbook of Fire Protection Engineering*, M. J. Hurley, D. Gottuk, J. R. Hall, K. Harada, E. Kuligowski, M. Puchovsky, J. Torero, J. M. Watts, and C. Wieczorek, Eds. New York, NY: Springer New York, 2016, pp. 2070–2114. doi: 10.1007/978-1-4939-2565-0_58.

[28] K. E. Boyce, T. J. Shields, and G. W. H. Silcock, 'Toward the Characterization of Building Occupancies for Fire Safety Engineering: Capability of People with Disabilities to Read and Locate Exit Signs', *Fire Technol.*, vol. 35, no. 1, pp. 79–86, Feb. 1999, doi: 10.1023/A:1015395318183.

[29] R. Passini and G. Proulx, 'Wayfinding without Vision: An Experiment with Congenitally Totally Blind People', *Environ. Behav.*, vol. 20, no. 2, pp. 227–252, Mar. 1988, doi: 10.1177/0013916588202006.

[30] J. G. Sørensen, Danmarks Tekniske Universitet, and DTU Byg, *Evacuation of people with visual impairments: PhD thesis*. Lyngby: DTU Civil Engineering, Technical University of Denmark, 2015.

[31] K. E. Boyce, T. J. Shields, and G. W. H. Silcock, 'Toward the Characterization of Building Occupancies for Fire Safety: Prevalence, Type, and Mobility of Disabled People', *Fire Technol.*, vol. 35, 1999.

[32] R. Passini, H. Pigot, C. Rainville, and M.-H. Tétreault, 'Wayfinding in a Nursing Home for Advanced Dementia of the Alzheimer's Type', *Environ. Behav.*, vol. 32, no. 5, pp. 684–710, Sep. 2000, doi: 10.1177/00139160021972748.

[33] R. Passini, C. Rainville, N. Marchand, and Y. Joanette, ‘Wayfinding in dementia of the Alzheimer type: Planning abilities’, *J. Clin. Exp. Neuropsychol.*, vol. 17, no. 6, pp. 820–832, 1995, doi: 10.1080/01688639508402431.
[34] G. Proulx, ‘Evacuation time and movement in apartment buildings’, *Fire Saf. J.*, vol. 24, no. 3, pp. 229–246, Jan. 1995, doi: 10.1016/0379-7112(95)00023-M.
[35] E.-S. Park, D. K. Yoon, and Y.-W. Choi, ‘Leave no one behind: Experiences of persons with disability after the 2017 Pohang earthquake in South Korea’, *Int. J. Disaster Risk Reduct.*, vol. 40, p. 101261, Nov. 2019, doi: 10.1016/j.ijdrr.2019.101261.
[36] J. D. Averill *et al.*, ‘Collapse of the World Trade Center Tower’, National Institute of Standards and Technology, 2005.
[37] K. Butler, E. Kuligowski, S. Furman, and R. Peacock, ‘Perspectives of occupants with mobility impairments on evacuation methods for use during fire emergencies’, *Fire Saf. J.*, vol. 91, pp. 955–963, Jul. 2017, doi: 10.1016/j.firesaf.2017.04.025.
[38] M. Spearpoint and H. A. MacLennan, ‘The effect of an ageing and less fit population on the ability of people to egress buildings’, *Saf. Sci.*, vol. 50, no. 8, pp. 1675–1684, Oct. 2012, doi: 10.1016/j.ssci.2011.12.019.
[39] E. Kuligowski, R. Peacock, E. Wiess, and B. Hoskins, ‘Stair evacuation of older adults and people with mobility impairments’, *Fire Saf. J.*, vol. 62, pp. 230–237, Nov. 2013, doi: 10.1016/j.firesaf.2013.09.027.
[40] J. D. Averill *et al.*, ‘Collapse of the World Trade Center Towers’. National Institute of Standards and Technology, 2005.
[41] P. Geoerg, R. M. Polzin, J. Schumann, S. Holl, and A. Hofmann, ‘Small-scale Studies on Evacuation Characteristics of Pedestrians with physical, mental or age-related Disabilities’, *J. Phys. Conf. Ser.*, vol. 1107, p. 072006, Nov. 2018, doi: 10.1088/1742-6596/1107/7/072006.
[42] E. Ronchi *et al.*, ‘Ascending evacuation in long stairways: Physical exertion, walking speed and behaviour’, Department of Fire Safety Engineering, Lund University, Lund, Sweden, 3192, 2015.
[43] K. E. Boyce, T. J. Shields, G. W. H. Silcock, and F. Sert, ‘Toward the Characterization of Building Occupancies for Fire Safety Engineering: Capabilities of Disabled People Moving Horizontally and on an Incline’, *Fire Technol.*, vol. 35, pp. 51–67, 1999, doi: https://doi.org/10.1023/A:1015339216366.
[44] A. Wickramasinghe, D. C. Ranasinghe, C. Fumeaux, K. D. Hill, and R. Visvanathan, ‘Sequence Learning with Passive RFID Sensors for Real-Time Bed-Egress Recognition in Older People’, *IEEE J. Biomed. Health Inform.*, vol. 21, no. 4, pp. 917–929, Jul. 2017, doi: 10.1109/JBHI.2016.2576285.
[45] R. M. Kesler *et al.*, ‘Egress Efficacy of Persons with Multiple Sclerosis During Simulated Evacuations’, *Fire Technol.*, vol. 53, no. 6, pp. 2007–2021, Nov. 2017, doi: 10.1007/s10694-017-0668-9.
[46] M. Hashemi, ‘Emergency evacuation of people with disabilities: A survey of drills, simulations, and accessibility’, *Cogent Eng.*, vol. 5, no. 1, p. 1506304, Jan. 2018, doi: 10.1080/23311916.2018.1506304.
[47] N. C. McConnell and K. E. Boyce, ‘Refuge areas and vertical evacuation of multistorey buildings: the end users’ perspectives’, *Fire Mater.*, vol. 39, no. 4, pp. 396–406, 2015, doi: 10.1002/fam.2205.
[48] K. E. Boyce, T. J. Shields, G. W. H. Silcock, and F. Sert, ‘Toward the Characterization of Building Occupancies for Fire Safe Engineering: Capability of Disabled People to Negotiate Doors’, p. 11, 1999.

[49] M. Lloyd and K. Roen, '"When you smell smoke…": "Risk factors" and fire safety in action', *Health Risk Soc.*, vol. 4, no. 2, pp. 139–153, Jul. 2002, doi: 10.1080/13698570220137033.
[50] B. Burian, 'Do You Smell Smoke? Issues in the Design and Content of Checklists for Smoke, Fire, and Fumes', in *Proceeding of the International Society of Air Safety Investigators 2005 Conference*, Forth Worth, Texas, USA, 2005.
[51] G. Proulx, B. Kyle, and J. Creak, 'Effectiveness of a Photoluminescent Wayguidance System', *Fire Technol.*, vol. 36, no. 4, pp. 236–248, 2000, doi: 10.1023/A:1015475013582.
[52] J. L. Roberts, 'An Area of Refuge: Due Process Analysis and Emergency Evacuation for People with Disabilities', *Va. J. Soc. Policy Law*, vol. 13, pp. 127–178, 2006 2005.
[53] E. Ronchi and D. Nilsson, 'Fire evacuation in high-rise buildings: a review of human behaviour and modelling research', *Fire Sci. Rev.*, vol. 2, no. 1, p. 7, 2013, doi: 10.1186/2193-0414-2-7.
[54] G. E. Hedman, 'Travel Along Stairs by Individuals with Disabilities: A Summary of Devices Used During Routine Travel and Travel During Emergencies', in *Pedestrian and Evacuation Dynamics*, R. D. Peacock, E. D. Kuligowski, and J. D. Averill, Eds. Boston, MA: Springer US, 2011, pp. 109–119. doi: 10.1007/978-1-4419-9725-8_10.
[55] A. Hunt, E. R. Galea, and P. J. Lawrence, 'An analysis and numerical simulation of the performance of trained hospital staff using movement assist devices to evacuate people with reduced mobility: MOVEMENT ASSIST DEVICES TO EVACUATE PRM', *Fire Mater.*, vol. 39, no. 4, pp. 407–429, Jun. 2015, doi: 10.1002/fam.2215.
[56] S. A. Lavender, G. E. Hedman, J. P. Mehta, P. A. Reichelt, K. M. Conrad, and S. Park, 'Evaluating the physical demands on firefighters using hand-carried stair descent devices to evacuate mobility-limited occupants from high-rise buildings', *Appl. Ergon.*, vol. 45, no. 3, pp. 389–397, May 2014, doi: 10.1016/j.apergo.2013.05.005.
[57] S. A. Lavender, J. P. Mehta, G. E. Hedman, S. Park, P. A. Reichelt, and K. M. Conrad, 'Evaluating the physical demands when using sled-type stair descent devices to evacuate mobility-limited occupants from high-rise buildings', *Appl. Ergon.*, vol. 50, pp. 87–97, Sep. 2015, doi: 10.1016/j.apergo.2015.02.008.
[58] J. P. Mehta, S. A. Lavender, G. E. Hedman, P. A. Reichelt, S. Park, and K. M. Conrad, 'Evaluating the physical demands on firefighters using track-type stair descent devices to evacuate mobility-limited occupants from high-rise buildings', *Appl. Ergon.*, vol. 46, pp. 96–106, Jan. 2015, doi: 10.1016/j.apergo.2014.07.009.
[59] K. Boyce, 'Safe evacuation for all - Fact or Fantasy? Past experiences, current understanding and future challenges', *Fire Saf. J.*, vol. 91, pp. 28–40, Jul. 2017, doi: 10.1016/j.firesaf.2017.05.004.
[60] E. R. Galea, L. Hulse, R. Day, A. Siddiqui, and G. Sharp, 'The UK WTC 9/11 Evacuation Study: an Overview of the Methodologies Employed and some Analysis Relating to Fatigue, Stair Travel Speeds and Occupant Response Times', in *Proceedings of the 4th International Symposium on Human Behaviour in Fire*, Robinson College, Cambridge, UK, 2009, pp. 27–40.
[61] A. Stewart, E. Elyan, J. Isaacs, L. McEwen, and L. Wilson, 'The Effect of Person Order on Egress Time: A Simulation Model of Evacuation From a Neolithic Visitor Attraction', *Hum. Factors J. Hum. Factors Ergon. Soc.*, vol. 59, no. 8, pp. 1222–1232, Dec. 2017, doi: 10.1177/0018720817729608.
[62] K. Kuklane and I. Holmér, *Respiratory flow patterns during physical work with respirators*. ARRAY(0x7d45a30), 2002.

[63] M. Hashemi, 'Dynamic, Stream-Balancing, Turn-Minimizing, Accessible Wayfinding for Emergency Evacuation of People Who Use a Wheelchair', *Fire Technol.*, vol. 54, no. 5, pp. 1195–1217, Sep. 2018, doi: 10.1007/s10694-018-0735-x.
[64] M. Lloyd and K. Roen, '"When you smell smoke…":'risk factors' and fire safety in action', *Health Risk Soc.*, vol. 4, no. 2, pp. 139–153, 2002.
[65] K. Fridolf, K. Andrée, D. Nilsson, and H. Frantzich, 'The impact of smoke on walking speed', *Fire Mater.*, vol. 38, no. 7, pp. 744–759, 2014, doi: 10.1002/fam.2217.
[66] K. Fridolf, E. Ronchi, D. Nilsson, and H. Frantzich, 'Movement speed and exit choice in smoke-filled rail tunnels', *Fire Saf. J.*, vol. 59, pp. 8–21, Jul. 2013, doi: 10.1016/j.firesaf.2013.03.007.
[67] T. Jin, 'Visibility and Human Behavior in Fire Smoke', in *SFPE Handbook of Fire Protection Engineering (3rd edition)*, Di Nenno P., Quincy, MA (USA): National Fire Protection Association, 2008, pp. 2-42-2–53.
[68] G. Proulx and R. F. Fahy, 'Human Behavior and Evacuation Movement in Smoke', *ASHRAE Trans.*, vol. 114, no. 2, pp. 159–165, Oct. 2008.
[69] E. Ronchi, K. Fridolf, H. Frantzich, D. Nilsson, A. L. Walter, and H. Modig, 'A tunnel evacuation experiment on movement speed and exit choice in smoke', *Fire Saf. J.*, vol. 97, pp. 126–136, Apr. 2018, doi: 10.1016/j.firesaf.2017.06.002.
[70] S. Arias, R. Fahy, E. Ronchi, D. Nilsson, H. Frantzich, and J. Wahlqvist, 'Forensic virtual reality: Investigating individual behavior in the MGM Grand fire', *Fire Saf. J.*, vol. 109, p. 102861, Oct. 2019, doi: 10.1016/j.firesaf.2019.102861.
[71] G. Carlsson, B. Slaug, S. Schmidt, L. Norin, E. Ronchi, and G. Gefenaite, 'A scoping review of public building accessibility', *Disabil. Health J.*, p. 101227, 2021.
[72] A. Calder, G. Sole, and H. Mulligan, 'The accessibility of fitness centers for people with disabilities: a systematic review', *Disabil. Health J.*, vol. 11, no. 4, pp. 525–536, 2018.
[73] A. M. Calder and H. F. Mulligan, 'Measurement properties of instruments that assess inclusive access to fitness and recreational sports centers: A systematic review', *Disabil. Health J.*, vol. 7, no. 1, pp. 26–35, 2014.
[74] K. A. Martin Ginis, J. K. Ma, A. E. Latimer-Cheung, and J. H. Rimmer, 'A systematic review of review articles addressing factors related to physical activity participation among children and adults with physical disabilities', *Health Psychol. Rev.*, vol. 10, no. 4, pp. 478–494, 2016.
[75] N. Welage and K. P. Liu, 'Wheelchair accessibility of public buildings: a review of the literature', *Disabil. Rehabil. Assist. Technol.*, vol. 6, no. 1, pp. 1–9, 2011.
[76] H. C. Ahn, E. E. McGovern, E. E. Walk, and R. F. Edlich, 'Architectural barriers to persons with disabilities in businesses in an urban community', *J. Burn Care Rehabil.*, vol. 15, no. 2, pp. 176–179, 1994.
[77] N. F. Al-Mansoor, 'Universal mosque/masjid design', *Stud. Health Technol. Inform.*, vol. 256, pp. 293–298, 2018.
[78] V. Alagappan, A. Hefferan, and A. Parivallal, 'Exploring accessibility issues of a public building for the mobility impaired. Case study: interstate bus terminal (ISBT), Vijayawada, India', *Disabil. Rehabil. Assist. Technol.*, vol. 13, no. 3, pp. 271–279, 2018.
[79] I. F. Andrade and others, 'Assessment method of accessibility conditions: how to make public buildings accessible?', *Work*, vol. 41, no. Supplement 1, pp. 3774–3780, 2012.
[80] K. P. Arbour-Nicitopoulos and K. A. M. Ginis, 'Universal accessibility of "accessible" fitness and recreational facilities for persons with mobility disabilities', *Adapt. Phys. Act. Q.*, vol. 28, no. 1, pp. 1–15, 2011.

[81] B. J. Cardinal and M. D. Spaziani, 'ADA compliance and the accessibility of physical activity facilities in western Oregon', *Am. J. Health Promot.*, vol. 17, no. 3, pp. 197–201, 2003.
[82] T. K. Crowe, S. Picchiarini, and T. Poffenroth, 'Community participation: Challenges for people with disabilities living in Oaxaca, Mexico, and New Mexico, United States', *OTJR Occup. Particip. Health*, vol. 24, no. 2, pp. 72–80, 2004.
[83] D. R. Dolbow and S. F. Figoni, 'Accommodation of wheelchair-reliant individuals by community fitness facilities', *Spinal Cord*, vol. 53, no. 7, pp. 515–519, 2015.
[84] L. N. Dos Santos and R. J. M. de Carvalho, 'Ergonomics and accessibility for people with visual impairment in hotels', *Work*, vol. 41, no. Supplement 1, pp. 1417–1424, 2012.
[85] J. K. Doshi, A. D. Furlan, L. C. Lopes, J. DeLisa, and L. R. Battistella, 'Conferences and convention centres' accessibility to people with disabilities.', *J. Rehabil. Med.*, vol. 46, no. 7, pp. 616–619, 2014.
[86] A. N. Evcil, 'Wheelchair accessibility to public buildings in Istanbul', *Disabil. Rehabil. Assist. Technol.*, vol. 4, no. 2, pp. 76–85, 2009.
[87] S. Figoni, L. McClain, A. Bell, J. Degnan, N. Norbury, and R. Rettele, 'Accessibility of physical fitness facilities in the Kansas City metropolitan area', *Top. Spinal Cord Inj. Rehabil.*, vol. 3, no. 3, pp. 66–78, 1998.
[88] C. L. Graham and J. R. Mann, 'Accessibility of primary care physician practice sites in South Carolina for people with disabilities', *Disabil. Health J.*, vol. 1, no. 4, pp. 209–214, 2008.
[89] D. B. Gray, K. A. Morgan, M. Gottlieb, and H. H. Hollingsworth, 'Person factors and work environments of workers who use mobility devices', *Work*, vol. 48, no. 3, pp. 349–359, 2014.
[90] T. Hamzat and O. Dada, 'Wheelchair accessibility of public buildings in Ibadan, Nigeria', *Asia Pac. Disabil. Rehabil. J.*, vol. 16, no. 2, pp. 115–124, 2005.
[91] L. I. Iezzoni, K. Kilbridge, and E. R. Park, 'Physical access barriers to care for diagnosis and treatment of breast cancer among women with mobility impairments', in *Oncology nursing forum*, 2010, vol. 37, no. 6, p. 711.
[92] C. S. Kim, D. Lee, S. Kwon, and M. K. Chung, 'Effects of ramp slope, ramp height and users' pushing force on performance, muscular activity and subjective ratings during wheelchair driving on a ramp', *Int. J. Ind. Ergon.*, vol. 44, no. 5, pp. 636–646, 2014.
[93] E. C. King, T. Dutta, S. M. Gorski, P. J. Holliday, and G. R. Fernie, 'Design of built environments to accommodate mobility scooter users: part II', *Disabil. Rehabil. Assist. Technol.*, vol. 6, no. 5, pp. 432–439, 2011.
[94] L. Leal Rocha, M. Vieira de Lima Saintrain, and A. Pimentel Gomes Fernandes Vieira-Meyer, 'Access to dental public services by disabled persons', *BMC Oral Health*, vol. 15, no. 1, pp. 1–9, 2015.
[95] L. M. Martin, 'Wheelchair accessibility of public buildings in Utica, New York', *Am. J. Occup. Ther.*, vol. 41, no. 4, pp. 217–221, 1987.
[96] L. McClain, 'Shopping center wheelchair accessibility: ongoing advocacy to implement the Americans with Disabilities Act of 1990', *Public Health Nurs.*, vol. 17, no. 3, pp. 178–186, 2000.
[97] L. McClain and C. Todd, 'Food store accessibility', *Am. J. Occup. Ther.*, vol. 44, no. 6, pp. 487–491, 1990.
[98] L. McClain, J. Lutz, D. Salmans, and S. Wright, 'Shopping mall wheelchair accessibility checklist based on the ADA guidelines', *Occup. Ther. Health Care*, vol. 11, no. 4, pp. 41–66, 1999.

[99] L. McClain *et al.*, ‘Restaurant wheelchair accessibility’, *Am. J. Occup. Ther.*, vol. 47, no. 7, pp. 619–623, 1993.
[100] A. R. Meyers, J. J. Anderson, D. R. Miller, K. Shipp, and H. Hoenig, ‘Barriers, facilitators, and access for wheelchair users: sbstantive and methodologic lessons from a pilot study of environmental effects’, *Soc. Sci. Med.*, vol. 55, no. 8, pp. 1435–1446, 2002.
[101] M. C. Mojtahedi, P. Boblick, J. H. Rimmer, J. L. Rowland, R. A. Jones, and C. L. Braunschweig, ‘Environmental barriers to and availability of healthy foods for people with mobility disabilities living in urban and suburban neighborhoods’, *Arch. Phys. Med. Rehabil.*, vol. 89, no. 11, pp. 2174–2179, 2008.
[102] A. Moyo, U. Useh, S. Siziya, and E. Munyonga, ‘Comparison of wheelchair accessibility of public buildings pre and post the International Year of Disabled Persons (IYDP) in Harare, Zimbabwe: a case study.’, *Cent. Afr. J. Med.*, vol. 46, no. 5, pp. 124–127, 2000.
[103] N. R. Mudrick, M. L. Breslin, M. Liang, and S. Yee, ‘Physical accessibility in primary health care settings: results from California on-site reviews’, *Disabil. Health J.*, vol. 5, no. 3, pp. 159–167, 2012.
[104] A. Mohammad, T. S. Al-Harbi, and others, ‘Design of the built environment and the integration of wheelchair users in the Kingdom of Saudi Arabia: Commentary and exploratory study’, *J. Dev. Disabil.*, vol. 22, no. 2, p. 121, 2016.
[105] D. Nary, A. K. Froehlich, and G. White, ‘Accessibility of fitness facilities for persons with physical disabilities using wheelchairs’, *Top. Spinal Cord Inj. Rehabil.*, vol. 6, no. 1, pp. 87–98, 2000.
[106] N. Reich, ‘Disability and accessibility: A look at shopping facilities’, *J. Rehabil.*, vol. 46, no. 3, p. 24, 1980.
[107] J. H. Rimmer, B. Riley, E. Wang, and A. Rauworth, ‘Development and validation of AIMFREE: Accessibility Instruments Measuring Fitness and Recreation Environments’, *Disabil. Rehabil.*, vol. 26, no. 18, pp. 1087–1095, Sep. 2004, doi: 10.1080/09638280410001711432.
[108] J. H. Rimmer, S. Padalabalanarayanan, L. A. Malone, and T. Mehta, ‘Fitness facilities still lack accessibility for people with disabilities’, *Disabil. Health J.*, vol. 10, no. 2, pp. 214–221, 2017.
[109] D. Rivano-Fischer, ‘Wheelchair accessibility of public buildings in Al Ain, United Arab Emirates (UAE)’, *Disabil. Rehabil.*, vol. 26, no. 19, pp. 1150–1157, 2004.
[110] M. M. Sá, R. Azevedo, M. C. Martins, O. Machado, and J. Tavares, ‘Accessibility of sports facilities for persons with reduced mobility and assessment of their motivation for practice’, *Work*, vol. 41, no. Supplement 1, pp. 2017–2023, 2012.
[111] N. Saigal and R. Narayan, ‘Structural barriers at the workplace for employees with vision and locomotor disabilities in New Delhi, India’, *Work*, vol. 48, no. 3, pp. 329–337, 2014.
[112] J. Sanchez, G. Byfield, T. T. Brown, K. LaFavor, D. Murphy, and P. Laud, ‘Perceived accessibility versus actual physical accessibility of healthcare facilities’, *Rehabil. Nurs.*, vol. 25, no. 1, pp. 6–9, 2000.
[113] J. Seliger, ‘Community mental health center readiness to comply with section 504 of the rehabilitation Act’, *Community Ment. Health J.*, vol. 17, no. 3, pp. 236–246, 1981.
[114] U. Useh AM Moyo, E. Munyonga, ‘Wheelchair accessibility of public buildings in the central business district of Harare, Zimbabwe’, *Disabil. Rehabil.*, vol. 23, no. 11, pp. 490–496, 2001.

[115] L. Zissermann and J. Tumiel, ‘The architectural accessibility of urban facilities to the disabled: a summary of descriptive survey results’, *Spinal Cord*, vol. 27, no. 5, pp. 370–371, 1989.
[116] The United States Department of Justice, ‘Americans with Disabilities Act of 1990’, 42 USC 12101, 1990.
[117] M. Dischinger, *Design for all Senses. Accessible Spaces for Visually Impaired Citizens*. Chalmers Tekniska Hogskola (Sweden), 2000.
[118] World Medical Association, ‘World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects’, *JAMA*, vol. 310, no. 20, pp. 2191–2194, Nov. 2013, doi: 10.1001/jama.2013.281053.
[119] E. Smedberg, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, and E. Ronchi, ‘Perspectives on egressibility of older people with functional limitations’, *Fire Saf. J.*, vol. 127, p. 103509, 2022.
[120] U. Flick, *The SAGE Handbook of Qualitative Data Analysis*. 1 Oliver’s Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd, 2014. doi: 10.4135/9781446282243.
[121] K. Säfsten and M. Gustavsson, *Research Methodology - For Engineers and Other Problem-Solvers*, 1st ed. Lund, Sweden: Studentlitteratur Ab, 2020.
[122] WHO, ‘Decade of healthy ageing: baseline report’, World Health Organization, Geneva, Switzerland, 2020.
[123] V. Braun and V. Clarke, ‘To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales’, *Qual. Res. Sport Exerc. Health*, pp. 1–16, Dec. 2019, doi: 10.1080/2159676X.2019.1704846.
[124] B. Saunders *et al.*, ‘Saturation in qualitative research: exploring its conceptualization and operationalization’, *Qual. Quant.*, vol. 52, no. 4, pp. 1893–1907, 2018, doi: 10.1007/s11135-017-0574-8.
[125] M. Mason, ‘Sample Size and Saturation in PhD Studies Using Qualitative Interviews’, *Forum Qual. Soc. Res.*, vol. 11, no. 3, 2011, doi: http://dx.doi.org/10.17169/fqs-11.3.1428.
[126] World Health Organization, *International classification of functioning, disability and health : ICF*. World Health Organization, 2001.
[127] QSR International Pty Ltd., *NVivo*. 2018. [Online]. Available: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home
[128] V. Braun and V. Clarke, ‘One size fits all? What counts as quality practice in (reflexive) thematic analysis?’, *Qual. Res. Psychol.*, pp. 1–25, Aug. 2020, doi: 10.1080/14780887.2020.1769238.
[129] V. Braun and V. Clarke, ‘Using thematic analysis in psychology’, *Qual. Res. Psychol.*, vol. 3, no. 2, pp. 77–101, 2006.
[130] A. Bryman, S. Becker, and J. Sempik, ‘Quality Criteria for Quantitative, Qualitative and Mixed Methods Research: A View from Social Policy’, *Int. J. Soc. Res. Methodol.*, vol. 11, no. 4, pp. 261–276, Oct. 2008, doi: 10.1080/13645570701401644.
[131] I. Korstjens and A. Moser, ‘Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing’, *Eur. J. Gen. Pract.*, vol. 24, no. 1, pp. 120–124, Jan. 2018, doi: 10.1080/13814788.2017.1375092.
[132] Y. S. Lincoln and E. G. Guba, *Naturalistic Inquiry*. SAGE Publications Ltd, 1985.
[133] D. Kahneman and A. Tversky, ‘Subjective Probability: A Judgement of Representativeness’, *Cognit. Psychol.*, vol. 3, pp. 430–454, 1972, doi: 10.1016/0010-0285(72)90016-3.
[134] L. C. Boer and S. J. van Wijngaarden, ‘Directional sound evacuation from smoke-filled tunnels’, *Safe Reliab. Tunn. Innov. Eur. Achiev. Prague Czech Repub.*, 2004.

[135] D. Withington and M. Lunch, ‘Directional Sound Evacuation . An Improved System for Way Guidance from Open Spaces and Exit Routes on Ships’, London, Mar. 2003, p. 6.
[136] E. Ronchi, K. Fridolf, H. Frantzich, D. Nilsson, A. L. Walter, and H. Modig, ‘A tunnel evacuation experiment on movement speed and exit choice in smoke’, *Fire Saf. J.*, vol. 97, pp. 126–136, Apr. 2018, doi: 10.1016/j.firesaf.2017.06.002.
[137] E. Smedberg and E. Ronchi, ‘Review of Alarm Technologies to Wake Sleeping People Who are Deaf or Hard of Hearing’. Fire Protection Research Foundation, 2021.
[138] E. Smedberg, E. Ronchi, and V. Hutchison, ‘Alarm Technologies to Wake Sleeping People Who are Deaf or Hard of Hearing’, *Fire Technol.*, vol. 58, no. 4, pp. 2485–2507, Jul. 2022, doi: 10.1007/s10694-022-01265-8.
[139] D. Kahneman, S. P. Slovic, P. Slovic, A. Tversky, and C. U. Press, *Judgment Under Uncertainty: Heuristics and Biases*. Cambridge University Press, 1982.
[140] M. J. Kinsey, S. M. V. Gwynne, E. D. Kuligowski, and M. Kinateder, ‘Cognitive Biases Within Decision Making During Fire Evacuations’, *Fire Technol.*, vol. 55, no. 2, pp. 465–485, Mar. 2019, doi: 10.1007/s10694-018-0708-0.
[141] M. Karemaker, G. A. ten Hoor, R. R. Hagen, C. H. M. van Schie, K. Boersma, and R. A. C. Ruiter, ‘Elderly about home fire safety: A qualitative study into home fire safety knowledge and behaviour’, *Fire Saf. J.*, vol. 124, p. 103391, Sep. 2021, doi: 10.1016/j.firesaf.2021.103391.
[142] M. T. Kinateder, E. D. Kuligowski, P. K. Reneke, and R. D. Peacock, ‘A Review of Risk Perception in Building Fire Evacuation’, National Institute of Standards and Technology, NIST TN 1840, Sep. 2014. Accessed: Feb. 18, 2015. [Online]. Available: http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1840.pdf
[143] T. J. Shields, K. E. Boyce, and N. McConnell, ‘The behaviour and evacuation experiences of WTC 9/11 evacuees with self-designated mobility impairments’, *Fire Saf. J.*, vol. 44, no. 6, pp. 881–893, Aug. 2009, doi: 10.1016/j.firesaf.2009.04.004.
[144] A. Sieben, J. Schumann, and A. Seyfried, ‘Collective phenomena in crowds—Where pedestrian dynamics need social psychology’, *PLoS ONE*, vol. 12, no. 6, Jun. 2017, doi: 10.1371/journal.pone.0177328.
[145] R. F. Fahy, G. Proulx, and L. Aiman, ‘Panic or not in fire: Clarifying the misconception’, *Fire Mater.*, vol. 36, no. 5–6, pp. 328–338, Aug. 2012, doi: 10.1002/fam.1083.
[146] M. Haghani, E. Cristiani, N. W. F. Bode, M. Boltes, and A. Corbetta, ‘Panic, Irrationality, and Herding: Three Ambiguous Terms in Crowd Dynamics Research’, *J. Adv. Transp.*, vol. 2019, pp. 1–58, Aug. 2019, doi: 10.1155/2019/9267643.
[147] J. Drury, C. Cocking, and S. Reicher, ‘Everyone for themselves? A comparative study of crowd solidarity among emergency survivors’, *Br. J. Soc. Psychol.*, vol. 48, no. 3, pp. 487–506, 2009, doi: 10.1348/014466608X357893.
[148] E. L. Quarantelli, ‘Conventional Beliefs and Counterintuitive Realities’, *Soc. Res.*, vol. 75, no. 3, pp. 873–904, 2008.
[149] S. Iwarsson, M. Haak, and B. Slaug, ‘Current Developments of the Housing Enabler Methodology’, *Br. J. Occup. Ther.*, vol. 75, no. 11, pp. 517–521, Nov. 2012, doi: 10.4276/030802212X13522194759978.
[150] T. Helle *et al.*, ‘The Nordic Housing Enabler: Inter-rater reliability in cross-Nordic occupational therapy practice’, *Scand. J. Occup. Ther.*, vol. 17, no. 4, pp. 258–266, 2010.
[151] S. Iwarsson, B. Slaug, and A. M. Fänge, ‘The housing enabler screening tool: feasibility and interrater agreement in a real estate company practice context’, *J. Appl. Gerontol.*, vol. 31, no. 5, pp. 641–660, 2012.

[152] L. Rubadiri, D. T. Ndumu, and J. P. Roberts, ‘Predicting the evacuation capability of mobility-impaired occupants’, *Fire Technol.*, vol. 33, no. 1, pp. 32–53, 1997.
[153] M. Hashemi and H. A. Karimi, ‘Indoor Spatial Model and Accessibility Index for Emergency Evacuation of People with Disabilities’, *J. Comput. Civ. Eng.*, vol. 30, no. 4, p. 04015056, Jul. 2016, doi: 10.1061/(ASCE)CP.1943-5487.0000534.
[154] P. Geoerg, R. Block, W. Heister, S. Holl, A. Pulm, and A. Hofmann, ‘A score regarding the need for assistance – considering pedestrians with impairments in evacuation planning’, in *Proceedings of the 5th Magdeburger Fire and Explosion Prevention Day*, 2017, p. 14.
[155] Boverket, ‘Boverkets byggregler (2011:6) - föreskrifter och allmänna råd.’, 2016. https://www.boverket.se/sv/lag--ratt/forfattningssamling/gallande/bbr---bfs-20116/ (accessed Dec. 14, 2020).
[156] National Fire Protection Association, ‘NFPA 101, Life Safety Code’, 2021.
[157] D. F. Polit and C. T. Beck, ‘The content validity index: Are you sure you know what’s being reported? critique and recommendations’, *Res. Nurs. Health*, vol. 29, no. 5, pp. 489–497, 2006, doi: https://doi.org/10.1002/nur.20147.
[158] B. Slaug, O. Schilling, S. Iwarsson, and G. Carlsson, ‘Typology of person-environment fit constellations: a platform addressing accessibility problems in the built environment for people with functional limitations’, *BMC Public Health*, vol. 15, no. 1, p. 834, Dec. 2015, doi: 10.1186/s12889-015-2185-4.
[159] T. K. Koo and M. Y. Li, ‘A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research’, *J. Chiropr. Med.*, vol. 15, no. 2, pp. 155–163, Jun. 2016, doi: 10.1016/j.jcm.2016.02.012.
[160] R Core Team, *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2021. [Online]. Available: https://www.R-project.org/
[161] W. Revelle, *psych: Procedures for Psychological, Psychometric, and Personality Research*. Evanston, Illinois: Northwestern University, 2021. [Online]. Available: https://CRAN.R-project.org/package=psych
[162] National Fire Protection Association, ‘Emergency evacuation planning guide for people with disabilities’, 2016.
[163] Department of Health, Social Services and Public Safety, *Fire safety law: the evacuation of disabled people from buildings.* Norwich: TSO, 2011.
[164] National Disability Authority, ‘Risk assessment checklist’, 2010. http://nda.ie/publications/environment-housing/environment-publications/safe-evacuation-for-all.html (accessed Dec. 14, 2020).
[165] Americans with Disabilities Act (ADA), ‘ADA accessibility checklist for existing facilities’. 2014. Accessed: Dec. 14, 2020. [Online]. Available: http://www.adachecklist.org/doc/fullchecklist/ada- checklist.pdf
[166] J. D. Sime, ‘Movement toward the Familiar: Person and Place Affiliation in a Fire Entrapment Setting’, *Environ. Behav.*, vol. 17, no. 6, pp. 697–724, Nov. 1985, doi: 10.1177/0013916585176003.
[167] D. Nilsson, *Exit choice in fire emergencies: influencing choice of exit with flashing lights*. Lund, Sweden: Dept. of Fire Safety Engineering and Systems Safety, Lund University, 2009.
[168] M. Kinateder, B. Comunale, and W. H. Warren, ‘Exit choice in an emergency evacuation scenario is influenced by exit familiarity and neighbor behavior’, *Saf. Sci.*, vol. 106, pp. 170–175, 2018.

[169] M. Kinateder *et al.*, 'Social influence on route choice in a virtual reality tunnel fire', *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 26, pp. 116–125, Sep. 2014, doi: 10.1016/j.trf.2014.06.003.
[170] R. Lovreglio, A. Fonzone, L. Dell'Olio, and D. Borri, 'A study of herding behaviour in exit choice during emergencies based on random utility theory', *Saf. Sci.*, vol. 82, pp. 421–431, 2016.
[171] M. Haghani, M. Sarvi, and Z. Shahhoseini, 'Evacuation behaviour of crowds under high and low levels of urgency: Experiments of reaction time, exit choice and exit-choice adaptation', *Saf. Sci.*, vol. 126, p. 104679, 2020.
[172] K. Andrée, D. Nilsson, and J. Eriksson, 'Evacuation experiments in a virtual reality high-rise building: exit choice and waiting time for evacuation elevators', *Fire Mater.*, vol. 40, no. 4, pp. 554–567, Jun. 2016, doi: 10.1002/fam.2310.
[173] E. Ronchi *et al.*, 'A Virtual Reality Experiment on Flashing Lights at Emergency Exit Portals for Road Tunnel Evacuation', *Fire Technol.*, vol. 52, no. 3, pp. 623–647, Maj 2016, doi: 10.1007/s10694-015-0462-5.
[174] L. Fu, S. Cao, W. Song, and J. Fang, 'The influence of emergency signage on building evacuation behavior: An experimental study', *Fire Mater.*, vol. 43, no. 1, pp. 22–33, 2019, doi: 10.1002/fam.2665.
[175] J. Kubota, T. Sano, and E. Ronchi, 'Assessing the compliance with the direction indicated by emergency evacuation signage', *Saf. Sci.*, vol. 138, p. 105210, Jun. 2021, doi: 10.1016/j.ssci.2021.105210.
[176] H. Xie, L. Filippidis, E. R. Galea, D. Blackshields, and P. J. Lawrence, 'Experimental analysis of the effectiveness of emergency signage and its implementation in evacuation simulation: EXPERIMENTAL ANALYSIS OF EMERGENCY SIGNAGE', *Fire Mater.*, vol. 36, no. 5–6, pp. 367–382, Aug. 2012, doi: 10.1002/fam.1095.
[177] Y. Zhu, T. Chen, N. Ding, M. Chraibi, and W.-C. Fan, 'Follow the evacuation signs or surrounding people during building evacuation, an experimental study', *Phys. Stat. Mech. Its Appl.*, vol. 560, p. 125156, Dec. 2020, doi: 10.1016/j.physa.2020.125156.
[178] United Nations, Department of Economic and Social Affairs, Population Division, 'World Population Ageing 2019', New York, ST/ESA/SER.A/444, 2020.
[179] N. Gaire, Z. Song, K. M. Christensen, M. S. Sharifi, and A. Chen, 'Exit Choice Behavior of Pedestrians Involving Individuals with Disabilities During Building Evacuations', *Transp. Res. Rec.*, vol. 2672, no. 1, pp. 22–29, Dec. 2018, doi: 10.1177/0361198118756875.
[180] D. Nilsson, H. Frantzich, and W. Saunders, 'Influencing exit choice in the event of a fire evacuation', *Fire Saf. Sci.*, vol. 9, pp. 341–352, 2008.
[181] J. J. Gibson, 'The theory of affordances', *Hilldale USA*, vol. 1, no. 2, pp. 67–82, 1977.
[182] E. D. Kuligowski, 'Human Behaviour in Fire', in *SFPE Handbook of Fire Protection Engineering*, 5th ed., New York Heidelberg Dordrecht London: Springer, 2016, pp. 2070–2114.
[183] M. Haghani, M. Sarvi, O. Ejtemai, M. Burd, and A. Sobhani, 'Modeling pedestrian crowd exit choice through combining sources of stated preference data', *Transp. Res. Rec.*, vol. 2490, no. 1, pp. 84–93, 2015.
[184] R. Lovreglio, D. Borri, L. dell'Olio, and A. Ibeas, 'A discrete choice model based on random utilities for exit choice in emergency evacuations', *Saf. Sci.*, vol. 62, pp. 418–426, Feb. 2014, doi: 10.1016/j.ssci.2013.10.004.
[185] R. Lovreglio, A. Fonzone, and L. dell'Olio, 'A mixed logit model for predicting exit choice during building evacuations', *Transp. Res. Part Policy Pract.*, vol. 92, pp. 59–75, Oct. 2016, doi: 10.1016/j.tra.2016.06.018.

[186] L. Benthorn and H. Frantzich, 'Fire alarm in a public building: how do people evaluate information and choose an evacuation exit?', *Fire Mater.*, vol. 23, no. 6, pp. 311–315, 1999, doi: https://doi.org/10.1002/(SICI)1099-1018(199911/12)23:6<311::AID-FAM704>3.0.CO;2-J.
[187] Y. Feng, D. C. Duives, and S. P. Hoogendoorn, 'Using virtual reality to study pedestrian exit choice behaviour during evacuations', *Saf. Sci.*, vol. 137, p. 105158, 2021.
[188] R. Lovreglio, E. Dillies, E. Kuligowski, A. Rahouti, and M. Haghani, 'Exit choice in built environment evacuation combining immersive virtual reality and discrete choice modelling', *Autom. Constr.*, vol. 141, p. 104452, 2022, doi: https://doi.org/10.1016/j.autcon.2022.104452.
[189] M. Kinateder *et al.*, 'Virtual Reality for Fire Evacuation Research', in *1st Workshop 'Complex Events and Information Modelling'*, Warsaw, 2014, pp. 319–327.
[190] D. A. Hensher, J. M. Rose, and W. H. Greene, *Applied choice analysis : a primer.* Cambridge University Press, 2005. [Online]. Available: https://ludwig.lub.lu.se/login?url=https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=cat07147a&AN=lub.1624650&site=eds-live&scope=site
[191] K. Train, *Discrete choice methods with simulation*, 2nd ed. Cambridge ; New York: Cambridge University Press, 2009.
[192] D. C. Duives and H. S. Mahmassani, 'Exit Choice Decisions during Pedestrian Evacuations of Buildings', *Transp. Res. Rec.*, vol. 2316, no. 1, pp. 84–94, 2012, doi: 10.3141/2316-10.
[193] M. Haghani, M. Sarvi, and Z. Shahhoseini, 'Accommodating taste heterogeneity and desired substitution pattern in exit choices of pedestrian crowd evacuees using a mixed nested logit model', *J. Choice Model.*, vol. 16, pp. 58–68, 2015, doi: https://doi.org/10.1016/j.jocm.2015.09.006.
[194] M. Haghani and M. Sarvi, 'Human exit choice in crowded built environments: Investigating underlying behavioural differences between normal egress and emergency evacuations', *Fire Saf. J.*, vol. 85, pp. 1–9, 2016, doi: https://doi.org/10.1016/j.firesaf.2016.07.003.
[195] M. Kinateder and W. H. Warren, 'Exit choice during evacuation is influenced by both the size and proportion of the egressing crowd - ScienceDirect', *Phys. A*, vol. 569, 2021, Accessed: Mar. 11, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378437121000182
[196] G. Ren-Yong and H. Hai-Jun, 'Logit-based exit choice model of evacuation in rooms with internal obstacles and multiple exits', *Chin. Phys. B*, vol. 19, no. 3, p. 030501, Mar. 2010, doi: 10.1088/1674-1056/19/3/030501.
[197] European Committee for Standardization, 'Building hardware - Emergency exit devices operated by a lever handle or push pad, for use on escape routes - Requirements and test methods, EN 179:2008', 2008.
[198] European Committee for Standardization, 'Building hardware - Panic exit devices operated by a horizontal bar, for use on escape routes - Requirements and test methods, EN 1125:2008', 2008.
[199] C. Wienrich, C. K. Weidner, C. Schatto, D. Obremski, and J. H. Israel, 'A virtual nose as a rest-frame-the impact on simulator sickness and game experience', in *2018 10th international conference on virtual worlds and games for serious applications (VS-Games)*, 2018, pp. 1–8.
[200] M. Usoh, E. Catena, S. Arman, and M. Slater, 'Using Presence Questionnaires in Reality', *Presence Teleoperators Virtual Environ.*, vol. 9, no. 5, pp. 497–503, Oct. 2000, doi: 10.1162/105474600566989.

[201] S. Arias, J. Wahlqvist, D. Nilsson, E. Ronchi, and H. Frantzich, 'Pursuing behavioral realism in Virtual Reality for fire evacuation research', *Fire Mater.*, vol. 1, no. 11, 2020, doi: https://doi.org/10.1002/fam.2922.
[202] S. Arias, S. La Mendola, J. Wahlqvist, O. Rios, D. Nilsson, and E. Ronchi, 'Virtual Reality Evacuation Experiments on Way-Finding Systems for the Future Circular Collider', *Fire Technol.*, Maj 2019, doi: 10.1007/s10694-019-00868-y.
[203] D. McFadden and K. Train, 'Mixed MNL models for discrete response', *J. Appl. Econom.*, vol. 15, no. 5, pp. 447–470, 2000.
[204] C. Arteaga, J. Park, P. B. Beeramoole, and A. Paz, 'xlogit: An open-source Python package for GPU-accelerated estimation of Mixed Logit models', *J. Choice Model.*, vol. 42, p. 100339, 2022.
[205] P. Virtanen *et al.*, 'SciPy 1.0: Fundamental Algorithms for Scientific Computing in Python', *Nat. Methods*, vol. 17, pp. 261–272, 2020, doi: 10.1038/s41592-019-0686-2.
[206] J. Lin, R. Zhu, N. Li, and B. Becerik-Gerber, 'Do people follow the crowd in building emergency evacuation? A cross-cultural immersive virtual reality-based study', *Adv. Eng. Inform.*, vol. 43, p. 101040, 2020.
[207] P. Geoerg, R. Block, W. Heister, S. Holl, A. Pulm, and A. Hofmann, 'A score regarding the need for assistance – considering pedestrians with impairments in evacuation planning', 2017, p. 14.
[208] B. Slaug, O. Schilling, S. Iwarsson, and G. Carlsson, 'Defining Profiles of Functional Limitations in Groups of Older Persons: How and Why?', *J. Aging Health*, vol. 23, no. 3, pp. 578–604, Apr. 2011, doi: 10.1177/0898264310390681.
[209] P. Geoerg, F. Berchtold, S. Gwynne, K. Boyce, S. Holl, and A. Hofmann, 'Engineering egress data considering pedestrians with reduced mobility', *Fire Mater.*, p. fam.2736, Aug. 2019, doi: 10.1002/fam.2736.
[210] SCB, 'Undersökningarna av levnadsförhållanden (ULF/SILC) år 2018-2019', Statistiska Centralbyrån, 2020.
[211] K. Butler, E. Kuligowski, S. Furman, and R. Peacock, 'Perspectives of occupants with mobility impairments on evacuation methods for use during fire emergencies', *Fire Saf. J.*, vol. 91, pp. 955–963, Jul. 2017, doi: 10.1016/j.firesaf.2017.04.025.
[212] N. C. McConnell and K. E. Boyce, 'Refuge areas and vertical evacuation of multistorey buildings: the end users' perspectives: REFUGE AREAS AND VERTICAL EVACUATION OF MULTISTOREY BUILDINGS', *Fire Mater.*, vol. 39, no. 4, pp. 396–406, Jun. 2015, doi: 10.1002/fam.2205.
[213] L. Kecklund, K. Andrée, S. Bengtson, S. Willander, and E. Siré, 'How Do People with Disabilities Consider Fire Safety and Evacuation Possibilities in Historical Buildings?—A Swedish Case Study', *Fire Technol.*, vol. 48, no. 1, pp. 27–41, Jan. 2012, doi: 10.1007/s10694-010-0199-0.
[214] A. Fänge and S. Iwarsson, 'Accessibility and usability in housing: construct validity and implications for research and practice', *Disabil. Rehabil.*, vol. 25, no. 23, pp. 1316–1325, Dec. 2003, doi: 10.1080/09638280310001616286.
[215] O. Bukvic, G. Carlsson, G. Gefenaite, B. Slaug, S. M. Schmidt, and E. Ronchi, 'A review on the role of functional limitations on evacuation performance using the International Classification of Functioning, Disability and Health', *Fire Technol.*, Sep. 2020, doi: 10.1007/s10694-020-01034-5.
[216] B. Slaug, O. Jonsson, and G. Carlsson, 'Public entrance accessibility: Psychometric approach to the development of a new assessment instrument', *Disabil. Health J.*, vol. 12, no. 3, pp. 473–480, Jul. 2019, doi: 10.1016/j.dhjo.2019.02.007.
[217] G. Carlsson, 'Travelling by urban public transport: exploration of usability problems in a travel chain perspective', *Scand. J. Occup. Ther.*, vol. 11, no. 2, pp. 78–89, 2004.

[218] A. Fänge, S. Iwarsson, and Å. Persson, ‘Accessibility to the public environment as perceived by teenagers with functional limitations in a south Swedish town centre’, *Disabil. Rehabil.*, vol. 24, no. 6, pp. 318–326, 2002.
[219] A. Alvarez, B. Meacham, N. Dembsey, and J. Thomas, ‘Twenty years of performance-based fire protection design: challenges faced and a look ahead’, *J. Fire Prot. Eng.*, vol. 23, no. 4, pp. 249–276, 2013.
[220] N. Thapar *et al.*, ‘A pilot study of functional access to public buildings and facilities for persons with impairments’, *Disabil. Rehabil.*, vol. 26, no. 5, pp. 280–289, Mar. 2004, doi: 10.1080/09638280310001649543.
[221] B. Latané and J. M. Darley, *The unresponsive bystander: why doesn’t he help?* New York: Appleton-Century Crofts, 1970.
[222] N. Ohtsu and A. Hokugo, ‘Velocity and transportation ability of vulnerable people during a community tsunami evacuation drill: Outdoor evacuation using a rollator, transport chair, wheelchair, and cart in Shinyo Bokomi, Kobe, Japan’, *Jpn. Archit. Rev.*, vol. 2, no. 4, pp. 576–587, 2019, doi: 10.1002/2475-8876.12118.
[223] J. Schumann and M. Boltes, ‘Tracking of wheelchair users in dense crowds’, *Int. Conf. Indoor Position. Indoor Navig.*, p. 4, 2017.
[224] L. Catovic, C. Alniemi, and E. Ronchi, ‘A survey on the factors affecting horizontal assisted evacuation in hospitals’, in *Journal of Physics: Conference Series*, 2018, vol. 1107, no. 7, p. 072001.
[225] G. Proulx, ‘Recollection, Identification and Perceived Urgency of the Temporal-Three Evacuation Signal’, *J. Fire Prot. Eng.*, vol. 13, no. 1, pp. 67–82, Feb. 2003, doi: 10.1177/1042391503013001004.
[226] C. Feliciani, H. Murakami, K. Shimura, and K. Nishinari, ‘Efficiently informing crowds – Experiments and simulations on route choice and decision making in pedestrian crowds with wheelchair users’, *Transp. Res. Part C Emerg. Technol.*, vol. 114, pp. 484–503, May 2020, doi: 10.1016/j.trc.2020.02.019.
[227] D. A. Purser, ‘Assessment of Hazards to Occupants from smoke, toxic gases and heat’, in *SFPE Handbook of Fire Protection Engineering (4th Edition)*, Quincy, MA (USA): Di Nenno P. J., 2008, pp. 2-96-2–193.
[228] M. Björkqvist and A. Franzén Broholm, *Människors benägenhet till utrymning vid alkoholpåverkan*. 2018.
[229] E. Ronchi, F. Nieto Uriz, X. Criel, and P. Reilly, ‘Modelling large-scale evacuation of music festivals’, *Case Stud. Fire Saf.*, vol. 5, pp. 11–19, Maj 2016, doi: 10.1016/j.csfs.2015.12.002.
[230] M. Runefors, N. Johansson, and P. Van Hees, ‘How could the fire fatalities have been prevented? An analysis of 144 cases during 2011–2014 in Sweden: An analysis’, *J. Fire Sci.*, vol. 34, no. 6, pp. 515–527, 2016.
[231] P. Geoerg, J. Schumann, S. Holl, and A. Hofmann, ‘The Influence of Wheelchair Users on Movement in a Bottleneck and a Corridor’, *J. Adv. Transp.*, vol. 2019, pp. 1–17, Jun. 2019, doi: 10.1155/2019/9717208.
[232] H. Pan, J. Zhang, and W. Song, ‘Experimental study of pedestrian flow mixed with wheelchair users through funnel-shaped bottlenecks’, *J. Stat. Mech. Theory Exp.*, vol. 2020, no. 3, p. 033401, Mar. 2020, doi: 10.1088/1742-5468/ab6b1c.
[233] M. Moussaïd and M. Trauernicht, ‘Patterns of cooperation during collective emergencies in the help-or-escape social dilemma’, *Sci. Rep.*, vol. 6, p. 33417, 2016.
[234] W. H. Warren, ‘Collective motion in human crowds’, *Curr. Dir. Psychol. Sci.*, vol. 27, no. 4, pp. 232–240, 2018.

[235] E. R. Galea, M. Sauter, S. J. Deere, and L. Filippidis, 'Investigating the Impact of Culture on Evacuation Response Behaviour', in *Proceedings of the 6th International Symposium on Human Behaviour in Fire,* London, 2015, pp. 351–360.
[236] L. L. Lien, C. D. Steggell, B. Slaug, and S. Iwarsson, 'Assessment and analysis of housing accessibility: adapting the environmental component of the housing enabler to United States applications', *J. Hous. Built Environ.*, vol. 31, no. 3, pp. 565–580, 2016.
[237] B. Ingstad and S. R. Whyte, *Disability and Culture*. University of California Press, 1995.
[238] S. Iwarsson and A. Ståhl, 'Accessibility, usability and universal design—positioning and definition of concepts describing person-environment relationships', *Disabil. Rehabil.*, vol. 25, no. 2, pp. 57–66, Jan. 2003, doi: 10.1080/dre.25.2.57.66.
[239] M. Kusenbach, 'Street Phenomenology. The Go-Along as Ethnographic Research Tool', *Ethnography*, vol. 4, no. 3, pp. 455–485, 2003.
[240] H. A. Linstone and M. Turoff, *The delphi method*. Addison-Wesley Reading, MA, 1975.