

Evacuation of People with Functional Limitations: Research Knowledge, Gaps and Modelling Implications

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ABSTRACT

While accessibility is an established and widely used concept in building design, the evacuation of people with functional limitations is still at a stage in which several research gaps exist. In this context, this work discusses the concept of Egressibility, intended as the accessibility to means of evacuation. The key results of a multi-disciplinary project carried out at Lund University in this domain are presented. This project first investigated the state-of-the-art of the research in the domain of Egressibility, focusing in particular on the role of functional limitations on evacuation performance using the International Classification of Functioning, Disability and Health (ICF). This was performed linking quantitative studies considering predominant activities in terms of the ICF and six categories of functional limitations with the engineering evacuation time-line. This study was followed by a qualitative study exploring the perspectives on egressibility of older people with functional limitations. This was achieved by reflexive thematic analysis of semi-structured interviews with 28 older people with functional limitations. A tool was then implemented to measure egressibility by considering environmental demands and functional limitations. This instrument, called the Egress Enabler, allows the investigation of the interaction between environmental demands and functional capacity during egress. The work is concluded looking into the future of needed research in the domain of evacuation of people with functional limitations, considering the current research knowledge, gaps and modelling implications.

Keywords: Evacuation, Functional limitations, Egress, ICF, Egressibility

1. INTRODUCTION

This work provides an overview of the findings of a three-year project called *Building Egressibility in an Ageing Society*, sponsored by the Swedish research council for sustainable development (FORMAS). Egressibility is a concept developed in parallel with accessibility for meeting the needs of people with functional limitations in case of emergency, which until a few years ago were partially or totally neglected in the architectural design of buildings (Carattin et al., 2016). Earlier considerations of Egressibility has generated several important changes in our way of designing buildings, including the development of special provisions for people with disabilities in case of emergency, e.g., areas of refuge, the possibility to use elevators for evacuation in special circumstances (Ronchi & Nilsson, 2013). Today, an inclusive society should take into consideration the full range of population demographics, which includes a rising proportion of senior citizens and people with functional limitations.

This project aimed at studying the concept of *Egressibility* and addressing the issues associated with the egress opportunities of people with functional limitations. Egressibility is here intended as

accessibility to means of evacuation. This issue has particular relevance worldwide, as demonstrated by the rising trend of fires in homes where older people live (Harpur et al., 2013; Jonsson et al., 2017) and the increasing emergency evacuation scenarios caused by terrorist attacks (Ronchi, 2015) and natural hazards linked to climate change (Jolly et al., 2015).

The key premise of this work is that many buildings are not currently designed from an egress standpoint for an aging society including people with functional limitations. In recent years, few attempts have been made to measure the impact of demographics on egress procedure effectiveness, but a limited number of studies addressed the specific issues of an aging society and how this can impact egress performance (Thompson et al., 2015).

Different activities to address the overall aim of egressibility were investigated in this project and are here reported:

- 1) Mapping the state-of-the-art of egress of people with functional limitations by performing a review of the role of functional limitations on evacuation performance,
- 2) The investigation of the perspectives on egressibility of older people with functional limitations through a qualitative study,
- 3) The development of an egressibility instrument which permits the operationalization of the vulnerable population opportunities during emergency egress,
- 4) Assessment of the implications of egressibility on evacuation modelling.

The categorization of older people (e.g., identifying vulnerable groups) from the egress standpoint, the associated egress performance, and the identification of recommendations and development of instruments to assess egressibility were performed. This means assessing different types of functional limitations and how those can affect egress opportunities in relation to building design features and a selected set of key emergency evacuation scenarios. For instance, aspects that were investigated included the impact of functional limitations on egress performance (i.e., hearing / perceiving / understanding an emergency message, mobility issues which make people able to use a certain egress route, etc.). This was deemed to be a fundamental first step to identify egress design solutions which are suitable for all, including vulnerable populations. To study these issues, a scoping review of information from the evacuation field was performed. This was performed together with the analysis of relevant findings from accessibility research. Semi-structured interviews (SSI) with people with functional limitations concerning the assessment of their egress abilities was also performed. This was followed by the development of the *Egress Enabler*, an instrument able to assess egressibility in relation to the people in a given building. This mixed-methods approach was useful to perform a comprehensive assessment of egressibility and pave the way towards a more inclusive building environment.

2. FUNCTIONAL LIMITATIONS AND EVACUATION PERFORMANCE

A first phase of the project included performing a scoping review to investigate the role of functional limitations on evacuation performance. This was coupled with a review of research in the domain of accessibility of public buildings (Carlsson et al., 2022). The domain of application of this work was public buildings, as those are of common interest and should be accessible to anyone, thus representing an optimal starting point for future regulatory developments. The idea behind this review was also to make use of existing research in the field of health sciences and accessibility research by using the International Classification of Functioning, Disabilities and Health – ICF (WHO, 2001). This classification had previously never been used in the field of fire safety. The ICF provides a well-defined universal terminology concerning functional limitations. Disability is seen as a wider term for impairments, activity limitations and participation restrictions. This allowed us to perform

a detailed classification of the links between evacuation activities, functional limitations and predominant activities based on ICF. A flowchart of the process adopted to connect evacuation activities, ICF classification and functional impairments is presented in Figure 1.

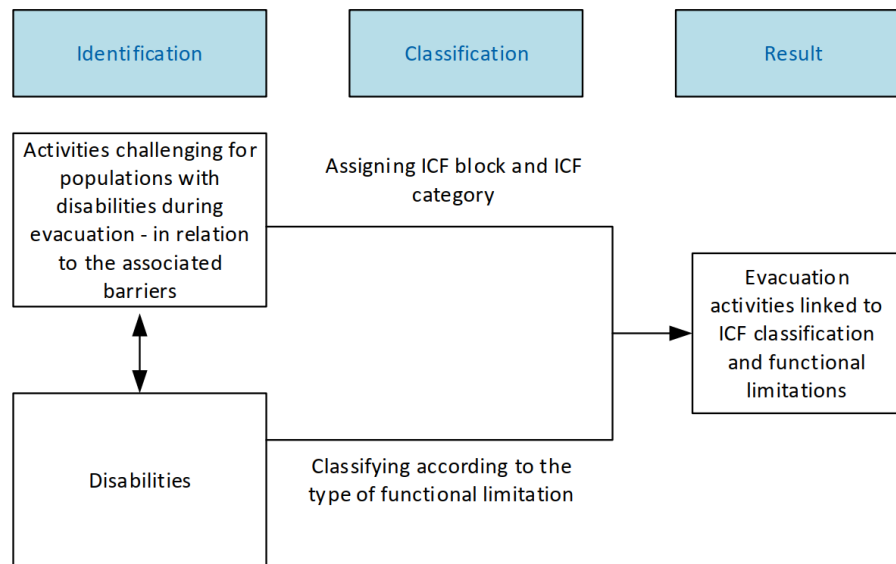


Figure 1: Flowchart of the linking process of the evacuation activities, ICF classification and functional limitations. Figure by O. Bukvic (Bukvic et al., 2020).

The scoping review identified a total of 7255 articles, which were reduced to 75 for inclusion in qualitative synthesis through a systematic process of screening, the PRISMA review process (Tricco et al., 2018). Papers were included if they addressed evacuation from public buildings with adults aged ≥ 60 years and/or adults aged ≥ 18 years with functional limitations. Policy papers, pure modelling papers and papers from residential settings or nursing homes were excluded. Further information on inclusion and exclusion criteria is presented in the article associated with this work (Bukvic et al., 2020).

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

3. PERSPECTIVES OF OLDER PEOPLE ON FUNCTIONAL LIMITATIONS

The second phase of the project involved performing a qualitative study exploring the perspectives on egressibility of older people with functional limitations. A set of 28 semi-structured interviews was conducted. Inclusion criteria required participants to be older than 60 years, have one or more self-reported functional limitations and be able to communicate in the Swedish language (as this was the language in which the interviews were conducted).

The sample characteristics in terms of functional limitation was defined using a self-assessment questionnaire, asking the participants to describe their functional limitations. Also in this case, the International Classification of Functioning, Disability and Health (ICF) was used to describe the functioning, health, and disability of individuals by informing the design of the self-assessment questionnaire. The interviews were performed remotely due to the Covid-19 pandemic in 2020. The topics discussed and associated questions in use related to the public environment, functional limitations, evacuation, the built environment and perceptions of others. The qualitative data collected were analysed using inductive reflective thematic analysis (Braun & Clarke, 2012). This method was chosen given the exploratory nature of the study and the focus on the perspectives of the interviewees. The analysis of the interview transcripts generated a set of three main themes (see Table 1).

The first theme, *Other people's difficulties in understanding* related to issues in making others understand the limitation and henceforth barriers. Feelings of exclusion were central in this theme. Visible limitations (such as the use of mobility aid) were perceived as receiving more considerations from others, and that in case people wanted to give help often they did not know how.

The second theme was *Strategies to cope with the limitation*. The sub-themes consisted of a set of strategies such as changes in behaviour, getting help from others, using other senses to compensate for their functional limitations, pushing through, etc. Considering the interactions with the built environment as a person-environment fit, these strategies mainly address the personal component, i.e., enhancing the ability to overcome barriers, rather than the interaction with the environment.

The third and last theme related to the *Uncertainty of evacuation*. This theme included both uncertainties in their own behaviour as well as the ones of other people. Participants stated that they generally did not worry about evacuation. This issue is closely connected to risk perception, as previous studies have indeed shown that risk perception was low among older people (Karemaker et al., 2021).

In conclusion, the qualitative approach used in this study was useful to complement existing quantitative studies (e.g., (Georg et al., 2019)) given its wider perspective. Furthermore, a self-assessment questionnaire was designed and publicly released (available in the publication associated with this study (Smedberg, Carlsson, et al., 2022)) to facilitate capturing the range and severity of different functional limitations. This was specifically designed for evacuation studies. Overall, the study findings demonstrated that older people with functional limitations perceive uncertainty and lack of reliance on the physical environment and others to be supportive in evacuation situations.

Table 1: Semi-structured interview findings (themes, sub-themes and code examples) (Smedberg et al., 2022).

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
	Using the other senses	I can see instead of hearing I use smells to help with orientation
		Accepting 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 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	
I do not worry about evacuation		

4. THE EGRESS ENABLER: AN EGRESSIBILITY ASSESSMENT INSTRUMENT

This research also proposed an egressibility assessment instrument called the *Egress Enabler*. This tool builds upon a known and research-based tool for the assessment and analysis of accessibility issues in the built environment called the Housing Enabler (Iwarsson, 1999; Iwarsson & Slaug, 2010). Mirroring the approach used for its development and validation, the concept of person-environment fit has been used as a starting point for the *Egress Enabler* development.

First a set of items related to the environmental component was selected from both the domains of egress and access. This was made reviewing a set of authoritative publications in this domain:

- *Emergency evacuation planning guide for people with disabilities* (2016),
- *Fire safety law: the evacuation of disabled people from buildings* (Department of Health, Social Services and Public Safety, 2011),
- *Risk assessment checklist in the context of safe egress for all* (National Disability Authority, 2010), and
- The Swedish building regulation related to fire safety, *BBR* (Boverket, 2016).
- The *Housing Enabler* (Iwarsson & Slaug, 2010),
- *AIMFREE* (Rimmer et al., 2004) and
- The *ADA checklist* (Institute for Human Centered Design, 2016).

A systematic approach was then used to identify a final pool of items to be included in the environmental component of the Egress Enabler. This included an expert panel review. Sub-components were defined based on common evacuation elements found in buildings: *Notification systems, Signage, Circulation space, Refuge areas, Occupant evacuation elevators (OEEs), Ramps, Stairs, Doors, and Outside environment*. The flowchart showing the process of identification and selection of items for the environmental component is presented in Figure 2.

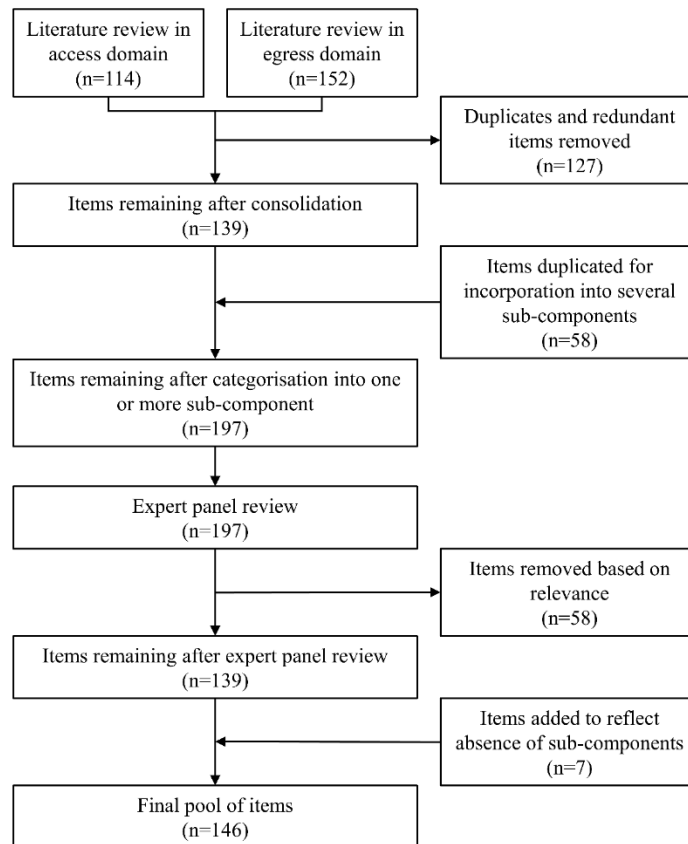


Figure 2: Flowchart depicting the identification and selection of items for the environmental component (Smedberg, 2022).

The items to be included in the personal component were then defined based on the list available in the Housing Enabler. The analysis of the interaction between the personal and the environmental component enabled the quantification of severity and range of egressibility issues (see Figure 3).

The Egress Enabler is then able to produce a score, where a higher score corresponds to a less egressible building considering the interaction between the functional limitations of the individuals in a given building and the present environmental features. The tool then was tested performing an evaluation of its psychometric properties, and a case study of a public building (a library) was used to test its applicability (Smedberg, 2022).

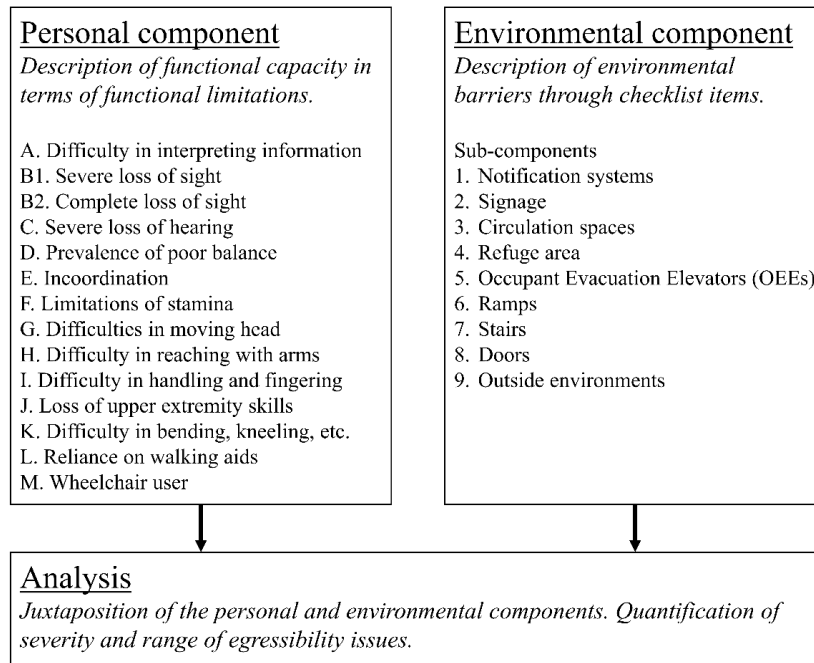


Figure 3: Schematic representation of the Egress Enabler, including the personal component, the environmental component, and the analysis (Smedberg, 2022).

Overall, the *Egress Enabler* can be used to measure egressibility considering that it should be seen as a person-environment fit issue. The *Egress Enabler* provides the opportunity for a comprehensive evaluation of egressibility, considering different features of the built environment and the prevalent functional limitations in a given population. In other words, the *Egress Enabler* should be seen as a useful tool covering a wide array of topics such as evacuation, accessibility, and functional limitations.

5. GAPS AND EVACUATION MODELLING IMPLICATIONS

This research highlighted several gaps in the knowledge related to people with functional limitations and egressibility in general. Those gaps can have important implications for modelling studies. First of all, the variety of conditions and impairments that may lead to functional limitations is associated with great complexity for a correct assessment of evacuation performance. This may lead in contrast to an oversimplification of their representation, which in turn may lead to a non-inclusive or non-conservative design solution. This is particularly important for buildings in which there is only one common evacuation strategy for the whole population (i.e., including people with functional limitations).

Most of the current research has focused on the representation of the impact of mobility limitations. This was expected, as this has been observed in real cases as one of the key limitations leading to longer evacuation times. Nevertheless, aspects linked to other limitations such as hearing limitations, (very prevalent in society (Smedberg et al., 2022)) or cognitive, visual or upper extremity limitations (as they could all have a strong impact on evacuation performance) need to be further investigated. Additional functional limitations that are important in fire safety scenarios were also identified (e.g., ability to smell and speech limitations).

Current evacuation models mostly address the physical representation of the personal component. This may lead to an oversimplification in the representation of the profiles of people with functional limitations. In fact, the current lack of data makes it difficult to represent the impact of certain types of limitations. The risk is that those limitations (i.e., other than linked to mobility) are largely ignored by evacuation model users. Future evacuation model developments should account explicitly for features aimed at representing the full range of functional limitations and their possible impact on evacuation. At this stage of research in which knowledge and experimental data are limited, it is at least desirable that evacuation models provide enough flexibility to be able to represent a variety of possible evacuation behaviour. Examples of such features may include alternative navigation behaviour or different pre-evacuation response behaviour which account for the limitations people may have (e.g., hearing, visual or cognitive limitations), or considering explicitly the impact on flow rates in case of heterogeneous populations. A long-term vision for evacuation models would be to be able to fully represent the interaction between each occupant profile (i.e., the personal component) and the environment (i.e., the environmental component) in the context of evacuation. This would need a transition towards evacuation models that represent more and more dynamic environmental features of buildings and the way they interact with evacuees. This would in turn make it possible to represent the interaction between environmental barriers and people with functional limitations in a more explicit manner, thus allowing the identification of design or procedural improvements aimed at Egressibility.

6. CONCLUSIONS

This work presented an overview of a research project conducted to investigate the area of Egressibility, intended as accessibility to means of evacuation. The work included different methodological approaches, such as reviews of literature, qualitative research and development of an assessment instrument. One overarching issue that has been identified is the need for a paradigm shift in the way egressibility is studied and considered in design. Individuals may have a great variety of functional limitations which means that assessment and design tools should be flexible enough to represent this heterogeneity. The development of those tools should go along with the collection of more experimental data concerning evacuation of people with functional limitations; therefore, these types of studies should be higher on research agendas for the coming years.

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