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Egressibility

Applying the concept of accessibility to the self-evacuation of people with functional limitations

Smedberg, Erik

2022

Document Version:

Publisher's PDF, also known as Version of record

[Link to publication](#)

Citation for published version (APA):

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

Total number of authors:

1

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Egressibility

Applying the concept of accessibility to the self-evacuation of people with functional limitations

ERIK SMEDBERG

DIVISION OF FIRE SAFETY ENGINEERING | FACULTY OF ENGINEERING | LUND UNIVERSITY





Faculty of Engineering
Division of Fire Safety Engineering
Department of Building & Environmental Technology

ISBN 978-91-8039-256-3
ISSN 1402-3504
ISRN LUTVDG/TVBB—1069—SE



Egressibility

Applying the concept of accessibility to the self-evacuation of people with functional limitations

Erik Smedberg



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LICENTIATE THESIS

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To be defended on June 16, 2022 at 09:15 in room V:A, V-huset,

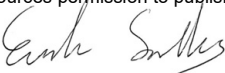
John Ericssons väg 1, Lund.

Faculty opponent

Associate Professor Jonas Andersson

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|---|----------------------------|---|-------------------|
| Organization LUND UNIVERSITY Faculty of Engineering, Division of Fire Safety Engineering | | Document name LICENTIATE THESIS | |
| | | Date of issue 2022-06-16 | |
| Author(s) Erik Smedberg | | Sponsoring organization FORMAS | |
| Title and subtitle Egressibility - Applying the concept of accessibility to the self-evacuation of people with functional limitations | | | |
| Abstract <p>The population is getting increasingly older, and old age is correlated with decreased functional capacity. In society, continuous improvements in accessibility of public environments is apparent. Together, these two factors contribute to the trend that the people that are expected to perform self-evacuation today are more diverse in abilities than ever. Functional capacity refers to the abilities to perform fundamental everyday activities such as seeing, hearing, moving around, etc., while a decrease in functional capacity is referred to as a functional limitation. In the field of accessibility, definitions have been developed to reflect the person-environment interactions that determine whether an environment is accessible or not. That is, accessibility can be investigated by assessing the interaction between the environmental demands and a person's functional capacity.</p> <p>The focus of this thesis has been the concept of egressibility, here defined as "accessibility to means of evacuation". The purpose has been to explore ways of identifying issues related to self-evacuation possibilities for people with functional limitations based on the notion of accessibility. This was achieved through two research studies including conceptual and methodological exploration on the topic. The first study was a qualitative interview study to investigate the perspectives on egressibility from older people with functional limitations in Sweden. The second study focused on a methodology implemented into an instrument to measure egressibility by juxtaposing environmental demands and functional limitations. The results from the qualitative study showed that older people may tend to favour self-reliance in mitigating egressibility issues, instead of relying on the physical and social environment to be supportive. The instrument developed in the second study, called the Egress Enabler, displayed promising attributes of validity and reliability during initial testing. However, the Egress Enabler is affected by the current lack of scientific knowledge regarding several aspects on the interaction between environmental demands and functional capacity during egress. Some of these knowledge gaps have already been identified and should be further investigated. The Egress Enabler represents a necessary step towards a comprehensive performance-based evaluation of self-evacuation possibilities for people with functional limitations, highlighting the complex interaction between evacuation and accessibility.</p> | | | |
| Key words Evacuation, Egress, Egressibility, Disability, Accessibility, Impairment, Functional limitations | | | |
| Classification system and/or index terms (if any) | | | |
| Supplementary bibliographical information Report 1069 ISRN LUTVDG/TVBB—1069—SE | | Language English | |
| ISSN and key title 1402-3504 | | ISBN 978-91-8039-255-6 (pdf) 978-91-8039-256-3 (print) | |
| Recipient's notes | Number of pages 126 | | Recipient's notes |
| | Security classification | | |

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Egressibility

Applying the concept of accessibility to the self-evacuation of people with functional limitations

Erik Smedberg



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Paper 2 © by the Authors (Manuscript unpublished)

Faculty of Engineering
Department of Building & Environmental Technology
Division of Fire Safety Engineering

Report 1069

ISBN 978-91-8039-255-6 (pdf)

ISBN 978-91-8039-256-3 (print)

ISSN 1402-3504

ISRN LUTVDG/TVBB—1069—SE

Printed in Sweden by Media-Tryck, Lund University
Lund 2022



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Acknowledgments

The research providing the foundation of my licentiate thesis would not have been possible without the support from financiers, employer, colleagues, and friends.

The Swedish Research Council FORMAS has provided financial support which enabled me to produce the research contained within the two appended papers. Additionally, the Fire Protection Research Foundation (FPRP) sponsored the work that is contained within some of the complementary documents related to alternative alarms for people who are deaf or hard of hearing.

Colleagues and friends at the division of Fire Safety Engineering have been supportive at all times, providing both personal and professional support in times of need. I would like to especially thank my fellow PhD students, present and graduated, who have made the education more fun and fruitful.

I would like to extend my sincere appreciation to my main supervisor, Dr. Enrico Ronchi, who has provided plenty of support in all aspects during my education. I could not have wished for a more supportive supervisor. The same appreciation goes out to my secondary supervisors, Dr. Gunilla Carlsson, Dr. Giedre Gefenaite, and Dr. Jonathan Wahlqvist who have all provided personal and professional support that enabled me to carry out the research.

The studies would not have been completed without the shared experience, knowledge, and feedback from my co-authors Dr. Björn Slaug, Dr. Steven Schmidt, Dr. Michael Kinsey, and Victoria Hutchison.

Last but not least, I would like to thank friends and family who have shown support and concern throughout my education. A very special thanks to the love of my life, Claude Pagnon Eriksson, for continuously providing love and encouragement!

Populärvetenskaplig sammanfattning

Världens befolkning blir allt äldre. Med stigande ålder minskar ofta kapaciteten att utföra basala vardagliga aktiviteter som att se, höra och röra sig. När den funktionella kapaciteten är begränsad, beskrivs ofta begränsningarna i termer av funktionsnedsättningar, eftersom olika delar av miljön blir olika viktig i förhållande till vilken funktionsnedsättning det gäller och ibland behöver personer använda hjälpmedel för att kompensera för dem. Diverse insatser inom politik, arkitektur, teknik och medicin har resulterat i att publika miljöer har blivit mer tillgängliga. Idag ses tillgänglighet som en integrerad del vid utformningen av byggnader och miljöer i Sverige och många andra länder, även om mycket återstår att göra.

En högre andel personer med funktionsnedsättningar i befolkningen och ökad tillgänglighet till publika miljöer bidrar till det faktum att de individer som idag förväntas kunna utrymma själva vid nödsituationer har en mer varierad funktionell kapacitet än vad som tidigare antagits. Termen "frångänglighet" har föreslagits för att belysa de specifika behov som finns kopplade till utrymning för personer med funktionsnedsättningar. I detta arbete tolkas frångänglighet som "tillgänglighet vid utrymning". Historiskt utformades tillgänglighet och utrymningsdesign primärt för personer med funktionsnedsättningar som använder rullstol, då det ansågs medföra de största utmaningarna för byggnadens utformning. Men funktionsnedsättningar finns i många olika former och de påverkar interaktionen med omgivningen på väldigt olika sätt.

Inom tillgänglighetsforskningen används bland annat den ekologiska modellen om åldrande, för att definiera tillgänglighet som en interaktion mellan person och miljö. Tillgänglighet kan undersökas genom att relatera kraven i miljön till funktionsförmåga. Miljökrav avser något i omgivningen som kräver en förmåga hos individen och vid utrymning en reaktion, till exempel ett hörbart brandlarm.

Denna licentiatuppsats syftar till att undersöka sätt att identifiera problem relaterade till möjligheterna för personer med funktionsnedsättningar att själva utrymma utifrån begreppet tillgänglighet. Detta studeras utifrån subjektiva perspektiv hos äldre personer med funktionsnedsättningar, samt genom utveckling och inledande testning av ett instrument avsett att möjliggöra en objektiv utvärdering av frångänglighet i publika byggnader.

Resultaten visar att äldre personer med funktionsnedsättningar kan ha en tendens att primärt förlita sig på sin egen förmåga för att minimera frångänglighetsproblem snarare än att förlita sig på att den fysiska eller sociala miljön ska verka stödjande. Utvecklingen av instrumentet, kallat Egress Enabler, belyser delar av det komplexa samspelet mellan tillgänglighet och utrymning. De inledande testerna av instrumentets psykometriska egenskaper visade på lovande giltighet och tillförlitlighet. Även om instrumentet för närvarande får anses begränsat på grund av bristen på empirisk kunskap inom området ses Egress Enabler ändå som ett viktigt steg i riktning mot en mer systematisk prestationsbaserad bedömning av frångänglighet.

Summary

The population in the world is getting increasingly older. Old age often overlaps with a decreased ability to perform fundamental daily activities such as seeing, hearing, and moving around. This ability is often referred to as functional capacity, and a decreased functional capacity is referred to as functional limitations. Through various efforts in policy, architecture, engineering, and medicine, an increased accessibility to the public environments can also be observed. Today, accessibility is seen as an integral part of building design in Sweden and in many other countries.

A lower functional capacity in the population and increased accessibility to public environments contributes to the fact that the occupants that today are expected to perform self-evacuation in case of emergency are more diverse in abilities than what has previously been assumed. The term 'egressibility' has been proposed to highlight the specific evacuation needs of people with functional limitations. Here, egressibility is interpreted as accessibility to means of evacuation. Initial considerations in accessibility and evacuation design were directed towards people using wheelchairs, seen as introducing the greatest challenges to building design. However, functional limitations exist in most domains of human functioning and affect the interactions with the environment in vastly different ways.

In accessibility research, models have been developed to better understand how accessibility issues arise. One such model is the person-environment fit model, stating that accessibility can be investigated through comparison of environmental demands and functional capacity. Environmental demands refer to something in the environment that demands a response, such as an audible fire alarm that needs to be heard.

This licentiate thesis aims to explore ways of identifying issues related to the self-evacuation possibilities for people with functional limitations based on the notion of accessibility. This is studied from the subjective perspectives of older people with functional limitations, as well as through development and initial testing of an instrument meant to facilitate the objective measurement of egressibility in public buildings.

The results show that older people with functional limitations may tend to favour self-reliance in mitigating egressibility issues rather than relying on the physical or

social environment to be supportive. The development of the Egress Enabler instrument highlights the complex interaction between accessibility and evacuation. Initial testing of the instrument reveals promising psychometric properties. Although currently impeded by the lack of empirical knowledge in the domain, the Egress Enabler is seen as a key development towards comprehensive performance-based assessments of egressibility.

Abbreviations and definitions

| | |
|----------------------------|--|
| Accessibility | <i>The relationship between functional capacity and environmental demands (Iwarsson & Ståhl, 2003)</i> |
| Disability | <i>An umbrella term for impairment, activity limitation and participation restriction in the International Classification of Functioning Disability and Health (World Health Organization, 2001)</i> |
| Egress Enabler | <i>An instrument to measure levels of egressibility in public buildings</i> |
| Egressibility | <i>The accessibility to means of evacuation</i> |
| Environmental barrier | <i>An entity in the surrounding environment that poses high environmental press</i> |
| Environmental component | <i>The demands of the physical/built environment making up the environmental component of accessibility (Iwarsson & Ståhl, 2003)</i> |
| Environmental demand/press | <i>Forces in the environment that together with an individual need evoke a response (Murray, 1938)</i> |
| Evacuation | <i>Movement of people from dangerous or potentially dangerous areas to places of safety</i> |
| Evacuation safety | <i>The life safety of occupants during evacuation</i> |
| Functional capacity | <i>A person's ability to perform daily activities (Jette, 2006)</i> |
| Functional limitation | <i>Limitation in performance at the level of the whole organism or person (Jette, 2006)</i> |

| | |
|--------------------------------|--|
| IBC | <i>International Building Code (International Code Council, 2021)</i> |
| ICF | <i>International Classification of Disability, Functioning, and Health (World Health Organization, 2001)</i> |
| Personal component | <i>The person's functional limitations and dependence on mobility devices making up the personal component of accessibility (Iwarsson & Ståhl, 2003)</i> |
| Person-environment fit | <i>The relationship between individual competence and environmental demand (Lawton & Nahemow, 1973)</i> |
| Person-environment interaction | <i>The interaction between individual competence and environmental demand</i> |
| SFPE | <i>Society of Fire Protection Engineers</i> |
| UNCRPD | <i>United Nations Convention on the Rights of People with Disabilities (United Nations, 2012)</i> |
| WHO | <i>World Health Organization</i> |

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1. Introduction

The evacuation of people from buildings due to fires or other threats has been of scientific interest since the 1900's (Bryan, 1999). Much of the initial interest mainly involved estimating the rate at which existing buildings could be evacuated (London Transport Board, 1958; Melinek & Booth, 1975; National Bureau of Standards, 1935). Since then, the scientific field of human behaviour in fire has come to include several parallel fields. For example social psychology (Kuligowski, 2017), cognition and perception (Proulx, 1993), and biomechanics (McGrath & Thompson, 2017). This research has led to improved policies and legislation related to fire safety and evacuation (Meacham, 1996), which to some extent may explain the decreasing trend of fire fatalities in buildings (Ahrens, 2017).

In parallel with fire safety, accessibility guidelines have been developed since the mid 1900's to ensure that all people can enter and use public buildings (Kose, 2021). However, accessibility has primarily been applied to public parts of buildings, and not necessarily to components or environments in use during evacuation. This has provided a new challenge for evacuation design, as buildings are not equipped to fulfil the evacuation needs of people with functional limitations that are now increasingly occupying them. Both accessibility and evacuation guidelines related to people with functional limitations have in common that the primary emphasis is on people using wheelchairs, perceived as introducing the greatest challenges in relation to building design (Kose, 2021; Shields et al., 2009). Nevertheless, functional limitations exist in various forms such as blindness, hearing impairments, mobility, etc., providing unique challenges for evacuation design.

To reflect the specific evacuation needs of people with functional limitations, the term 'egressibility' has been proposed (Proulx, 1995). An early mentioning of egressibility can be found in an article in *The American Journal of Occupational Therapy* from 1984 (Schroeder & Benedict, 1984). The article explains that many public buildings have been made accessible to wheelchair users through the provision of ramps, elevators, and electric doors, but that provisions for evacuation have not been made. The article then continues to state that, unfortunately, the individuals need to take responsibility for their own safety. Although a historical anecdote, it is still true today that people with functional limitations are often not afforded the same levels of fire safety.

Today, accessibility is recognized as an integral part of public building design, and access to public institutions are seen as a basic human right (United Nations, 2012). As of 2011, the World Health Organization estimates that 15% of the world's population experience functional limitations, and the prevalence is anticipated to increase due to an ageing population (World Health Organization, 2011). Increased prevalence of functional limitations along with improved accessibility means that today more than ever, people with functional limitations are frequent visitors of public buildings and environments. Although evacuation guidelines and requirements for people with functional limitations have been developed since the mid 1900's (Levin, 1980), more efforts are still needed. This is highlighted through statistics showing that people with functional limitations are at higher risk from dying in fires (Ahrens, 2014; Fernández-Vigil & Echeverría Trueba, 2019; Murdy et al., 2011; Xiong et al., 2015).

To facilitate the implementation of efficient means to improve egressibility, a systematic understanding of the concept is needed. The disability rights movement has through lobbying changed the way we define disability and hence accessibility (Petasis, 2019). Previously, the emphasis has been on the individuals, stating that it is the impairments of individuals that cause disability (Imrie, 1997). This emphasis has shifted and today disability is more often seen as a function of the mismatch between the capacity of individuals and the demands from the environment (World Health Organization, 2001). Such understanding facilitates the identification of accessibility issues and should be adopted in the domain of fire safety as well.

1.1. Purpose

The purpose of this work has been to explore ways to identify issues related to self-evacuation possibilities for people with functional limitations in public buildings based on the notion of accessibility. Furthermore, the concept of egressibility has been investigated through methodological and conceptual exploration of the definitions and assumptions made.

1.1.1. Research objectives

The purpose of this thesis has been further specified in two research objectives relating to the two appended research papers.

- a) To investigate the subjective perspectives on egressibility of older people with functional limitations, including person-environment interaction and strategies to mitigate issues.
- b) To develop an assessment instrument for egressibility in public buildings and explore its validity and reliability.

1.2. Delimitations

The purpose has been to investigate ways of identifying egressibility issues rather than solving them. Hence, this thesis does not aim to provide alternative design solutions related to egressibility but rather puts existing knowledge into context.

Evacuation can be initiated by different events such as fires, terror threats, toxic releases, and false alarms. The evacuation safety of the building occupants is important regardless of initiating event, and this thesis aims to be as general as possible in this regard. Nonetheless, the main focus of this work is evacuation safety in the context of fire safety, assuming that fire is an important threat to consider in many public buildings.

The focus of this thesis is on self-evacuation and not on assisted evacuation. In addition, the egressibility issues are mainly studied in the context of public buildings. It is argued that society has a larger responsibility and mandate to influence the design of the built environment in public buildings. Nonetheless, most fire fatalities occurs in residential settings (Winberg, 2016) and some of the work contained within this thesis could be further developed and applied to residential buildings.

Further, organizational aspects are not included. The United Nations characterize an accessible society as one that promotes inclusivity, participation and autonomy of all people, irrespective of functional capacity (United Nations, 2022). Progresses in the accessibility field have shown that different technical and non-technical solutions increase people’s possibilities to live an independent life (Vaughan et al., 2016). It is therefore crucial to investigate to which extent the fire safety among individuals with functional limitations is addressed, and what opportunities they have to evacuate independently. Nonetheless, assistance and organizational measures have a positive influence on the evacuation safety for people with functional limitations, but it is not within the focus of this thesis.

1.3. Publications

Two scientific journal papers provide the basis for this thesis, both of which are appended.

- I. Smedberg, E., Carlsson, G., Gefenaite, G., Slaug, B., Schmidt, S. M., & Ronchi, E. (2022). Perspectives on egressibility of older people with functional limitations. *Fire Safety Journal*, 127, 103509.
- II. Smedberg, E., Slaug, B., Carlsson, G., Gefenaite, G., Schmidt, S. M., & Ronchi, E. (2022). The Egress Enabler - Development and Psychometric Evaluation of an Instrument to Measure Egressibility. Submitted to an international journal.

Both papers are original research papers. The author’s contribution to the two papers is presented in Table 1. Major contribution is defined as contributing to at least three quarters of the realization of the activity.

Table 1. The author’s contribution to the appended papers.

| | Contribution | |
|---------------------------------|--------------|----------|
| | Paper I | Paper II |
| Planning and preparation | Major | Major |
| Execution | Major | Major |
| Analysis | Major | Major |
| Writing of manuscript | Major | Major |

Apart from the appended papers described above, the author has co-authored the following relevant documents which should be seen as complementary publications not included in the thesis.

- III. Smedberg, E., & Ronchi, E. (2021). Review of Alarm Technologies for Deaf and Hard of Hearing Populations (FPRF-2021-09). Fire Protection Research Foundation.
- IV. Smedberg, E., Ronchi, E., Hutchison, V. (in press), Alarm technologies to wake sleeping people who are deaf or hard of hearing. Fire Technology.
- V. Ronchi, E. Smedberg, E., Carlsson, G., Slaug, B. (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.
- VI. Smedberg, E., Kinsey, M. & Ronchi, E. (2021). Multifactor Variance Assessment for Determining the Number of Repeat Simulation Runs in Evacuation Modelling. Fire Technology 57, 2615–2641. <https://doi.org/10.1007/s10694-021-01134-w>

1.4. Thesis outline

The thesis consists of six sections. The thesis is based upon the work conducted within the two appended papers. Below is an overall description of each of the six sections.

Section 1 (Introduction) presents a brief background to the research area of evacuation and functional limitations, including previous research. This background leads to the formulation of purpose and objectives that this thesis sets forward to address. The delimitations of the current work are also presented. The publications that provide the foundation for this thesis are presented along with the author's contribution to their realisation.

Section 2 (Theoretical background) provides the necessary theoretical background that has guided the author in the research presented in this thesis.

Section 3 (Methods used to identify egressibility issues) presents the methods used in the two appended papers. The section provides an overview of the methods, and a discussion on scientific quality in both methods.

Section 4 (Research results & outcomes) presents briefly the studies of the two appended papers and a joint reflection on the results.

Section 5 (Discussion & outlook) discusses methodological and conceptual challenges relevant for the research field and presents relevant future research objectives that have been identified based on the results from the two appended papers.

Section 6 (Conclusions) presents the conclusions that can be drawn from the results of the two appended papers, in relation to the purpose and objectives set forward in section 1.

2. Theoretical background

This section provides a theoretical background to the research presented in this thesis. The aim of this section is to present the founding framework that has guided the author in the research. The section covers a variety of topics including human functioning, evacuation performance of people with functional limitations, prevalence of functional limitations, accessibility, and assessments of accessibility and egressibility.

2.1. Human functioning and functional limitations

Within the field of human functioning there are many terms used, and the terminology is constantly changing to reflect and highlight different aspects of the construct. There are also sometimes conflicting views on the definitions and use of terms. Generally speaking, the definitions can be described as going from an almost exclusive focus on the individuals, towards the recognition of the environment in creating disability (Whiteneck, 2006).

In disability theory, several distinct models of disability exist. The medical model, the social model, and the biopsychosocial model (Petasis, 2019) have been selected for inclusion in this thesis as they are relevant in the context and well-known. A schematic application of the three models is presented in Figure 1 to highlight some of the conceptual differences between them. Although these models co-exist in different domains, the medical model of disability was the first of the three to have been developed. Disability in the medical model is seen as a characteristic of the person that can be explained through the underlying medical conditions solely (Brisenden, 1986). Impairments (problems in body function and structure such as significant deviation or loss (World Health Organization, 1980)) of sufficient severity were seen as causing disability and hence, elimination or reduction of the impairment removed the disability.

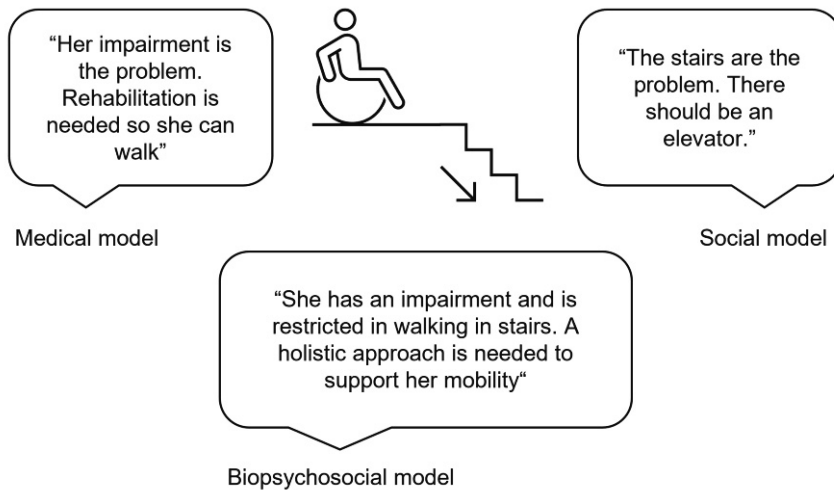


Figure 1. Schematic application of the three models of disability (medical, social, and biopsychosocial) discussed in the thesis.

As a critical response to the medical model of disability, the social model of disability was developed and advocated for (Oliver, 2013). Whereas the medical model focused on the individual, the social model instead highlighted the role of society as the cause of disability. The social model describes that it is through society's inability to accommodate the needs of all individuals that disability is created. This includes the environment (e.g., inaccessibility due to the type of evacuation components, technical installations/systems, communication), attitudes (e.g., prejudice, stereotyping, discrimination) and organization (e.g., inflexible evacuation procedures and practices). Although the social model was developed more as a critical response rather than an all-encompassing model, it has had a considerable influence on how disability is viewed today, especially within the disability rights movement.

The biopsychosocial model can be described as a combination of the medical and social model of disability (Wade & Halligan, 2017). The biopsychosocial model is used in the International Classification of Functioning, Disability and Health (ICF) developed by the World Health Organization (WHO) (2001). The classification was approved for use in 2001 and has since been used as a unifying framework for health and disability. ICF conceptualises disability not solely as an issue that belongs to the individual, but as an experience that occurs in a social and environmental context (Kostanjsek, 2011). According to the ICF model, disability and functioning are outcomes of interactions between *health conditions* (diseases, disorders and injuries) and *contextual factors*. The biopsychosocial model of the ICF widens the perspective of disability and allows medical, individual, social, and environmental effects on functioning and disability to be assessed. The ICF describes the components of Body Function and Structures, Activities and Participation,

Environmental Factors and Personal Factors. A schematic representation of the biopsychosocial model used in the ICF is presented in Figure 2.

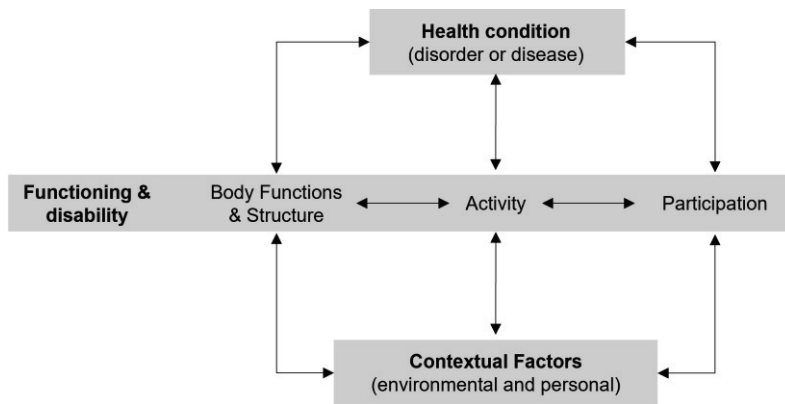


Figure 2. Biopsychosocial model of the International Classification of Disability, Functioning, and Health. Redrawn based on (World Health Organization, 2001).

The figure highlights the interactions of the components of the ICF and the links between body function and structures (for example impairments linked to cognitive functions, sensory functions and pain, neuro-musculoskeletal and movement-related functions), activity (for example activity restrictions linked to purposeful sensory experiences, communicating, walking and moving) and participation (involvement in different life situations). Those are related to environmental and personal factors that can affect egress. Examples of environmental factors include natural and human-made environments that may be inaccessible due to evacuation components, technical installations/systems, communication, etc.; attitudes such as prejudice, stereotyping, discrimination, etc.; and services, systems and policies such as inflexible evacuation procedures and practices. Personal factors include for instance age, past experience, etc.

In the presented research, the biopsychosocial model of disability as presented by the ICF (World Health Organization, 2001) has been used as a guiding framework. Additionally, this research is largely based on the field of accessibility (Iwarsson & Slaug, 2010; Iwarsson & Ståhl, 2003) in which slightly different terms are sometimes used. The discrepancies relate to another model of disability, namely the Disablement model as described by Nagi (1965, 1991). For a comparison between the disablement model and the ICF, see (Jette, 2006). In Table 2 below, redrawn from (Jette, 2006), components and their definition in the ICF and the Disablement model is displayed.

Table 2. Terminology used in the Disablement model (Nagi, 1965, 1991) compared to the International Classification of Disability, Functioning, and Health (World Health Organization, 2001) focusing on both functioning and disability. Redrawn from (Jette, 2006).

| Disablement model (Nagi, 1965, 1991) | ICF (World Health Organization, 2001) |
|---|--|
| Active Pathology— interruption or interference with normal processes, and effort of the organism to regain normal state | Health Conditions—diseases, disorders, and injuries |
| Impairment— anatomical, physiological, mental or emotional abnormalities | Body Function—physiological functions of body systems Body Structures—anatomical parts of the body Impairments—problems in body functions or structure |
| Functional Limitation—limitation in performance at the level of the whole organism or person | Activity— the execution of a task or action by an individual Activity Limitation— difficulties an individual may have in executing activities |
| Disability— limitation in performance of socially defined roles and tasks within a sociocultural and physical environment | Participation — involvement in a life situation Participation Restriction—problems an individual may experience in involvement in life situations |

Hereinafter, the term functional limitation will be used as a descriptor of limitation in performance at the level of the person for reasons of consistency.

Although functional limitations often refer to permanent conditions, they exist in various forms. Considering the definition, many circumstances can lead to limitation in performance at the level of the person. Permanent conditions include for example those acquired at birth or through an injury. While injuries can lead to permanent functional limitations, they can also lead to temporary limitations. Consider for example a person using crutches following rehabilitation from a bone fracture, or a person wearing an eye-patch following eye treatment. Temporary functional limitations may also include issues associated with pregnancy, limiting the person’s ability to maintain a standing position or their stamina for example. Another cause for functional limitations could be described as situational. A person carrying heavy boxes is temporarily limited by the situation in using their hands, seeing, and perhaps maintaining balance. A person evacuating through smoke may have trouble seeing architectural elements. Loud evacuation alarms may decrease a person’s ability to hear other auditory cues. The distinction between situational functional limitations and activity limitations as described by the ICF (World Health Organization, 2001) is not always clear, considering that the environment may be associated with the situation creating the functional limitation. Nonetheless, recognizing that functional limitations are not only permanent highlights that inclusive design, i.e., design that is usable by as many as possible (Clarkson et al., 2003), is not only relevant for a specific delimited group of people, but can become relevant for all people due to temporary and situational circumstances.

2.2. From accessibility to egressibility

Accessibility is a wide concept that has been applied in diverse fields such as web accessibility (Paciello, 2000), building accessibility (Iwarsson & Ståhl, 2003), and spatial accessibility (Guagliardo, 2004). In this thesis, accessibility refers to building accessibility. Although the definitions are many, it often includes characteristics of being reachable or usable, especially for people with functional limitations. The United Nations describes accessibility in article 9 of the Convention on the Rights of Persons with Disabilities (UNCRPD) (United Nations, 2012);

Article 9

Accessibility

To enable persons with disabilities to live independently and participate fully in all aspects of life, States Parties shall take appropriate measures to ensure to persons with disabilities access, on an equal basis with others, to the physical environment, to transportation, to information and communications, including information and communications technologies and systems, and to other facilities and services open or provided to the public, both in urban and in rural areas. These measures, which shall include the identification and elimination of obstacles and barriers to accessibility, shall apply to, inter alia:

(a) Buildings, roads, transportation and other indoor and outdoor facilities, including schools, housing, medical facilities and workplaces;

(b) Information, communications and other services, including electronic services and emergency services.

The UNCRPD has been ratified by 184 parties as of the 5th of January 2022 (United Nations, 2022), including Sweden and the EU.

In 2021, the European standard SS-EN 17210:2021 *Accessibility and usability of the built environment – Functional requirements* was published (Svenska institutet för standarder, 2021). The standard is the first European standard of its kind, being based upon the previously published ISO 21542 (International Organization for Standardization, 2021). The standard adopts a modified version of the definition of accessibility from ISO 21542:2011. In contrast to many other definitions of accessibility, this definition explicitly includes evacuation;

Accessibility

provision of buildings, parts of buildings, or outdoor built environments for people, regardless of disability, age or gender, to be able to gain access to them, into them, to use them and exit from them.

Note 1 to entry: Accessibility includes ease of independent approach, entry, evacuation and/or use of a building and its services and facilities, and outdoor spaces by all of the potential users with an assurance of person health, safety and welfare during the course of those activities.

In an effort to provide a common language to be used by professionals, researchers, and practitioners, Iwarsson & Ståhl (2003) proposed the following three-step definition of accessibility;

- (1) The personal component (description of functional capacity in the individual or group at target, based on knowledge on human functioning).
- (2) The environmental component (description of barriers in the environment at target, in relation to the norms and standards available).
- (3) An analysis juxtaposing the personal component and the environmental component (description of accessibility problems).

The definition highlights accessibility as a relative concept. It also emphasizes accessibility as being an objective and measurable entity in contrast to the related concept of usability (Iwarsson & Ståhl, 2003). A theoretical basis for the definition can be found in the Ecological Theory of Ageing, also known as the competence-press model or the person-environment fit model (Lawton & Nahemow, 1973). The person-environment fit model describes the relationship between functional capacity and environmental demands. The main focus of the environmental demands in this thesis is the physical environment. Functional capacity includes functional limitations as described in the previous section. Environmental demands is defined as “forces in the environment that together with an individual need evoke a response” (Murray, 1938).

Included in the person-environment fit model is the environmental docility hypothesis, stating that people with lower functional capacity are more susceptible to environmental demands. The person-environment fit model can be depicted in a graph as shown in Figure 3.

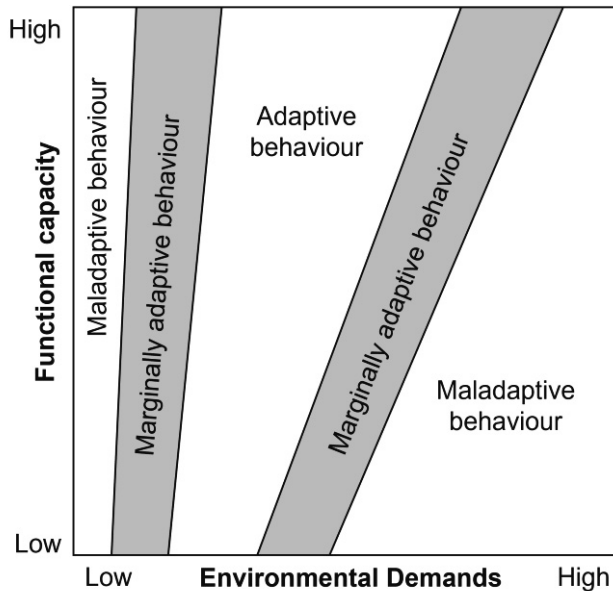


Figure 3. Simplified person-environment fit model. Redrawn from (Lawton & Nahemow, 1973).

‘Adaptive behaviour’ in Figure 3 represents circumstances where functional capacity and environmental demands match, and the fit provides a positive outcome. An example could be a building that is designed with the appropriate measures so that a safe evacuation is made possible for the individual. A ‘maladaptive behaviour’ refers to the opposite, where there is a misfit and apparent risk for harm or suffering. A ‘marginally adaptive behaviour’ could for example be where an individual accomplishes an evacuation with some struggle, e.g., a person in a wheelchair bumping his way down a set of stairs to reach safety. The last example is a real experience from a museum evacuation described by Boyce (2017). Notable, the leftmost part of Figure 3 where low environmental demands generates ‘marginally adaptive-’ or ‘maladaptive behaviour’ is not relevant for evacuation but could be in the context of physical activity or work.

Considering the person-environment fit model, accessibility revolves around the systematic comparison between environmental demands and functional capacity. In situations where elements of the physical environment pose too high demands in relation to an individual with a certain functional capacity, the term ‘environmental barrier’ is used to describe the element.

Egressibility is a concept that can be argued to be similar, if not identic, to accessibility. The difference is the environmental arena under consideration including the physical and social environment. Differences in environmental arenas

result in different features of the physical environment that need consideration. Accessibility is derived from Latin *accessus* and means in simple terms ‘affording access’ or the capability of being approached or reached. The term egressibility can be seen as a play on words, where ‘access’ in ‘accessibility’ is interpreted as access to buildings or going into buildings. Egress on the other hand is interpreted as the process of leaving a building. It can be argued though if ‘access’ should be interpreted as mentioned, or if access should be interpreted as reaching what is necessary in the situation (as in the SS-EN 17210:2021 definition). Consider for example the use of the word accessibility in web and information applications. Hence, accessibility as a term could be used also to describe accessibility during egress. However, the term egressibility will be used in this thesis to highlight the difference in environmental arenas.

An early mentioning and definition of egressibility can be found in the works by Gylène Proulx (1995). Egressibility is there described as meaning ‘the possibility of leaving a building or reaching an area of safety in case of emergency’. Although the definition is deemed to be accurate, it lacks in distinctness. Given the above definition, egressibility as a concept can be argued to be redundant given the similarities with the concept of evacuation safety in general. The work contained in this thesis at large revolves around conceptualising egressibility and operationalising it. Hence, the objective definition of accessibility proposed by Iwarsson & Ståhl (2003) has been adopted also for egressibility, with the difference being the environmental arena of application as stated.

2.3. Evacuating with functional limitations

According to ISO 22300:2021, evacuation refers to “organized, phased and supervised movement of people from dangerous or potentially dangerous areas to places of safety” (International Organization for Standardization & European Committee for Standardization, 2021). Notably, this definition is somewhat idealistic, and evacuations can become both disorganized and unsupervised. Taking the case of fire as an example, buildings can become dangerous to people due to toxic gases, increasing temperatures, and structural collapse (Meacham, 1997). This thesis deals with the evacuation of people with functional limitations in the public built environment. While the end goal of evacuation is to ensure the safety of occupants, there are numerous strategies to achieve it. The strategies could be characterized both by spatial and temporal aspects as well as by who carries out the evacuation. Spatial and temporal aspects include total evacuation strategies, phased evacuation, defend-in-place and delayed evacuation (Ronchi & Nilsson, 2013). The first two rely on the relocation of occupants, while the latter relies on ensuring that the occupants are safe where they currently are by means of structural integrity, fire

and smoke prevention. Relocation could be carried out autonomously by the occupants, referred to as ‘self-evacuation’, or by means of others, referred to as ‘assisted evacuation’. On top of general strategies aimed at ensuring safety for the whole building population, individual emergency plans can be developed through Personal Emergency Evacuation Plans (PEEP’s) (National Fire Protection Association, 2016). The purpose of a PEEP is to provide people who may be unable to evacuate on their own with a tailored escape plan. The plan could include information on for example the individuals need for assistance in various evacuation activities and how that need is fulfilled. As such, a PEEP is used primarily as a tool for planning.

An accessible society is often characterized by promoting inclusivity, participation and autonomy of all people, irrespective of functional capacity (United Nations, 2012). Progresses in the accessibility field have shown that different technical and non-technical solutions increase people’s possibilities to live an independent life (Vaughan et al., 2016). It is therefore crucial to investigate to which extent the fire safety design addresses the needs of individuals with functional limitations, and what opportunities they have to evacuate independently. Therefore, the focus of this thesis is on self-evacuation, ensuring that all occupants have the possibility to evacuate by own means. Defend-in-place and delayed evacuation strategies will not be discussed further in this thesis for the same reasons.

It is essential to describe the evacuation process in order to identify the different activities that take place. The identification of activities is imperative for understanding evacuation in general and the potential influence of functional limitations in particular. Two descriptive evacuation models are the engineering model and the behavioural model (Frantzich et al., 2016; Proulx, 2002b). Both models have their advantages and disadvantages, and as the names imply, the engineering model is suitable for engineering purposes, and the behavioural model is useful for describing the behaviour of the occupants. Whereas the engineering timeline describes the phases awareness (alarm), pre-movement (pre-evacuation), and movement (travel), the behavioural timeline includes the phases detection and alarm, recognition, and response. The main difference being that some activities related to the pre-movement in the engineering timeline are characterized as response in the behavioural timeline, considering that some activities revolve around decisions taken to reduce consequences.

As stated in previous sections, limitations in performance of common daily activities are referred to as functional limitations. For example, walking in stairs is one common activity. The ability to walk in stairs can be reduced by various impairments, such as stiffness in the legs, inability to use the leg muscles, or an inability to use the muscles in a coordinated way. By identifying common evacuation activities, it is possible to define the functional capacity required by

individuals to perform self-evacuation. It is also possible to identify what evacuation activities should be facilitated, and which barriers should be minimized or eliminated to facilitate self-evacuation for people with lower functional capacity. Figure 4 presents an engineering evacuation time-line and associated evacuation activities based on the work by Bukvic et al. (2020). Considering the person-environment fit model, improving egressibility involves enhancing functional capacity or removing environmental barriers, or both.

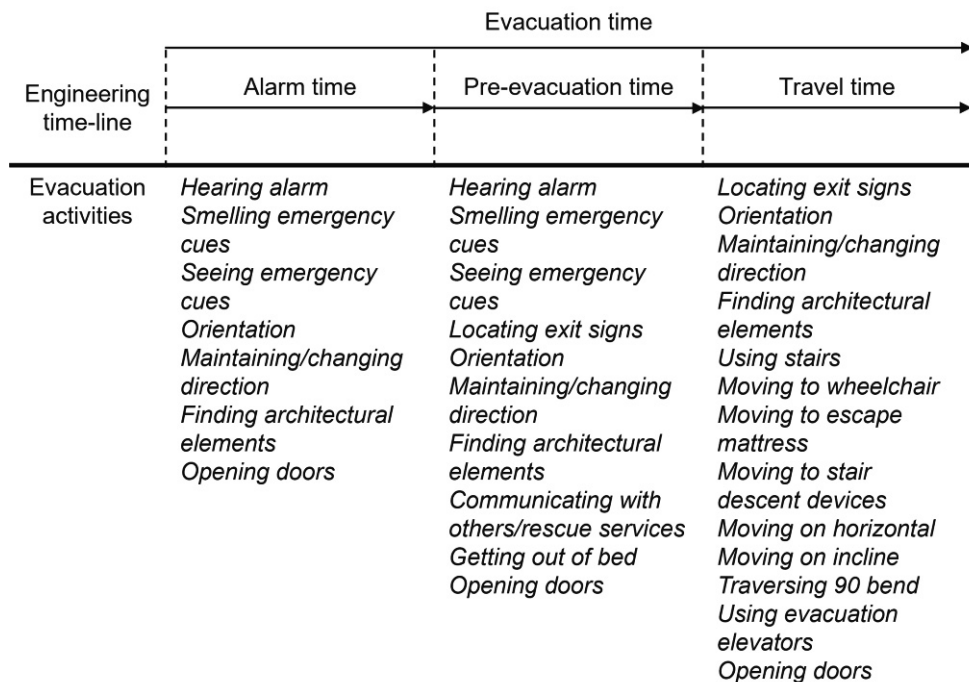


Figure 4. Engineering evacuation time-line and associated evacuation activities. Based on (Bukvic et al., 2020).

In a recent effort to consolidate available information on the evacuation of people with functional limitations in the domain of public buildings, Bukvic et al. (2020) performed a scoping review and classification of studies. The classification was based on the understanding of functional limitations as described by the ICF (World Health Organization, 2001). The evacuation process was described using the engineering model and divided further into more specific evacuation activities such as hearing alarm, using stairs, and opening doors as shown in Figure 4. These were then classified according to the ICF categories of activities and participation. The assigned ICF category was aimed towards describing the most predominant activity/activities related to the identified evacuation activity. The full list of ICF classifications can be found in the ICF online browser (World Health Organization,

2022). For example, the evacuation activity of hearing alarm was classified as 'Listening'. 'Opening doors' was classified as containing several predominant activities, namely 'Lifting and carrying object', 'Fine hand use', 'Hand and arm use', 'Walking', and 'Moving around in different locations'. The other part of the classification referred to common functional limitations. These included visual limitation, hearing limitation, mobility limitation, upper extremities limitation, cognitive limitation, and other limitation. With these two classifiers (functional limitations and evacuation activity), the identified studies were classified in a matrix. This novel approach in the fire safety domain provides a guide and classification framework necessary for a more systematic understanding of egressibility issues in line with more modern understandings of human functioning.

Bukvic et al. (2020) concluded that there was an evident research gap relating to the impact of cognitive limitations on evacuation performance. Olfactory limitations (the ability to smell smoke) were also identified as a research gap. Some studies were identified in relation to sensory limitations including hearing and visual limitations and the recognition phase of evacuation. Unsurprisingly, most studies were found relating to lower body mobility limitations and the travel phase.

The recognition phase of evacuation includes the perception of cues, information seeking, communication, decision-making etc. (Frantzich et al., 2016). As such, it relates primarily to sensory functions of seeing, hearing, smelling, and cognition. Audible alarms are often used as a way of notifying building occupants of imminent threat, and to instruct them to evacuate. Hearing limitations can have a significant impact on the ability to respond promptly to an alarm (Huey et al., 1996; Moinuddin et al., 2017). Hearing deteriorates with age starting at the higher frequencies and this deterioration is the most common cause of hearing loss (Liu & Yan, 2007). There may therefore be delays in response since alarms are often emitting sounds in the mid to high frequency range (Huey et al., 1996; Kecklund et al., 2012; Moinuddin et al., 2017; Proulx, 2002a). Low-frequency alarms have been shown to be significantly more efficient in waking up people with moderate hearing loss (Bruck & Thomas, 2009; Smedberg & Ronchi, 2021). Visual limitations would affect the ability of residents to see visual cues of a fire (Kuligowski, 2016b). Additionally, fires can be perceived through smelling, but the impact of functional limitations on this issue was identified as a research gap by Bukvic et al (2020).

For engineering purposes, the engineering data chapter of the SFPE handbook of fire safety engineering (Gwynne & Boyce, 2016) contains valuable quantitative data related to evacuation performance. In an effort to complement the data in this chapter with more recent data relating to the evacuation performance of people with functional limitations, Geoerg et al. (2019) performed a scoping review in this field. The gathered data related to the pre-movement and movement phases and included people with physical, cognitive, and age-related functional limitations. They

concluded that the amount of data is limited. Engineering data in this domain can be classified in two types: data relating to the evacuation performance of people with functional limitations, and data relating to the impact on crowd evacuation performance by the presence of people with functional limitations. Although the latter is essential for engineering purposes, it is not the focus of this thesis. As a general conclusion, people with functional limitations, particularly mobility related, tend to move slower during evacuation (Christensen et al., 2006; Georg et al., 2019). Heterogenous crowds including people with functional limitations also tend to move slower, primarily influenced by the space requirements by certain assistive devices such as wheelchairs and persons assisting people with functional limitations (Christensen et al., 2006; Georg et al., 2019). In relation to the influence of heterogenous populations on overall evacuation performance, it has been suggested that individual movement speed has the largest influence when occupant density is low, and that space requirements (e.g., assistive devices, assisting people) have larger influence when occupant density is higher (Boyce, 2017).

As highlighted by several reviews in the domain, the movement during evacuation of people with functional limitations has been shown most interest, while their decision-making and behaviour has been shown less (Boyce, 2017; Bukvic et al., 2020; Georg et al., 2019; Hashemi, 2018). Considering that the pre-movement phase constitutes a large proportion of the total evacuation time (Forssberg et al., 2019), this is an issue in need of further investigation. Although it is fair to assume that some of the decision-making processes taking part during pre-movement are similar for people with and without functional limitations, living with a functional limitation involves the adaptation of various coping strategies (Persson & Rydén, 2006) which could influence decision-making. For example, results from an exit-choice experiment (Gaire et al., 2018) involving people with and without functional limitations suggested that people with functional limitations may tend to choose an exit chosen by others with functional limitations. The opposite was observed for people without functional limitations, i.e., they may tend to avoid an exit chosen by people with functional limitations.

Additionally, there is an overemphasis regarding measuring the capabilities of people with functional limitations, rather than looking at the potential supportive role of the environment (Christensen et al., 2006). A good example integrating both the personal component and the environmental component of the person-environment fit of egressibility is a series of studies conducted by Boyce, Shields and Silcock (1999a, 1999b, 1999c). The studies included people with visual and mobility limitations. The three studies related to three separate potential environmental barriers, namely exit signs, horizontal and inclined/declined movement, and doors. The study series is particularly useful as it reports evacuation performance not simply as a characteristic of the people with functional limitations, but rather as a consequence of the specific person-environment fit. They conclude

for example that certain exit signs are easier seen by people with visual limitations, that the negotiation performance depends upon the type of mobility limitation and opening force required, and that movement speed is affected by the type of mobility limitation and surface configuration.

It has been recognized that building design, especially in relation to evacuation, mostly considers two groups of people: people without functional limitations, and people using wheelchairs (Boyce, 2017). In fact, functional limitations are continuous rather than discrete, and functional limitations exist in many different forms which present unique challenges for fire safety. Therefore, characterisation of the population and understanding of individual needs are imperative for inclusive evacuation design.

2.4. Prevalence of functional limitations

To understand the extent of the potential issues with non-accessible evacuation design, this section provides some statistics and discussion related to permanent functional limitations in Sweden. Statistics Sweden (SCB) regularly investigates living conditions in the Swedish population through structured interviews, the Survey of living conditions (Swedish: ULF) (Statistiska centralbyrån, 2020). Functional limitations are among the conditions surveyed. The questionnaires are distributed to a selected sample (11 248 people in the 2018-2019 survey) that is intended to be representative for the Swedish population aged 16-84. Statistics for the survey of 2018-2019 are given in Table 3.

Table 3. Prevalence of functional limitations in Sweden 2018-2019 (Statistiska centralbyrån, 2020).

| | Age | | | | |
|--|--------------|--------------|--------------|------------|--------------------|
| | 16-29 | 30-44 | 45-64 | 65+ | 16+ (total) |
| At least one functional limitation | 28.7% | 25.4% | 35.2% | 53.9% | 36.2% |
| At least two functional limitations | 8.1% | 5.9% | 10.3% | 17.7% | 10.6% |
| Severe loss of sight | - | - | 5.3% | 9.5% | 4.95% |
| Severe loss of hearing | 6.0% | 8.2% | 19.0% | 38.4% | 18.4% |
| Mobility | - | - | 5.6% | 15.5% | 5.9% |
| Use of mobility aid | - | - | - | 10.8% | 3.4% |

A substantial proportion of the adult population (36.2%) experiences at least one functional limitation (this includes severe allergies and severe psychological issues). Mobility limitations, recognized as one of the major challenges for evacuation

safety, is experienced by 5.9% of the total population in Sweden. More than three times as many (18.4%) experience severe loss of hearing which is the most prevalent functional limitation. Evidently, functional limitations are more common in older age for all functional limitations mentioned. Mobility-related functional limitations are roughly three times more frequent in the oldest age group (65+) when compared the adult population overall (16+). Sensory limitations (seeing and hearing) are roughly twice as frequent.

Although these statistics provide insights into the characteristics of the population, they should be treated with caution. The validity of statistics on functional limitations is often severely impeded by the data collection techniques (World Health Organization, 2011). Furthermore, functional limitation prevalence studies in different regions or from different institutions are seldom comparable due to differing measuring approaches and assumptions (World Health Organization, 2011). Nevertheless, functional limitations are frequent and the prevalence is anticipated to increase in the future due to demographic changes (World Health Organization, 2011). Increased prevalence and continuous improvements in accessibility mandates the need for inclusive evacuation design recognizing varying functional capacity in the population.

2.5. Assessments of egressibility

Given the definition of egressibility as a person-environment fit proposed in this thesis, assessing egressibility should reflect the (potential) outcomes of the interaction between the functional capacity of individuals and the environmental demands. Assessments could relate to quantitative evacuation performance such as walking speeds as is the case in many previous studies (Boyce, 2017; Bukvic et al., 2020; Geoerg et al., 2019; Hashemi, 2018), but it could also relate to the identification and quantification of potential barriers in the environment through the use of instruments, methods, or tools. The latter is the focus of this thesis.

Since the recognition of the role of environmental barriers in creating disability, effort has been put in the accessibility domain to develop systematic instruments for the identification of barriers and accessibility issues. When first implemented, the Americans with disabilities act (ADA) (The United States Department of Justice, 1990) was pioneering the field of disability rights. Part of the ADA includes the removal of environmental barriers as defined by the 2010 ADA standards (The United States Department of Justice, 2010). These barriers are minimal requirements that need to be fulfilled for the environment to be accessible, for example maximum allowable height of thresholds, minimum door widths etc. For practicing purposes, some of the information in the 2010 ADA standards have been

implemented in a checklist instrument for compliance verification (Institute for Human Centered Design, 2016). The checklist includes items that relate to environmental barriers, and the user of the checklist is asked questions that determine if environmental barriers exist or not. Since its implementation, this checklist has been proven useful for practitioners and have been implemented widely in the field of accessibility. The simplicity of the instrument renders it unable to quantify the negative effects of inaccessibility, nor does it differentiate between different functional limitations.

Another pioneering instrument for accessibility assessments is the Housing Enabler developed by Iwarsson & Slaug (2010) at Lund University. The methodology is a further development of the Enabler methodology presented by Steinfeld (1979). One of the developers, Susanne Iwarsson, is also one of the co-authors of the positioning paper that proposed the definition of accessibility (Iwarsson & Ståhl, 2003) adopted in this thesis as a definition for egressibility. Hence, the Housing Enabler methodology is consistent with the definition and provides a necessary framework on which further assessment instruments can be built. As stated previously, one difference between accessibility and egressibility is the environmental arena in which person-environment interactions occur. The environmental arena includes the social and physical environment, and both static and dynamic aspects. The Housing Enabler was developed for accessibility assessments in the homes of people in Sweden. Since then, it has been adapted to other regional domains and other physical environments (Lien et al., 2016; Slaug et al., 2019).

In the evacuation field, a set of instruments have been developed to evaluate different aspects of the evacuation of people with functional limitations (Georg et al., 2017; Hashemi & Karimi, 2016; Rubadiri et al., 1997). The indoor spatial model (Hashemi & Karimi, 2016) is described as a route choice algorithm designed with people with functional limitations in mind. It makes use of the ADA guidelines to compute an accessibility index for all routes, and then finds the optimum route. The indoor spatial model does not differentiate between different functional limitations and treats the ADA guidelines as Boolean, not accounting for differences in severity. In the Evacuation Performance Index (EPI) (Rubadiri et al., 1997), a new procedure for evaluating the evacuation capabilities of people with functional limitations was proposed. The EPI accounts for both individual functional limitations as well as environmental demands and is as such consistent with the notion of person-environment fit. The approach is based on identifying time delays in negotiating evacuation elements for people with functional limitations. This approach is deemed useful for performance-based evaluations of evacuation time but may be argued to be idealistic in terms of feasibility in collecting all the necessary data. Further, some interactions between people and environment during evacuation are difficult to measure in terms of time, as has been shown in the accessibility domain (Thapar et al., 2004). Some interactions may for instance result in unnecessary harm rather than

time delays, and some interactions may increase the risk of delays due to inappropriate decisions, which could be very individual and hence difficult to quantify. It is recognized by the authors that interactions that result in impossibilities to evacuate cannot be accounted for by the EPI (Rubadiri et al., 1997). Nonetheless, the EPI was shown to correlate well with empirical data in relation to evacuation times on well-defined routes (Rubadiri et al., 1997).

A score regarding the need for assistance (Score RNA) has been developed by Georg et al. (2017). The score considers individual functional limitations and the potential need for assistance in three dimensions of evacuation: reception, perception, and realisation. As such, different functional limitations may need assistance in these dimensions. Age was also included as a moderating variable, where older age was said to result in more need for assistance. This method does not account for the environmental design when evaluating the need for assistance.

It is evident that different approaches to assess egressibility differ in conceptual foundation, perhaps largely influenced on the understanding of egressibility and disability that it is based on. Further, all efforts to assess levels of egressibility will have their limitations due to the many dimensions of the construct. Perhaps most important in the development process is that the foundations and underlying assumptions made are explicitly mentioned, as they influence the interpretation of the results.

3. Methods used to identify egressibility issues

This section presents an overview of the research methods used in the presented studies. This includes examples of previous studies and quality of research in the two domains of qualitative inquiry and quantitative assessment instruments.

3.1. Qualitative inquiry

As presented in section 2, egressibility is seen as a topic covering many aspects of the relationship between people and the surrounding environment. Human behaviour in fire, often linked to the engineering domain, has a tradition of favouring quantitative research methods. Advantages of quantitative research methods include the possibility to identify key quantitative evacuation characteristics, such as the movement speed of individuals, delays in response to fire alarms and cues, route choice, etc. (Gwynne & Boyce, 2016). These quantitative characteristics are essential for engineering purposes, where the aim is often to predict and model the response of occupants during evacuation. However, they provide limited insight into the internal processes and decision-making of the evacuating occupants.

When investigating intangible subjects of perspectives, motivations, and interpretations, qualitative research methods are seen as the preferred type of research (Flick, 2014). As such, qualitative research is considered a necessary complement to quantitative research methods in the human behaviour in fire discipline (Kuligowski, 2017).

Although qualitative research methods used in social sciences were very influential in the early days of human behaviour in fire research (Latané & Darley, 1970; Sime, 1980, 1985; Tong & Canter, 1985), they received less attention since then. A review of trends regarding topics and methods of human behaviour in fire studies highlighted that ‘unobservable’ processes of human behaviour in fire had been given less research attention (compared to observable aspects) (Kuligowski, 2017). Unobservable aspects include perceptions, motivations, and interpretations.

Furthermore, it was concluded that the primary emphasis was on aspects during fire events, rather than before or after (Kuligowski, 2017).

The purpose of qualitative research is collecting and analysing primarily non-numerical data from human subjects. Intangible subjects such as perspectives, opinions and thoughts are often at focus of the investigation (Flick, 2014). The collection and analysis of data is sometimes separate, and sometimes highly intertwined. Non-numerical data for qualitative analysis can be collected through many different methods, including surveys, interviews, documents and observations (Flick, 2017). Each method has its set of advantages and disadvantages, and their suitability depends on the research questions and context. After the data has been collected, it needs to be analysed to generate findings. In qualitative research, there are numerous techniques to analyse the data, including grounded theory (Charmaz & Bryant, 2016), content analysis (Elo & Kyngäs, 2008), discourse analysis (Gill, 2000), narrative analysis (Cortazzi, 1994), interpretive phenomenological analysis (Eatough & Smith, 2008), thematic analysis (Braun & Clarke, 2012), etc. As with data collection methods, the methods of analysis have their specific sets of advantages and disadvantages, and the choice of method should rely on the research questions and context under investigation.

In relation to the evacuation of people with functional limitations in public environments, some studies have incorporated qualitative research methods, including interviews, focus groups and questionnaires for data collection. Shields, Boyce, & McConnel (2009) conducted an analysis of interview transcripts, coded time, location and experience data from the High-rise Evacuation Evaluation Database (HEED) relating to six survivors from the 9/11 attacks on the World Trade Center who had self-designated mobility impairments. The study reports that their evacuation experiences, which were mostly contained to negotiating the stairs, were different both in terms of movement speed and social interactions. This highlighted that 'mobility impaired' is an insufficient description of evacuation capabilities.

Kecklund et al. (2012) conducted a focus group study in Sweden, involving four focus groups each containing four to six participants. Each focus group involved participants with similar functional limitations. The aim of the study was to investigate the participants perspectives and opinions regarding fire safety in historical buildings. Results included accounts of real-life experiences of how well the evacuation design accounted for their individual needs, as well as suggestions for improvement. Using the definitions proposed in this thesis, these are examples of environmental barriers. Kecklund et al. (2012) concluded that both physical environmental aspects as well as organizational aspects have to be improved, and that the needs of individuals were very dependent on the type of functional limitation experienced.

Fire risk perception of three groups of people: laypersons, healthcare professionals working with vulnerable populations, and fire victims were investigated through a qualitative research method by Tancogne-Dejean & Laclémence (2016). The sample consisted of eleven participants, and data was collected through interviews and questionnaires, later analysed through 'analysis of content'. They concluded that there is a difference in risk perception for the three groups included, and that fire risk perception consists of three dimensions: individual, environment, and risk. Trust was highlighted as particularly important and divided into three areas: self-confidence, trust in others, and trust in the organization. Building evacuation was seen not simply as a response, but rather a psychological process involving cognition and emotion.

Vertical evacuation is a major challenge for people who are unable to negotiate stairs. In light of this, alternative strategies have been developed including refuge areas and occupant evacuation elevators (Proulx & Pineau, 1996). Butler et al. (2017) set out to investigate the perspectives of people with mobility-related functional limitations on five evacuation methods: emergency stair travel devices, areas of refuge, existing passenger elevators, existing freight or service elevators, and occupant evacuation elevators. Fifty-one participants with mobility-related functional limitations were interviewed. The interviews were transcribed and coded with the use of a code list. A full description of the method and sample can be found in Butler et al. (2016). The results were displayed in a table, giving examples of benefits and concerns for each evacuation method based on the perspectives of the participants. The authors concluded that emergency stair travel devices were associated with concerns of losing mobility aid device, areas of refuge with anxiety of being left behind, and elevators with concerns of reliability and lack of priority use (Butler et al., 2017).

To investigate the knowledge surrounding refuge areas, and to provide guidance on how they should be designed, Andrée et al. (2015) performed a questionnaire study and a Virtual Reality (VR) study involving 71 and 15 participants with mobility impairments respectively. The questionnaires were used to assess needs and the VR study was used to test different configurations of the refuge area itself as well as the communication system installed within. The VR study was accompanied by both questionnaires and interviews. Results showed that the participants were positive towards the existence of refuge areas, but only half knew of their existence at the time of the study. Additionally, half of the participants stated that they were confident in using the refuge during an evacuation, while the other half would try to evacuate to another place of safety. It was also found that a two-way voice communication system was preferable over a one-way voice communication system or a button and light-based system.

As stated, stair travel devices have been developed and implemented as an alternative means of vertical evacuation, often with assistance from others. In relation to this, Hedman et al. (2021) conducted a qualitative study involving 14 participants with mobility impairments investigating their opinion on 14 different stair-travel devices. The stair-travel devices were divided into three groups: carry-type, track type, and sled-type. Perspectives were sought in the domains of usability and feelings of safety. A carry-type device that allowed the frontmost assisting person to face in the direction of travel and an inflatable sled-type device were perceived to be the most acceptable designs for evacuation. Although not strictly relevant for self-evacuation, this study and the study mentioned above (Andrée et al., 2015) highlight the importance of incorporating the target group in the design process of assistive devices and procedures for evacuation.

The above-mentioned qualitative studies involving evacuation and people with functional limitations highlight the benefits of adopting a qualitative research method. As evacuation is to a large degree a physiological process, qualitative research looking at the perspectives, motivations, and interpretations is necessary to understand the situation at hand.

As for the study presented in paper I, the data collection took the form of questionnaires and semi-structured interviews. It was deemed that these data collection methods would allow answering the formulated research questions. Given that the field of egressibility is relatively unexplored, an explorative approach was deemed necessary and the analysis method of reflexive thematic analysis as described by Braun and Clarke (2012) was deemed appropriate. Thematic analysis is described as “a method for systematically identifying, organizing, and offering insight into patterns of meaning (themes) across a data set” (Braun & Clarke, 2012) and has gained popularity for its accessibility and flexibility. Furthermore, conducting qualitative research involves taking a lot of decisions regarding the research process apart from simply choosing a methodology, all of which should be sufficiently documented. Hence, readers interested in a detailed description of the applied research process in paper I are referred to the original publication appended this thesis.

Regardless of research method, the research conducted needs to be of adequate quality for it to be trustworthy. Given the wide array of qualitative methods and procedures, there is an ongoing debate as to how to best assess the quality of qualitative research (Braun & Clarke, 2020; Bryman et al., 2008; Smith, 2018). Practitioners often opt for either assessing quality through the methodology used (Dixon-Woods et al., 2004), or through the interpretation of the findings (Lincoln et al., 2011). Common quality criteria for research include internal validity, generalisability, reliability, and objectivity (Bryman et al., 2008). These criteria are well established in quantitative research, while less so in qualitative research

(Bryman et al., 2008). In fact, the above-mentioned terms frequently figure in the quantitative or positivist research paradigm, and Lincoln & Guba (1985) proposed four new terms to be used in qualitative research: credibility (internal validity), transferability (generalisability), dependability (replicability), and confirmability (objectivity). Further, they argue for the use of the term “trustworthiness” rather than quality. While discussing research quality in relation to qualitative research in this thesis, the criteria proposed by Lincoln & Guba will be used as they are deemed more accurate in the context.

Credibility in qualitative research resembles what is known as internal validity in quantitative research (Korstjens & Moser, 2018; Lincoln & Guba, 1985), meaning that the findings presented are plausible interpretations of the original data, e.g. the interview transcripts, the documents, the observations, or whatever is the data collected. As such, credibility is consistent with the constructivist “assumption of multiple constructed realities” rather than the positivistic assumption of a “single tangible reality that an investigation is intended to unearth and display” (Lincoln & Guba, 1985). Transferability on the other hand resembles what is known as external validity or generalisability in quantitative research. Korstjens & Moser (2018) (based on (Lincoln & Guba, 1985)) describes transferability as “the degree to which the results of qualitative research can be transferred to other contexts or settings with other respondents.” Transferability is facilitated by a “thick description of the participants and the research process” (Korstjens & Moser, 2018). As such, the transferability judgement is made by the reader rather than by the researcher (Korstjens & Moser, 2018).

Reliability, interpreted as replicability, is perhaps useful in quantitative research, but less so for qualitative research which often takes place in environments that are not replicable by nature. Instead, reliability in qualitative research should be interpreted as dependability, interpreted as the stability of findings over time (Korstjens & Moser, 2018; Lincoln & Guba, 1985).

Confirmability describes “the extent to which the findings of the research study can be confirmed by other researchers” (Korstjens & Moser, 2018). Confirmability is meant to mirror objectivity in that it is facilitated by a thorough description of the research process from the idea formulation to the presentation of findings.

3.2. Quantitative assessment instruments

The purpose, functionalities, and design of assessment instruments can be vastly different. Assessment instruments are for example used in evaluating student performance (e.g., an exam), the symptoms of a patient to establish a diagnose, the sustainability of buildings, etc. Due to the wide applicability of assessment instruments, there is limited universal guidance on how to develop them. However, commonalities include expert assessments and an iterative design process.

The basic purpose of any assessment instrument is to assess a construct (“A well-defined and precisely demarcated subject of measurement”) (de Vet et al., 2011). Assessment instruments are often developed and applied to make different assessments comparable, and to make the assessment less cumbersome for the user. Hence, developing assessment instruments often involve trying to operationalise an abstract construct into more comprehensible parts that are more easily assessed (de Vet et al., 2011). This is done in several steps as described in the flowchart in Figure 5, based on the description by Abell et al. (2009). Firstly, the target construct needs to be described in as broad a way as possible, representing the “true” definition of the construct. A reduction of the construct towards conceptualised components follows. These components are then operationalised and described in measurable terms. Lastly, a pool of items is generated and included in the instrument.

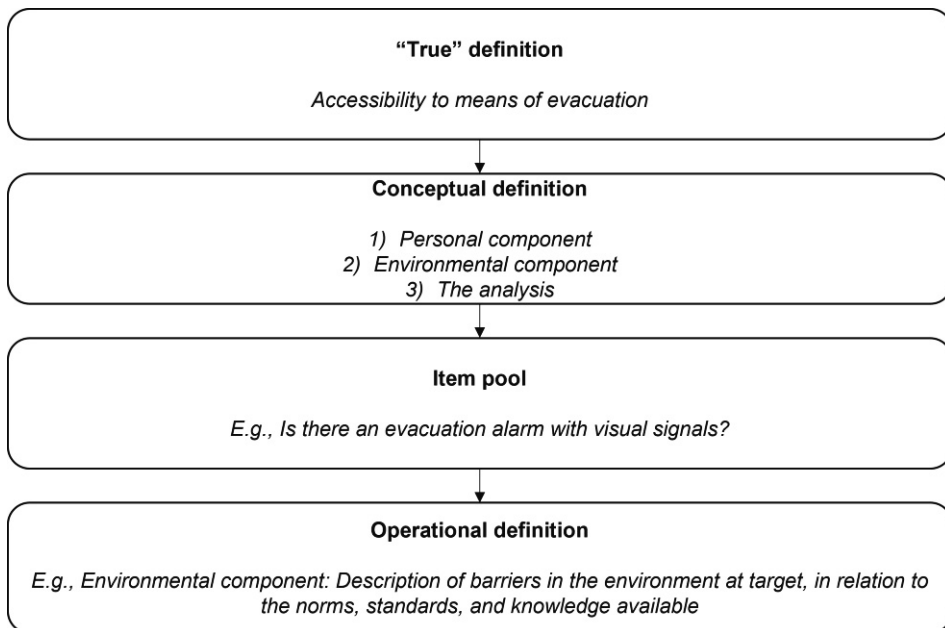


Figure 5. Scale development flowchart of egressibility. Based on (Abell et al., 2009).

A more abstract or diverse construct may involve more items than a less abstract or diverse construct. In the example of egressibility, an assessment instrument to measure egressibility needs to contain items that are relevant to the construct, e.g., items related to the environment under evaluation, and items related to functional capacity of individuals.

While there is limited universal guidance for its development, an assessment instrument needs to be both valid and reliable to serve its purpose (Streiner et al., 2015). It is therefore essential in any effort to develop such an instrument to test the validity and reliability of the instrument continually and transparently. Such testing is often referred to as psychometric testing (DeVon et al., 2007).

There are many schools of thought concerning scale validation. In this thesis, the description will be based on the *trinitarian* view (Guion, 1980) dividing scale validation into three main categories: content, criterion and construct validity. For the purpose of this thesis, content validity has been replaced with translational validity (Trochim, 2001). In conceptual terms, validity of measurement can be described as the “degree to which the results of measurement (the numbers or scores) represent magnitudes of the intended attribute” (Guion, 1980). In practical terms, validity refers to traditional hypothesis testing (Landy, 1986) and is only limited by the creativity of the assessor. The three categories of validity can be further divided into sub-categories. One such categorisation is presented in Figure 6. Although validity can be divided into different categories, they are all connected to the overarching ideal of validity. Hence, validity needs to be evaluated by providing evidence for all aspects of validity.

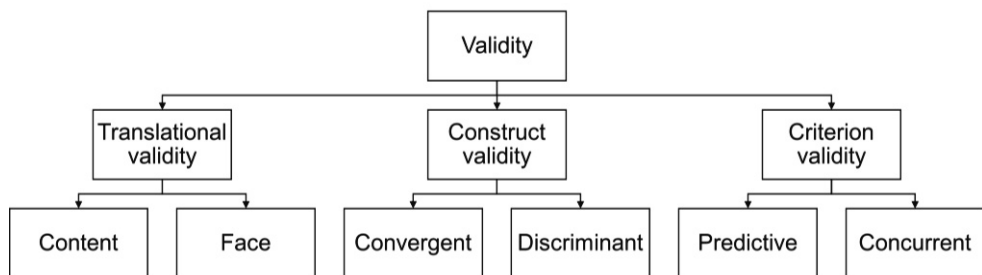


Figure 6. Schematic representation of different categories of validity in relation to measurement. Based on (Guion, 1980; Trochim, 2001).

Translational validity is described as how well the instrument reflects the construct, or how well the construct has been translated into operationalised terms (Trochim, 2001). Translational validity is divided into face and content validity. In order to evaluate translational validity, there needs to be a clear definition of the construct by which to base the evaluations. Face and content validity are closely related, but

face validity is more informal and subjective. Evaluating face validity involves screening the instrument “by the face of it” to see if the instrument reflects the construct. “Does the building have a yellow roof?” would be an example when an item has low face validity if the construct is egressibility, as the item seem irrelevant for egressibility.

Content validity can be seen as a more systematic and thorough evaluation of translational validity. Nonetheless, both face and content validity should be assessed during the iterative design process of an assessment instrument. Evaluating content validity often involves the use of experts. The experts should have sufficient expertise of the construct in order to provide meaningful input. The experts are asked whether or not the items of the instrument reflect or are relevant for the construct. The content validity index (Polit & Beck, 2006) is one example of a method to evaluate content validity.

Construct validity is sometimes seen as the preferred overarching term for validity of measurements (Trochim, 2001). Here, construct validity is understood as “the extent to which scores on a particular instrument relate to other measures in a manner that is consistent with theoretically derived hypotheses concerning the concepts that are being measured” (Terwee et al., 2007). Convergent construct validity refers to if the measurement produces the expected result according to a theoretically derived hypothesis. An approach for this could involve the use of expert evaluation compared to measurement output. Discriminant construct validity is here referred to as the measurements ability to differentiate between inputs in a way that is consistent with a theoretically derived hypothesis. In the context of egressibility, this could relate to the ability of the measurement instrument to differentiate between environmental designs or functional limitations that are consistent with an informed hypothesis, e.g., through expert judgment.

Criterion validity refers to the performance of the instrument against another established criterion (DeVon et al., 2007) and are divided into two kinds of validity: concurrent and predictive. Concurrent validity refers to the correlation between the output of the instrument and some other established measure of the construct. An assessment instrument to measure self-reported disability due to chronic nonspecific low back pain should for example correlate positively with performance tests of disability to demonstrate good concurrent validity (Reneman et al., 2002). Predictive validity is a similar concept and differs from concurrent validity only by the time at which the measurement is taken. Predictive validity refers to the comparison of two measures (the instrument and another) at different times. Important for criterion validity is that the other construct or the measure is closely related to the construct under evaluation. For this to be possible, the definition of the construct needs to be clear, as for the translational validity.

Apart from validity, reliability is an essential feature of any assessment instrument. Reliability is described as the assessment instrument's ability to produce consistent results. It can be argued that reliability is a prerequisite for validity, establishing the maximum achievable validity (Streiner et al., 2015). Reliability can be divided into two types relevant for the kind of assessment instruments discussed here: inter-rater and intra-rater reliability. Inter-rater reliability refers to the variability in results stemming from inconsistencies between different raters or observers (Streiner et al., 2015). The objective of an assessment instrument is to provide an objective assessment of an abstract construct and should hence not vary between different raters. Intra-rater reliability refers to the variability in results stemming from inconsistencies between the application of an instrument at two different times (Streiner et al., 2015). As long as the construct of assessment does not change from one application of the instrument to another, the results should not change either. Some argue that intra-rater reliability is not as essential as inter-rater reliability, as inter-rater reliability also includes the variation found within an observer or rater (Streiner et al., 2015). That is, if sufficient evidence of inter-rater reliability can be presented to establish that it is high, intra-rater reliability should be the same or higher seeing that it contains only some of the variation found within inter-rater reliability. Methods to evaluate inter-rater and intra-rater reliability include various correlation coefficients such as Pearson's correlation, Cohen's kappa, and Intraclass correlation (Streiner et al., 2015).

As the definition of egressibility is based on a definition of accessibility (Iwarsson & Ståhl, 2003), existing assessment instruments for accessibility form a framework on which new assessment instruments for egressibility can be developed. Specifically, the research presented in this thesis is based on the Housing Enabler methodology developed by Iwarsson & Slaug (2010). The Housing Enabler methodology is based on the systematic collection of data in two components: the personal and the environmental, and a subsequent analysis by juxtaposition. The personal component contains a description of functional capacity in terms of functional limitations. The personal component is assessed through interviews and observations and contains twelve Boolean variables representing functional limitations (present or not present), and two Boolean variables representing dependence on mobility aid. The environmental component of the Housing Enabler contains 161 checklist items aimed towards identifying environmental barriers. The definition of environmental barriers is based on existing norms or accessibility guidelines, meaning that an environmental barrier is identified when the environment does not comply with current regulations. Each environmental barrier has an associated severity score describing the anticipated accessibility issues in the intersection between the environmental component and the functional limitation. The analysis establishes the magnitude of accessibility issues by summation of the severity scores in which the associated environmental barrier and functional limitation is present simultaneously.

4. Research results & outcomes

Paper I approaches egressibility from an individual perspective, whereas paper II approaches the topic from a more deterministic design angle. Therefore, the results and outcomes from the two papers are first presented separately. In section 4.3, reflections on the combined results from papers I and II are presented.

4.1. (I) The perspectives of older people

A qualitative study was performed to investigate the perspectives on egressibility of older people with functional limitations living in Sweden. An interview study was designed, and people aged 60 years or older with functional limitations were recruited from senior citizen and interest organizations. The concept of saturation (Saunders et al., 2018) was used to determine the sample size and was therefore not established beforehand. In this study, saturation was defined to have been reached once the inclusion of more data (e.g., interviews) was deemed not to result in the construction of additional or revised themes. Twenty-eight participants eventually took part in the study.

Prior to conducting the interviews, a self-assessment questionnaire developed for the purpose of this study was administered to the participants. The self-assessment questionnaire was inspired by the Housing Enabler (Iwarsson & Slaug, 2010) and the ICF (World Health Organization, 2001). As highlighted in previous sections, the type and extent of functional limitations affect people's ability to self-evacuate. The self-assessment questionnaire aimed towards characterizing the study sample in terms of functional limitations. The development of the self-assessment questionnaire focused on activities relevant for evacuation. The self-assessment questionnaire contained 22 items covering ten different functional limitations and use of mobility aid and wheelchair. Each item related to functional limitations had answer options on a scale from 0 (no limitation) to 6 (extensive limitation) which were later assigned to the categories none (0), low (1-2), moderate (3-4), or severe (5-6) functional limitation. The frequency of reported functional limitations of the participants is presented in Figure 7.

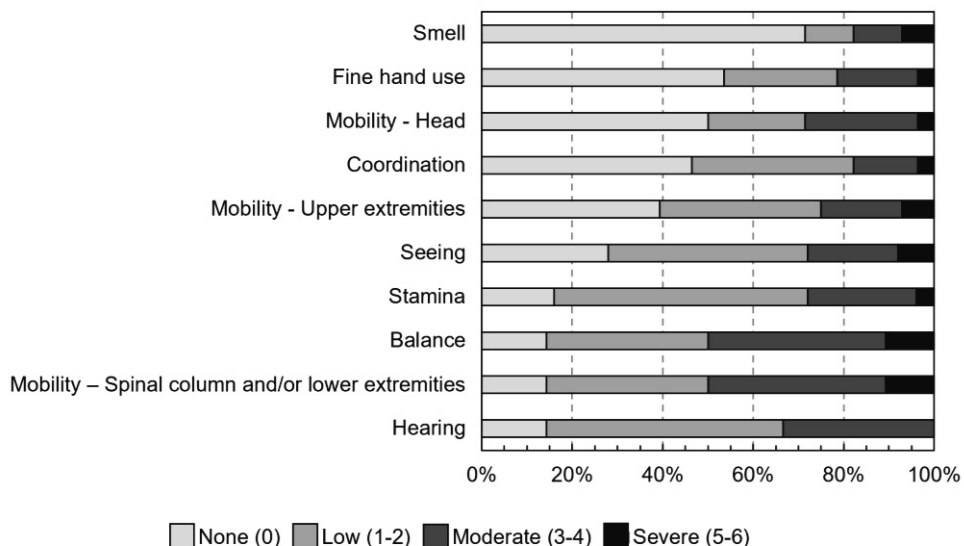


Figure 7. Participant characteristics in terms of functional limitations from the qualitative study presented in paper I (N=28). Redrawn from paper I.

Although the main intent was not to recruit a representative sample, functional limitations that are more prevalent in the Swedish population (see Table 3) were more frequent in our sample as well (e.g., hearing loss). Apart from the characteristics presented in Figure 7, the participants were also asked about their reliance on mobility aid. Seven percent (n=2) stated that they relied on the use of a wheelchair indoors, and 21% (n=7) stated that they were reliant on some other mobility aid indoors.

Due to the Covid-19 pandemic, the semi-structured interviews were conducted remotely via telephone. One interview was conducted via text-email due to the specific functional limitations of the interviewee. The interviews lasted between 25 and 90 minutes. The interview guide covered topics such as related issues in the public environment, their link with functional limitations, evacuation, the built environment, and the social environment. The interviews were transcribed and imported into NVivo 12 (QSR International Pty Ltd., 2018). Later, the transcripts were analysed through thematic analysis as described by Braun & Clarke (Braun & Clarke, 2012).

The credibility of the study, i.e. ensuring the findings presented are plausible interpretations of the original data (Lincoln & Guba, 1985), was strengthened through iterative meetings, where the interpretations of the primary investigator were discussed in a group of six researchers to reach consensus. This involved

reviewing the formulation and application of codes, as well as the construction of themes and sub-themes. Furthermore, credibility was strengthened by the presentation of interview excerpts in the published manuscript. By presenting the excerpts, the plausibility that the resulting themes and sub-themes represent the content of the interviews is made more evident to the reader. Transferability was supported through a thorough description of the participants of the study and the research process, enabling the reader to determine if the findings are transferable to another context of interest.

During the data analysis three themes were constructed that described a patterned meaning within the data, namely 1) Other people's difficulties in understanding, 2) Strategies to cope with the limitation, and 3) Uncertainty of evacuation. The themes, sub-themes, and examples of codes are given in Table 4. A brief account of the results contained within the three themes are provided thereafter.

Table 4. Themes and sub-themes constructed from the perspectives of older people with functional limitations, as well as examples of codes. Redrawn from paper 1.

| 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 |
| 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 |

Other people's difficulties in understanding (theme 1): The participants of the study had vastly different functional capacities, including mobility and sensory related limitations. They stated that sometimes people had difficulties anticipating and understanding the types of issues that they experienced as a result of their specific functional limitations. Stated experienced issues were found in several interviews where people with functional limitations described situations where others sometimes tried to help but did not know how. One example was given by a participant using a wheelchair, where others sometimes tried to hold doors or gates open for him to pass, but instead blocked his passage so that he could not get

through. The same participant also stated that he perceived others showed more consideration towards him when he used his wheelchair compared to when he used to use a cane instead. Another participant stated that she did not expect to receive assistance from others because she did not think that her functional limitation was evident.

Strategies to cope with the limitation (theme 2): The participants, experiencing functional limitations, stated that they faced challenges relating to inaccessibility on a regular basis. In the extension, this meant that they had developed and used coping strategies to mitigate negative effects of such situations. Some strategies included making use of other senses if one is impaired. Examples from the interviews include people with hearing impairments stating that they may look at others to be informed of an emergency. A participant who was blind stated that he regularly used sounds and smells to orient himself. In the uncertain event of an evacuation however, many participants stated that they may have an ability to ‘push through’ or go beyond their normal abilities to evacuate. This could for example mean that a person in a wheelchair decides to try to crawl down a staircase, or that a person who experiences pain in walking longer distances could do so if it was urgently necessary.

Uncertainty of evacuation (theme 3): As anticipated, most participants had never experienced a real-life evacuation, especially not at their current functional capacity. This led in many cases to significant uncertainty regarding how an evacuation situation may look like, possible reactions, and how others will react. Many participants stated that they did not worry about evacuation, stating that they were not the kind of person being worried in general. Despite this, many participants saw themselves as more vulnerable in emergency situations due to their age and functional limitations. Nonetheless, many participants were uncertain whether or not people around them would provide assistance during an evacuation, and that it may be difficult for them to evacuate if needed.

Considering the three themes developed, the results from the study showed that older people with functional limitations to a great extent relied on their own ability to overcome challenges during a hypothetical evacuation scenario by adopting coping strategies. They were uncertain about whether the built and social environment would be supportive in case of evacuation. Considering the person-environment relationship, the interviewees mostly highlighted the personal dimension when hypothesizing about evacuation situations. Most coping strategies mentioned involved adjusting own behaviour to overcome issues with few references of how the environment could be designed to be supportive. Furthermore, there were several uncertainties regarding the social dimension of evacuation, hence being perceived as an unreliable source of assistance. It is unclear whether this perception was related to the limited evacuation experiences of the participants.

These findings highlight two important aspects to consider in fire evacuation design. Firstly, in order to increase people's confidence in their abilities to self-evacuate, the design of the built environment should accommodate the evacuation needs of our increasingly diversified population, accounting for the presence of functional limitations. Secondly, the strategies adopted by people with functional limitations to overcome daily challenges should be identified, considered, and incorporated in fire evacuation design.

4.2. (II) The Egress Enabler

In contrast to the subjective nature of the interview study, the Egress Enabler has been developed as an objective instrument to measure a construct of egressibility. The Egress Enabler was based on the definition of egressibility as a person-environment fit issue, similar to accessibility (Iwarsson & Ståhl, 2003). Based on this, the development of the Egress Enabler was inspired by accessibility instruments. Several accessibility instruments exist, but it was deemed that the Housing Enabler methodology (Iwarsson & Slaug, 2010) shared a similar conceptual foundation and hence was a good fit for the application (hence the similarities in names).

As stated previously, developing an assessment instrument in this context involves operationalising the construct through items (de Vet et al., 2011). In the definition of egressibility proposed, three components of egressibility could be identified: the personal component, the environmental component, and the analysis. The personal component, the analysis procedure, and the link between the three components were heavily inspired by the Housing Enabler methodology (Iwarsson & Slaug, 2010). The environmental component was based on the same notion as in the Housing Enabler methodology, but with different contents in order to reflect the construct of egressibility rather than accessibility.

The personal component contains a description of functional capacity in terms of functional limitations. As in the Housing Enabler, the personal component contains Boolean variables of twelve functional limitations and two Boolean variables related to use of mobility aid. These fourteen variables are presented in Figure 8. For a more detailed description of the functional limitations and use of mobility aid, the reader is referred to the Housing Enabler (Iwarsson & Slaug, 2010).

The environmental component contains a description of the built environment through the identification of environmental barriers. For the Egress Enabler, these environmental barriers were identified from guidance documents, norms, legislation, and scientific knowledge in the fields of evacuation and accessibility

(e.g., (Boverket, 2017; Department of Health, Social Services and Public Safety, 2011; Institute for Human Centered Design, 2016; Iwarsson & Slaug, 2010; National Disability Authority, 2010; National Fire Protection Association, 2016; Rimmer et al., 2004)). In order to identify potential environmental barriers for egress, a careful examination of the activities involved in self-evacuation was used as a basis. Such characterisation of the self-evacuation time-line has been established in a recent literature review (Bukvic et al., 2020). Potential environmental barriers were identified and reformulated into checklist items consistent with the Housing Enabler methodology. Iterative consensus discussions within a set of six researchers working on its development were used to evaluate the face validity of the identified items. Given the definition of the construct, the guiding principle in this endeavour was “does the presence or absence of this feature affect the self-evacuation possibilities of people with any of the included functional limitations compared to a person without any functional limitation?”. The latter part, i.e., the comparison with people without functional limitations means that the Egress Enabler is only able to measure the difference in self-evacuation possibilities with or without functional limitations, and not absolute self-evacuation possibilities.

After a first list of items had been constructed and checked for face validity by the project group, the items were categorised in different sub-components reflecting various evacuation elements in use during evacuation. These are presented in Figure 8. Some identified items were considered relevant for several sub-components, e.g., high thresholds are relevant both for doors and circulation spaces, and appropriate handrails for stairs and ramps.

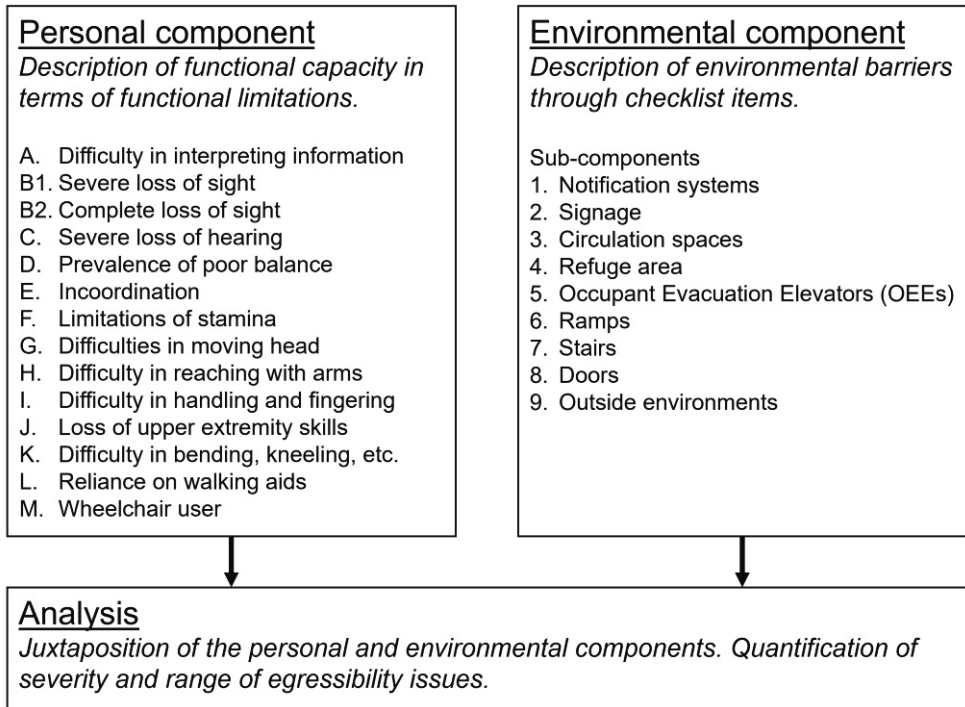


Figure 8. The Egress Enabler methodology and the three components: personal component, environmental component, and the analysis. Redrawn from paper II.

Content validity of the identified items was assessed through an expert panel approach involving five experts in both the accessibility and evacuation domain. The experts were asked to assess the relevance of the environmental barriers for the self-evacuation possibilities for people with functional limitations according to the defined personal component. The relevance assessments were used to calculate content validity indices (Polit & Beck, 2006). Results suggested that the content validity was good and in line with previous efforts of translating the Housing Enabler to other domains (Slaug et al., 2019). Items that scored low on relevance were considered for removal or reformulation after discussions. After the removal of low-scoring items, the content validity was improved further.

In the final version as presented in the appended paper, the environmental component of the Egress Enabler consisted of 146 individual items in nine different sub-components. As environmental barriers affect people with functional limitations differently depending on the specific functional limitation experienced, each item is assigned a set of 14 severity scores. These scores relate to the 14 descriptors of the personal component (A to M in Figure 8). Consistent with the Housing Enabler methodology, the severity scores range from 0 (no issue) to 4 (impossibility). To assign the scores, the activities relevant for the items were

identified and iterative project meeting discussions proposed and refined the scoring patterns.

Through the use of a case study, construct validity and inter-rater reliability were assessed. The case study consisted of applying the developed Egress Enabler to a public library in Lund, Sweden. Construct validity was at large evaluated in a qualitative fashion given the limited empirical data of a single case. Construct validity was assessed both by qualitatively analysing the results in the different sub-components and for the different functional limitations of the personal component. By considering the environmental design of the case study along with what is previously known regarding egressibility issues (representing a theoretically derived hypothesis), the resulting scores from applying the Egress Enabler could be discussed. In general, the obtained results reflected what could be anticipated. Preferably, the results from the Egress Enabler should have been compared to the results of another similar instrument. Given the fact that no such instruments exist that would produce results that could be compared, it was not done. Construct validity was also qualitatively discussed by implementing a set of fictitious changes to the environment and analysing the difference in results. All fictitious changes resulted in reasonable changes in results, but more empirical data is needed to determine if these findings are consistent.

Inter-rater reliability was assessed through dividing the project team in three rater pairs, each conducting their assessment of the case study using the Egress Enabler independently. The data were analysed using the Intraclass Correlation Coefficient (Koo & Li, 2016). Results suggested that inter-rater reliability was ‘good’ to ‘excellent’, with some sub-components receiving a lesser inter-rater reliability. Again, these results should be seen as indicative and more empirical data should be gathered.

4.3. Knowledge integration

The two studies (papers I and II) are both related to the person-environment interactions of evacuation, but adopt two different yet complementary approaches, namely subjective experiences and objective identification of environmental barriers. It could be argued that the two studies relate to the same concept of egressibility, but different constructs. This means that the concept has been interpreted and operationalised in two different ways, allowing for a nuanced and complementary understanding of the issues.

Paper I highlighted that egressibility was seen as influenced by personal factors such as functional limitations and motivations, as well as the built and social

environment. The participants tended to rely on the built and social environment to be supportive to a lesser extent, and primarily relied on own abilities to mitigate issues. The current study cannot conclude if this relates to the participants' limited knowledge of evacuation scenarios and provisions, or if it relates to inadequacies in current evacuation designs. This also goes to show that people may tend to favour self-reliance in terms of evacuation, seeing that it is considered more reliable from their perspective. Nonetheless, many misconceptions regarding evacuation situations (e.g., panic (Fahy et al., 2012)) were identified in the interviews, and education may mitigate this tendency. Given the findings from this interview study along with contemporary policy regarding the evacuation of people with functional limitations (Svenska institutet för standarder, 2021), self-evacuation should be considered the first and foremost approach to the evacuation of people with functional limitations.

The second study (paper II) was used to explore ways of objectively measuring one aspect of self-evacuation possibilities for people with functional limitations, namely egressibility. Although the current version of the Egress Enabler should be considered impeded by the current lack of scientific knowledge regarding self-evacuation with functional limitations, it provides a proof of concept and a nuance or complementary approach to the issues of egressibility. Accessibility and evacuation are often treated separately, and the Egress Enabler presents a link between the two fields. While the Egress Enabler should not be used as the sole decision aid to evaluate egressibility or evacuation safety for people with functional limitations, it represents a useful instrument in highlighting the key issues arising in the intersection between accessibility and evacuation.

5. Discussion & outlook

While this research has been both quantitative and qualitative, highlighting aspects of person-environment interaction related to the concept of egressibility, it should be noted that neither of the two studies covers the whole spectrum of topics that should be attributed to egressibility. The qualitative study takes a broader approach incorporating the perspectives of people, but it lacks in operationalisability. The Egress Enabler on the other hand provides an operationalised construct and allows for an objective assessment, but it excludes important aspects such as motivations, hazard mitigation strategies (e.g., fire mitigation such as sprinkler systems or smoke extraction systems), and overall complexity of person-environment interactions. Nonetheless, the two papers are deemed to provide a significant contribution to the field of egressibility, highlighting the complex interaction between accessibility and evacuation.

In relation to investigating perspectives linked to egressibility, the interview study design resulted in interesting findings otherwise not visible through observational quantitative studies. In theoretical terms, it can be argued that the interview study focused on usability during evacuation rather than accessibility (Iwarsson & Ståhl, 2003) considering that the subjective perspectives constituted a large part of the discussions. One issue with the interview study design was that since the participants had limited first-hand experiences of real-life evacuations, they had trouble imagining such a scenario but instead drew parallels to inaccessible everyday situations. Nonetheless, the inexperience found in the study sample is presumably representative of the population, considering that evacuation situations are rare events. Another source of evacuation experience could be through evacuation drills. However, it is often suggested that people with functional limitations may be excluded from evacuation drills due to ethical concerns (Gwynne et al., 2020). Albeit often undefined in reality, the purpose of an evacuation drill could be either to measure performance or to provide training (Gwynne et al., 2020). The inclusion of all building occupants assumed to evacuate if need be is imperative for fulfilling either of the two purposes.

In research in general, and qualitative research in particular, triangulation of data collection and analysis methods are often considered beneficial for quality assurance (Flick, 2007). As such, other methods should be applied to study the perspectives of individuals on egressibility. In this context, a useful future

qualitative research method to apply to egressibility can be ethnographic go-alongs (Kusenbach, 2003) in which the researcher accompanies the participant during a mock-up scenario of an evacuation. This includes observations and interviews of the participant and could generate interesting findings regarding the interaction with the physical environment.

The Egress Enabler mostly includes static properties of the environment and persons. Additionally, the personal component reflects only the functional limitations present and not any other influencing personal factors such as motivations (Ronchi et al., 2016), attitudes, and risk perception (Kuligowski, 2009). Depending on the threat that initiates the evacuation, some properties may change during the process presenting dynamic environmental demands. For example, during a fire incident, the rate of change in these properties is affected by different mitigation systems, which have not been included in the Egress Enabler. Evacuation can be initiated by fire, and fire produces soot that will obstruct the visual elements of the environment, ultimately raising the environmental demands. This highlights one of the limitations of the measurement of egressibility as proposed. However, examples of initiating events are many, and they all present unique challenges and are hence difficult to account for in full. Another view on these dynamic demands is that analysing and improving egressibility provides benefits for the entire population, not only for those experiencing permanent functional limitations. Consider for example the presence of smoke during an evacuation situation. This situation in a way (not considering toxicity or irritability) resembles the normal situation for a person with visual limitations, and environmental adaptations that aim to reduce environmental demands for people with visual limitations may benefit all, given that the intent of the alternative design solutions are not impeded by the presence of smoke. The same applies for situations in which there is crowding, restricting our movement and visual field, and for situations where there is a loud evacuating crowd, restricting our hearing capabilities.

Furthermore, future research should focus on including human behaviour aspects in the Egress Enabler. The Egress Enabler focuses mainly on the interaction between functional limitations in the person and the physical characteristics of the environment, and less so on the psychological processes taking place during evacuation. Nonetheless, descriptive models of human decision-making during evacuation scenarios exist in the field. For example, Kuligowski (2011) presented a human behaviour in fire model based upon the protective action decision model (PADM) (Lindell & Perry, 2012) aimed towards describing human behaviour during fire events. This model, along with others, describes a crucial aspect of evacuation safety (i.e., decision-making) not fully addressed in the Egress Enabler. Nonetheless, egressibility as a person-environment fit can be combined with models of other dimensions of evacuation safety. For example, time is a crucial aspect during evacuation, and systematic evaluations should be done on how different

person-environment fit constellations affect the evacuation time, such as is the case in the Evacuation Performance Index model (Rubadiri et al., 1997). This would also allow for including person-environment fit issues in current evacuation models commonly applied in fire safety engineering (Kuligowski, 2016a; Ronchi, 2021). In the PADM (Lindell & Perry, 2012), the perception and interpretation of information is included as one aspect. We know that this can be influenced by functional limitations (Bukvic et al., 2020), and a combination of the PADM and egressibility as person-environment fit can further expand the applicability of the PADM to populations with functional limitations.

As stated previously, most fire fatalities occur in the residential setting (Winberg, 2016) and functional limitations are sometimes highlighted as a risk factor (Ahrens, 2014; Fernández-Vigil & Echeverría Trueba, 2019; Murdy et al., 2011; Xiong et al., 2015). Hence, a further development of the Egress Enabler to adopt it to residential setting may prove to be beneficial in assessing where issues related to self-evacuation may exist. A key difficulty that would need consideration includes a wider array of functional capacity, primarily the presence of severe mobility limitations that may render self-evacuation impossible regardless of environmental adaptations. Hence, in a residential setting other strategies to improve fire safety is sometimes necessary. This involves removing the threat rather than the person through fire mitigation and prevention strategies. This is not within the scope of this thesis, and not within the scope of the current version of the Egress Enabler.

The importance of including the target group, i.e., people with functional limitations in the design and research process, is commonly highlighted in studies related to accessibility (Iwarsson et al., 2019). Primarily, future studies should validate the results from applying the Egress Enabler to the evacuation experiences of people with functional limitations. The Egress Enabler should be consolidated with people with functional limitations in workshops or real-life situations with practical examples.

Evacuation design and research should not only focus on the personal component, but also on how the environment can be designed to facilitate safe evacuation for all. As highlighted in section 2, evacuation research often focuses on measuring the physical capabilities in existing environments. Although quantifying physical capabilities in a given environment is essential for evacuation modelling efforts, adjustment to the environmental design as a way to improve evacuation performance of people with functional limitations deserves more attention. The Egress Enabler for example would allow investigating how evacuation performance is affected by different levels of accessibility in terms of fulfilment of prescriptive criteria. A previous study (Christensen, 2011) investigated the difference in evacuation time between people with and without mobility limitations through agent-based modelling in an environment designed according to the IBC regulations

of accessible means of egress (International Code Council, 2021). It was found that the evacuation time was significantly longer for people with mobility limitations, primarily due to the fewer number of accessible exits available. Of course, a similar study in another environment and/or designed according to other regulations would yield different results.

While the research presented in this thesis has identified a useful framework for egressibility, there are numerous knowledge gaps that still need to be filled. This relates to for example the impact of cognitive limitations on evacuation performance and how upper body mobility limitations affect the evacuation performance relating to opening doors and finding architectural elements (Bukvic et al., 2020). Perhaps one of the most urgent research gaps relate to how the environmental demands during a dynamic event such as a large-scale evacuation affects people with functional limitations. Traditionally in evacuation design, the environmental demands that are considered include for example travel distance, widths, crowding, visibility, heat, and toxicity. Some of these are less researched from the perspective of their impact on people with functional limitations.

Whilst evacuation research has much to learn from accessibility, the same may apply vice versa. Accessibility, here intended as a broader construct including accessible evacuation as in the definition in EN-17210 (Svenska institutet för standarder, 2021), is often focused on prescriptive details such as the height of handrails, width of doors, etc. (Grangaard & Gottlieb, 2019). Even quantitative assessments of accessibility usually revolve around the fulfilment of prescriptive criteria, sometimes with a coupled semi-quantitative assessment of severity and range such as in the Housing Enabler (Iwarsson & Slaug, 2010) and the Egress Enabler presented in paper II. Evacuation design often allows for two methods: prescriptive design and performance-based design. The prescriptive design of evacuation is in many ways similar to accessibility guidelines based on prescriptive requirements, where criteria on widths, thresholds, opening forces, and more need to be fulfilled. A difference is that the prescriptive criteria in evacuation design are often affected by other variables used to represent a level of risk. Such links seem non-existent in accessibility practice. Performance-based design on the other hand involves fulfilling functional requirements by any means necessary.

Performance-based regulations related to accessibility are scarce, and disability advocates have argued that the gap between people with functional limitations and the industry is too large to ensure that performance-based guidelines can be fulfilled (Salmen, 2001). Nonetheless, the recently published standard SS-EN 17210:2021 (Svenska institutet för standarder, 2021) provides performance-based criteria (functional requirements) for accessibility, incorporating aspects of evacuation. The basis for the standard has been to contribute to the implementation of the UNCRPD through Universal Design or Design for All principles. Considering these premises,

it is argued that fire safety engineers, like architects, need to be equipped with sufficient knowledge regarding human functioning and functional limitations to be able to design environments that are egressible using performance-based design. Imperative for any efforts in evaluating accessibility or egressibility from a performance-based perspective is the use of reliable anthropometric and biomechanical data related to people with functional limitations (Caltenco et al., 2014; Thompson et al., 2022).

In fire safety engineering and evacuation design, analytical tools exist to quantitatively evaluate the risk associated to a given hazardous scenario (Hurley, 2016). Although similar tools exist for accessibility (e.g., (Han et al., 2002)), the application is not as widespread. For a complete integration of the fields of accessibility and evacuation, it is deemed necessary that analytical tools allowing for performance-based evaluation of accessible evacuation are developed. The Egress Enabler presented in this thesis provides a first necessary step in this direction.

6. Conclusions

The purpose of this thesis has been to explore ways to identify and quantify issues related to self-evacuation possibilities for people with functional limitations in public buildings. Recognizing that self-evacuation is a psychological process as much as it is a physical activity, incorporating tangible and intangible subjects, the research included both qualitative inquiry and quantitative assessments.

Research objective a)

The qualitative study presented in paper I highlighted that the participants stated that they may rely less on the environment in providing support for self-evacuation, but instead perceived to be reliant on their own ability to mitigate issues caused by functional limitations and old age. The topic of subjective experiences related to perceived egressibility deserves further exploration, and the findings from paper I could be used to guide further studies.

Research objective b)

In an effort to explore ways to quantitatively assess egressibility, the Egress Enabler was developed in paper II. Given the definition of egressibility as a person-environment fit, similar to definitions of accessibility, the Egress Enabler represents a key development of existing accessibility instruments to cover the domain of evacuation. Initial psychometric testing showed promising attributes of validity and reliability. The application of the Egress Enabler highlights the complexity of egressibility and its interaction with evacuation safety and provides a necessary first step towards comprehensive performance-based evaluations of accessible evacuation.

7. References

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