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Exploring behavioural aspects

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Elevator evacuation

Exploring behavioural aspects

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Elevator evacuation – Exploring behavioural aspects

Elevator evacuation

Exploring behavioural aspects

Axel Mossberg

DOCTORAL DISSERTATION

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Abstract
As tall buildings and deep underground structures around the world increase in both numbers and complexity, the issues with evacuation of such structures, e.g., fatigue during evacuation or difficulties for people with functional limitations to evacuate, become more prominent. Elevator evacuation could be a possible solution to these matters but in order for such elevators to be an effective solution for evacuation, they have to be used by the evacuees. Thus, the human behaviour aspects of elevator evacuation, such as willingness to use the elevators and accepted waiting times, are crucial for their effectiveness. The current research aims to increase the knowledge of these aspects in order to improve the possibility to utilise elevator evacuation in buildings and other structures. To achieve this, three different experiments were conducted using different experimental methods and performed in different settings (i.e., high-rise buildings and a virtual underground metro station) to collect human behaviour data on elevator evacuation. The results show that even though there is a general reluctancy towards the use of elevators in a hypothetical evacuation scenario, most people tried to use an elevator to exit in a unnannounced evacuation scenario in a high-rise hotel building. In experiments performed in a virtual underground metro station, the willingness to use evacuation elevators was significantly increased by technical systems, such as information and guidance systems. In a similar manner, longer waiting times were accepted when count-down timers were present above the elevators, showing how long the evacuees had to wait before an elevator would arrive. To help designers consider the uncertainties associated with the behavioural aspects of elevator evacuation, a design strategy is proposed. This strategy can be used when incorporating evacuation elevators in the evacuation design of a building, or other facility.

Key words
Elevator evacuation, evacuation, human behaviour, exit choice, waiting time, occupant evacuation elevator, lift

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MADE IN SWEDEN

Den mätta dagen, den är aldrig störst.
Den största dagen är en dag av törst.

Nog finns det mål och mening i vår färd,
men det är vägen, som är mödan värd.

I rörelse
Karin Boye

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Finally, I would like to thank my wonderful wife Therese and my two amazing boys Lowe and Tage for being a spark of joy even in the most difficult times. I am also thankful for the support and inspiration from my family. My dear mother, Ingrid, who I miss every day, my father, Håkan, and my sisters Johanna and Maria.

Summary

Evacuation of buildings, and other structures, where vertical travel is a crucial part of the building function, have gotten more attention in recent years. Since the 9/11 terrorist attack in 2001, several research studies have highlighted how elevators can increase evacuation efficiency of tall buildings. Despite a proven efficiency, elevator evacuation is a rarely implemented solution in buildings. An important reason for this is probably uncertainties concerning the behavioural aspects of elevator evacuation. As most people have been taught not to use elevators in case of fire, it is uncertain if they will use occupant evacuation elevators in an evacuation scenario. Furthermore, the accepted waiting times if choosing an elevator for evacuation are also uncertain. Therefore, it is complicated to predict the expected evacuation behaviour. Furthermore, the studies performed on the behavioural aspects of elevator evacuation are mostly performed as hypothetical scenario experiments, which is an experimental method that has a lower level of validity compared to other methods. The main objective of this thesis is to increase the knowledge of the behavioural aspects of elevator evacuation. Furthermore, the overall goal is to increase the feasibility of including elevators for evacuation in building design.

In order to fulfil the objective, the research was divided into two separate parts. In the first part, a review of the available research on the subject was performed. With a basis in this review, a design strategy for including elevator evacuation in the building design was proposed. The reason for developing the strategy was to provide guidance on how to systematically assess behavioural aspects in evacuation designs where elevators are to be used. In the second part of the research, three different experiments were performed to further explore behavioural aspects of elevator evacuation. In the experiments, the willingness to use evacuation elevators were studied along with accepted waiting times if evacuation elevators were used. Experiments were performed for both tall buildings and deep underground metro stations.

The results of the experiments show that there is general reluctance towards using elevators for evacuation in the case of hypothetical scenario experiments. However, almost all participants tried to use the elevators for evacuation in field experiments, which were performed as unannounced evacuation from the 16th floor of a high-rise hotel building. Thus, an important conclusion is that there is a difference in the predicted behaviour (or behavioural intent) and the performed behaviour for

elevator evacuation. Furthermore, the willingness to use an elevator for evacuation in an actual evacuation scenario seem to be significantly higher than predicted in previous studies.

Furthermore, the results show that different guidance- and information systems can be effective to increase both the willingness to use an evacuation elevator and the accepted waiting times for elevators in an evacuation. This was studied in an experiment performed in a deep underground metro station setting using Virtual Reality. In the experiment, the willingness to use an elevator for evacuation was low when only static evacuation signs were used. However, the elevator usage was significantly increased when different guidance- and information systems were incorporated in the design. In a similar way, the accepted waiting time for the elevator during evacuation was increased when the expected elevator arrival time was displayed above the elevator.

This thesis provides new knowledge on behavioural aspects of elevator evacuation. However, we still have a lot to learn about these aspects and trying to predict elevator evacuation behaviour is still a challenge. Therefore, it is important to systematically assess the uncertain elements when proposing an evacuation design that incorporates elevators. The proposed design strategy can be used for such an assessment.

Sammanfattning (Swedish summary)

En fråga som tidigare inte fått mycket uppmärksamhet, men som på senare tid hamnat i fokus, är utrymningsmöjligheterna vid brand i byggnader där vertikal förflyttning är en förutsättning. Sedan terroristattacken mot World Trade Center 2001 har flertalet studier belyst att användandet av hissar för utrymning skulle kunna vara en möjlig lösning för att effektivisera utrymningen av höga byggnader. Trots detta är dock strategin med utrymningshissar fortfarande en ovanlig lösning runt om i världen. En viktig orsak till att utrymningshissar inte förekommer oftare är sannolikt på grund av osäkerheter i människors agerande kopplat till sådana hissar. Det inlärda beteendet att hissar inte ska användas vid brand gör det förväntade beteendet vid utrymning komplext. De studier som tidigare genomförts inom ämnet har primärt varit hypotetiska enkätstudier och validiteten hos denna forskningsmetod på området har inte studerats vidare. Huvudsyftet med forskningen inom denna avhandling har därför varit att öka kunskapen om människors agerande i utrymningssituationer med utrymningshissar. Målet är att en ökad kunskapsbas även ska öka möjligheterna för att tillämpa lösningen i byggnader och andra anläggningar.

För att uppfylla syftet delades forskningen in i två delar. I den första delen genomfördes en sammanställning av tidigare utförd forskning samt en utveckling av en designstrategi som kan användas som stöd när utrymningshissar ska tillämpas. Syftet med strategin är att stödja praktiserande ingenjörers arbete i fall där utrymningshissar ska ingå i utrymningskonceptet. I den andra delen av forskningen utfördes tre olika experiment för att studera människors beteende kopplat till utrymningshissar. Experimenten utfördes med olika försöksmetoder och i olika miljöer. Resultaten från försöken innebär ny kunskap om människors beteende vid hissutrymning både i höga byggnader och i djupt belägna undermarkstationer.

Resultaten från de utförda försöken visar att det finns en generell motvilja till att använda utrymningshissar när personer tillfrågas i ett hypotetiskt scenario. Dock använde nästan alla deltagare utrymningshissar när ett oannonserat utrymningsförsök genomfördes på sextonde våningen i en hotellbyggnad. En viktig slutsats är därför att det finns en skillnad mellan uppfattningen av det egna beteendet och det faktiska beteendet när utrymningshissar ska användas. Det kan även konstateras att det faktiska användandet av utrymningshissar i en utrymningssituation sannolikt är väsentligt högre än det som visats i tidigare studier.

Resultaten visar även att viljan att använda en utrymningshiss kan påverkas med hjälp av olika informations- och vägledningssystem. Detta studerades i försök utförda i Virtual Reality där en djupt belägen undermarkstation skapades. I grundfallet, med endast statisk utrymningsskyltning som vägledning, var viljan att använda utrymningshiss låg. Genom att inkludera olika informations- och vägledningssystem i utformningen ökade dock denna vilja avsevärt. På liknande sätt visade försöken att den accepterade väntetiden för utrymningshissar är relativt kort om ingen information ges. Om information om förväntad tid tills hissen anländer förmedlas vid hissen så ökar dock den accepterade väntetiden.

Denna avhandling tillför ny kunskap till ämnet men komplexiteten och osäkerheterna i människors beteende kopplat till utrymningshissar är fortfarande relativt omfattande. Vikten av att systematiskt behandla dessa osäkerheter är därför väsentlig. Detta kan exempelvis göras genom att använda den föreslagna designstrategin. Genom att använda informationen som presenteras i denna avhandling kan tillämpning av utrymningshissar i byggnader och andra anläggningar underlättas.

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1 Introduction

With population and urbanisation increasing in the world, new challenges to the built environment arise. Furthermore, the ageing of the urban population has recently been declared one of the Societal Grand Challenges of fire safety science by the International Association of Fire Safety Science (IAFSS) (McNamee et al., 2019).

The urbanisation increases the need to use land more efficiently; and is, thus, driving the development of more and taller high-rise buildings and moving more of the worlds metro systems below ground. Proof of this development can be seen in the average height of the 100 tallest buildings in the world, which reached 399 meters in 2020 (CTBUH, 2021). This is an increase of almost 50 % since the year 2000 (CTBUH, 2019). During the same time period, the number of metro systems around the world have increased by 70 % (UITP, 2018); and, because of conflicting tunnels and geological factors, some of these systems are built deeper below ground than ever before (SLL, 2018).

With these changes in the built environment, vertical travel is more important than ever. In order to keep up with increased demands, the elevator industry has made significant development, and elevators are faster and more efficient than ever (Strakosch & Caporale, 2010). However, the evacuation design of these challenging structures has not kept up with the development. As an example, in most cases, the evacuation is still solely reliant on stairs, and possibly places of refuge for the people who are not able to use the stairs.

Vertical travel can be problematic for several reasons. Firstly, and possibly most obviously, vertical travel present an obstacle in the evacuation path for people who are not able to use stairs, e.g., wheelchair users. Furthermore, fatigue may occur when stairs are to be used for long vertical travel distances (Ronchi et al., 2015). To solve parts of this puzzle, several building codes, such as the Swedish building code (Boverket, 2018) and the International Building Code (ICC, 2015) have introduced areas of refuge. An area of refuge is usually a separate fire compartment where people who are not able to use the stairs can wait for further assistance during their evacuation. While areas of refuge are a common solution, they have been shown to be quite unfamiliar and is not a appreciated solution by the intended end users (Andrée, 2018; Andrée et al., 2015; McConnell & Boyce, 2015). Further, areas of refuge do not provide the evacuee with a possibility to exit the building during a fire, which increases the complexity to the fire protection of a building.

An alternative to areas of refuge is to use the elevators for evacuation (sometimes referred to as Occupant Evacuation Elevators - OEE[1]). The use of elevators for evacuation was discussed as early as in the first half of the 20th century (NBS, 1935; NFPA, 1914), and has been proven efficient in several studies over the years (Klote, 1993; Siikonen & Hakonen, 2002; Kinsey, 2011; Ronchi & Nilsson, 2013; Hammarberg et al., 2020). Even though elevator evacuation has been included in several building codes within the last decade (Boverket, 2011; ICC, 2009; NFPA, 2009), it is still not implemented as a generally accepted solution in most building codes to date. An important reason for this could be that the intended use of such an elevator is contradictory to the expected behaviour in a fire emergency, i.e., avoiding the elevator. This issue was highlighted as a reason to avoid implementation as early as in the 1976 Life Safety Code (NFPA, 1976).

Despite the efficiency of evacuation elevators, the behavioural aspects of elevator evacuation are still not sufficiently understood. The subject is sparsely studied, but there are some studies that have been performed to investigate the willingness to use an elevator as an escape route depending on different factors, i.e., which floor in a building is being evacuated (Andrée et al., 2016; Heyes & Spearpoint, 2009; Kinsey et al., 2010), the number of occupants in the elevator lobby (Kinsey et al., 2010) and the expected elevator waiting time (Andrée et al., 2016; Heyes & Spearpoint, 2009; Kinsey et al., 2010). However, these studies show inconsistent results and they are either performed as hypothetical scenario questionnaire studies (Heyes & Spearpoint, 2009; Kinsey et al., 2010) or in Virtual Reality (VR) (Andrée et al., 2016). Furthermore, for underground metro stations, only one hypothetical scenario questionnaire study has investigated the willingness to use elevators for evacuation (Engstrand & Näslund, 2014).

Due to the inconsistency in the results concerning willingness to use an evacuation elevator between experimental methods, the validity of the experimental methods used needs to be addressed. However, there is a lack of studies on the validation of the methods applied within the topic. Therefore, there are still significant knowledge gaps related to the understanding of human behaviour and elevator evacuation. For evacuation elevators to be a viable alternative in buildings and underground structures, more knowledge is needed on the human behavioural aspects associated with the use of such elevators as an escape route. Performing experiments with similar setups, but using different experimental methods, would shed more light on the validity of the previous research conducted within the subject.

[1] The term Occupant Evacuation Elevator, OEE, can be linked to specific requirements in the International Building Code. The purpose of this thesis is not to address the safety level given by this building code and because of this, the term will not be used further.

Another behavioural aspect where more research is needed is the effects of technical systems, such as information or guidance systems, on exit choice and accepted waiting times in situations with elevator evacuation. It has previously been established that different technical guidance systems can be successful in promoting certain evacuation routes in other situations, e.g., in tunnels (Fridolf, 2015; Nilsson, 2009). However, for elevator evacuation, the effects of technical systems have only been studied regarding exit choice in the VR study by Andrée et al. (2016). In the study, a green flashing light enforcing the evacuation signage towards the elevator was tested and the results showed an increased willingness to use the evacuation elevators when the flashing light was present (Andrée et al., 2016). However, no other information or guidance system have been tested, and thus, there is a need of further studies on the effects of such systems on both exit choice and accepted waiting times for elevator evacuation.

In addition to more knowledge on the behavioural aspects of elevator evacuation, more guidance is needed on how to assess such aspects when incorporating elevators in an evacuation design. In the building codes accepting elevator evacuation as an option, the guidance on how to account for the human behaviour aspects is virtually non-existent. The same is true for guidance documents and standards on the subject, such as the SFPE Handbook of Fire Protection Engineering (Hurley, 2016), the SFPE Guide to Human Behavior in Fire (SFPE, 2019), the SFPE Engineering Guide on Fire Safety for Very Tall Buildings (SFPE, 2022) the Australian Building Codes Boards handbook on Lifts used during evacuation (ABCB, 2013), SIS-CEN/TS 81-76:2012 (SIS, 2012), ISO/TS 18870 (ISO, 2014) and BD 2466 (Charters & Fraser-Mitchell, 2009). In these documents, the general issue associated with the human behavioural aspects of elevator evacuation are mentioned, but no practical guidance is given on how relevant aspects should be identified and dealt with when evacuation elevators are to be implemented in the evacuation design.

To summarise, there is a lack of research on key behavioural components of elevator evacuation, such as the willingness to use an evacuation elevator and the accepted waiting time if doing so. Furthermore, there is a need for guidance to aid the implementation of elevator evacuation in buildings, as current regulations, standards and recommendations lack in describing how to adhere to the behavioural aspects in the design process.

1.2 Research objectives

The main objective of the research is to increase the knowledge on the behavioural aspects of elevator evacuation. Furthermore, the overall goal is to increase the feasibility to include elevators for evacuation in building design. More specifically, this is achieved through the following three sub-objectives:

Objective I: Develop a design strategy for considering behavioural aspects when incorporating elevator evacuation in buildings, and other structures.

Objective II: Explore the willingness to use elevators for evacuation and whether this willingness can be affected by technical systems.

Objective III: Quantify accepted waiting times for evacuation elevators in case of evacuation, and to explore if these waiting times can be affected by technical systems.

As part of this work, key future research areas within the subject area will be identified and discussed.

1.3 Publications

This thesis is primarily based on the research presented in appended papers. However, the author has been involved in more research related to the subject of evacuation, e.g., studies of pre-evacuation times and computer simulation studies of elevator evacuation. Some of these studies are mentioned in the thesis and are listed as related publications below.

Note that the author changed last name from Jönsson to Mossberg in 2016.

1.1.1 Thesis papers

The papers included in the thesis have been submitted to either scientific journals or presented at conferences. For paper III, an extended abstract was peer-reviewed and Paper II is currently in the peer-review process. The other papers have been fully peer-reviewed.

Paper I Nilsson, D. & **Jönsson, A.** (2011) Design of Evacuation Systems for Elevator Evacuation in High-Rise Buildings, *Journal of Disaster Research*, Vol.6, No.6, pp. 600-609. doi: 10.20965/jdr.2011.p0600

Paper II	**Mossberg, A.**, Nilsson, D. & Frantzich, H. (202X) Evaluating new evacuation systems related to human behaviour using a situational awareness approach – a study of the implementation of evacuation elevators in an underground facility, *Submitted to Fire Safety Journal.*
Paper III	**Jönsson, A.**, Andersson, A. & Nilsson D. (2012) A Risk Perception Analysis of Elevator Evacuation in High-Rise Buildings, *Proceedings of the 5th Human Behaviour in Fire symposium*, Cambridge, UK.
Paper IV	**Mossberg, A.**, Nilsson, D. & Wahlqvist, J. (2020) Evacuation Elevators in an Underground Metro Station: A Virtual Reality Evacuation Experiment, *Fire Safety Journal*, 2020, doi: 10.1016/j.firesaf.2020.103091
Paper V	**Mossberg, A.**, Nilsson, D. & Andrée, K. (2020) Unannounced Evacuation Experiment in a High-Rise Hotel Building with Evacuation Elevators – A Study of Evacuation Behaviour Using Eye Tracking, *Fire Technology, 2020,* doi: 10.1007/s10694-020-01046-1

The author of the present thesis has been actively involved in all the work conducted in these five papers. The contribution to each paper is shown in Table 1. The degree of responsibility and work effort for each paper have been divided in to the following three categories:

Minor	The author had minor responsibilities and performed a small amount of the workload (less than 1/3 of the responsibility and work effort)
Medium	The author took medium responsibility and performed approximately half of the work (between 1/3 and 2/3 of the responsibility and work effort)
Major	The author had the main responsibility and performed most of the work (more than 2/3 of the responsibility and work effort)

For each paper, five different steps have been identified and the degree of work and responsibility have been graded in Table 1.

The first step, *planning and preparation*, includes the formulation of relevant research questions and a plan of how to answer these questions. Further, this step includes experimental planning and preparation as well as writing applications for ethical approval, when relevant.

In the second step, *execution*, data collection and similar activities are performed. This includes activities like reading literature, conducting experiments, making observations, collecting questionnaire data and conducting interviews.

In the third step, *analysis,* the data collected in step two is assessed and analysed. This includes systematically studying different forms of results to identify possible patterns and relating these patterns to current knowledge, as well as performing statistical analysis on different datasets.

The fourth and fifth step, *preparation of paper* and *presentation at conference,* deals with packaging the previous steps into papers and presentations. In the fourth step, revisions after review are also included. It should be noted that not all papers have been presented at a conference. The journal papers that have been presented have either been selected for a special issue in connection to the conference, i.e., Paper II, or been presented at a conference in addition to being published in a peer reviewed journal, i.e., Paper IV.

Table 1. The author's contribution to the thesis papers.

STEP	DEGREE OF RESPONSIBILITY AND AMOUNT OF WORK				
	PAPER I	PAPER II	PAPER III	PAPER IV	PAPER V
1. Planning and preparation	Medium	Major	Medium	Major	Major
2. Execution	Medium	Major	Medium	Major	Major
3. Analysis	Medium	Major	Medium	Major	Major
4. Preparation of paper	Medium	Major	Major	Major	Major
5. Presentation at conference	N/A	Major	Medium	Major	N/A

1.1.2 Related publications

The author has contributed to a number of publications related to the topic of the thesis. These are listed below. Some of these publications are research reports, which may include further reading on the work performed. The research reports are primarily written in Swedish.

Andersson, J. & **Jönsson, A.** (2011). Utrymning av höga byggnader – En analys av riskperception [Evacuation in High-rise Buildings – An analysis of risk perception]. Report 5373. Lund University: Lund

Hammarberg, J., Niva, H. & **Mossberg, A.** (2018). Incorporation of elevator evacuation from a specific floor – A numerical study on an office building, *Collective Dynamics*, *5*, pp 431–438

Mossberg, A., Nilsson, D., Andrée, K. & Herbst, C-J. (2018). Utvärdering av informationssystem för utrymning i hotellmiljö – Fältförsök med

utrymningshissar [Evaluation of information systems for evacuation in hotel environments - Experiments with evacuation elevators]. Report 3217. Lund University: Lund

Mossberg, A. & Nilsson, D. (2018). Användande av utrymningshiss vid utrymning av tunnelbanestation [Using elevator evacuation for evacuation of underground metro stations]. BSL 2018:02. Brandskyddslaget: Stockholm

Mossberg, A., Nilsson, D. & Wahlqvist, J. (2018). Utformning av utrymningssystem i en tunnelbanestation med utrymningshissar – Försök i Virtual Reality-miljö [Design of evacuation systems in a subway station with evacuation elevators – experiments in a Virtual Reality environment]. Report 7044. Lund University: Lund

Mossberg, A., Nilsson, D., Wahlqvist, J. & Frantzich, H. (2020). Utrymningshissar – Vidareutveckling av informationssystem [Evacuation elevators in underground metro stations – A Virtual Reality experiment]. Brandforsk 2020:4. Brandforsk: Stockholm.

Arias, S., **Mossberg, A.**, Nilsson, D., & Wahlqvist, J. (2021). A Study on Evacuation Behavior in Physical and Virtual Reality Experiments. *Fire Technology*. https://doi.org/10.1007/s10694-021-01172-4

1.4 Delimitations

All research is conducted within certain boundaries, and it is important to acknowledge what these boundaries are. In the current research, a number of delimitations are important to consider. The key delimitations of this work are briefly mentioned below.

Cultural aspects

The experiments conducted were all performed in Sweden with mostly Swedish participants. Sweden is a country where tall buildings historically have been quite rare. This could influence the attitude towards elevators in general and people that live in countries where tall buildings are more common might be more familiar with elevator use, which might influence how they would act in a situation with evacuation elevators.

Familiarity

In the experiments performed in Paper IV and Paper V, the participants were unfamiliar with the experimental environment. While this could be representative for the situations studied, this limits the possibility to generalise the results to occupancies where people are expected to be more familiar with the environment, e.g., residential buildings.

Training/education

The studies performed did not include the aspects of training and/or education. Elevator evacuation is rarely used in buildings and underground metro stations in Sweden and thus, the participants were unfamiliar with the solution when the studies were performed.

Fire and/or fire service intervention

The focus in the present research is on evacuation behaviour. In certain cases, this behaviour could be affected by the presence of a fire or by fire service intervention. However, such aspects are highly random in their nature and therefore, they have not been included in the performed studies.

2 Elevators and elevator evacuation from a historical perspective

Depending on how definitions are set, the hisstory[2] of the elevator could be argued to be quite long. There are documents citing the use of a primitive sort of elevator as early as 236 B.C. in ancient Greece (Schumm, 2018). A few hundred years later, manpowered elevators are believed to have transported gladiators and animals to the arena at the Colosseum in ancient Rome (Blitz, 2015). Despite these early inventions, modern motor driven elevators were not invented until the 19th century and; even then, they were initially only trusted to transport goods due to safety issues (Prisco, 2019).

The turning point for passenger elevators was allegedly a demonstration during the New York version of the Exhibition of the Industries of All Nations[3] (also known as the World's Fair) in May 1853 (Strakosch & Caporale, 2010). In this demonstration, the American engineer and inventor Elisha Otis showcased a new safety device for elevators by riding a motor driven elevator platform up in the air and then ordered an assistant to cut the rope for the platform. Once the rope was cut, the safety device, which consisted of a ratchet that precipitated on racks along the side of the elevator, was activated and the platform halted safely. Upon the stop of the platform, Otis is said to have proclaimed "All safe" to the crowd watching (Encyclopaedia Britannica, 1999). This event is illustrated by the sketch in Figure 1. However, it should be noted that the actual details of this story have been questioned (Bernard, 2014).

[2] English readers: sorry for the misspelling. Swedish readers: pun intended.

[3] The exhibition was held in the Crystal Palace in New York, a building that burned to the ground in 1858.

Figure 1. A sketch of Elisha Otis proclaiming his elevator safe during the demonstration on the World's Fair in New York 1853. Image by © Bettmann/CORBIS.

Following the presentation at the World’s Fair, the evolution of safe passenger elevators, along with other advancements in building technique, lead to the introduction of the first building labelled “skyscraper” in 1885 (Prisco, 2019). The first building to be dubbed with this term was the Home Insurance Building in Chicago, with its 10 floors and approximately 42 meter height. This building was equipped with four passenger elevators (Bernard, 2014). Undoubtedly, this was the starting point for a rapid development of tall buildings in the world, which can be seen in Figure 2. Observe that the buildings accounted for in this figure are only buildings labelled as “skyscrapers”, but the term has had different definitions throughout history (Encyclopedia Britannica, 2021). It should be noted that religious buildings (e.g., cathedrals), castles and constructions like broadcast masts and oilrigs, are excluded in this definition.

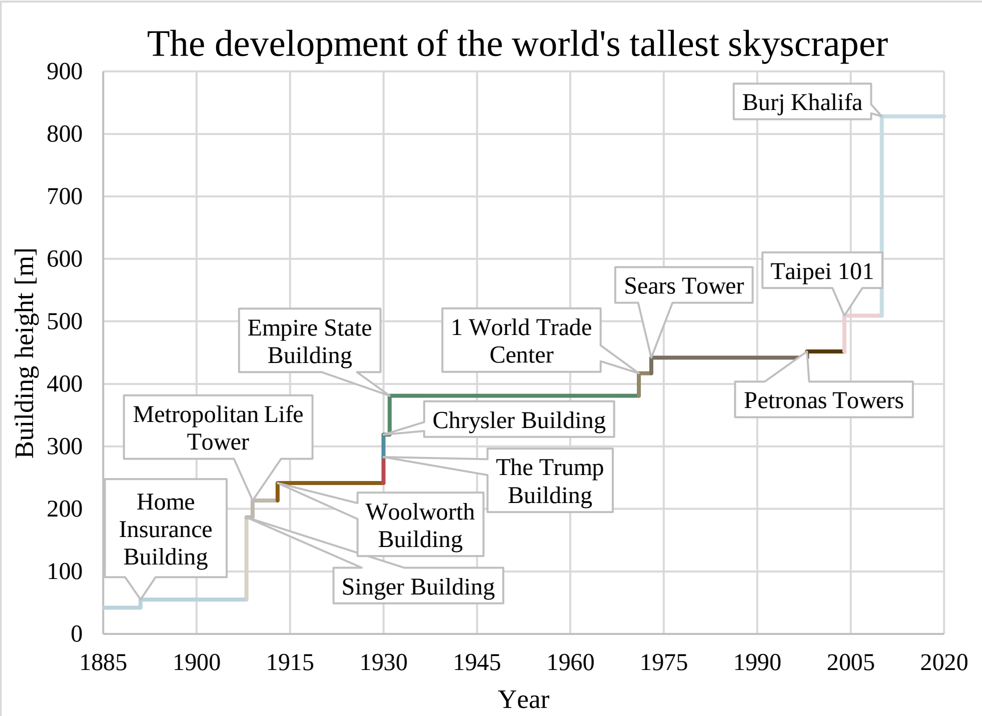

Figure 2. Development of the world's tallest skyscraper. Based on Bellis (2020); Cooperstein (2013) & Encyclopedia Britannica (2021). Observe that the Home Insurance Building had two floors added in 1889, beating itself for the title.

Together with the revolution of travelling up in a building using elevators came issues concerning how to exit tall buildings safely. In the early 20th century, there are several records of elevators being used for evacuation. One such example was in the catastrophic Triangle Shirtwaist fire in New York City in March 1911. The fire, which started on the 8th floor in the 10 storey tall Asch building, is one of the deadliest workplace accidents in the history of the United States with 146 casualties (Kiger, 2019). During the fire, the doors to the evacuation staircases were locked, allegedly to prevent workers from taking unlawful breaks and thus slowing down production. Naturally, this had catastrophic consequences and the lack of staircases meant the elevators played an important role in the evacuation. Eye-witness records from one of the two elevator operators[4] on duty during the fire stated that "[we] must have brought down a couple of hundred girls" (Stein, 2011).

A few years after this catastrophic incident, possible benefits of elevator evacuation was discussed by National Fire Protection Agency (NFPA) at the 8th annual meeting of the committee on safety to life (NFPA, 1914), in 1914. The report from this meeting contains recommendations that elevator shafts need to be protected, from fire and smoke spread but also to facilitate the operation of elevator cars. Further, the training of the elevator operators was discussed, and it was concluded that there was a need to drill these operators to prioritize the evacuation of upper floors in a building.

Some years later, not long after the opening of the Empire State Building in 1931, the National Bureau of Standards (NBS) in the U.S. released a publication on *Design and Construction of Building Exits* (NBS, 1935). In this publication *Credit for elevators* is mentioned in the section on calculating exit width in a building. It is described that calculations have been made to study whether elevators could be used for some of the evacuation exit width and that five elevators could compensate for "one unit of stairway width", with the reservation that the relationship would depend on several factors, e.g., building height and elevator speed. Further, behavioural aspects are discussed, and it is mentioned that the elevators have "the merit of being familiar means of egress to which people would naturally turn in time of need". However, new inventions in elevator operation procedure are questioned and the use of so-called "automatic push button elevators" is described as "problematic" as the elevator would not be under manual control. The publication concludes that it is safer not to accredit the elevators any exit width but the fact that they could be available for evacuation in a tall building gives a redundancy to the stair width requirement.

In the meantime, elevators kept developing and push button elevators were invented as early as 1894, making elevator operators less important (Otis Elevator Company, 1953). However, the push button elevators struggled with acceptance from the general public, possibly due to people's psychological resistance in entering a moving enclosure without direct human operation (Bernard, 2014). Even when push buttons took over in the elevator cars, most elevators were still "driven" by elevator operators, giving the passengers a sense of security. This continued until several elevator operator strikes were initiated in the middle of the 20th century and automatic push button elevators, without elevator operators, became the industry standard in the 1950-1960's (Elevators Ltd, 2018).

[4] The story of the fire is enthralling, and the Italian elevator operators have been honoured with medals, ballads, and theatre plays.

The development of automatic push button elevators came with scepticism against the elevators performance in a fire situation and allegedly a number of incidents were reported in the 1970-1980's (Bukowski, 2011; National Elevator Industry, Inc, 2015). In these incidents, it was said that the elevator call buttons were activated by heat, calling the elevator to the fire floor and trapping the people inside as the doors would not close due to smoke interfering with the close mechanism of the elevator door. This fear was communicated to the public through a change in elevator standards, introducing the now common warning signs not to use the elevator during a fire, but also through educational material from NFPA (National Elevator Industry, Inc, 2015; NFPA, 1970).

In the light of the hesitation related to elevator travel in general, the worldwide impact of this advice is understandable. It should be noted, however, that according to Bukowski (2011) when the elevator fire warning signs were introduced, it was indicated that the number of incidents with deadly fires and elevators were significant, but a review from NFPA performed in 2006 show that such incidents have been scarce in the U.S. and approximately 19 deaths in seven different fires are recorded from the introduction of the elevator to the date of the review[5] (Hall, 2006). This is emphasised by the fact that fire is not even included as a reason for injuries related to elevator use in the US Statistics for 1992-2003 (McCann & Zaleski, 2006). Similarly, when reviewing Swedish fire death statistics, no cases related to elevator use can be found.

The lack of cases of injuries and deaths in elevators connected to fire incidents could partly be explained by the advice in itself. However, there are several cases recorded where the elevator has been successfully used for evacuation in a fire, even though it was not designed for this purpose and the advice not to use it was present, e.g., the Joelma Building fire in Sao Paulo, Brazil, 1974 (Averill et al., 2005), the Forest Laneway fire in Ontario, Canada, 1995 (Proulx et al., 1995), the Hiroshima City fire in Hiroshima, Japan, 1996 (Sekizawa et al., 1999), the 9/11 World Trade Center terrorist attack in New York, 2001 (Averill et al., 2005), the Grenfell Tower fire in London, UK, 2017 (Agerholm, 2018), just to name a few. Therefore, it can be noted that fire related elevator deaths and injuries are rare and that there is a possibility that the elevator will be used in a fire evacuation of a high-rise building, even if advice is given not to do so.

Research on elevator evacuation was first performed in the 1970's (Bazjanac, 1977) and elevators as a possible means of evacuation was mentioned in the 1976 Life Safety Code (NFPA, 1976). However, the research did not make much impact until the 1990's when the National Institutes of Standards and Technology (NIST) in the

[5] This could be compared to an annual number of fire deaths of approximately 3000-7500 in the U.S. during the period 1977-2020 (*U.S. Civilian Fire Deaths 1977-2020*, 2022)

U.S. initiated a research program concerning elevator evacuation, focusing on both the feasibility of the technical aspects of the elevator as an escape route (Klote et al., 1992) and the behavioural aspects of elevator evacuation (Groner & Levin, 1992). Further, an elevator evacuation calculation program called ELVAC was developed at NIST (Klote & Alvord, 1992).

Despite these early efforts, the true surge of elevator evacuation research was after the World Trade Center terrorist attack in 2001 (9/11). After this event, much attention was given to high-rise building evacuation and elevators were discussed as a means of escape in a more prominent way. The main part of the research studies published following 9/11 have focused on how evacuation elevators could improve the effectiveness of evacuation in high-rise buildings, e.g., Hammarberg et al. (2020), Kinsey et al. (2009), Kuligowski (2003), Ronchi & Nilsson (2013) and Siikonen & Hakonen (2002). In most of these studies, behavioural aspects are not fully addressed, despite often being mentioned as something that will have a large impact on the possible effectiveness of elevator evacuation and thus needs further research. Further, the use of elevators to evacuate underground facilities, e.g., metro stations, has not been discussed much in the research community. Despite the lack of research, this is a solution that is being implemented in ongoing infrastructure projects (Fehr, 1991; Region Stockholm, 2019). In such environments, behavioural aspects may be even more difficult to predict.

As mentioned, elevator evacuation are now included as a possible egress option in several building codes (Boverket, 2011; ICC, 2009; NFPA, 2009). However, there is still a lack of guidance, and knowledge, concerning the behavioural aspects of elevator evacuation. The available research, along with the contributions of this thesis, on these aspects are further discussed in chapter 5.

3 Method

In order to achieve the research objectives, the behaviour of people needed to be investigated in a scientific manner. To perform a scientific study, a research method needs to be chosen, and data needs to be collected and interpreted (Leedy & Ormrod, 2016). The combination of research methods and data collection techniques is usually labelled as the research strategy (Nilsson, 2009). The choice of research strategy is generally determined by the objectives of the research conducted (Yin, 1994).As not all research methods are appropriate to use for all research questions, the choice of a proper research method, along with the formulation of the research questions, can be argued to be the most critical steps in a research study (Yin, 1994).

In previous publications on the subject (Fridolf, 2015; Nilsson, 2009), a difference is made between case studies and experiments as research methods. This distinction is also made in other publications (e.g., Yin, 1994). Case studies are of mainly observational nature, which has been argued to limit the possibility to find causality in the results (Andersson, 2012). However, such studies can still be used to gain an understanding about human behaviour in fires, and this research method have been used to form the basis of some of the most influential theories within the field, such as the behavioural sequences by Canter, Breaux & Sime (1980) and the affiliation theory by Sime (1985). Further, elevator usage in fire emergencies has been investigated using this research method, for example the cases of the Hiroshima building fire (Sekizawa et al., 1999) and the evacuation of the World Trade Center following the 9/11 terrorist attack (Averill et al., 2005).

In contrast to case studies, experiments are characterized by the fact that the researcher actively and purposely manipulates something in order to study the response (Andersson, 2012). By doing such a manipulation, the researcher aims to study what the response is and why. Thus, experiments aim to find causation, while case studies mainly aim to identify correlation (Andersson, 2012). It should be noted though, that causation could probably be identified using case studies as well, but it takes more effort in the research design (Rohlfing, 2012).

In the current thesis, the overall objective is to increase the knowledge about behavioural aspects of elevator evacuation. This is a challenge since elevator evacuation is not commonly applied in buildings. Due to this issue, it is hard to find cases with real evacuation behaviour recorded with elevators as a part of the intended evacuation strategy. Furthermore, the behavioural aspects of elevator evacuation are complex. On one hand, people tend to evacuate towards the familiar route (Sime, 1985), which could be the elevator in many cases. On the other hand, the general instruction given to people is to avoid the elevator in case of fire, which could create an aversion towards using the elevator for evacuation. Due to these competing factors and the lack of fire incidents in existing buildings and structures with evacuation elevators, experimentation was identified as a key research method. However, as pointed out by Yin, (1994) the foundation for a research study is in many cases a literature review, and this was identified as an important first step within the chosen research strategy.

The research process is illustrated in Figure 3. First, a review of relevant literature was performed in Paper I and Paper II as a foundation for the work. Then, the first research objective was assessed by the development of a design strategy for considering behavioural aspects of elevator evacuation in Paper I and II. The work related to the review and the strategy development is described further in section 3.1. Then, the following two research objectives were assessed through experimental work in Paper III, IV and V. The experiments are further described in sections 3.3 and 3.5.

A more detailed explanation of the different parts of the research process is given in the sections below. A short section on experimental theory is also presented.

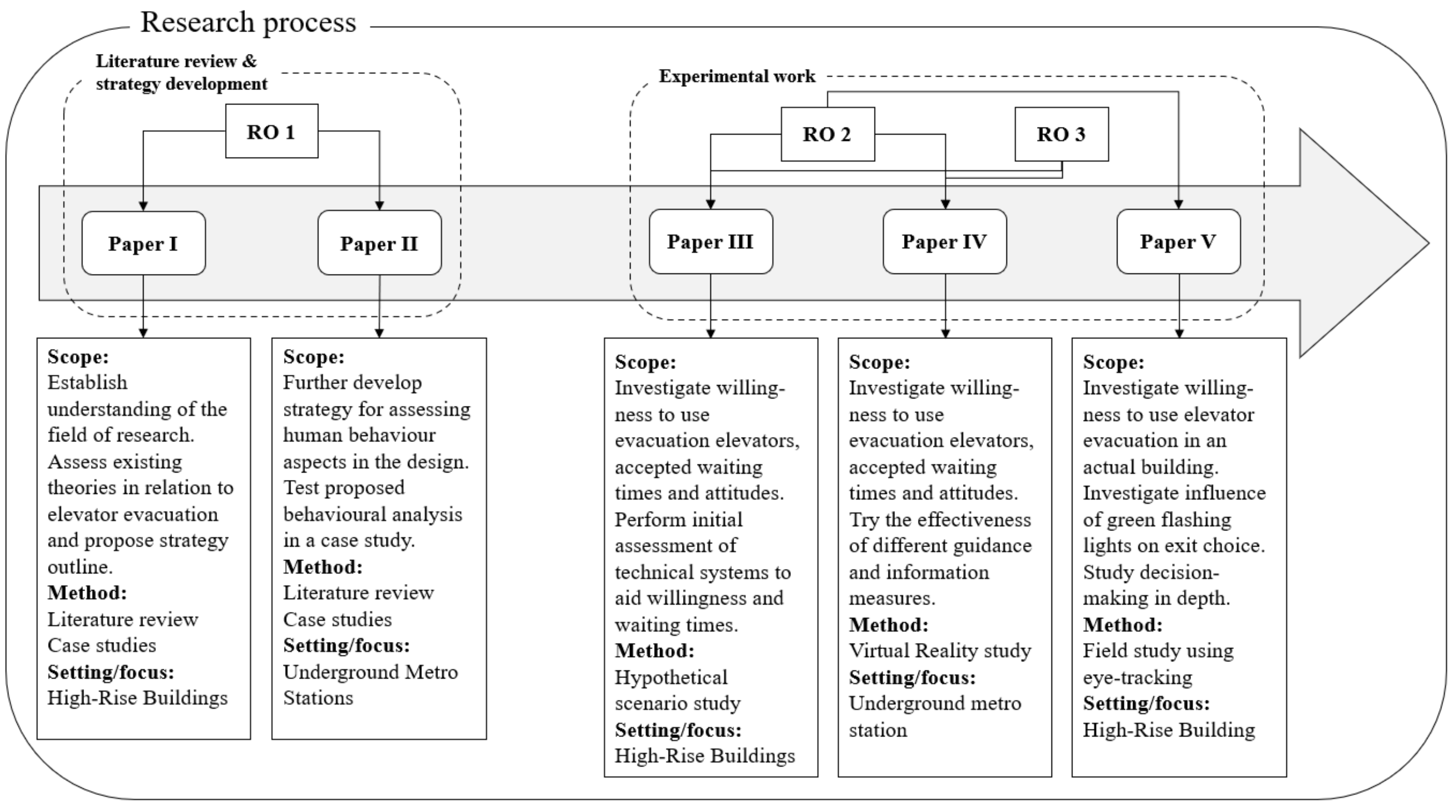

Figure 3. Illustration of the research process.

3.1 Experimental theory

Validity and reliability are key concepts for evaluating the quality of the research. For the field of human behaviour in fire, extensive discussion on the validity and reliability of different research methods and data collection techniques have been presented by Nilsson (2009) and Fridolf (2015). Thus, only a short overview is given here.

Reliability refers to the possibility to reproduce a study and record similar results, i.e., the consistency of the experimental results (Chiang et al., 2015). To achieve good reliability, the precision and consistency of the data collection techniques used are important as well as proper documentation of the study. A study with good reliability can be reproduced and show similar results.

Validity refers to the extent a study measures what it is intended to measure, i.e., the accuracy of the study (Chiang et al., 2015). Several different subcategories of validity have been proposed, but for the purposes of this thesis, internal and external validity are those deemed most relevant. Internal validity refers to how well causal relationships can be established in the study (Christensen, 2007), e.g., if a certain guidance system can be expected to affect the exit choice of the participants in an experiment. External validity refers to the generalisation of the results from an experiment into a broader context (Christensen, 2007). In the field of human behaviour in fires, a high level of external validity is challenging to achieve, as the experiment then need to reflect a real evacuation situation. For example, if a participant is aware of being part of an evacuation study, this naturally affects the behaviour of the participant, which in turn has a negative effect on the external validity of the study.

Naturally, reliability and validity will be affected by the choice of experimental methods and data collection techniques used. Thus, these aspects need to be considered when a research study is being performed.

3.2 Literature review and strategy development

As mentioned above, the foundation of the research work was a review of the literature relevant to the subject. This was performed with several aims, i.e., to provide a basis for the continued work, to identify how to formulate the research objectives and as a foundation for assessing each research objective. Thus, the review included literature on fundamental psychological principles and models applicable for human behaviour in fires, and evacuation design, as well as specific research on evacuation elevators.

The review was performed using relevant keywords and searching available research databases, e.g., Scopus, Google Scholar etc. Further, the snowball method was used, i.e., publications from the reference lists of the works found in the first stage were studied to identify further literature of interest. In addition to this, the proceedings of relevant conferences on the subject, e.g., the International Symposium on Human Behaviour in Fire, was studied to see if relevant literature had been presented.

For the specific case of evacuation elevators, the review aimed at giving an overview of the research performed in the area, as well as in connected areas, e.g., evacuation from high-rise buildings (see Paper I) and from deep underground metro stations (see Paper II). The focus was on studies of human behaviour, but when deemed relevant, studies with a different focus, such as evacuation calculation studies, were also included.

Through the review of psychological principles and models, three frameworks for assessing evacuation systems were identified, i.e., the research strategy for developing and testing evacuation systems proposed by Nilsson (2009), Situation Awareness (Endsley, 1995) and the Theory of Affordances (Hartson, 2003). These frameworks were used, and combined, into a design strategy for considering behavioural aspects in evacuation designs with evacuation elevators, i.e., to fulfil research objective I. The aim was to develop a strategy that is able to aid designers of complex evacuation systems whenever behaviour is an important aspect to consider.

In the development of the design strategy, the relevant frameworks listed above were tested using different example cases (applied in Paper I and Paper II). The strategy was then further developed in accordance with the learnings from these case studies in an iterative manner. This is described further in section 5.1.

3.3 Experimental methods

Even though several aspects of elevator evacuation behaviour could be of interest to investigate, for the research presented within this thesis, the focus has been on the evacuee’s acceptance to use an evacuation elevator during an evacuation. This was deemed to be a fundamental factor when including elevators as part of an evacuation design. However, for elevator evacuation, acceptance of the evacuation route is complex, and not as straight forward as for a building evacuating only using stairs. The complexity is due to the fact that the selection of elevators as an exit is comprised of two separate but related choices; (1) the initial exit choice, i.e., the willingness to use the elevator instead of a staircase, and (2) the subsequent accepted waiting time for the elevator. The waiting time is relevant because at some point, all evacuees willing to use the elevator for evacuation will reconsider and change to the stairs if the waiting time is too long and they are able to walk the stairs. Thus, the research performed aimed to explore both components.

For the purpose of this thesis, the experimental work is categorized into three different methods, i.e., hypothetical scenario studies, laboratory experiments and field experiments. This division is in line with previous publications (Fridolf, 2015; Kinateder et al., 2014; Nilsson, 2009). However, the definition of these categories varies within the field, and thus, further explanations on how these terms are used is given in the sections below.

3.3.1 Hypothetical scenario studies

Hypothetical scenario studies could be performed in different ways, but they are characterized by the fact that the participants are presented with a described scenario and asked to make predictions about their behaviour, e.g., how they think they would behave in a fire scenario. Thus, behaviour per se is not studied in this sort of experiments, but rather the participants own predictions about their response to the hypothetical scenario, i.e., their behavioural intent.

In relation to evacuation behaviour, hypothetical scenario studies have been used to study the willingness to use elevators for evacuation (Heyes & Spearpoint, 2009; Kinsey et al., 2012). In these studies, the participants were told to imagine that they were located on a given floor and had to evacuate the building. They were then asked to answer if they would prefer to evacuate using stairs or an evacuation elevator. Thus, the studies were hypothetical both in regard to the given setting and to the given evacuation scenario.

As with all experimental methods, there are several strengths and weaknesses associated with hypothetical scenario studies. For example, for fire related research it offers the possibility of collecting results from a large number of participants with relative ease. Further, it can capture the behavioural intent of the participants in a fire scenario without exposing the participants to harm or stress. However, there could be issues with conveying realistic scenarios to the participants and the participants' answers could be biased. A common type of bias is where the participant are prone to answer in the way they think is most socially acceptable (Paulhus, 2002). An example of such a bias in evacuation research could be that the participants would be more prone to predict their own behaviour in line with what they think is the expectation by the researcher. Furthermore, the participants may think that they will act in a way in a certain situation, but this belief does not necessarily correspond to how they really act in such a situation. This is an especially important aspect in evacuation research, since it is research related to behaviour under unfamiliar circumstances, with a high stress impact on the decision-making, making behaviour hard to predict.

3.3.2 Laboratory experiments

Christensen (2007) defines a laboratory experiment in psychological research as an experiment performed in a setting controlled by the researcher and not familiar to the participants. This definition is deemed relevant for the purposes of this thesis. While this sort of experiment has the potential to provide the researcher with a high degree of control of the setting of the experiment, the setting and experimental setup could reveal the purpose of the experiment to the participant before the experiment is conducted. This could affect the behaviour recorded in the experiment, especially in evacuation research.

The benefits of laboratory experiments is illustrated by the fact that many fundamental psychological experiments have been performed in a laboratory setting, e.g., Asch conformity experiment (Asch, 1956) and the Marshmallow experiment (Mischel & Ebbesen, 1970). In evacuation research, laboratory experiments have been used to study several different relevant situations, e.g., evacuation in rail and road tunnels (Fridolf, 2015; Nilsson, 2009) and people flow through openings (Pauls, 1977).

A recent development in behavioural research is the use of Virtual Reality (VR) for experimentation. As with many experimental methods, the definition of VR experiments varies, and is not consistent through the field of research. Further, the definition of VR itself is not always consistent. In this thesis, VR is defined as a digital environment that the participants can be immersed into, using visualisation and audio equipment. When immersed in this environment, the participants can move, interact and act within the boundaries set by the researcher. For a further description of VR and the use of VR as an experimental method for investigating human behaviour in fire, see Arias (2021) or Kinateder et al. (2014).

As the VR environment that the participant is immersed into is under the control of the researcher and is, in most cases, unfamiliar to the participant, it falls within the definition of a laboratory experiment given above. In addition to these factors, to be immersed into a virtual environment, the participants usually need to visit some sort of laboratory or similar. As the researcher controls the premises in the virtual world, the participant will always know that the elements they encounter are put there on purpose. Thus, a participant in an unannounced evacuation experiment will, in some ways, always be aware that the evacuation is a part of the experiment as soon as the evacuation alarm is activated. This is an important difference to field experiments.

A benefit of the application of VR technology for evacuation research is that some of the effects of smoke and fire could be added without presenting physical harm to the participants. One potential of VR is thus to perform studies of behaviour which would otherwise be problematic to conduct, e.g., to study how smoke from wildfires affect the way people drive (Wetterberg et al., 2020) and behaviour in scenarios based on previous fire accidents (Arias et al., 2018). Another benefit of VR is that the technology allows guidance and/or information systems to be easily adjusted within an environment and also, systems that are not yet fully developed can be tested for real world application.

3.3.3 Field experiments

As pointed out previously by both Nilsson (2009) and Fridolf (2015), there is not always a clear distinction between laboratory and field experiments. Both Nilsson (2009) and Fridolf (2015) define field experiments as experiments that are performed in a field (or natural) environment, e.g., a real building or tunnel, that the participants encounter or could encounter during everyday routines. Thus, field experiments are contrasted to laboratory experiments by the context of the setting that the experiments are performed in. However, even if an experiment is performed in a natural setting, if participants are not representative for that environment, the experiment is not seen as a field experiment according to Nilsson (2009). This definition of field experiments is deemed relevant, but it is not without problems. For example, for a setting that people would not encounter in their everyday routine, but only visit at special occasions, e.g., a cinema, hotel or similar, a field experiment would be problematic to perform within the given definition.

The field experiment performed in this thesis was performed in a hotel environment (see section 3.5.3 for further details). This is an environment that could be encountered in the everyday routine of a person, but for most people, it is not. However, it is an environment that by its nature is unfamiliar to most people in it, and thus, the participants familiarity with evacuation exits and the building layout is argued to be representative for people in such an environment in general. Hence, for the purposes of this thesis, a field experiment is defined as an experiment performed in a setting that the participants could encounter on a regular day and where they are representative for the people that can be expected to occupy the environment used for the experiment. An important difference to laboratory experiments is that in an unannounced field evacuation experiment, the participants cannot be certain that the evacuation is not a real situation. Thus, the actions of the participants can be expected to be representative for a real evacuation situation. Because of this, field experiments have been frequently used to record evacuation behaviour (Frantzich, 2001; Shields & Boyce, 2000).

Because of the factors mentioned above, field experiments have the potential to achieve a high level of external validity, i.e., the results can be argued to be representative for situations outside the specific experiment. Nevertheless, the environmental factors are significantly harder to control, which could create issues with internal validity, i.e., there could be methodological issues (confounding factors or similar) that affect the quality of the results.

3.3.4 Discussion on experimental methods

As mentioned, the distinction between different kinds of experiments is not always clear. There is undeniably a sliding scale within the definitions of the described experimental methods. For example, a hypothetical scenario experiment can be performed in a purely hypothetical setting (i.e., a setting only described in text or in conversation), a recorded setting (i.e., the participants get to watch a scene on video) or in a real setting. The differences between these settings, within the same experimental form, would be expected to affect the validity of the results. Furthermore, in many cases, laboratory experiments, e.g., VR experiments, can be argued to have certain hypothetical scenario elements. Thus, as discussed previously, in this thesis, the distinction between a hypothetical scenario experiment and a lab/VR experiment is that in the former the participants describe their actions, or behavioural intent, while in the latter the actions are performed within the given setting.

It could be argued that if VR was made realistic enough, this could constitute as a field experiment. However, this comes with some issues. A precondition for the participants to be in the virtual environment is that they were recruited and that the equipment needed for the immersion into the VR was mounted on them by the researcher. Thus, the participants undeniably know that all they encounter in the virtual environment has been put there purposely by the researcher. So even if a participant is unaware of the evacuation part of an experiment conducted, as soon as the alarm goes off in the virtual environment, the participant knows that this is included by the researcher on purpose. Therefore, within the definitions of this thesis, a VR-experiment, no matter how realistic, is always defined as a laboratory experiment.

3.3.5 Application of experimental methods

In this thesis, the three different experimental methods were used to study the same research questions, i.e., the exit choice and accepted waiting times connected to elevator evacuation. With regard to the advantages and disadvantages of each method, the methods were applied in different ways and the focus of the experiments differed. Thus, for some of the results, triangulation can be used to further understand the recorded behaviour in the performed experiments. A summary of the experiments and experimental methods used can be found in Figure 3.

In the first experiment (Paper III), a hypothetical scenario study was performed. The reason for choosing this experimental method was that the review had identified that there were only a few relevant publications available looking at elevator evacuation exit choice and these were performed with both hypothetical scenarios and hypothetical locations of the participants (Heyes, 2009; Kinsey et al., 2010). Thus, the first experiment was conducted to see if the trends identified in the previous studies were evident when participants answered with a basis of their actual location in a building. However, the given scenario was still hypothetical, i.e., the participants only described their behavioural intent for a given situation (see section 3.5.1). Furthermore, the experimental form was chosen because of the advantage that large volumes of data could be collected easily, e.g., without setting up an evacuation scenario in a building or recruiting people to a lab. Because of these advantages, a hypothetical scenario experiment was used not only to study the participants willingness to use evacuation elevators and to estimate their accepted waiting time, but also to rank several different evacuation systems. This was done to see whether the participants believed such systems could affect their exit choice and waiting time in order to get a general idea of what systems to test in the following experiments.

In the second and third experiment (Paper IV and Paper V), elevator exit choice (Paper IV and V) and waiting times (Paper IV) were recorded in different settings. Further, the effects of different guidance and information systems were tested. These experiments were performed as a VR laboratory experiment (Paper IV) and as a field experiment (Paper V). Due to the more complex setups and procedures of these experiments, they were performed with fewer participants. However, the external validity of the experimental methods in these experiments are generally argued to be higher than in hypothetical scenario experiment (Fridolf, 2015; Kinateder et al., 2014; Nilsson, 2009).

Since different experimental methods were used to assess the same research questions, the validity of common conclusions can be argued to be higher, i.e., if an evacuation system is ranked high in a hypothetical scenario experiment and recorded to have a high impact when tested in a laboratory or field environment, it is deemed more likely that it will work in a real-world situation.

3.4 Data collection techniques

Regardless of the chosen research method, data needs to be collected to provide basis for evaluation. To collect data, different data collection techniques are used. As with research methods, different techniques have different strengths and weaknesses. Thus, a combination of different techniques may provide further insights to the study, as it provides triangulation of the data (Yin, 1994). For example, a recording (observation) may show what exit choice a participant decides to use in an experiment, but it will not give an explanation on why. However, this explanation could be given by either a questionnaire or an interview. Thus, using several different data collection techniques may provide more depth and meaning to the results.

In the present thesis, three different data collection techniques are used, i.e., questionnaires, interviews, and observations. These three data collection techniques are introduced below.

3.4.1 Questionnaires

Questionnaires are commonly used for data collection. In principle, the participants are asked to answer a series of questions by hand on a paper, a computer or similar. Typically, either closed or open questions may be used. For closed questions, the participants are given different options to choose from but for open questions, the participants get to answer a question with their own words. Typically, for closed questions, there are different types of answering options, e.g., yes or no questions, Likert scale alternatives, multiple choice questions or rating scale options (Foddy, 1993). The different types of questions come with different advantages and disadvantages, which are briefly discussed below.

Open questions gives the respondent the possibility to answer a question with their own words and without influence of different options set by the researcher (Foddy, 1993). This gives a possibility for more nuanced answers and answers that differ from the assumptions of the researcher. However, the risk is that the respondent leaves out information that they feel is obvious, which will then not be included in the answer (Foddy, 1993). There is also a risk that the respondent feels hesitant about writing certain information in an answer (e.g., sensitive information) or that they feel it is too tedious to answer a question thoroughly.

Another issue with answers from open questions is that they can be harder for the researcher to code and thus the analysis of the data may be more problematic. Coding answers from open questions may be time consuming and require certain experience (Oppenheim, 1992). Even with an experienced researcher, there may be answers that are possible to interpret in different ways, which may lead to answers being labelled incorrectly in the data analysis. To prevent this and to increase the internal validity, the data could be coded by different researchers separately and then compared. However, this increases the time required for the study.

With closed questions, the coding and thus the analysis may be faster and easier. However, it will often be hard to cover all alternatives that the respondents may have in mind. Thus, information may be lost due to the alternatives given by the researcher. Researcher experience may be needed to cover all relevant options when constructing the questions and answer options.

Due to the issues with formulating questions properly and coding the data from the received answers, a pilot study is typically needed. The study is used to make sure that the respondents interpret the questions in the intended way, to verify that all necessary questions are being asked and to identify possible answer categories (Foddy, 1993).

In the present thesis, questionnaires with both open and closed questions were used depending on the purpose of the specific question. Questionnaires were used in Paper III, IV and V. In all experiments, pilot studies were performed on the questionnaire format in order to identify questions that was difficult to understand, possible coding issues and if there were alternatives missing (when relevant).

3.4.2 Interviews

Another way to collect data is to perform interviews. This is similar to questionnaires in the way that the researchers ask questions and the respondents answers from their perspective but differs in how the response is given. Interviews are commonly divided into the following sub-categories: structured, semi-structured and unstructured (Smith, 1995). Structured interviews are quite similar to the closed questions on a questionnaire, i.e., the interviewer has a set of pre-defined questions, which are read in the exact order specified in before-hand. Furhter, the respondent could be given set alternatives to answer. In semi-structured interviews, the researcher has prepared a set of questions beforehand, and certain alternatives may also be given for the answers, but both the researcher and the interviewer are given more freedom to elaborate or deviate from the prepared material. For unstructured interviews, there is little preparation in regard to specific questions and this may be seen as more of a conversation between the researcher and the respondent on the subject.

The different interview techniques have similar advantages and disadvantages as questionnaires with open and closed questions. However, with semi-structured interviews, the respondent is given the possibility to ask the researcher to elaborate if they do not understand the question, or to elaborate themself if they feel they need to do so. On the other hand, the risk that the researcher affects the respondent in some way during the interview may be greater. Thus, in a similar fashion as for questionnaires, a pilot study may be important to increase the internal validity when performing interviews (Smith, 1995).

In the present thesis, a semi-structured framework was applied. This means that some general questions were prepared but most of the questions were intended to lead the participant into elaborating on their choices during the experiment. Interviews were used in Paper IV. A pilot study on the interview format was performed to ensure that the questions were formulated properly and that no relevant subject was left out.

3.4.3 Observations

Observations as a data collection technique may be employed in different forms in an experimental study. When utilizing observations in an experimental study, different parts of the experiment, or the whole experiment is observed by the researcher. Usually, this includes some sort of recording devices (Fridolf, 2015). If the experiment is recorded, this enables the researcher to study the recording several times and to include more researchers in the process.

One important aspect of observations is that the actual behaviour of the participant can be studied. In interviews and questionnaires, the participant is in control of the information, and they may, consciously or unconsciously, answer in ways that deviate from their actual behaviour in a given situation. This may be a very important aspect in unannounced evacuation experiments, as the participants answers may be influenced by the deception in the experimental construction (Nilsson, 2009). It has, therefore, been argued that observations are imperative for studies of human behaviour in such situations (Latane & Darley, 1970).

As with all techniques, observations include a degree of subjectivity of the researcher and is therefore not without problems. The researcher may expect certain outcomes of the experiment, and this may affect the observations made. Further, there may be blind spots or other aspects that makes it impossible to observe all details of an experiment, which may affect the conclusions that can be drawn through such observations. Further, intent and motivation for actions performed may not be possible to derive from observation alone, and important aspects of behaviour may thus not be recorded through observation.

To allow the researcher to make observations, the first person view of the participant were recorded in the experiments in Paper IV and V. In the experiment performed in Paper IV, a first-person video of the participants VR experience was recorded that the researchers could review. In the experiment performed in Paper V, eye-tracking equipment was used, giving the researchers a video recording of where the visual focus of the participants was along the experiment. A more detailed description on eye-track and the technical equipment used is given in Paper V.

3.5 Experimental procedure

As previously discussed, the willingness to use the elevator as an escape route and the accepted waiting time for an elevator in an evacuation scenario were identified as key aspects that needed more investigation. These factors were investigated in different settings using different experimental methods and data collection techniques. The settings, key investigated aspects, experimental method, and data collection technique used in each experiment are summarized in Table 2.

Table 2. Summary of experimental work in Paper III-V.

PAPER	EXPERIMENTAL SETTING	KEY ASPECTS INVESTIGATED	EXPERIMENTAL METHOD	DATA COLLECTION TECHNIQUE USED
Paper III	High-rise building	Willingness, waiting times, possible measures	Hypothetical scenario using questionnaires	Questionnaire
Paper IV	Underground metro station	Williningness, waiting times, possible measures	Laboratory experiment using VR	Observation, questionnaire and interview
Paper V	High-rise building	Willingness, possible measures	Field experiment	Observation and questionnaire

The methods and settings of each experiment are described briefly below. For further details, the reader is referred to the separate papers.

It should be noted that for the experiments conducted in Paper IV and Paper V, several data collection techniques were applied. This allowed for some triangulation of the data collected, which had a positive impact on the validity of the results. Further, as different experimental methods were applied to study the same phenomenon, some observations about similarities, and differences, in the results using different data collection methods could be made. These different phenomena are further discussed in section 5.

3.5.1 Paper III – Hypothetical scenario study in high-rise buildings

The aim of this study was to quantify the willingness to use an evacuation elevator and to explore how long evacuees would be willing to wait for an elevator during an evacuation at different floors in a building. Further, perceived risks associated with elevator evacuation were investigated and the estimated usefulness of different information systems were examined. In the experiment, questionnaires were used as the data collection technique and these were distributed to people housed in different types of high-rise buildings, i.e., office buildings, residential buildings and hotels.

The questionnaire described a hypothetical evacuation scenario, for which the participants were asked to choose to evacuate the building using either stairs or an evacuation elevator. The study was performed by distributing the questionnaires to participants in their offices, apartments or hotel rooms. Thus, the scenario described was hypothetical but the setting from which they were supposed to imagine the evacuation was real. The reason for this choice was to increase the validity of the study by reducing the hypothetical elements in the questionnaire compared to past studies (Heyes & Spearpoint, 2009; Kinsey et al., 2012).

There was a total of 573 respondents to the questionnaire. The participants were situated in ten of Sweden's 30 tallest buildings at the time. The respondents ages ranged from 12 to 93 years old, with most respondents in the age range 20 to 65 years old. The number of floors in the buildings studied ranged from 15 to 54, but most of the respondents were situated on building floor 4 through 16.

In the study, the willingness to use an evacuation elevator in an evacuation scenario was recorded along with an estimation of how long the participants would accept to wait for an elevator during an evacuation. Further, the participants were asked to rank the risk associated with using the elevator on a seven-point Likert scale.

In addition to the above, the participants were asked to estimate how different information and/or technical systems would improve their perception of the evacuation elevator on a Likert scale. The investigated items were:

- information about what is going on in the building (e.g., why the alarm was activated),
- information that the elevator lobby is a safe place to wait for an elevator in an emergency,
- two-way communication, from the elevator and the lobby, between the evacuees and the emergency response team,
- information on how long it will take for the elevator to arrive,
- a display in the lobby that shows the elevator waiting time and an approximation of how long it will take to evacuate using the stairs,
- an information sign in the lobby that contained information about the difference of evacuation elevators and regular elevators,
- an alarm consisting of a voice alarm informing people that it is okay to use the elevator for evacuation in the building.

The participants ranking of the items above was then tested against each other statistically. The reason to perform the ranking was to investigate if there were statistical differences in how the respondents perceived the benefits of the systems.

3.5.2 Paper IV – Laboratory experiment in a virtual underground metro station

Similar to Paper III, the aim of this study was to quantify the willingness to use the evacuation elevator and the waiting times accepted during an evacuation. However, the study setting was a deep underground metro station, and the focus was to test specific guidance and information systems. Due to the lack of appropriate environments to perform a real-world study in and the need of high experimental control, the study was performed by creating a virtual metro station. In the virtual metro station, the participants could experience the environment using a Head Mounted Display (HMD) and headphones. Movement in the model was performed using hand controllers.

The virtual environment was based on a planned Swedish underground metro station, which was the same used for the case study in Paper II. An overview of the model is shown in Figure 4. Participants started at the platform level, from which evacuation was only possible through the elevator, stair or escalator that led to the pathway level. When the participants reached the pathway level, there was a possibility to enter an escape route to an evacuation staircase or to continue to the pathway leading to the elevator lobby. In the elevator lobby, there were eight evacuation elevators that could be called by using elevator buttons adjacent to the elevator doors. If called, the elevators arrived after eight minutes, but this time was unknown for the participants.

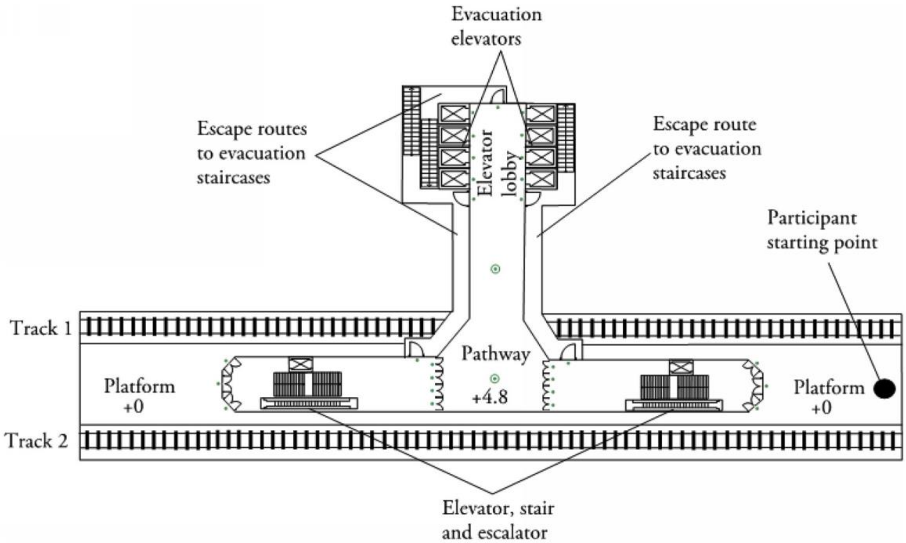

Figure 4. An overview of the station layout. The small dots above the doors show where exit signs were located in the model. The two dots that have a circle around them show signage that was reinforced in two of the scenarios. Numbers with a + sign indicate relative height in meters in the model.

Four different scenarios investigating different guidance and information systems were studied:

1. *Base line scenario*; a scenario with a basic guidance system, i.e., regular evacuation signage (including signs above the evacuation elevators) and a regular voice alarm.
2. *Enhanced scenario*; a set of information measures was introduced, i.e.:
    a. the voice alarm included information that elevators can be used for evacuation,

b. the voice alarm changed in the elevator lobby, and informed participants that they were in a safe area and that the elevators could be used for evacuation,
c. the evacuation signage leading to the elevator lobby were reinforced by green flashing lights,
d. blue information signs were put next to the doors leading to the evacuation staircase. These signs informed participants that they were situated 100 m below ground and that this is approximately equated to the height of a 30-floor building,
e. green information signs were put next to the elevators providing information identical to the voice alarm (see item b.).
f. a communication box in the elevator lobby[6].

3. *Smartphone scenario*; similar to the base line scenario but the scenario included guidance through a smartphone provided in the model. The smartphone showed real time guidance with arrows and messages throughout the evacuation and included similar messages that it was safe to use the elevators and encouraged the participants to do so.
4. *Timer scenario*; similar to the enhanced scenario but included a count-down timer above each of the elevators that counted down from 3 to 5 minutes for the different elevators. Note that the elevators did not arrive when the timers reached zero, but at eight minutes from the push of the elevator call button, as in all scenarios.

The study included 134 participants, 74 men (55%) and 60 women (45%). The age range of the participants was 18–28 years with a mean age of 21.1 years. All participants were fluent in Swedish, which was the language used on information signs and in messages given in the virtual environment.

The participants were not informed about the evacuation part of the study in beforehand but were told that they were to participate in a metro station design study. They were told to walk around on the station in the virtual environment and that the researcher would extract them after a while and ask them a number of questions about the environment they had experienced. However, after 30 to 60 seconds, an evacuation alarm was activated in the model. Once the alarm had activated, the researchers monitoring the experiment remained passive, regardless of communication efforts from the participants. The experiment was terminated once the participant reached the stairs or entered an elevator. After termination, the

[6] This mimicked equipment normally present in places of refuge in Sweden, but it was not noticed by any participants and will therefore not be described further.

participants were asked to fill out a questionnaire about their experience and an interview was conducted where the researcher asked a number of questions while watching the recording of the evacuation together with the participant.

3.5.3 Paper V – Field study in a high-rise building

The main purpose of this study was to explore the willingness to use evacuation elevators in a field environment. As no previous field studies on this topic were found, there was a need to increase the knowledge on actual behaviour in relation to elevator evacuation. Further, the experiment was performed to study the validity of previous studies, such as the hypothetical scenario study in Paper III and the VR study by Andrée et al. (2016). In the experiment in Paper V, the waiting times were not studied due to limitations in the building used, i.e., the elevators could not be controlled as the rest of the building was in normal use. The study was conducted on a hotel floor of a Swedish high-rise mixed-use building. The building has 35 floors of mainly hotel and office use, and the 16th floor was used for the experiment.

The study was performed as an unannounced evacuation experiment with partly informed participants, i.e., the participants were recruited to be part of a research study, but participants were not informed about the evacuation part on beforehand. Instead, the participants were told that they were recruited for a hotel design study. The participants were met in the hotel lobby by a researcher who informed them about the bogus study and equipped the participant with eye-tracking glasses. The information they got was that they would go to their given hotel room and "act as if checking in" and that the researchers would come get them after some time. The eye-tracking glasses were explained by the researchers being interested in what design features in the hotel room the participants looked at during their time in the room. The participants were then given a room key to a hotel room at the 16th floor and shown to the elevators. A few minutes after the participants had entered the hotel room, the evacuation alarm was remotely activated by a researcher.

The building used is equipped with one evacuation staircase and six evacuation elevators. A floor plan of the 16th floor can be seen in the figure below. It should also be noted that the door to the elevator lobby was self-closing and thus closed when the alarm was activated, and that one of the elevators was two-sided and could be reached from the end of the corridor. In the corridor, there were two illuminated evacuation signs, one outside the staircase door and one outside the elevator lobby door. There were also one photoluminescent evacuation sign on the self-closing door to the elevator lobby. The building was equipped with a voice alarm informing people that the elevators were possible to use for evacuation of the building.

In the experiment, a total of 67 participants, 37 women (55 %) and 30 men (45 %), took part. The age of the participants was 20 to 71 years with a mean of 33.2 years. Recruitment was done from the general public in the Stockholm region of Sweden using a website for participation in research studies.

Three separate scenarios were studied (see Figure 5):

1. *Scenario 1*; evacuation from Room 1 with regular evacuation guidance signs.
2. *Scenario 1-FL*; evacuation from Room 1 with a green flashing light attached to the sign towards the elevator lobby (see Figure 6).
3. *Scenario 2*; evacuation from Room 2 with regular evacuation guidance signs.

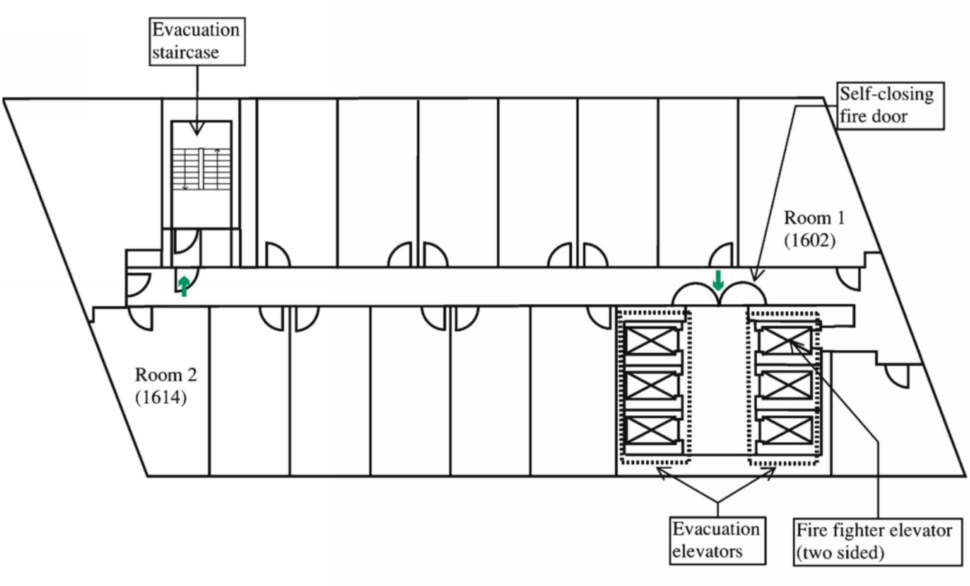

Figure 5. Floor plan of the hotel floor. The two marked rooms (Room 1 and 2) were the ones used in the experiment. The green arrows indicate the location of the evacuation signs.

As mentioned above, the participants were equipped with eye-tracking glasses, which allowed the researchers to observe the participants behaviour. Using these glasses, the researchers could monitor the participants' actions in real-time from an adjacent hotel room. Due to the inability to shut down the elevators and the fact that the building, except for the 16th floor where the experiments were performed, was in regular use, the experiment was terminated once the participant pressed the elevator call button or entered the staircase. After termination, the participants were debriefed and then asked to fill out a questionnaire about their experience.

Figure 6. The hotel corridor as seen from outside Room 1 in Scenario 1-FL. Note the green flashing light mounted on the evacuation sign toward the elevator lobby.

4 Ethical considerations

In research involving human participation, research ethics is of major importance. When studying the present subject, i.e., evacuation behaviour, experiments with human participants are an important component. To perform this sort of experiments in an ethically safe manner, there are certain principles that should be evaluated.

As a response to unethically performed human experiments, ethical frameworks have been developed, e.g., the Nuernberg code (Nuernberg Military Tribunals, 1949), which was developed as a response to Nazi lead research during World War II and consists of ten ethical principles for experimentation with human participants. Another, more recent, example is the Declaration of Helsinki (World Medical Association, 2013), which was developed by the World Medical Association (WMA), to provide ethical principles for medical research involving human participants. The main difference between these documents is, in summary, that the Nuernberg code focuses on the human rights of the participant while the Declaration of Helsinki focuses on the obligations of the researcher performing the research.

Both of the documents mentioned above provide ethical principles with focus on human participation in medical research. With a basis in these codes, Nilsson (2009) identified five ethical principles to be addressed when performing research with human participants in the field of human behaviour in fires. These principles are:

1. Restriction of harm and suffering
2. Outweighing of risks by benefits
3. Informed consent
4. Right to terminate the experiment
5. Protection of integrity

Research studies performed in Sweden involving human participants or human biological material are bound by the Swedish Act concerning the Ethical Review of Research Involving Humans (SFS 2003:460 with changes 2019:1144). The purpose of this act, which is stated in the first paragraph, is to protect the humans involved in research studies and to protect the human rights within research.

When a research study with human participants is planned, an assessment is made by the researcher of whether the study is covered by the law. For the current research area, the primary assessment that was needed is whether the research is performed "*according to a method that aims to affect the participant physically or mentally or* *that involves an obvious risk of harming the participant physically or mentally*" (SFS 2003:460). If this is the case, an ethical approval needs to be applied for at the Swedish Ethics Review Authority. However, this authority was formed in 2019 and before the authority was formed, the application was handled by regional Ethical Review Boards. Thus, at the time for the research performed in this thesis, the ethical approvals were decided by the Ethical Review Board associated to Lund University.

The study performed in Paper V is the only study that underwent such a process in full. The research performed in Paper IV was deemed to be covered by a previous approval regarding evacuation behavioural studies in VR given by the secretary at the Ethical Review Board in Lund, stating that such studies did not require ethical approval by the board (Arias, et al., 2021). However, both Paper III and Paper IV underwent internal ethical reviews.

The ethical assessments performed for the experimental studies in Paper III-V are described below. In the section below, the five bullets listed above are discussed for each experiment. The purpose of the section is to describe the ethical principles in regard to the performed experiments, and this may cause some repetition of experiment procedure information.

4.1 Ethical considerations in Paper I and II

For Paper I and Paper II, no experiments were conducted. Thus, no ethical consideration in relation to human participants were taken.

4.2 Ethical considerations in Paper III

In Paper III, a questionnaire study with a hypothetical evacuation scenario was performed. The study was performed in hotels, office and residential buildings located in either Stockholm or Malmö. The questionnaire was distributed to apartments, offices or hotel rooms within the selected buildings and the participation was thus entirely voluntary. There was no information asked for in the questionnaire that could be used to identify a participant in the study.

As this study was based on a written hypothetical evacuation scenario it was deemed that there was very limited risk for harm and suffering for the participants involved. Thus, the risks of the study were deemed to be small, which meant that the benefits connected to the possible study results were considered to outweigh the possible suffering of the participants.

The questionnaire included a cover page with information stating the purpose of the study and contacts to the responsible researcher should there be any questions. Due to this and the fact that it was voluntary to fill out the questionnaire and send it in, informed consent and the right to terminate the experiment at any time was deemed to be fulfilled. Furthermore, no identifiable information was asked for in the questionnaire, and thus, the protection of the participants integrity was deemed to be satisfied.

The study went through an internal ethical review at the department before it was conducted. However, this sort of study is relatively easy to perform in an ethically safe fashion. Because of the low risk and voluntary fashion of the study, all participants that had answered were included in the results, i.e., underaged participants were not excluded.

4.3 Ethical considerations in Paper IV

In Paper IV, a Virtual Reality evacuation experiment of an underground metro station was performed. The study was performed in the VR laboratory of the division of Fire Safety Engineering at Lund University and the participants were students at the university. The study involved deception, meaning that the participants were recruited to take part of a VR design experiment and were given a bogus task in the beginning of the experiment. No information was given about the evacuation part of the study before the experiment was conducted.

The participants were given information about the VR model and instructed how to terminate the experiment before it was conducted. Further, all participants were asked to sign an informed consent form before the experiment. After the experiment, participants were asked whether they were stressed or felt sick due to the VR experience. They were also informed about the true purpose of the study and given a chance to ask the researchers any questions on the research topic. Finally, they were asked to fill out a questionnaire and were interviewed about their experiences. One question asked was whether they accepted their data being included in the study, as they were not given full information in the informed consent form signed before the experiment.

Since the study was performed in VR, there was a low risk for physical harm and suffering for the participants involved. The participants were standing still in one place when performing the study and they were monitored the entire time so they would not accidentally start moving into objects in the physical world. The main risk in a VR study would be motion sickness or experienced stress and the participants were informed about this before the experiment, as well as given instructions on how to terminate the experiment if this occurred. The benefits of evacuation training and gained knowledge about one's reaction to an evacuation situation was deemed to outweigh the risks for the participants.

As mentioned above, all participants were asked to sign an informed consent form before the study. Further, this consent was reinforced after the experiment to make sure that the participants still gave consent. The participants were instructed how to terminate the experiment at any time, and they were told that this would not affect their reimbursement.

All experiments were recorded, but since the recording only show first person footage of the participants experience in the VR model, this could not be linked to any individual person. Further, the questionnaire and interview data were not linked to any identifiable information about the participant. Thus, the participants integrity was protected.

Before it was conducted, this study went through an internal ethical review at the division for fire safety engineering. It could be argued that a formal ethics application would be needed. However, at the time for the experiment, a similar VR evacuation study had recently been discussed with the regional Ethical Review Board and deemed not to require a formal ethics approval (Arias, Nilsson, et al., 2021). That study aimed to investigate behaviour during a fire incident in a replica of the participants home environments, and included movement on a treadmill. Thus, that study was deemed to be a higher strain on the participants than the one performed in Paper IV and, because of this, an internal ethical review considering the ethical principles listed above was deemed sufficient.

4.4 Ethical considerations in Paper V

In paper V, an unannounced evacuation experiment was performed in a field setting. The study was performed in the hotel part of a high-rise mixed use building in a suburb to Stockholm. The participants were recruited from a research recruitment website[7] and the only requirement to participate was to be at least 18 years old. Similar to the experiment in Paper IV, the study involved deception, and the recruitment information did not include any information about the evacuation part of the experiment. Instead, the participants were recruited to take part in a hotel room design study and told that eye-tracking equipment was an essential part of the experiment.

Before the experiment and again upon arrival at the hotel, the participants were given general information about the study. Information about how to terminate the

[7] www.studentkaninen.se

experiment, which was through calling the researcher in charge, was included. Before the experiment started, all participants were asked to sign an informed consent form. This consent form did not explicitly include the evacuation part of the study, as this would have compromised the validity of the experimental results. However, the participants were asked to sign the consent again after the experiment, to make sure that they approved of the data collected being used when knowing about the true purpose of the study.

After signing the consent form the first time, participants were equipped with the eye-tracking device, given a hotel room key for the 16th floor and shown to the elevators. From there, the participants went alone to the hotel room and a few minutes after arrival, the evacuation alarm was activated. The experiment was terminated by a researcher once the participant had activated the elevator call button on the floor, entered the evacuation staircase or if the participant decided not to evacuate within 15 minutes. The participants were monitored by researchers in adjacent rooms through a live stream of the eye-tracking equipment and the peephole to the corridor. After termination, the participant was debriefed and asked to fill out a questionnaire. Finally, the researcher made sure that the participant was feeling alright and did not show any elevated stress levels before they were told they could leave.

As this study aimed to explore evacuation in a highly realistic manner, the ethical considerations were of key importance in order to protect the participants during and after the experiment. To restrict the harm and suffering, participants were monitored during the experiment and upon showing high levels of stress, the researchers terminated the experiment. Further, the participants were stopped, and the experiment terminated as soon as an escape route was chosen. Thus, the participants did not move downstairs or use the elevator. As soon as the experiment was terminated, the researcher informed the participant that it was a research study and that there was no real emergency. The participant was then accompanied to the ground floor, where the researchers further informed the participant about the study.

The risks of physical and psychological harm to the participants were deemed to be minimized by the procedure mentioned above. The most important benefit for the participants was that they got to experience, and practice, an evacuation in a hotel building. This was mentioned as a useful experience by many of the participants, since it may otherwise be hard to imagine how one will react to such a situation. Participation in an evacuation experiment has been shown to increase the awareness of evacuation safety of participants for some time (Andrée & Bengtson, 2012). The participants were given two movie tickets as reimbursement for their participation.

As mentioned, consent was given by all participants before the experiment. The consent form was sent to the participants a few days before they were to take part in the experiment. As this consent form did not include the evacuation parts of the experiment, it was only a partially informed consent. Accordingly, all participants were asked to sign the informed consent form again after the experiment, to give consent to the use of the data collected when they knew the true purpose and method of the study.

The experiment was recorded through the eye-tracking equipment. This means that there was video footage of the experiment, which could be sensitive for the participants. However, no information was saved concerning the participants identity linking to specific recordings after the experiment. Thus, the participants could only be identified through the recording if they looked into a mirror or similar. Due to this, only one researcher watched all recordings, and all recordings were saved encrypted according to the University policy on recorded material.

This study underwent the full process of ethical approval from the regional Ethical Review Board. The ethical application to the board included information on the purpose of the study, the procedure of the experiment, reimbursement of the participants and the plan of how to ensure the participants safety and protection of integrity during and after the experiment. The application was granted and the procedure in the ethical approval was followed (Dnr 2017/962).

5 Discussion of behavioural aspects of elevator evacuation

In this section, the results of the research are discussed in relation to the research objectives (RO's) listed in section 1.1. The results are briefly put into context of previous research on the subject, which is given in a separate subsection for each research objective. The findings from the performed research are given in the subsections called contribution. A short summary is also provided for each objective.

5.1 RO1: Design strategy for considering behavioural aspects in elevator evacuation designs

As mentioned in the introduction, the lack of guidance on how to account for the behavioural aspects of elevator evacuation could be an important reason for hesitation in the incorporation of evacuation elevators. In Paper I and Paper II, available publications on the behavioural aspects of elevator evacuation are summarised. Furthermore, strategies for development of evacuation designs and psychological frameworks for decision-making were studied in the papers. Finally, relevant parts of the studied literature were combined and developed into a design strategy for considering behavioural aspects when incorporating elevator evacuation in buildings, and other structures. The strategy (or parts thereof) was then tested in different applications and refined to fit with the fire safety engineering design perspective of elevator evacuation.

5.1.1 Previous research

There are several frameworks for the decision-making process in fire situations that can be useful when assessing expected behaviour in any generic evacuation scenario, e.g., the behaviour sequence model developed by Canter et al., (1980) and the Protection Action Decision Model (PADM) developed by Lindell & Perry (2004) and adapted to evacuation by Kuligowski (2013). However, research specifically on the decisions and behaviours associated with evacuation elevators is a more sparsely studied subject. There are some studies performed on the behavioural aspects of elevator evacuation per se, which are presented further in section 5.2.1 and 5.3.1, but there are few publications on how to identify and treat the behavioural aspects that are relevant when elevator evacuation is to be a part of the evacuation strategy.

The only framework previously proposed to deal with the situation of elevator evacuation behaviour is an analytical approach based on Situation Awareness (SA) published by Groner (2009). The concept of Situation Awareness can be defined as “the accuracy with which people perceive, understand and anticipate changes in their environment that are relevant for achieving their goals” (Endsley, 1995). The concept of SA have previously been used to analyse decision-making in different stressful situations, such as pilots in military air crafts (Endsley, 1995) and pipeline emergency response (Groner & Jennings, 2012). SA has also been used to analyse suitable evacuation systems in single tube road tunnels (Frantzich et al., 2016).

In the framework proposed by Groner (2009) a Situation Awareness Requirement Analysis (SARA) is proposed. In this approach, the evacuation design is analysed from a user-perspective. The approach consists of four steps: (1) define a scenario, (2) list possible roles and their responsibilities, (3) list decisions required to fulfil the responsibilities and (4) describe the information needed to perform the listed decisions. The scenario is typically qualitative in nature, e.g., “a fire occurs on an occupied floor in a building and is not threatening the elevator lobby”, and the roles proposed by Groner are occupants, emergency team members, emergency coordinator and elevator router. An example of a decision given for occupants is whether they should evacuate via stairs or the elevator and the information needed to take such a decision is proposed to be in relation to the risk associated with the available choices. The approach is described as a tabletop exercise that could be performed as a workshop with several members in the design team. However, it does not include any guidance on how to evaluate different information sources or how the evacuation design should be assessed holistically, i.e., how different decisions may differ for the same role at different times and locations during the same evacuation scenario.

Apart from the SA/SARA approach, Nilsson (2009) proposed a research strategy concerning how to test the designs of technical information systems in evacuation applications in order to avoid misinterpretations and design errors. This research strategy consists of three steps, (1) identify problem, (2) solve problem and (3) test system, performed in an iterative loop. In each step, Nilsson proposes different experimentation procedures to evaluate the design.

Within the same work, Nilsson (2009) advocated the use of the Theory of Affordances to analyse design proposals. The Theory of Affordances is a framework to analyse how people perceive things they see, hear or feel and was originally proposed by Gibson (1978) and expanded by Hartson (2003). In essence, the framework can be used to analyse designs from the perspective of what they can offer (or afford) to the user. In the expansion of the theory by Hartson, four types of affordances are used, i.e., sensory (how a design supports being sensed or seen), cognitive (how a design supports being understood correctly), physical (how a design supports being used physically) and functional (how the design supports the user to fulfil their goals). This framework can be, and has been, used to systematically analyse the design of evacuation exits (Nilsson et al., 2008).

Although useful, the research strategy and proposed framework by Nilsson (2009) is focused on design of single evacuation exits or information systems. It was not developed to assess an evacuation design situation in full, which would usually be needed for evacuation elevators. Further, the strategy is designed for research and relies heavily on experimentation in a way that is not always feasible in the engineering design process.

To summarise, there have been different efforts to use psychological frameworks to analyse evacuation designs and the decision-making process during an evacuation. However, there is only one previous publication assessing the process of elevator evacuation design with a focus on the information needed for proper decision-making during the evacuation (Groner, 2009). This publication does not discuss how to identify the important behavioural aspects nor how to verify that the information needed by the user is conveyed in the way intended by the designer. Thus, a holistic way to assess elevator evacuation designs has been missing. Because of the complexity in the behavioural aspects of elevator evacuation, this could be a major issue when designers intend to incorporate elevators in the building evacuation strategy.

5.1.2 Contribution

In Paper I and Paper II, the main contribution to this research objective is related to the design strategy proposed to account for the behavioural aspects of evacuation designs where evacuation elevators are included. The papers investigate different frameworks and theories of human behaviour in fires and their applicability in the situation of elevator evacuation design. In both papers, the proposed design strategy is described, but in Paper I, the focus is on how to assess specific parts or information systems within the overall design, while Paper II focuses on the design problem more holistically. Further, within Paper II the first step of the design strategy, which consists of a behavioural analysis is elaborated. It should be noted that the proposed strategy was further developed between Paper I and Paper II, and thus, there are some differences in the descriptions given.

In Paper I, the Theory of Affordances is introduced as a possible tool to aid the analysis of evacuation systems. In Paper I, the theory is proposed as a tool to aid the design of evacuation systems promoting elevator evacuation. The purpose of using the theory in this context is to systematically identify how a system, or parts thereof, will be perceived and understood by an evacuee. In the paper, the application of the Theory of Affordances is exemplified by analysing the differences between the affordances provided by the guidance systems used in two evacuations of the former World Trade Center towers in New York, i.e., the evacuations following the 1993 and the 2001 terrorist attacks. In addition to this, a separate analysis is performed on proposed evacuation signage for elevator evacuation in Sweden, illustrating how the theory can be used when assessing individual parts of an information system. The conclusion of these cases is that the theory can be utilised to identify and explain improvements in the design of individual parts of an evacuation system.

Furthermore, in Paper I, the strategy for developing and testing new evacuation systems for elevator evacuation is proposed. In the paper, the proposed strategy is discussed with a research focus and the outline is the same as the one originally proposed by Nilsson (2009). The motivation for using this strategy is to minimise design errors in the development of new evacuation systems, which is achieved by thorough empirical testing of the proposed systems. The importance of such testing has been pointed out in previous research, e.g., where evacuation portals in train tunnels were perceived as oncoming trains rather than evacuation exits (Fridolf et al., 2013). As it is difficult for the designer to fully understand the perception of the evacuee, in particular with regard to the complexity of elevator evacuation, testing was deemed an important tool for developing new evacuation systems. However, this strategy focuses on individual systems, e.g., design of signage or door environments, and not on the full evacuation design within a building or other structure. Further, the strategy assumes that the designer has identified relevant systems to test and compare. Thus, the strategy does not include the process of analysing the evacuation design holistically to identify important decision nodes and relevant measures to support the decisions in such nodes.

In Paper II, this strategy was further developed and refined in the process of analysing the evacuation situation in a deep underground metro station using elevator evacuation. In underground metro stations, elevators are uncommon both as a means of primary entry but also as means of evacuation. Because of this, and due to the lack of research performed on elevator evacuation in underground metro stations, the importance of a structured design strategy, when assessing an evacuation design with elevator evacuation in such a facility, was emphasised. The step of identifying important decision-nodes and possible measures to communicate proper information to the evacuees in these nodes were highlighted in the process. Thus, much emphasis in the paper was on developing a framework for behavioural analysis which was identified as an important initial step in the design strategy. The design strategy is illustrated in Figure 7.

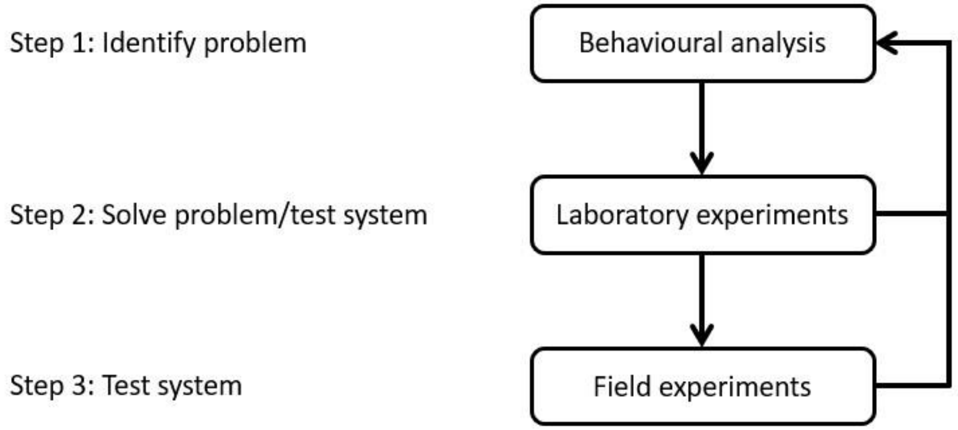

Figure 7. The design strategy proposed in Paper II, developed from Nilsson (2009).

In addition to the behavioural analysis as a first step in the strategy, the empirical testing of the system was reduced by one step. The main reason for this was to better align the strategy to the practical design workflow of a building project. The value of including hypothetical scenario studies, as in the original research strategy by Nilsson (2009), can be questioned due to the validity of this research method with regard to elevator evacuation. Thus, the strategy now starts with a behavioural analysis, which will be described further below, that is performed on a design proposal. This analysis will most likely result in a number of measures to improve the evacuation design. In step 2, these measures are tested in a laboratory scale, e.g., VR, to ensure that they are perceived in the intended way. In the last step, the design is tested as a whole in the field. This step could be performed in the last stages of a building project and the purpose is to ensure no design mistakes were missed in the trials performed in the previous step.

As previously discussed, a main factor of elevator evacuation is to overcome the preconception of not using the elevator if there is a fire situation. Because of the importance of this behavioural aspect, the evacuee’s understanding of the evacuation information systems was identified as a crucial factor in the design. Thus, to achieve a successful design, a framework for behavioural analysis was included as the initial step of the design strategy. To form a basis for this framework, the previously presented SARA model (Groner, 2009) was used. However, this model was further developed into a more practically applicable framework within the work of the case study in Paper II. The purpose of the framework is to provide a foundation for the design of the guidance and information systems that will be evaluated in the next step of the design strategy. The framework for behavioural analysis consists of the steps presented below:

1. **Define scenario** – A qualitative description of the fire scenarios is made. Because of the uncertainties connected to fire scenarios, the description should be held at a general level. Note that several scenarios probably need to be evaluated.

2. **Define the different roles of persons in the evacuation** – The different roles are defined by their initial position when the evacuation is initiated but are also dependent on other factors like familiarity with the environment, physical and cognitive abilities, and incentives to stay or leave the premises.

3. **Define different information zones within the facility/building** – As different information may be suitable to convey in different areas, this is a key parameter for the structure of the analysis. The zones could be enclosures, e.g., different rooms, or parts thereof within the building or structure analysed.

4. **Define desired behaviour for the different roles** – This is typically the behaviour that is deemed to generate the most efficient evacuation. For example, a desired behaviour could be to use the evacuation elevator instead of a staircase, if this is deemed beneficial for the evacuation by the designer.

5. **Define needs of the evacuees to achieve the desired evacuation behaviour** – This could be informational needs, need of guidance and similar. The need of information and guidance could be assumed to be greater if the evacuation contains unfamiliar routes or systems for evacuation. When designing for elevator evacuation, the needs for information and guidance encouraging the use of such an escape route is probably larger than in a case where stairs are used for evacuation. Further, the needs for evacuation of people experiencing difficulties walking in stairs are different from people without such difficulties, which needs to be addressed here.

6. **Define suitable measures to accommodate the needs** – This could for example be technical guidance system, instructions from personnel or other aids.

The workflow when using this framework is illustrated in Figure 8. To ensure that the needs of the evacuees are accommodated throughout their evacuation, it is recommended that the designer "follows" the evacuee step-by-step in their evacuation. Using this perspective, it is easier to consider whether new information in a zone may be ambiguous relative to previously given information, or similar.

Thus, the workflow starts with a scenario and a role identification, then it continues to perform step 4-6 above in each of the information zones identified in step 3.

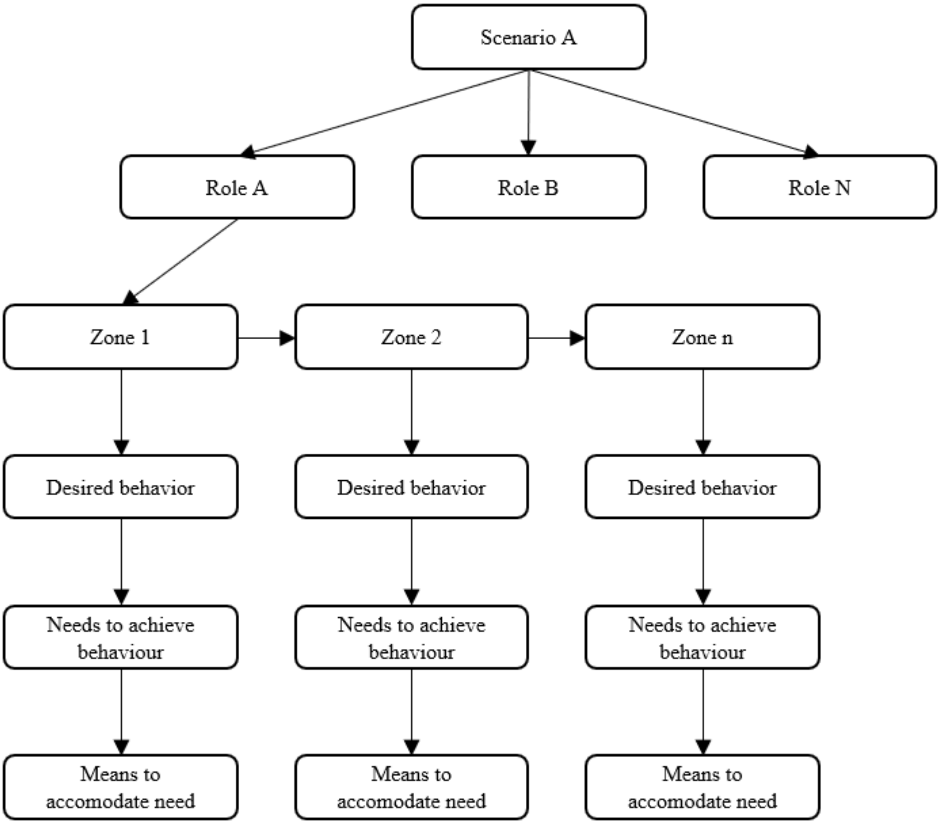

Figure 8. Illustration of the working flow in the framework for behavioural analysis presented in Paper II. It should be noted that different roles may initiate their evacuation from different information zones.

When evaluating the measures to accommodate the needs in the last step of each iteration, the Theory of Affordances was identified as a suitable tool. A benefit of the behavioural analysis is that it breaks the design down into smaller pieces, making the application of the theory easier and more relevant. The application of the theory is then similar to the use exemplified in the cases presented in Paper I. Furthermore, the framework for behavioural analysis is illustrated in a case study in Paper II.

Another benefit of using the presented behavioural analysis is that it can serve as a foundation for identifying important knowledge gaps within a design solution. As the designer analyses the information needs of the evacuees and the measures to accommodate these needs in each relevant step of the evacuation, this facilitates identification of areas where available research data or guidance is insufficient. Thus, even if major parts of a design solution consist of well-established guidance and information systems, the analysis may pinpoint certain areas where further testing is needed to reach a satisfactory level of confidence in the evacuation solution.

It should be noted that proving the usefulness of a developed strategy or framework is challenging. This is true also for the work presented above. However, the behavioural analysis framework was used when developing the improved scenario for the experiments performed in Paper IV (called *Enhanced scenario* in the paper and in section 3.5.2). In the results from this experiment, that could be seen as the second step in the design strategy presented in Figure 7, the *Enhanced scenario* outperformed a regular evacuation design significantly. This should not be seen as absolute proof that the strategy always will lead to successful designs, but together with the case studies in Paper I and Paper II, the result indicates that the evacuation system design can be improved by applying a systematic procedure, such as that proposed.

Another important observation in Paper IV was a design error in the suggested design (this design error is further described and discussed in section 5.2), which could have caused significant impact in a real evacuation scenario. However, the identification of this error emphasises the benefits of following the proposed design strategy when developing evacuation systems with elevator evacuation.

5.1.3 Summary

In Paper I and Paper II, previous theories, research strategies and frameworks have been combined and further developed into a design strategy with the purpose to aid the design of evacuation systems with elevator evacuation. Similar efforts have been made previously, but with focus on research and on individual parts of a design. Thus, the design strategy presented provide designers with a structured procedure that can be used for assessing behavioural aspects of elevator evacuation in building, and other structures. This has previously been lacking but is important due to the complexity of predicting behaviours relating to elevator evacuation. The first step of the design strategy, i.e., the behavioural analysis, can also be used to highlight uncertainties or specific knowledge gaps associated with an evacuation design, which is another important aspect to consider when elevators are to be implemented.

5.2 RO2: Willingness to use an evacuation elevator

The willingness to use an elevator for evacuation is a fundamental aspect to consider when implementing such elevators in buildings and other structures. If no one is willing to use the elevator for evacuation, there is no benefit of implementing the solution. The reluctance to use the elevator during an evacuation scenario has been mentioned as a potential difficulty for decades (Klote et al., 1992). At the same time, the use of elevators has been recorded in numerous real fire evacuations, despite the elevators not being built as evacuation elevators.

To bring further light on this situation, experiments were performed and presented in Paper III, IV and V where the willingness to use evacuation elevators was studied in different ways. Furthermore, previous research studies on the subject are summarised to provide context to the studies performed.

5.2.1 Previous research

The reluctance for evacuation elevator use was initially recorded in an interview study performed by Klote et al. (1994). In this study, air traffic controllers and facilities personnel at 13 different air traffic control towers in the U.S. were interviewed. There is no quantitative data in the report and the number of interviewees is not given, but the report claims that "nearly all those interviewed expressed a strong preference for using stairs as their first choice of escape route". Further, the study reports that some of the participants in the study felt so reluctant to use the elevator that they would rather wait for helicopter assistance than use the evacuation elevator if the stairs were blocked by smoke. However, if they had no other option, the majority of the participants would use the elevator for evacuation but with "considerable concern".

In subsequent years, the topic was not given much research attention. However, the tragic collapse of the World Trade Center Towers on September 11, 2001, shed new light on the concerns of high-rise building evacuation. Following this event, the NFPA commissioned a survey through the Fire Protection Research Foundation to investigate the level of fire safety knowledge of high-rise building occupants across the U.S. The survey, performed by Zmud (2008), included 244 residential respondents and 228 commercial (office) respondents. When asked about the perception of using elevators during an emergency, 80 % of the commercial participants and 73 % of the residential participants answered that they believed that elevators are never safe to use in such a situation. Most remaining participants answered that they thought that the elevators are rarely safe and only a few percent believed that the elevator are usually safe or as safe as the stairs. No difference in the perception of elevator evacuation depending on respondent building floor was reported (Zmud, 2008).

In 2009, a theoretical relationship between the willingness to use an elevator for evacuation and the occupied floor in a building was presented (Heyes, 2009; Heyes & Spearpoint, 2009). The theory was that occupants would be more prone to use evacuation elevators the higher up in a building they were located. Furthermore, it was proposed that some people would probably always use the elevator due to functional limitations, or other reasons. Similarly, it was proposed that some people would probably never use the elevator due to phobia or immense fear of the elevator in an evacuation scenario, see Figure 9.

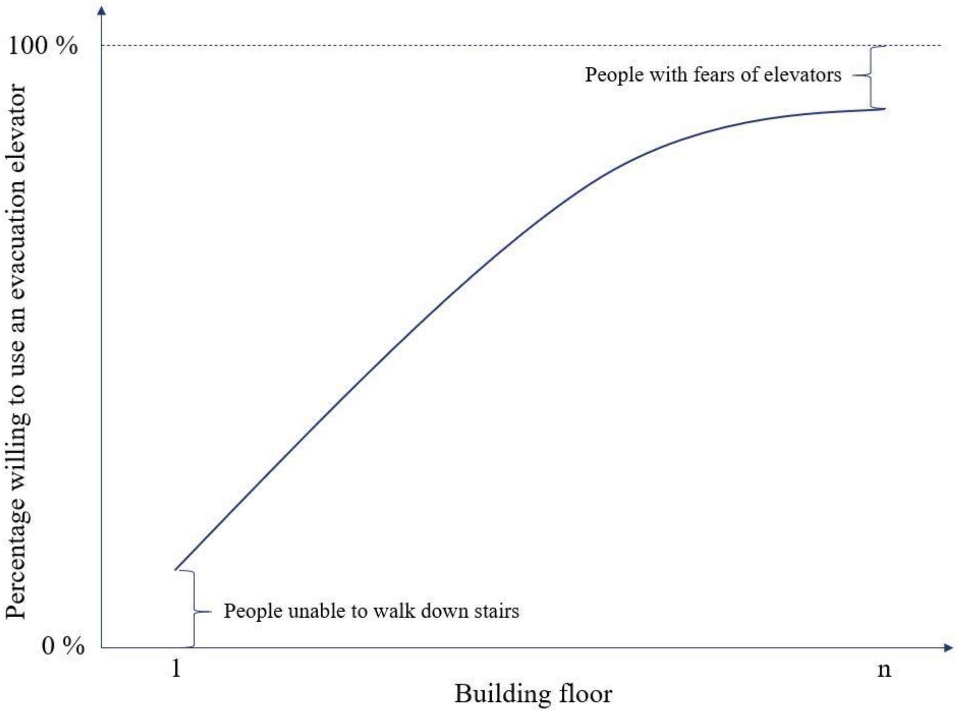

Figure 9. Hypothetical relationship between willingness to use an evacuation elevator and the occupied floor in a building, reproduced from Heyes & Spearpoint, 2009 (with permission). In the figure, n represents a building floor where everyone except those with fear of using elevators will be willing to use an elevator for evacuation.

To test the hypothetical relationship, two different surveys were conducted (Heyes & Spearpoint, 2009). One survey was performed with 229 students at the University of Canterbury. The students were asked to imagine that they were working on the 5^{th}, 30^{th} or the 60^{th} floor of a building and had to evacuate using either evacuation stairs or evacuation elevators. They were then divided into an "educated" and an "uneducated" group, where the "educated" group was given information about the fire safety systems in buildings with evacuation elevators prior to completing the questionnaire.

Another online survey was performed in the same research study with 138 Arup employees in offices located in Perth, San Francisco and Singapore (Heyes & Spearpoint, 2009). In this survey, the respondents were asked to make a decision of the exit choices of imaginary people in a hypothetical evacuation scenario. The imaginary people were located on either the 5th, 20th or 60th floor of a building.

The results of these two surveys were combined into a linear correlation of expected evacuation elevator use depending on the building floor. The data points show a significant scatter, e.g., 20-50 % on the 20th floor and ~30-55 % on the 30th floor, but the correlation show a high R^2-value of 0.88. This indicates that the correlation actually is based on the average numbers of the data points on each floor in the data set, which has also been assumed in other literature on the subject (Kinsey, 2011). The correlation developed by Heyes & Spearpoint (2009) is:

$$p = 1.14f + 5.3 \qquad 5 \leq f \leq 60\, floors \qquad (1)$$

p = Percentage of occupants expected to use the elevator for evacuation,

f= Building floor.

In a similar manner as the study by Heyes & Spearpoint (2009) an online questionnaire study with a hypothetical evacuation scenario was performed by Kinsey et al. (2012). The study included 468 participants from 23 different countries. In the study, the willingness to use elevators was recorded both for a base case, i.e., not an evacuation situation, and for a hypothetical evacuation situation.

For the evacuation scenario, the participants were given a progressively higher floor number in a hypothetical building and were continuously asked whether they would be willing to use an elevator for evacuation. This was done until they either said yes or reached the 60th floor, which was the highest floor included in the study (Kinsey et al., 2012). The results were then sorted into floor ranges of 9-10 floors, i.e., floor 2-10, 11-20, 21-30, etc., with the associated percentage of participants willing to use the elevator for evacuation for each floor range. Using the mid-points of these floor ranges, a regression analysis was performed giving the relationship below:

$$p = 0.3207 * \ln(f) - 0.4403 \qquad 5 \leq f \leq 55\, floors \qquad (2)$$

p = Percentage of occupants expected to use the elevator for evacuation,

f= Building floor.

The correlation above showed a R^2-value of 0.95, indicating a good representation of the underlying data set.

The study by Kinsey et al. (2012) investigated whether a number of demographics, i.e., gender, age, country of residence and Body Mass Index (BMI), had any effects on the evacuation elevator acceptance. It was concluded that no statistically significant difference existed, aside from country of residence. A difference was identified when comparing the participant groups from the different countries included in the study, i.e., the UK, China, the U.S. and Germany.

Apart from the hypothetical scenario studies, Andrée et al. (2016) performed VR evacuation experiments on the 16th floor in a virtual high-rise hotel building where the participants could evacuate either using an evacuation stair or by using evacuation elevators. The participants in the experiment were told that they were to take part in a study on evacuation safety in high-rise buildings, but not given more in-depth information about how the study would be performed. Thus, the participants were partly informed of the objective of the experiment.

The study included 72 participants and once these participants were immersed in the virtual environment, they were put in the lobby of the virtual hotel building and given instruction to use the elevator to travel to a given hotel room the 16th floor. When in the hotel room, a voice alarm message was activated telling the participants that there was a fire and that they should evacuate. The alarm message contained the information that the elevators could be used for evacuation in the building. Following this alarm, the exit choice of the participants was recorded. Two different scenarios were studied: one with green flashing lights reinforcing the evacuation signage towards the evacuation elevators and one with regular signage. The study results showed that approximately 60 % of the participants were willing to use the evacuation elevator in the scenario without the green flashing lights, while 90 % were willing to use the elevator in the scenario with such lights (Andrée et al., 2016). The study concluded that technical systems, such as green flashing lights, can influence the use of evacuation elevators in high-rise buildings.

After the study performed in Paper V had been published, a VR replication of the study was performed by Arias et al. (2021). This study was similar to that conducted by Andrée et al. (2016) but performed with the participants wearing an HMD instead of in a CAVE virtual environment and without the scenario with flashing lights. Instead, the study included two scenarios where “Scenario 1” had the participants evacuate from a room adjacent to the elevators and “Scenario 2” had the participants evacuate from a room adjacent to the stairs, i.e., replicas of Scenario 1 and 2 in Paper V.

The study by Arias, et al. (2021) included 62 participants and the results showed that 94 % of the participants choose to use the elevator for evacuation as their primary evacuation route in Scenario 1 compared to 84 % in Scenario 2. In addition to these results, several comparisons were made with Paper V that is outside the scope of this thesis. The interested reader is referred to the paper by Arias et al. (2021) or the thesis by Arias (2021) for more information.

In addition to the research studies listed above, it should be noted that elevator usage has been recorded in several real high-rise building evacuation situations. However, in all these identified cases, elevator evacuation was not part of the evacuation design. Thus, the intended action has not been to use the elevator for evacuation. Further, the data show a significant scatter in elevator usage. These factors make it difficult to draw any conclusions from real evacuation events, except that certain elevator use can be expected in most cases.

The studies above focus on evacuation elevators in high-rise buildings, which is the most studied application for such elevators. However, the use of evacuation elevators from underground metro station environments has also been studied (Engstrand & Näslund, 2014). Similar to Heyes & Spearpoint (2009) and Kinsey et al. (2012), the study was performed as a questionnaire study with a hypothetical evacuation scenario, but the scenario was set in an underground metro station located either eight meters below ground or 30 meters below ground. The study was performed with two groups, the first group was random volunteers in Stockholm (Group 1) and the second group was members of different organisations for people with functional limitations (Group 2).

The study results show that, in Group 1, 9.9 % of the participants preferred to evacuate the underground metro station using evacuation elevators. A statistically significant difference was shown when comparing the answers from the different given station depth as the willingness to use an elevator for evacuation increased from 4.9 % for the eight-meter-deep station to 15.6 % for the 30-meter-deep station. However, it should be mentioned that 7.2 % of the participants answered that they could not ascend stairs without difficulty in this group.

In Group 2, only the 30-meter-deep station was analysed and in this group 62 % of the participants answered that they difficulties walking in stairs. In this group, 57.1 % of the participants were willing to use an elevator for evacuation. It is notable that some of the participants who would have difficulties to walk up the stairs would still prefer to use stairs over elevators.

It should be noted that the waiting times accepted for the elevator during an evacuation scenario in a high-rise building were collected in the studies by Heyes & Spearpoint (2009), Kinsey et al. (2012), Andrée et al. (2016) and in the study by Arias et al. (2021). Waiting times accepted for elevator evacuation in an underground metro station were recorded in the study by Engstrand & Näslund (2014). These results are discussed further in section 5.3.1.

5.2.2 Contribution

The following presentation is divided into separate sections for high-rise buildings and underground metro stations.

High-rise buildings

The study performed in Paper III was based on a hypothetical evacuation scenario, similar to the previous studies by Heyes & Spearpoint (2009) and Kinsey et al. (2012). However, the study was performed on-site in a number of Swedish high-rise buildings, meaning that the participants only had to imagine the hypothetical evacuation scenario, while the context of their setting was real. Thus, the participants stated what floor they were on when filling out the questionnaire, and then worked through the hypothetical scenario and answered whether they would accept using an elevator for evacuation or not.

In total, approximately 10 % of the participants answered that they would accept the elevator as an escape route in the fire evacuation scenario described. As in the previous hypothetical studies discussed above, a correlation of elevator acceptance depending on floor level in the building was developed.

$$p = 0.84f + 1.05 \qquad 5 \leq f \leq 24\,floors \qquad (3)$$

p = Percentage of occupants expected to use the elevator for evacuation,

f= Building floor.

The correlation derived is linear and fits the dataset with a R^2-value of 0.90. The correlation is illustrated in Figure 10.

Notable was that around 3-5 % of the participants regarded themselves as unable to walk down the stairs unassisted if there was an evacuation. To account for these evacuees, it is proposed that p never assumes a value below 5 %, regardless of building floor. This is the case for floor 1-4, which explains the lower boundary of the correlation given above. Further, the study included buildings with 15-54 floors, but the participants answering the questionnaire were only located up to the 24^{th} floor. Thus, this is the upper limit of the data set and the given correlation.

The correlation from Paper III and the other correlations discussed previously are shown together in Figure 10. A noticeable spread in the expected evacuation elevator use can be observed for the different correlations. Due to different methods being used and different studied populations, a certain difference would be expected. As mentioned previously, the method of the study in Paper III has a few strengths compared to the datasets from the other hypothetical studies. First and foremost, it was performed with actual high-rise building inhabitants making a decision of their escape from their current position in an actual building. This is different compared to the other studies, where the participants had to imagine both the scenario and their position in a hypothetical environment. Further, the study in Paper III had more participants than the other studies despite ranging over fewer building floors and the dataset contained participants for each building floor within the applicable range. Thus, the correlation was not based on averaging over several building floors or on a small number of datapoints within the given range, which is an issue observed for the other correlations.

Another possible explanation of the difference between the correlations may lie in the studied populations. The study in Paper III was performed in Swedish buildings and as mentioned, the building floor of the participants gives the upper boundary of the correlation. As indicated, buildings in Sweden are not very tall and even though the study was performed in 10 of the 30 tallest buildings in Sweden, the upper building floor boundary is not very high in an international context. In the study performed by Kinsey et al. (2012), the only demographic factor shown to have statistically significant difference on the willingness to use an evacuation elevator was the country of residence. Thus, some of the difference observed can be assumed to be cultural and may be explained by the Swedish participants being less used to high-rise buildings compared to the participants of the other studies.

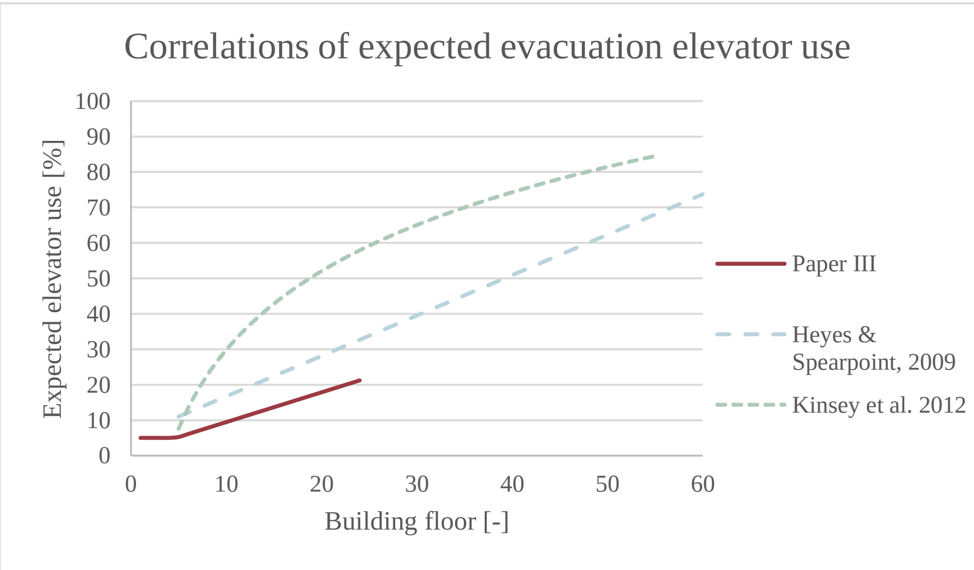

Figure 10. Correlations of expected evacuation elevator use depending on building floor in different publications on the subject.

An important aspect is that all correlations are based on the participants own perception of how they would evacuate in a hypothetical scenario, i.e., the correlations show the behavioural intent of the participants, and not their recorded behaviour. Being an estimation of their own actions, the answers can be biased by the participants willingness to answer in a way that they think is socially acceptable rather than in the way they would really behave, i.e., the so-called response bias, or social desirability bias (Paulhus, 2002). Further, the situation given, i.e., a fire evacuation scenario, is a rare and stressful event. Thus, the participants may have trouble imagining how they would react in such a scenario. This is emphasised by the substantial difference between the predictions given by all three correlations and the data collected in the VR-experiments by Andrée et al. (2016) and Arias et al. (2021) as well as the difference to the results in Paper V. These differences are illustrated in Figure 11.

To deepen the understanding of actual behaviour in relation to behavioural intent the field experiment in Paper V was performed in a high-rise building with evacuation elevators as one of the two available escape routes. The building was the actual building that both Andrée, et al. (2016) and Arias, et al. (2021) replicated in their VR studies and similar to those studies, the evacuation in the field experiment was performed from a hotel room on the 16th floor in the building. As mentioned in section 3.5.3, three different scenarios were studied including two different starting hotel rooms for the participants (adjacent to the elevators or adjacent to the evacuation stair) and a scenario with green flashing lights towards the elevator lobby. Thus, all the scenarios in Paper V are covered in the different VR studies, with the variation of evacuation from a room adjacent to the elevators with and without flashing lights in Andrée, et al. (2016) and the variation of the participants starting point at the time of the evacuation in Arias, et al. (2021).

The results from the field experiment in Paper V showed a high evacuation elevator usage from the participants, which can be seen in Figure 11. In total, approximately 95 % of the participants choose to evacuate using the elevators, which is a significantly higher number than predicted by all the correlations based on the questionnaire studies mentioned above. It is also higher than the results from the VR experiment presented by Andrée, et al. (2016), if comparing the scenarios without flashing lights. However, when comparing the scenarios with flashing lights, the number of evacuation elevator users is quite similar. This is also true when comparing the different scenarios to the VR experiment performed by Arias, et al. (2021). This indicates that VR experiments could be a useful tool for further research on the subject. For more discussion on the similarities and differences between the VR experiments and the field experiment, see Arias, et al. (2021) and for more discussion on the validity of VR see Arias (2021).

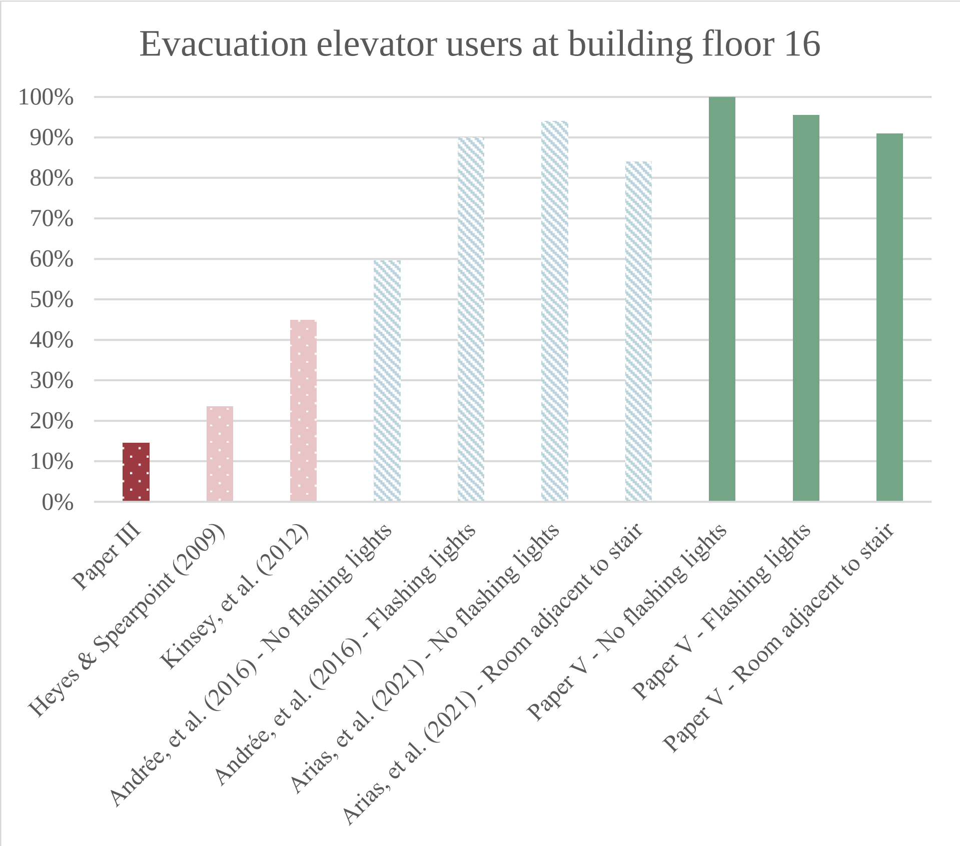

Figure 11. Evacuation elevator usage on floor 16 in different studies. Studies dotted in red are hypothetical scenario studies, studies with diagonal lines in blue are VR-studies and studies in one colour (green) are field experiments. Studies included in this thesis have darker colour while other studies are more transparent.

There could be several reasons for the differences between the experimental methods, but the results indicate that the behavioural intent given in questionnaire studies concerning elevator evacuation in a hypothetical scenario is not valid. Further, due to the higher level of external validity of the field experiment, the result indicates that the number of persons who are willing to use the elevator for evacuation is higher in reality than recorded in previous experiments. This could be an important factor, as the field experiment in Paper V indicates that almost everyone may be prone to use an elevator for evacuation in a high-rise building, even if the building is not very tall. As can be seen in Figure 11, this is a major difference to the predictions given by the correlations developed in previous questionnaire studies.

Furthermore, almost 80 % of the participants in the field experiment did not perceive that there were any alternative evacuation routes except for the elevators. This indicates that even if fire safety professionals may assume that building occupants expect at least two escape routes, most people are probably unaware of such requirements or customs. Thus, building inhabitants that are not familiar with the building in question may only be aware of the route they entered the building as a possible escape route.

Another important factor for the high evacuation elevator usage in the field experiment could be the voice alarm message, which stated that elevators could be used for evacuation in the building. In the questionnaire, almost 40 % of the participants stated that the alarm message was important for their exit choice. Thus, a voice alarm system, when applying elevator evacuation, could be important for the evacuation design.

In the studies on the willingness to use an elevator for evacuation in high-rise buildings, i.e., Paper III and Paper V, the participants attitude towards elevator evacuation was investigated. This was explored in order to assess what major concerns the participants could have relating to elevator use in evacuations. In contrast to the difference in exit choice discussed above, the major risks perceived with elevator evacuation were similar in the studies. In both studies, the participants primary concern with elevator evacuation was the risk of having to wait or to get stuck in a queue to the elevator. The second biggest concern that the participants had with elevator evacuation was the same in both studies, i.e., to get stuck in the elevator while travelling. Thus, there was consistency in the perceived risks with elevator evacuation between the studies.

Underground metro stations

Concerning the willingness to use evacuation elevators in underground metro stations, this aspect was investigated in Paper IV by performing an evacuation experiment in a VR setting. In the experiment, three different information and guidance system designs were tested. This was primarily done to study two aspects: (1) the willingness to use an evacuation elevator in an underground metro station designed without any specific information or guidance systems towards such elevators and (2) whether, and in what way, the willingness was affected by different information and guidance measures. The first point was investigated in the Baseline scenario and the second point was investigated in the other scenarios. Furthermore, it should be noted that the information and guidance measures included in the Enhanced scenario of the study, were based on a behavioural analysis performed using the framework developed in Paper II.

The results from the study can be seen in Figure 12. As can be seen, only 3 % of the participants were willing to use an elevator for evacuation in the Baseline scenario of the study. This showed some similarity to the results from the previous questionnaire study, which indicated a willingness to use evacuation elevators of 5-15 % depending on station depth. However, with information and guidance systems, the willingness was increased to 30 % for the Smartphone scenario and 68 % in the Enhanced scenario. It should be noted that the VR study was performed with students who all answered that they did not have any troubles walking up stairs. This makes comparisons to the results from the study by Engstrand & Näslund (2014) difficult because of the difference in physical abilities, especially for the results from Group 2.

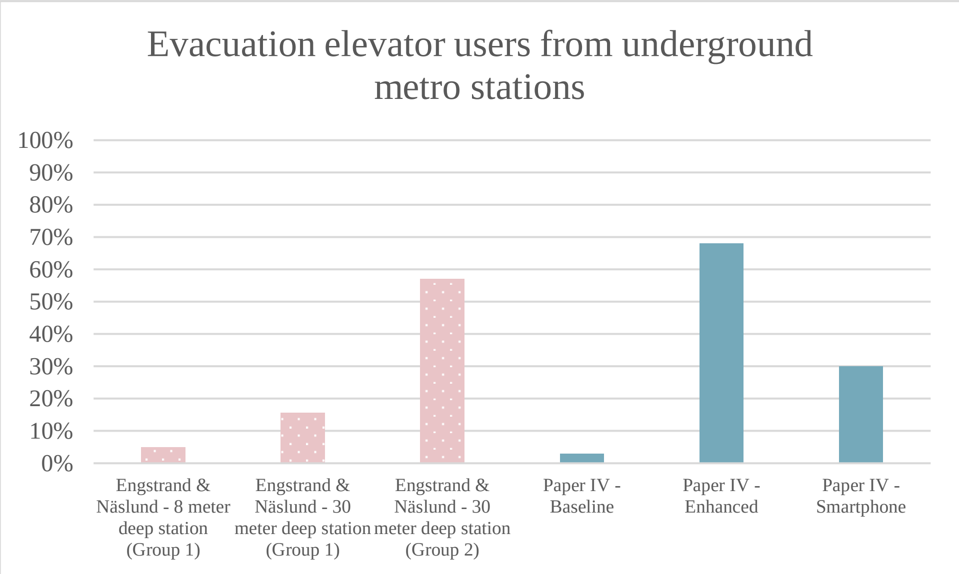

Figure 12. Evacuation elevator usage from an underground metro station in different studies. The results in pink with dots are from a hypothetical scenario study and the study in full colour blue are from the VR study in Paper IV.

In contrast to the studies on the willingness to use evacuation elevators in high-rise buildings, the questionnaire study shows similar results to the Baseline scenario in VR. An important reason for this is probably that the common way to enter and exit underground metro stations in Sweden (where both studies were performed) are with stairs or escalators. Thus, using elevators to evacuate would be an unfamiliar way to try to exit the station and it would therefore require a more conscious decision by the evacuee.

The results presented in Paper IV (and illustrated in Figure 12) show that information measures can have a significant impact on the willingness to use an evacuation elevator in an underground metro station. As previously mentioned, when utilising the framework for behavioural analysis, presented in Paper II: in the evacuation design, the willingness to use an evacuation elevator increased from 3 %, in the Baseline scenario, to 68 % in the Enhanced scenario. The main components driving this difference was the voice alarm that included information that the elevators could be used for evacuation, the information signs about the evacuation elevators and the station depth, as well as the reinforced evacuation signage at important decision nodes.

The importance of the voice alarm was highlighted by the results, as 25 % of the participants tried to use the elevator from the platform in the Enhanced scenario. At this stage of the evacuation, the only difference between the Baseline scenario and the Enhanced scenario was that the voice alarm in the Enhanced scenario included the phrase: "*Elevators can be used for evacuation in this station*".

The view from the platform can be seen in Figure 13. As the elevator only had a lift height of a few meters and the participants could clearly see the top of the stairs on the side of the elevator, it was not expected that any participants would choose to use elevator at this stage. Thus, the impact of the information in the voice alarm is an important aspect for elevator evacuation, and for evacuation designs in general.

Figure 13. The elevator and stairs from the platform in the VR study in Paper IV.

Another result indicating the importance of the voice alarm was that 92 % of the participants in the Enhanced scenario mentioned that the alarm included the information that the elevators could be used for evacuation. Several participants described the importance of this system for their decision-making, e.g.:

Are you really supposed to use the elevators? They can malfunction … But the voice said that they could be used so I tried.

(Participant from the Enhanced scenario in Paper IV)

The guidance from a smartphone was less successful in directing the participants towards the evacuation elevators and the willingness "only" increased to 30 %. However, there were several difficulties with the design of this system such as several participants not noticing the smartphone (13 % of the participants) and guidance malfunction due to missed waypoints along the way (happened to 15 % of the participants). Further, 35 % did not stay engaged with the smartphone guidance along the way and did only look at the phone in the initial parts of the evacuation. Thus, for the participants who noticed the smartphone, stayed engaged with it during the evacuation and did not experience any guidance malfunction, the willingness increased to 69 %, i.e., similar to the Enhanced scenario. This indicates that an improved smartphone guidance system has the potential to increase the willingness to use an evacuation elevator in a similar manner as the design tested in the Enhanced scenario. The issues experienced with the smartphone guidance highlights the importance of testing the systems systematically, as proposed in Paper I and II.

Again, similar to the guidance in the Enhanced scenario, the information given by the smartphone had a similar impact on the participants as the voice alarm message. An example of this is the similar reactions given in the interviews, as can be seen in the quote below:

I saw the message on the phone and thought "What? Are you supposed to use the elevators in a fire situation?" But then I thought that I better follow the instructions.

(Participant from the Smartphone scenario in Paper IV)

Another interesting aspect is that the attitude towards elevator evacuation varied between the participants in the different scenarios. This was recorded by measuring if the participant expressed negative feelings about elevator evacuation in the interview after the experiment. The following statement is an example of expressed negative feelings:

You should never use the elevator if there is a fire and not the escalator either.

(Participant from the Smartphone scenario in Paper IV)

The number of participants who expressed negative feelings about elevator evacuation is shown in Figure 14. Overall, 51 % of the participants expressed negative feelings, but the variation ranged from 38 % in the Enhanced scenario to 73 % in the Baseline scenario. This indicates that information and guidance systems can increase the trust in elevators for evacuation. The difference could also stem from people being less eager to critique their own exit choice, but since all participants changed escape route to the stairs at a certain point of the experiment (see more on this in section 5.3.2) this effect is probably not significant.

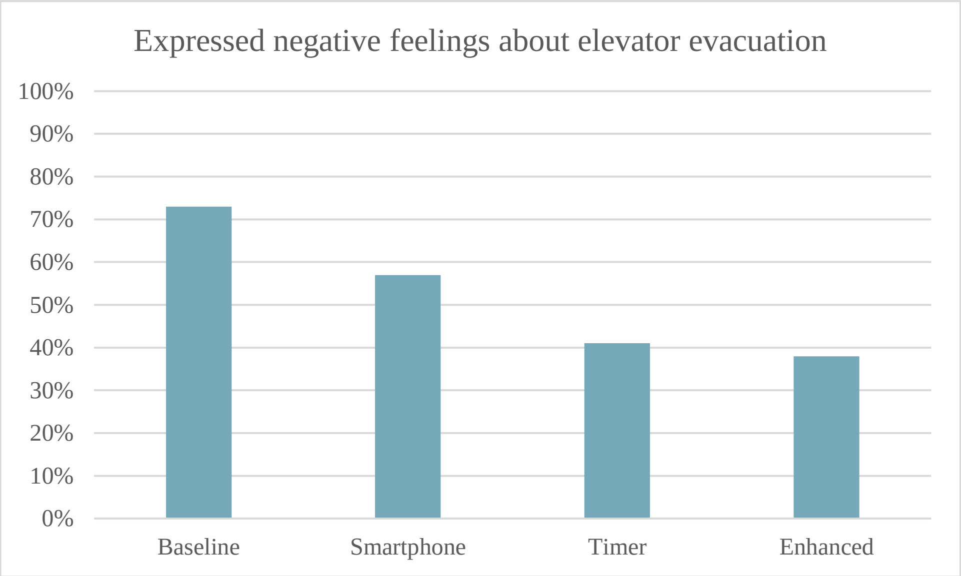

Figure 14. The number of participants who expressed negative feelings about elevator evacuation in the interviews following the experiment in Paper IV.

5.2.3 Summary

Prior to this thesis work, the willingness to use evacuation elevators has mainly been investigated using questionnaire studies with several hypothetical components. These studies have provided correlations for high-rise buildings with estimates of the willingness to use evacuation elevators depending on building floor. Paper III provides further data on this topic and was performed on-site in actual buildings with the aim of minimising the hypothetical components and thus aiming to provide more accurate data.

However, the field experiment in Paper V raises some concerns about the validity of the correlations based on questionnaire studies. The field experiment is the only published experiment measuring the willingness to use an evacuation elevator in an unannounced evacuation scenario of an actual high-rise building, which is an important contribution to the research area. In contrast to the hypothetical scenario questionnaire studies, the VR experiments performed before and after the field experiment indicate that there is potential to measure the willingness of elevator use in such an experimental setting. Thus, VR experiments could prove to be an important method for future studies. Furthermore, the results provide legitimacy to the study performed in Paper IV, even if this is in a different setting.

For underground metro stations, the previous questionnaire study correlates quite well with the VR experiment performed in Paper IV with the Baseline scenario setting. However, in this experiment it is shown that information and guidance measures have the potential to significantly increase the willingness to use an evacuation elevator. The experiment in Paper IV is the only known evacuation experiment performed in an underground metro station setting with evacuation elevators that is not a hypothetical questionnaire study. Thus, this experiment provides an important contribution to the knowledge on the behavioural aspects of elevator evacuation in such a setting. This information is important when evaluating evacuation elevators as an alternative in the design of underground stations in the future. Further, complex evacuation guidance with a smartphone was tested and evaluated in the experiment, which is something that has not been performed in such an environment previously. The results from this experiment could thus provide some important insights if such a guidance system would be further developed in the future.

5.3 RO3: Accepted waiting times in elevator evacuation

Elevators are a travelling system which in many cases depends on the user waiting for a certain time. Because of this, an important factor of elevator evacuation is the accepted waiting time for the elevators in an evacuation scenario. The waiting time for an elevator is normally unknown and forces the evacuee to stand still while waiting. Thus, the evacuee gets no feedback of the evacuation progressing from moving in a queue as would be the case in many other evacuation situations, e.g., in a stair or corridor. How to keep the evacuee engaged with the evacuation and keep the trust that the elevators are working and will arrive is thus important questions to consider.

In order to study this in more detail, the experiments in Paper III and Paper IV explored accepted waiting times in different situations and with different methods. Results from previous research on the subject is provided to put the results in context.

5.3.1 Previous research

Similar to the previous research on willingness to use an elevator for evacuation, the accepted waiting times in elevator evacuation situations have only been explored in a few publications. In the hypothetical scenario study by Heyes & Spearpoint (2009), which has been described in more detail in section 5.2.1, a correlation was developed for the accepted waiting time. The correlation is given below:

$$p = (-0.0016 * \mathrm{t} + 1.06) * f \quad 5 \leq f \leq 60\, floors\,;\ 0 \leq t \leq 600\, seconds \quad (4)$$

p = Percentage of occupants expected to use the elevator for evacuation,

f = Building floor,

t = Elevator waiting time.

It should be noted though that the correlations show a R^2-value of 0.76, after some of the results had been discarded, i.e., the results from engineers were removed. Due to scatter in the results, the authors therefore state that the correlation should be used with caution (Heyes & Spearpoint, 2009). However, the study indicates that accepted waiting times are probably shorter than 5-10 minutes for most buildings and that the waiting time increases higher up in the building. It should be noted that 5-20 % of the respondents stated that they would wait longer than 10 minutes if needed.

Kinsey, et al. (2012) also studied accepted waiting times in their hypothetical study. The waiting times were not developed into a correlation but they were plotted for different floor ranges. Similar to the study by Heyes & Spearpoint (2009), higher floor numbers indicated longer accepted waiting times, even if the differences were small. Furthermore, some general observations were made by the authors. One such observation was that for all floors 0-7 % (with an average of 5.8 %) of the participants stated that they would wait "as long as it takes", indicating they did not consider the stair a viable option for their evacuation. In addition to this, 6.1 % of the participants stated that they would not be willing to wait at all for an elevator. More than half of the participants on floor 2 to 40 would be prepared to wait less than 5 minutes for an evacuation elevator. On floor 40 to 60, the proportion increased to most being willing to wait 5 to 10 minutes. However, overall, less than 10 % were willing to wait more than 15 minutes.

In the previously mentioned VR experiment performed by Andrée, et al. (2016), a majority of the participants (55 %) waited less than 5 minutes for the evacuation elevators. Furthermore, around 6 % of the participants waited 6-10 minutes, 8 % of the participants waited 11-15 minutes and 31 % waited more than 20 minutes, which was the time of termination of the experiment. In the subsequent, similar, VR experiment performed by Arias, et al. (2021), only 6 % of the participants accepted waiting times above 5 minutes.

For underground metro stations, Engstrand & Näslund (2014) recorded accepted waiting times in their hypothetical scenario study. Similar to the willingness to use an evacuation elevator presented previously, there were significant differences between their participant groups. In Group 1, with randomly selected participants from a general population, 68 % of the participants answered that they would not wait at all for an elevator, 22 % of the participants answered that they would wait 0-2 minutes and 10 % of the participants accepted waiting times longer than two minutes. In Group 2, which consisted of people that were members of organisations for people with functional limitations, the spread was different. Thirty-four percent of the participants answered that they would not wait at all, 38 % of the participants answered that they would wait 0-2 minutes and 28 % of the participants answered that they would wait more than two minutes. It should be noted that the results for Group 1 were similar for both station depths examined, i.e., 8- and 30-meter-deep stations.

5.3.2 Contribution

For high-rise buildings, the research contribution on the topic is presented in Paper III. As discussed previously, this study was performed on-site in actual buildings with the aim of minimising the hypothetical components and thus aiming to provide more accurate data. However, the hypothetical scenario of waiting for an elevator during an evacuation was similar as in the previous studies.

According to the results from the study, 58 % of the participants answered that they would not wait at all for an elevator during an evacuation. In addition to this, 39 % of the participant answered that they would not wait more than 5 minutes, giving a total of 97 % willing to wait less than that time. Further, only 1 % of the participants were willing to accept waiting times longer than 10 minutes. The results showed a small difference in the number of participants accepting a waiting time up to 5 minutes for floors 13 and above compared to those below. However, this difference was not noticeable at longer waiting times.

There is a significant scatter in the data from the different studies on the subject. Only in the hypothetical scenarios, the difference in people who are not willing to wait at all ranges from 6 to 58 % in the performed studies. Similarly, the estimated number of people willing to wait for an evacuation elevator more than 10 minutes ranges from 1 to 20 %. Similarly, differences are seen in the VR experiments, where the same setting performed with two different VR methods generated differences ranging from 6 to 45 % of people willing to wait 5 minutes or more.

For underground metro stations, the accepted waiting times for elevator evacuation were generally lower than in high-rise buildings, i.e., if comparing the results from Paper III to those presented by Näslund & Engstrand (2014). This could indicate that the accepted waiting times in an underground metro station environment would be shorter than those in high-rise buildings.

In the VR experiment performed in Paper IV, accepted waiting times were collected when the participants choose to evacuate using the elevators. In the Enhanced scenario and the Smartphone scenario, the elevator indicated that it was moving by displaying running arrows above the elevator doors. As for the Timer scenario, count-down timer systems were put above the elevator doors in addition to the running arrows, in order to investigate if this system could help to increase the accepted waiting times. Except for the timers above the elevators, the Timer scenario was identical to the Enhanced scenario. The accepted waiting times for the different scenarios can be seen in Figure 15. Note that there were no one waiting for the elevator in the Base-line scenario.

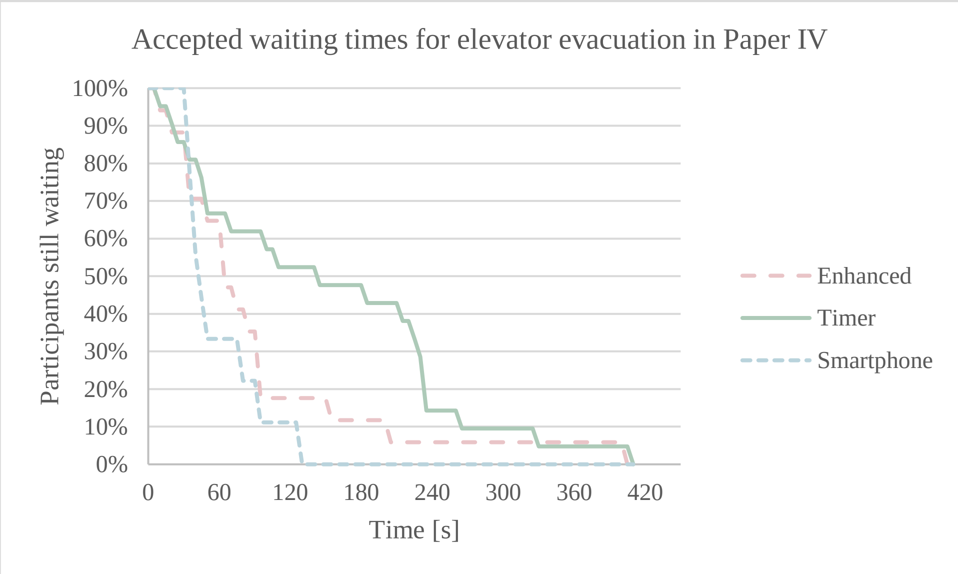

Figure 15. The accepted waiting times for elevator evacuation in the different scenarios studied in Paper IV.

As can be seen in the results from Paper IV, the accepted waiting times are generally low in the virtual underground metro station studied. In the Smartphone scenario, 11 % accepts a waiting time longer than two minutes, similar to the result predicted in the hypothetical study on underground metro stations mentioned above. However, in the Enhanced scenario, 18 % of the participants accepts waiting times longer than two minutes and 6 % of the participants are willing to wait almost seven minutes for the elevators before changing their escape route. One reason for this increased patience was probably the information signs in the Enhanced scenario which stated that the participants were situated 100 meters below ground. This was mentioned in the interviews after the experiment, which is illustrated by the following statement:

I saw the sign and thought "I can't walk 30 floors in a stair, so I better wait some more".

(Participant from the Enhanced scenario in Paper IV)

As for the accepted waiting times in the Timer scenario, it was not possible to identify a statistical difference to the Enhanced scenario. However, there is a noticeable difference in the number of participants who are willing to wait up to three minutes. After three minutes, the number of participants willing to wait further drops rapidly. This is explained by the fact that the first timer above the elevators reached zero after three minutes, without any elevator arriving. Thus, most participants still waiting at this time did no longer trust the count-down timers. It can be noted that at three minutes, no one is still waiting in the Smartphone scenario, 12 % of the participants are still waiting in the Enhanced scenario and 48 % of the participants are still waiting in the Timer scenario. This indicates that increased information about the station depth, as given in the Enhanced- and Timer scenario, but not in the Smartphone scenario, as well as count-down timers can increase accepted waiting times for elevator evacuation in underground metro station environments.

5.3.3 Summary

Accepted waiting times for evacuation elevators is not an easily studied topic. For high-rise buildings, the data is mostly from hypothetical studies, including the data presented in Paper III, except for a few data points from VR studies. The differences between studies are vast and there is a need for further studies on the topic. Unfortunately, the waiting times were not possible to study in the field experiment presented in Paper V, but such studies focusing on accepted waiting times are certainly needed.

In underground metro stations, only one previous study is available, and thus the same conclusions about the data spread cannot be given. However, from the results of the VR experiment presented in Paper IV, it can be concluded that the accepted waiting times can be affected by information measures, such as information signage and count-down timers for elevator arrival. The impact of such measures on the accepted waiting time for evacuation elevators has not previously been studied, and this research is therefore an important step towards testing such measures in the field.

6 Conclusions

The main objective of this thesis is to explore the behavioural aspects of elevator evacuation and to aid the implementation of such elevators in building design. In order to achieve this, a design strategy was developed, and three different experiments were performed to investigate important behavioural aspects. The major conclusions of the presented research are summarised below.

The first research objective focused on improving the possibility to incorporate evacuation elevators in buildings and other structures. A design strategy to account for the behavioural aspects in an evacuation design was presented. The adoption of such a strategy will arguably increase the probability of reaching the intended number of evacuation elevator users where such elevators are incorporated in the evacuation design. The usefulness of using the strategy is difficult to prove in a scientific manner, but some of the benefits have been exemplified in the presented work.

In relation to the second research objective, i.e., exploring the willingness to use an elevator for evacuation, three experiments were performed. In these experiments, the willingness to use elevators for evacuation was studied using different experimental methods and settings. The most important findings from these experiments are:

- In high-rise buildings, the willingness to use an evacuation elevator seems to increase with building floor.
- The field experiment performed within this research shows that previous proposed correlations severely underpredict the evacuation elevator usage. In the experiment, almost all participants used the elevator as their escape route from the 16th floor of a hotel building.
- The results indicate a low external validity for hypothetical scenario studies in relation to measuring the willingness to use an evacuation elevator. Experiments performed in VR show better agreement with the results collected in the field.
- For underground metro stations, it is unlikely that people will be willing to use elevators for evacuation if there are no specific guidance or information measures. However, if specific guidance and information measures are

added, the willingness to use evacuation elevators from such a setting can be significantly increased.

- Guidance with a smartphone has potential to increase the willingness to use an elevator for evacuation, and to improve the evacuation behaviour in general. However, such systems need further testing and development.

As for the third research objective, i.e., investigating accepted waiting times for evacuation elevators in an evacuation scenario, two experiments collected data on this aspect. The accepted waiting times were studied in the hypothetical scenario experiment and the VR experiment. The most important findings from these experiments are:

- The accepted waiting times for evacuation elevators are generally low. Furthermore, when estimated in questionnaires, the accepted waiting times were generally lower in underground metro stations than in high-rise buildings.
- For high-rise buildings, the hypothetical scenario experiment shows that only 3 % of the participants stated that they would accept waiting times longer than 5 minutes.
- For underground metro stations, the VR experiment performed shows that 0-10 % of the participants accepted waiting times of 5 minutes or more, depending on the information system provided.
- The results indicate that the accepted waiting time for an evacuation elevator can be increased using information measures such as informative signage and a count-down timer showing the elevator arrival time. However, it should be noted that this increase in waiting time was not shown to be statistically significant in the presented research.

7 Future research

Even though the research presented in this thesis provides novel data on the behavioural aspects of elevator evacuation, one important insight is that more research is needed in the area. A number of suggestions of possible future research topics are therefore given below.

7.1 More studies on the willingness to use evacuation elevators and the accepted waiting time

As discussed previously, much of the existing data on both the willingness to use elevators for evacuation and the accepted waiting times for such elevators are from questionnaire studies. As these types of studies have low external validity and show a low level of agreement with data from experiments using methods with higher levels of external validity, more research is needed.

Experimental studies performed in VR could have the potential to produce valid results. Hence, VR studies could be a possible way to generate more data. However, the validity of the VR setting could be tied to the studied situation and further validation studies are needed before concluding that VR can be used to give valid data. Thus, to provide a foundation for validation of other experimental methods, more field studies are needed. To stress the importance of such studies, there are currently no field studies of accepted waiting times for elevator evacuation.

7.2 Social influence

The impact of other people on our decisions is important in many situations. With regard to fire evacuation decisions, the importance of such influences has been discussed since the 1960s (Latane & Darley, 1968). However, in relation to elevator evacuation, the effects of social influence on the decision-making are complex. On the one hand, there may be factors influencing an evacuee to follow others, so if a number of people choose to evacuate using the elevator, this would promote even more to do so. On the other hand, a queue in the elevator lobby could have the opposite effect on the evacuee, and other evacuation options could be considered if this que is perceived as too long. This aspect of elevator evacuation has only been studied in one hypothetical scenario questionnaire study (Kinsey et al., 2012). Due to the problems with external validity of such studies on this behavioural aspect, further studies using other research methods are needed.

7.3 Elevator loading and unloading

In addition to the topics mentioned above, the loading and unloading situations in elevator evacuation needs further exploration. In recent work, this factor has been identified as an important contributor to the overall expected evacuation time (Mårtensson & Johansson, 2022). Despite this, there is only one study on the topic in which an evacuation setting is mimicked (Ding et al., 2017). The study provides useful data but is limited in regard to the number of participants, a repeated trial procedure and a fixed setting, i.e., only studying one floor in a high-rise building. More data is needed, especially in unannounced evacuation settings, to explore possible behaviours. Further, effects of information systems on loading and unloading efficiency (see further discussion on this in Paper II) as well as the risk of blocking behaviour on elevator doors needs further investigation.

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Appendix – Papers

Paper I	Nilsson, D. & **Jönsson, A.** (2011) Design of Evacuation Systems for Elevator Evacuation in High-Rise Buildings, *Journal of Disaster Research*, Vol.6, No.6, pp. 600-609. doi: 10.20965/jdr.2011.p0600
Paper II	**Mossberg, A.**, Nilsson, D. & Frantzich, H. (202X) Evaluating new evacuation systems related to human behaviour using a situational awareness approach – a study of the implementation of evacuation elevators in an underground facility, *Submitted to Fire Safety Journal.*
Paper III	**Jönsson, A.**, Andersson, A. & Nilsson D. (2012) A Risk Perception Analysis of Elevator Evacuation in High-Rise Buildings, *Proceedings of the 5th Human Behaviour in Fire symposium*, Cambridge, UK.
Paper IV	**Mossberg, A.**, Nilsson, D. & Wahlqvist, J. (2020) Evacuation Elevators in an Underground Metro Station: A Virtual Reality Evacuation Experiment, *Fire Safety Journal*, 2020, doi: 10.1016/j.firesaf.2020.103091
Paper V	**Mossberg, A.**, Nilsson, D. & Andrée, K. (2020) Unannounced Evacuation Experiment in a High-Rise Hotel Building with Evacuation Elevators – A Study of Evacuation Behaviour Using Eye Tracking, *Fire Technology, 2020*, doi: 10.1007/s10694-020-01046-1

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