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Abstract

The purpose of this report is to provide an overview of the use of elevators for occupant evacuation from high-rise buildings with a focus on the safety of *mobility impaired occupants*. It addresses the specifics of evacuation via elevators, relevant building codes, and its technical challenges. Information was collected on how selected buildings around the world incorporate elevators into their emergency evacuation procedures. Six building complexes around the world were identified and reviewed in this report. A section of this report is devoted to each building, providing general building information (height, number of floors etc.) and the building's evacuation procedures during fire emergencies, with a special focus on *mobility impaired occupants*. After discussing the limitations of the review process, the report gives an overview of the scientific background of the human factors of evacuation via elevators and identifies research gaps. Furthermore, methodological aspects of empirical evacuation research as well as potential beneficial measures for evacuation via elevators are discussed.

Keywords: evacuation via elevators, human factors, building codes

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The Use of Elevators for Evacuation in Fire Emergencies in International Buildings

Max T. Kinateder, Hidemi Omori, and Erica D. Kuligowski

National Institute of Standards and Technology

1 Introduction

The General Services Administration (GSA) and the National Institute of Standards and Technology (NIST) have completed a multi-year collaboration on advancing technology to promote the safe use of elevators by emergency responders to transport fire fighters and equipment to a staging area two floors below the floor of fire origin and for building occupants to use elevators for self-evacuation, particularly in tall (e.g., high-rise) buildings. This collaboration, among others, resulted in the 2009 editions of both U.S. model building codes (i.e., International Code Council (ICC), International Building Code (IBC), and National Fire Protection Association (NFPA) 5000, Building Construction and Safety Code) containing requirements for the installation of fire service access elevator(s) in all new buildings exceeding 36.6 m (120 ft) in height. These model codes also introduced new occupant evacuation elevator provisions for architects and engineers to consider when designing tall buildings that permit the use of passenger elevators by building occupants for evacuation during a fire emergency. The use of these elevators by building occupants would reduce the overall building evacuation time compared to occupants only utilizing the building exit stairs and more importantly, would improve the evacuation capability for *mobility impaired occupants*. At the 2009 ICC Final Action Hearings, the adoption of occupant evacuation elevator provisions was described as "… the greatest enhancement in the safety of high-rise buildings since the adoption of sprinkler requirements" (David Collins, American Institute of Architects). The results of this multi-year collaboration is collected in a compendium of the NIST/GSA research on elevator safety [1].

The technological ability to use elevators for evacuation promises substantial improvement for occupant evacuation from high-rise buildings. *Mobility impaired occupants*, defined in this report as occupants with reduced mobility, who (without assistance) cannot use or have significant difficulties using exit stairs to egress, may especially benefit from these developments. Although the public has been educated for years not to use elevators for evacuation during a fire emergency, numerous high-rise buildings around the world have already incorporated such strategies during fires (and for other emergencies requiring building evacuation). This report gives an overview of the current state of elevator usage for occupant evacuation during a fire emergency and is divided into four sections:

1) a literature review of the research on occupant behavior using elevators for evacuation during fire emergencies;
2) a summary of emergency procedures (specifically procedures for fire evacuation using elevators) from six buildings that use elevators for the evacuation of *mobility impaired occupants*;
3) an overview of the human factors literature with regard to elevator usage for evacuation and the identification of research gaps based on the previous sections, and;
4) a short summary and conclusions.

2 Elevators for occupant evacuation during fire emergencies

Exit stairways are provided as the primary construction feature for occupants to use to safely evacuate from high-rise buildings during a fire emergency. However, exit stairways may not offer equal opportunity to reach safety for all building occupants. *Mobility impaired occupants* may experience severe difficulties negotiating exit stairways during an evacuation, including not being able to traverse the stairways at all. Therefore, and especially since the tragic loss of life in the 2001 World Trade Center attacks, engineering efforts have refocused on efficient evacuation procedures, especially for occupants who cannot negotiate exit stairs without assistance.

The GSA's general approach to the construction of new facilities and projects in existing buildings is to incorporate cost-effective fire protection, life safety systems, and procedures that result in overall building safety that meets or exceeds the levels required by local building codes. As previously stated, recent code changes in ICC and NFPA have introduced new provisions for architects and engineers to consider when designing tall buildings that permit the use of passenger elevators by building occupants for evacuation during a fire emergency [2-4]. However, little research has been performed on the development of guidance and recommendations for standardized and data-driven procedures to safely evacuate *mobility impaired occupants* from tall buildings using these elevator systems. The following section will give a summary of the literature in the field. It addresses general aspects of evacuation via elevators for *mobility impaired occupants*, technical and administrative aspects such as building codes as well as technical challenges.

2.1 Current evacuation strategies for mobility impaired occupants

One of the most crucial human factors in evacuation research is the general physical ability of occupants to evacuate. According to the US Census Bureau (2010), 12.1% (~37 million) of the U.S. population have one or more permanent disabilities (other estimates provide even higher numbers) [5]. In addition to occupants with permanent disabilities, occupants with temporary disabilities, respiratory conditions, or stamina-limiting conditions have also been observed to require longer times and frequent rest stops during evacuation [6, 7]. Since these occupants may have difficulties during exit stair evacuation, there is a clear need to understand the behavior and address the needs of *mobility impaired occupants* for evacuation.

Developments in evacuation research led to important safety improvements for *mobility impaired occupants* [8]. Of these, occupant evacuation elevators are one of the most significant means to improve the evacuation capability of *mobility impaired occupants*. These type of elevators would give *mobility impaired occupants* equal access to egress [9, 10, 11].

Other evacuation means for *mobility impaired occupants* can involve the use of stair travel devices [12]. However, these can be associated with a number of problems. First, not all *mobility impaired occupants* can make use of stair travel devices. For example, people who use wheelchairs that provide vital life support systems, e.g., ventilators/respirators, portable oxygen concentrators, or posture support, may be unable to transfer into stair travel devices during an emergency. Second, *mobility impaired occupants* who use stair travel devices will likely have to rely on the help of others (e.g., to assist with transfer or to assist the device down the exit stairs). This requires the willingness and ability of bystanders to help [9]. Third, slow groups of assisted evacuees, including those using stair travel devices, have been shown to slow down the evacuation speed of others on the same set of exit stairs [13].

Refuge areas are another approach that has been used to establish safety during a fire emergency for *mobility impaired occupants*. Refuge areas refer to an “area that is both separated from the fire by fire-resisting construction and provided with a safe route to a floor exit, thus constituting a temporarily safe space for *mobility impaired persons* to await assistance for their evacuation“ [14]. However, concerns have been identified with such refuge areas. For example, at least some occupants are not comfortable spending long periods of time in refuge areas and fear that they might not be rescued if the situation becomes life-threatening [15].

In addition, different occupant evacuation strategies for *mobility impaired occupants* have been analyzed for their effectiveness using computer modeling tools [16]. For example, in one simulation study with a heterogeneous population (5% *mobility impaired occupants*), the use of mixed evacuation strategies (i.e., emergency stair travel devices, exit stairs, elevators, transfer floors, and skybridges) improved the evacuation time results compared to only using the exit stairs for evacuation. In this study, reduced waiting times in the elevator lobbies and effective signage improved evacuation timing results from the strategies using elevators [17].

Another simulation study of heterogeneous occupant populations showed that elevators could be used effectively for the evacuation of *mobility impaired occupants* at the same time as other occupants [18]. With that said, other studies showed that with an increasing number of heterogeneous occupant types in the building, the risk of congestion, e.g., bottlenecks at the stair landings, rises [19, 20].

2.2 Building and life safety codes for occupant evacuation elevators

Building and life safety codes around the world address the use of elevators during a fire emergency. In 1973, the ASME/ANSI A17.1 Safety Code for Elevators and Escalators mandated that passenger elevators stop functioning if smoke is detected in the building’s lobbies, machine rooms, or hoistways. Specifically, there are two distinct phases to fire fighter’s emergency elevator operation. Phase I emergency recall operation refers to the operation of an elevator that either automatically recalls to the designated level due to the detection of smoke in the lobby, hoistways, or machine room, or that is manually recalled by the fire fighters and removed from normal service, halting its functions. Phase II emergency in-car operation allows the responding fire fighters to take control of the elevator and decide whether or not to use the manual functions of the elevator for rescue purposes during a fire or other emergency operation initiatives.

Current codes, such as the American Society of Mechanical Engineering *Safety Code for Elevators and Escalators* (ASME A17.1-2010), the ICC *International Building Code* (IBC) - 2012, NFPA 101-2012, *Life Safety Code*, NFPA 5000-2012, *Building Construction and Safety Code*, the European Standards EN 81-73 2006 (Safety rules for the construction and installation of lifts - Particular applications for passenger and goods passenger lifts), the British Standard (BS 9999:2008- Code of practice for fire safety in the design, management and use of buildings), the *Singapore Fire Safety Code* -2013, and the *Life Safety of National Building Code* of India (IS SP 7 2005) have specified that elevators may be used for evacuation from high-rise buildings [2, 4, 14, 21-25].

NFPA 101 and 5000 define an elevator evacuation system. According to NFPA 101, an elevator evacuation system is "a system, including a vertical series of elevator lobbies and associated elevator lobby doors, an elevator shaft(s), and a machine room(s), that provides protection from fire effects for elevator passengers, people waiting to use elevators, and elevator equipment so that elevators can be used safely for egress" (p.36) [21]. In addition, NFPA 101 Section 7.14 and NFPA 5000 Section 11.14 contain specific requirements for elevators used for occupant-controlled evacuation prior to the phase I emergency recall operations.

The IBC includes Section 3008, which is dedicated to occupant evacuation elevators. This section of the Code permits the use of passenger elevators by building occupants for evacuation during a fire emergency, as long as specific requirements are complied with. For example, these specific requirements include, but are not limited to: (1) the building has an approved fire safety and evacuation plan; (2) occupant evacuation elevators are only permitted to be used up and until the elevator is recalled on Phase I, emergency recall operation; (3) the building has an emergency voice/alarm communication system; (4) the building is protected throughout by an approved automatic sprinkler system; (5) the occupant evacuation elevators are located in hoistways that are constructed of materials having the necessary fire resistance; (6) the elevator hoistways have to be designed to prevent water from infiltrating from the discharge of a sprinkler located outside the enclosed elevator lobby; (7) the elevator lobby has to have direct access to an exit stair; (8) the elevator lobbies have to be enclosed by a smoke barrier having a 1-hour fire resistance rating; (9) elevator lobby doors have to consist of a ¾ hour fire door assembly; and (10) the elevator lobby size has to have a minimum floor area based on occupant load square footage factors and reasonable percentages of the occupant load.

National regulations also take *mobility impaired occupants* into account. The Americans with Disabilities Act (ADA) defines an individual with a disability as a person who (1) has a physical or mental impairment that substantially limits one or more major life activities, (2) has a record or history of such impairment, or (3) is regarded as having such impairment [27]. The ADA

Accessibility Guidelines suggest elevators as a means of non-fire emergency egress for buildings with access above the third floor [28].

Looking outside of the U.S., British Standard (BS 9999:2008) provides information on improving accessibility for *occupants with mobility impairments* in fire safety design and management plans [14]. It complies with the requirements of the British Disability Discrimination Act and the principles of inclusive design and gives recommendations for elevator use for evacuation purposes [29]. BS 9999:2008 states that elevators operated under the direction and control of fire safety management are to be used for evacuation of *mobility impaired occupants*, but not for the general public.

2.3 Organizational challenges for occupant evacuation elevators

Occupant evacuation elevators enable *occupants with mobility impairments* to self-evacuate, without depending upon the help of others. In several research papers, Bukowski states that when evaluating the overall egress strategy for a building, the use of occupant evacuation elevators would enable full evacuation of any building within less than one hour, given that all elevators are fully functional and follow the design metric for normal operation (i.e., that elevators have the capacity to transport ten percent of the building population within five minutes) [9-11].

It is crucial to understand the organizational and technical preconditions of evacuation via elevators. A comprehensive overview of the technical challenges can be found in the NIST Special Publication 1620 [1]. As mentioned in the previous section, most of these technical challenges regarding the safe use of elevators for evacuation have been overcome successfully. However, there are still numerous social, organizational and human factors challenges for occupant use of elevators for evacuation [30, 31]. The following list gives a summary of the organizational challenges.

1. Space for occupants is limited in elevators and elevator lobbies [31, 32]. This is problematic if elevators are used by numerous occupants for evacuation, especially in elevators which are designed for a limited use [30].
2. As space is limited, an important open question is priority; i.e., which occupants should be given priority during evacuation and how should a building establish compliance with priority guidelines?
3. For some regions, earthquake resistance of elevators is another important issue [31]. ASME A17.1 provides requirements for elevators in earthquake zones, including seismic and counterweight displacement switches, as well as additional visual and audible information systems. However, the lack of testing of these systems raises the question of their applicability in a real event [30].
4. Elevators need to be designed in a way that all occupants are willing and able to use them for evacuation [30]. NFPA 101 and 5000 and IBC require two-way communication and signage as part of the elevator system. However, there are still significant knowledge gaps about the cognitive, perceptive, emotional, and social processes during evacuation via elevators. (See Chapter 4: Human factors for an overview on the use of Emergency Elevator Evacuation Systems.)

In summary, numerous high-rise buildings around the world already incorporate the use of elevators for occupant evacuation. However, there are still organizational challenges and a need for further behavioral research. The next section gives an overview of six high-rise buildings and building complexes that already use elevators for occupant evacuation.

3 Summary of high-rise building's using elevators for occupant evacuation

Twelve international high-rise buildings were pre-selected based on literature reviews of buildings that contain elevators for occupant evacuation (Abu Dhabi Sky Tower, BT Tower, Burj Khalifa, Canary Wharf (several buildings), Eureka Tower, Kingkey Finance Tower, Petronas Twin Towers, Shanghai World Financial Center, Swiss Re Tower, Taipei 101, The Shard, Wrangel Palace) [33]. From the initial sample, six buildings were selected for discussion in this report based on the following requirements: (1) a high-rise building, (2) the use of elevators for evacuation is included as an emergency procedure for certain types of emergencies (sometimes fire), and (3) information is available regarding the procedures using elevators for evacuation, including those for *mobility impaired occupants* (either available publicly or upon request).

The selected buildings come from a range of different regions around the world in order to shed light on cultural differences and similarities in approaches to the use of elevators for evacuation. All of the buildings reviewed used a combination of exit stairs and elevators for occupant evacuation. The database for this study was based on publicly available information as well as informal discussions with specific building managers. Table 1 gives an overview of the buildings and building complexes considered in this report.

Table 1. Overview of the buildings reviewed (alphabetical order).

Building Name	Country	Number of Elevators	Floors	Building Codes	Year opened
Burj Khalifa	AE	58	163	IBC 2003: LSC 2003	2010
Canary Wharf buildings	UK	36-43	10-50	EN 81-73	1991[1]
Eureka Tower	AU	13	91	IBC	2006
Petronas Twin Towers	MY	78	88	BS 5588 part 5	1997
Shanghai World Financial Center	CN	91	101	Chinese Building Code	2008
Taipei 101	TW	61	101	Not publicly available	2004

IBC = International Building Code; BS = British Standard; Country Codes: AE = United Arab Emirates; UK = United Kingdom; AU = Australia; MY = Malaysia; CN = People's Republic of China; TW = Taiwan; [1]for One Canada Square, the highest building in Canary Wharf

3.1 Burj Khalifa

3.1.1 General building information

The Burj Khalifa is located in Dubai, United Arab Emirates. It was completed in 2010, and currently stands at 829.8 m (2,722 ft) (163 floors) as the tallest building in the world (2014). The building functions include office, residential, and hotel. There are 304 hotel rooms which are on floors 1 to 39. The occupant load for the Burj Khalifa ranges from 9,000 to 15,000 building occupants [34-37].

The Burj Khalifa was constructed to comply with the requirements of the 2003 IBC and 2003 NFPA 101, Life Safety Code. In general, the building met the requirements to the extent feasible, with some exceptions in the means of egress and helicopter landing area.

As part of the fire alarm system, the Burj Khalifa is equipped with an emergency communication system and visual monitors for the dissemination of emergency information to both affected and non-affected occupants. Fire emergency announcements include current information on the incident and instructions to the occupants. Emergency voice instructions are disseminated via pre-recorded or live voice messages and can be transmitted to the entire building or to different zones of the building. In addition, there is a GPS wireless phone system for fire fighter use.

There are a total of 58 elevators in the Burj Khalifa. A full building evacuation uses ten enhanced elevators[1]. Three of the elevators are designated for fire fighter use for emergency rescues. Of these three, two fire fighter elevators travel from the first floor to the 111th floor, and the other travels from level 112 to 160. The Burj Khalifa is the first high-rise building that uses programmed elevators to permit controlled evacuations for certain fire or emergency events [38]. The observation deck on floors 122 and 123 at 452 m (1,483 ft) have double deck elevators that can hold 12 to 14 people per cab [36].

There are multiple egress routes for each floor leading to pressurized and fire rated exit stairways. Photoluminescent strips have also been installed inside the exit stair enclosures to define the exit stair, its landings, and exit doors. Refuge areas are located on floors 41, 42, 74, 75, 110, 111, 137, and 138 [36]. The refuge areas are pressurized and separated from the rest of the building by two-hour fire resistance rated construction. Some of the refuge areas have direct access to an exit stair. This allows occupants who no longer want to wait for an elevator to leave

[1] The literature states that a specific number of elevators exceed standard code requirements and are used to assist occupant evacuation [36]; however, it is unclear if the literature is referring to the 10 elevators used for full building evacuation. These elevators (again, number unknown) are enhanced via shaft visual inspection capabilities, raised elevator door thresholds, water-resistant equipment, and stand-by emergency power.

via the exit stair without having to leave the protected environment provided by the refuge area enclosure [36].

3.1.2 Evacuation procedures for occupants during fire emergencies

The Burj Khalifa uses a building evacuation strategy that includes the use of exit stairs, elevators and refuge areas. Occupants in a fire zone are required to evacuate via the exit stairs and local elevators until they reach a transfer floors (43, 76, and 123). Occupants will then access the express elevators which will transport them from the transfer level directly to the ground floor for direct egress out of the building [35].

3.1.3 Evacuation procedures for mobility impaired occupants during fire emergencies

No information pertaining to specific evacuation procedures for *mobility impaired occupants* was publically available.

3.2 Canary Wharf

3.2.1 General building information

Canary Wharf is a building complex in the financial district of London, United Kingdom, with 27 buildings. The high-rise buildings range from 10 to 50 floors [39, 40]. One Canada Square, the highest building in the complex, rises up to 201 m (660 ft).

Canary Wharf buildings comply with European Standards EN 81-73. The fire protection features are generally the same for all buildings, with some alterations made by individual tenants [41, 42]. All buildings in Canary Wharf have an emergency communication system which is part of the fire alarm system, however it is fully addressable via a manual override facility if specific information is required to be given to a particular floor [43]. If occupants need to be notified of an evacuation, a pre-recorded announcement will be made notifying occupants that the building is being evacuated and instructing occupants to use the elevators or exit stairs to leave the building and proceed to the pre-designated assembly areas located a safe distance away from the building. The emergency voice communication system also has the capability of making live voice announcements, which can be used depending on the emergency [41, 42].

There are two to four fire fighter elevators in each building, with the larger buildings having four fire fighter elevators [41, 42]. The buildings are supported by trained, 24-hour on-site facilities management teams that provide assistance during an emergency evacuation. This includes mechanical and electrical engineers, as well as security officers [41, 42]. Canary Wharf also has a team of 'Fire Duty Officers' in place who are former operational fire fighters, who attend each fire alarm activation and provide assistance. [43].

Refuge areas for people with mobility impairments are located in all buildings. The refuge areas are enclosed by construction having not less than a 1-hour fire-resistance rating. A two-way communication system is installed within the refuge area for the purpose of initiating communication with the fire command center. Refuge areas are located near at least one of the exits on each floor and are large enough to accommodate at least two wheelchairs without impeding the flow of occupants moving to the exit stairs [43]. Occupants have direct access to an exit stair from the refuge area [41, 42].

3.2.2 Evacuation procedures for occupants during fire emergencies

Although elevators are used for evacuation from other types of emergencies, only exit stairs can be used during a fire emergency. The only exception to this rule is that individuals with mobility impairments can use the elevators during a fire emergency (more information is provided in the following section). In cases where horizontal evacuation is appropriate, a skybridge that connects buildings is available. After leaving the building, evacuees must go to their designated assembly area. Each building has a particular assembly area [41, 42]. If a fire occurs only on one floor, building procedures do not specify full-building evacuation. Instead, only the affected floor and the floor above have to be evacuated. Occupants on these floors would use the exit stairs in this case (unless they are individuals with mobility impairments) [41, 42].

3.2.3 Evacuation procedures for mobility impaired occupants during fire emergencies

Building management gives priority to occupants with mobility impairments by evacuating them via elevators before the fire department arrives. Occupants with mobility impairments are evacuated using the fire fighter elevators[2] with the help of fire fighters during fire emergencies [42]. As buildings in Canary Wharf have a minimum of two fire fighter elevators, the London Fire Brigade allows the use of one of the fire-fighting elevators to assist in the evacuation of *mobility impaired occupants*. Should one of the fire fighter elevators be out of operation, then the remaining one will be kept free for the sole use by the attending fire brigade.

In addition, each business office within a building has individuals who have been assigned the role of a fire warden. The fire wardens within each business office are trained in the necessary evacuation procedures. Upon activation of the fire alarm, the fire warden will assist any known *mobility impaired occupant* to the nearest refuge area and inform the fire command center of the numbers of occupants who require use of the fire fighter elevator. The fire command center will confirm this information and relay status information on whether an elevator is available. Other fire wardens on the floor will be 'sweeping' the floor, and if they encounter any *mobility impaired occupants* previously unknown, these occupants will be directed or assisted to the nearest refuge area. The fire warden will stay with the *mobility impaired occupant*(s) until the elevator arrives and will assist them into the elevator car. If space in the elevator car is available, the fire warden will accompany the *mobility impaired occupants* to assist them in exiting the building. If for any reason an elevator is unavailable, the fire warden will discuss the situation

[2] Fire fighter elevators, also referred to as phase II elevators, which can be handled manually by fire fighters during a fire emergency, are required in buildings that are taller than 18 m, according to BS 9999. For more information on the fire fighter elevators referred to here, please visit BS 9999.

with the *mobility impaired occupant*, based on information provided from the fire command center, i.e., how long an elevator may take to be available, and then decide on the best course of action. This information would have been previously discussed and agreed upon, as part of the Personal Emergency Evacuation Plan in which all *mobility impaired occupants* are encouraged to participate [43].

3.3 Eureka Tower

3.3.1 General building information

The Eureka Tower is a residential high-rise building in Melbourne, Australia with 91 floors and 556 apartments. The high-rise was completed in 2006 and is currently the tallest building in Melbourne. The height from ground to the tip of the building is 301.3 m (989 ft). The building has 13 passenger elevators [44].

The Eureka Tower was constructed to meet the requirements of the *Building Code of Australia* (1996) [45] and Australian Standard AS 2220, Emergency Warning and Intercommunication Systems in Buildings [46][3].

The building's fire alarm system can be used to disseminate voice alert and evacuation information to building occupants. As part of the emergency communication, two different sound signals are disseminated to different floors/locations, depending on the severity of the emergency and the location of the fire. Fire wardens are located on each floor to manage occupant egress [47, 48].

Within the building, floors 24 and 52 are transfer levels for building occupants. Express elevators for evacuation from transfer levels are located in separate shafts to avoid smoke/water damage and provide fire fighter access to the fire floors. These express elevators move between transfer levels and ground floor without stopping at the floors in between [44, 48].

3.3.2 Evacuation procedures for occupants during fire emergencies

The Eureka Tower uses a building evacuation strategy that includes the use of exit stairs and elevators. The building is split into vertical evacuation zones and occupants in a fire zone are required to evacuate via the exit stairs until they reach a transfer floor (i.e., either level 24 or 52). Occupants will then access the express elevators which will transport them from the transfer level directly to the ground floor for direct egress out of the building.

[3] AS 2220 was in place when the building was constructed but is no longer in existence and has been superseded by AS1670 Part 4.

3.3.2.1 Evacuation proce*d*ures for mobility impaired occupants during fire emergencies

No information pertaining to specific evacuation procedures for *mobility impaired occupants* was publically available.

3.4 Petronas Twin Towers

3.4.1 General building information

The Petronas Twin Towers are a two-tower high-rise complex located in Kuala Lumpur, Malaysia. There are 88 floors above and five floors below ground level. The towers were completed in 1998, and currently remain the tallest buildings in Kuala Lumpur at 451.9 m (1482 ft) in height. The towers are connected through a skybridge located at the 41st and 42nd floors [49].

The Petronas Twin Towers were constructed to meet the requirements of BS 5588 part 5: Fire Precautions in the Design, Construction and Use of Buildings -- Access and facilities for fire-fighting (1991) [38]. More detailed information on the building, including information on the fire alarm system and fire protection features, was not publically available.

3.4.2 Evacuation procedures for occupants during fire emergencies

The Petronas Towers have developed fire safety procedures for different levels of emergencies. First, if there is no danger to life, and minimal risk of damage to property, the situation can be controlled by the local in-building emergency response team. If necessary, the fire department and relevant authorities are called to help assess the situation. Second, in case of danger to life and risk of damage to property, i.e. the situation goes beyond the capabilities of the in-house Emergency Response Team, the fire department is notified [49].

In fire emergencies, occupants evacuate either via exit stairs or elevators. Before the September 11, 2001 attacks on the World Trade Center [49], the evacuation procedure for the Petronas Twin Towers assumed that emergencies would only affect one tower at a time. Therefore, occupants below the skybridge in one tower would use exit stairs to reach the ground floor, and occupants above the skybridge in the same tower, would use exit stairs to reach the bridge, and evacuate horizontally into the adjacent tower. Since September 11, 2001, and in case both towers have to be evacuated simultaneously, new plans consist of the use of elevators for evacuation in fire emergencies, rather than the skybridge. In the new plan, occupants below the skybridge exit using exit stairs (as before); however, occupants above the skybridge in each tower, use elevators to reach the ground floor and exit the building [38, 49].

3.4.3 Evacuation procedures for mobility impaired occupants during fire emergencies

Mobility impaired occupants are evacuated using the service and fire fighter elevators with the aid of security personnel [49]. Additional procedural information, including information about the types of elevators (service vs. fire fighter elevators) and who is responsible for operating elevators during evacuation of persons with mobility impairments, was not publicly available.

3.5 Shanghai World Financial Center

3.5.1 General building information

The Shanghai World Financial Center was completed in 2008 and functions as a hotel and office building. It is currently the second tallest building in Shanghai at a height of 494.3 m (1622 ft; 101 floors). There are 91 elevators in the building [50, 51]. Lower floors in the building have a standard floor plate area of 3,300 m^2 (10826 ft^2), and each floor area in the upper section of the building varies due to the building's shape. The total building population is estimated at 10,000 occupants [52].

The Shanghai World Financial Center complies with and exceeds the 1995 Chinese code for the fire protection design of tall buildings (GB50045-95) [53], which requires a refuge floor every 15 floors in the building. However, the Shanghai World Financial Center provides refuge floors every 12 floors in the building [54].

The elevator system consists of nine zones throughout the building. There are single and double deck elevators in the Shanghai World Financial Center [55]. Designated emergency elevator lobbies (dooryards before the emergency elevators [53]) are enclosed by fire rated walls with the entrance doors being fire rated doors. These lobbies are each connected to one exit stairway [53]. Non-designated emergency elevators lobbies are not enclosed by fire rated walls. The average floor area of a designated emergency elevator lobby is 14 m^2 (151 ft^2), and the average floor area for a non-designated emergency elevator lobby is 24 m^2 (258 ft^2)[56].[4]

3.5.2 Evacuation procedures for occupants during fire emergencies

Elevators and exit stairs are used in combination for evacuation in this building. Emergency elevators are located within the designated emergency elevator lobbies [53][5]. During fire emergencies, the normal operation of all passenger elevators is stopped and all emergency elevators are operated by fire department personnel [53]. These emergency elevators are only used for firefighting or evacuating *mobility impaired occupants*. Shuttle elevators that serve the office, hotel, and observation floors are used for emergency evacuation with prioritization for *mobility impaired occupants*.

The steps for a building evacuation are as follows:

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[4] More detailed information on the building, including information on the fire alarm system and fire protection features, was not publically available.

[5] Note that information on the number of designated emergency elevator lobbies in this building was not publicly available.

1. As part of the fire alarm system, the emergency communication system provides emergency announcements to occupants.
2. Evacuation of occupants on the fire floor and the floor above is prioritized.
3. Building officials analyze the situation and provide emergency guidance to occupants.
4. Occupants take the exit stairs down to the nearest refuge floor. They can then choose to take the exit stairs to the ground floor, or rest at the refuge floor until they are ready to continue evacuation. There are 29 total exit stairs for the basement and upper floors.
5. A full building evacuation will only be considered in the case of a severe disaster [53].

A full building evacuation drill is conducted once per year for this building. The drills are conducted with assistance from fire department personnel and are performed by the building personnel (i.e., security, property and parking management staff), security personnel, and higher management within property management [53]. The drills comprise the following: testing the fire alarm system, practicing with in-building firefighting equipment (including fire extinguishers), inspecting egress systems and emergency communication, and managing traffic and emergency response vehicles. From the publicly available information, it does not appear that practicing occupant evacuation (i.e., people movement on exit stairs) is involved in this drill. Rather, each building tenant independently conducts evacuation drills as often as desired [57].

3.5.3 Evacuation procedures for mobility impaired occupants during fire emergencies

Emergency elevators operated by fire fighters are used for firefighting and/or evacuating *mobility impaired occupants* [55, 57]. Building personnel will assist *mobility impaired occupants*' evacuation and, if necessary, ask for further support from the local fire department, upon arrival [53].

3.6 Taipei 101

3.6.1 General building information

Taipei 101 is the third tallest building in the world (2013), located in Taiwan. The building was completed in 2004. There are 101 floors with an occupied height of 438 m (1437 ft) and a public outdoor observatory platform on the 89th floor [58].

The average area of each floor plate in Taipei 101 ranges from 2,500 m^2 to 3,000 m^2 (26910 to 32292 ft^2). There are about 11,000 people working in the building and less than 700 people in the observatory at one time. The building's main occupancy is business, with exceptions of mercantile occupancies on floors 85 and 86 which hold restaurants, and assembly occupancies on floors 88 and 89 [58].

Taipei 101 was constructed to meet the requirements of the IBC (2000) [59, 60].

There are a total of 61 elevators in Taipei 101, two of which are fire fighter elevators. The elevator system consists of three zones. The elevator cars are mostly double-deck, with some single-deck cars [59]. Building elevator lobbies are not enclosed but have direct access to exit stairs. The two elevator lobbies have floor areas of 86.95 m^2 (935.92 ft^2) and 84.85 m^2 (913.32 ft^2), and all of the elevator lobbies have smoke detectors. Elevator machine rooms are protected by an automatic sprinkler system and smoke detectors [61].

On every eighth floor, there are mechanical rooms which contain refuge areas. Every refuge area has access to exit stairs which discharge at the ground level.

3.6.2 Evacuation procedures for occupants during fire emergencies

Exit stairs and emergency/service elevators are used for occupant evacuation during fire emergencies[6]. Passenger elevators are not used for evacuation. Also for evacuation, the building contains two exit stairs and an additional stair that connects only floors 9 to 16, as the floor plate on these floors is larger than other floors in the building [59].

During a fire emergency, the building's emergency communication system notifies the building occupants to evacuate via the exit stairs [60]. All personnel and occupants are encouraged to use exit stairs. As mentioned in the earlier section, refuge areas are located on every eight floors for those occupants who cannot make it to the ground floor to wait for rescue by fire fighters. The evacuation plan states that occupants can evacuate using emergency/service elevators only if they are on floors below the fire. If occupants are located above the fire floor, they should use the exit stairs only. The number and width of the exit stairs have not been reduced due to the use of elevators for occupant evacuation [38, 60, 61].

Building staff and employees are assigned specific tasks to help during emergencies, such as checking if anyone is left on the floor or directing occupants to the exit stairwell. Fire drills are conducted twice per year [61].

3.6.3 Evacuation procedures for mobility impaired occupants during fire emergencies

Mobility impaired occupants are encouraged to use the emergency/service elevators for evacuation [60]. In case of an emergency, the floor warden assists *mobility impaired occupants* to the elevator lobby [59]. Although it seems that all occupants can use elevators for evacuation (if located below the fire), the publicly available sources could not verify this fact or whether evacuation via elevator is exclusively for *mobility impaired occupants*.

3.7 Limitations of the Literature Review

There are limitations in this review of evacuation procedures for six buildings or building complexes that incorporate the use of elevators during fire emergencies. Limitations include, but are not limited to:

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[6] The total number of service elevators used for occupant evacuation was publicly not available.

1. The selection of the buildings in this report is not intended to be statistically representative of all high-rise buildings around the world. Although more buildings than the ones listed here were reviewed for this report (e.g., the Shard in Great Britain, Kingkey Finance Tower in China), it was not possible to find publicly available information about building codes and/or evacuation procedures, and thus, some were omitted.
2. The buildings considered in this report are from Great Britain, Asia (China, Taiwan, Malaysia), Middle East and Australia. That is, they may not be representative of all high-rise buildings around the world. However, the vast majority of tall and supertall (building height over 300m/ 984 feet) buildings outside the US are situated within those regions [62].
3. The quality and quantity of information available varied for each building. Online search and informal discussion with building managers were used to obtain information. However, it was not possible to obtain information from building managers for all the buildings, and the amount of information provided online varied in quality and quantity from building to building. Consequently, the information included in this report varies between the buildings and sometimes relevant and/or specific information on building features (e.g., location of rescue areas, emergency communication system, etc.) could not be addressed. It is possible that some of the buildings for which we did not find any information might nonetheless comply with certain building codes, use occupant evacuation elevators, or have evacuation procedures for *mobility impaired occupants*.
4. Although most evacuation plans describe or at least mention evacuation procedures for *mobility impaired occupants*, from the documents reviewed, there was little information available pertaining to the details of the plans and procedures for each of the specific buildings.

4 Human factors

One topic not yet discussed is how building occupants might respond to using elevators during a fire emergency evacuation. The review of building codes and evacuation procedures and plans of high-rise buildings in the previous section demonstrates that human factors have been addressed only to a very limited extent. The importance of understanding underlying behavioral and psychological processes, also referred to as human factors, of occupant evacuation[7] from high-

[7] Note that human factors are relevant for both occupants and life safety professionals (e.g., fire fighters, building personnel). The focus of this report is on occupants.

rise buildings has been demonstrated in the analysis of studies on the evacuation from the WTC towers on 09/11 [63-69].

According to the International Ergonomics Association, human factors is defined as *"*the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance" [70]. This includes environmental (e.g., smoke, signage), organizational (e.g., instructions, evacuation plans), social (e.g., social roles and norms), psychological (e.g., appraisal processes, decision-making), and physiological factors (e.g., fitness, disabilities). Human factors are already represented to some extent in building codes (e.g., in the design of communication systems or signage) [10, 11]. However, as the knowledge about the human factors of evacuation is still limited, many problems of occupant use of elevators for evacuation remain to be solved and may not even be known yet. Questions that need to be considered include - will occupants use elevators to evacuate during a fire emergency, if they are available? What are *mobility impaired occupants'* perceptions of using elevators during the evacuation process?

Understanding of behavioral and psychological processes requires a theoretical foundation. Several theories have evolved in the last decades in the field of evacuation research. Of these, the Protective Action Decision Model (PADM) offers a holistic descriptive theoretical approach to human evacuation behavior. At the core of the model are recursive processes of information processing and decision-making during evacuation. It takes a variety of predispositions, such as environmental or social context into account. Furthermore it stresses the importance of appraisal processes, and thus links cognitive psychological approaches with classic safety engineering models [71]. The PADM postulates a series of steps, from perception to decision making to protective actions, occupants have to pass through when they are confronted with stimuli (cues) indicating an emergency situation (e.g. fire alarms) [72]. Such cues initiate a series of processes necessary for an occupant to perform protective actions. These can be differentiated into pre-decisional and decision-making processes [72].

1. Perception: occupants must perceive or receive the cue(s).
2. Attention: occupants have to direct their attention to the cue(s).
3. Comprehension: occupants must understand the information that is being conveyed by the cues.
4. Appraisal of threat: occupants must interpret the incident suggested by the information as a credible threat.
5. Attribution of threat: occupants must attribute cues as a threat to their own well-being and feel that protective action is required;
6. Strategy identification: occupants search for available behavioral options.
7. Selection of strategy: occupants appraise the feasibility and most likely outcome and select an action based on that appraisal.
8. Protective action: occupants perform protective action if they assume that immediate action is necessary.

The PADM is applicable to occupant evacuation via elevators and the following paragraphs will address specific human factors moderating occupants' use of elevators for evacuation. Each of the human factors discussed below is relevant during several steps of the PADM. For example, observing evacuation behavior of others (social influence) may be a cue to increase awareness of an emergency (step 1-3 in the PADM) and inform about possible evacuation strategies (step 6). The following paragraphs give an overview on relevant human factors for occupant evacuation with a focus on elevator use.

4.1 Modulating factors of occupant use of elevators for evacuation

Evacuation behavior, and occupants' use of elevators during emergency evacuation is influenced by a number of human factors. These can either improve or thwart the use of elevators for evacuation and knowledge of these factors can contribute to design better evacuation concepts. Unfortunately, there is a lack of data on mobility impaired and able-bodied occupants' delay activities, awareness about the notification systems in the building, availability and use of information during drills, and obstacles encountered during evacuation via elevators.

4.1.1 Awareness of occupant evacuation via elevators

For successful occupant evacuation via elevators, occupants need to be aware of evacuation elevators in the first place. In a recent survey study with mobility impaired participants (in this case, patients with multiple sclerosis), over 80% of the participants stated that they had little or no awareness of occupant evacuation elevators. The majority of participants also had little or incorrect knowledge of other safety systems, such as refuge areas [15]. Lack of awareness of evacuation options may increase the affiliation to familiar exits, which has been demonstrated in several studies [e.g. 73, 74]. Occupants in high-rise buildings may not be aware of the location of exit stairs, as some evacuation routes may not be chosen simply because they are so rarely used [75]. Observations from unannounced fire drills in department stores showed that occupants mainly egressed through the main entrance, ignoring several emergency exits on their way out [76]. One may speculate that the same is possible for evacuation via elevators, especially those elevators that are not used on a daily basis for ingress into the building.

Awareness of occupant evacuation via elevators alone does not guarantee occupants will use elevators during a fire evacuation. In a study on road tunnel safety, the majority of the participants were aware of the safety installations in road tunnels, however, only few of them stated that they would consider using them during an emergency [77].

4.1.2 Readiness to use elevators for evacuation

For elevator usage to occur during a fire emergency, occupants need to consider evacuation elevators as a safe option. This might be the most problematic human factor with regard to evacuation via elevators, since declarative and procedural knowledge influence occupants' expectations, risk-perception, and decision-making. Over decades, occupants have been educated not to use elevators for fire evacuation. Consequently, various studies looking into occupants' readiness to use elevators for evacuation found that a significant part of the occupant population might be hesitant to use elevators during fire emergencies. Most of these studies were questionnaire studies and, to our knowledge, there is still no study which evaluates the actual use of elevators for fire evacuation. A first survey from the 1990s found that the majority of employees at air traffic control towers stated a strong preference for evacuation via exit stairs [78]. Another study based on observations from fire drills in high-rise buildings stated that about half of the occupants chose elevators for evacuation [79]. In a more recent online survey, two thirds of the participants stated that they would not use elevators for fire evacuation. Interestingly, the authors found a more pronounced trend in U.S. participants to use the elevators compared to participants from China [80]. Future studies should evaluate whether these findings reflect cultural differences in evacuation behavior or are caused by other factors (e.g. training, experience). In another Chinese study on attitudes towards occupant evacuation elevators, over 80% of the participants reported that they would use elevators instead of exit stairs in high-rise buildings [81]. Although these contradicting findings underline the need for further research in this field, it is noteworthy that even in the more optimistic studies, 20% of the participants stated that they would rather not use elevators for evacuation.

A significant factor determining the willingness to use elevators for evacuation is the *floor level* on which the occupants are located. The higher the location in a building, the more likely participants are to use elevators instead of exit stairs [48, 69, 82] and the safer use of elevators for evacuation is considered [83]. However, it is unclear whether the absolute floor level, or the relative floor height compared to the building height had a stronger influence here [48].

Next to the floor level, the *acceptable waiting* time for an elevator is important. According to a survey study, the acceptable waiting time increases with floor levels [48, 82]. In the same study, there was a strong negative correlation between waiting time and readiness to use elevators for evacuation. Furthermore, the most prominent reason to use exit stairs was that the participants assumed that exit stair evacuation was faster, according to the official emergency procedures for the building. The authors conclude that real-time information provided for both estimated elevator and exit stair evacuation time could foster occupant's informed decisions [48, 82].

Readiness to use any means of egress is also dependent on its *perceived reliability*. One study found that past low reliability of elevators decreased the readiness of participants to use evacuation elevators, even when the elevator's fire safety features were described to the participants [78]. That is, designated evacuation elevators need to work reliably during non-emergency use as well. Some buildings reviewed for this report use fire fighter or freight elevators for evacuation of *mobility impaired occupants* (See Chapter 3: Summary of high-rise buildings). Given that occupants may have little information about the reliability of freight elevators, they may be hesitant to use them even if these elevators are clearly indicated as evacuation elevators and, instead, prefer an evacuation strategy with high perceived reliability.

Adequate measures such as information dissemination, signage, training, and drills may enhance the readiness to choose elevators for evacuation. Not all occupants, however, may trust information that is conflicting with their prior beliefs. This may lead to behavioral uncertainty, and other factors, such as social influence, may have stronger effects on occupant behavior.

4.1.3 Perception

Certain factors can inhibit perception during a fire emergency, including hearing impairments, visual impairments, and situational conditions (e.g. low visibility) and thus reduce occupants' mobility. Although there is some evidence that the perception of fire cues (e.g. smoke) increases compliance with evacuation signage [84], there are no studies that directly address the interaction of such cues with the use of evacuation elevators.

4.1.4 Social influence

Social bonds affect evacuation. Observation from fire emergencies show that family members stay with each other and may even reenter a burning building to rescue others [85, 86] (for an overview, see [87]). Social-evaluative stress may trigger pro-social behavior but also may lead to slower evacuation [88, 89]. Groups with strong social bonds may be reluctant to use elevators if they would have to split up to use an elevator.

Next to social bonds, two forms of social influence are relevant for evacuation via elevators. First, perceived social norms and expectations can trigger non-compliance with safety procedures (normative social influence)[90]. Second, the behavior of others is a source of information about how to react in an ambiguous or insecure situation (informative social influence) [91, 92]. Both forms of social influence may have beneficial effects, if other occupants (especially those with high perceived social authority, such as fire wardens) follow adequate evacuation procedures. For example, during the evacuation from World Trade Center 2 on September 11, 2001, occupants actually used elevators for evacuation because they had seen others doing so or had been instructed by fire wardens to use the elevators [65]. However, the effects could also be detrimental, if occupants follow others onto inappropriate evacuation routes or stay passive [93]. Indeed, one questionnaire study found that a significant number of participants, who either took the exit stair (17%) or the elevator (30%), stated that their evacuation choice was based on the observation of others [48, 82]. These findings suggest that occupants with highly responsible roles during fire evacuation may play a crucial role for the use of elevators for evacuation.

4.1.5 Stress and evacuation via elevators

Occupants may need to decide to use an elevator for evacuation although they may experience stress and anxiety during a fire emergency. Increased levels of stress are accompanied by more impulsive processing and a decrease in cognitive resources[8] [94]. This may not only lead to occupants focusing on few salient stimuli and neglecting less salient stimuli, but also possibly to inadequate decision-making during evacuation from complex buildings [87]. Considering this,

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[8] This does not imply that occupants are incapable of rational decisions, or even panic.

emergency communication needs to provide clear and unambiguous information to occupants. The literature underlines the importance of information for building occupants, as this is crucial for the occupants' ability to make adequate decisions [10, 11, 95].

Studies show that people tend to take conservative decisions under acute stress. Depending on the circumstances and their appraisal, this effect could be either beneficial or detrimental during evacuation [96]. Conservative decision-making may lead occupants to distrust information that is contradictory to common knowledge. On the one hand, heuristics such as "Do not use the elevator in case of emergency" may be deeply rooted and may require a highly credible source of information for occupants to act against these heuristics. On the other hand, occupants are even more reluctant to use elevators for evacuation if they perceive elevators as unreliable [78]. That is, sources of information that support occupants to use elevators for evacuation have to be obviously credible and elevators have to be well maintained and known to be reliable during non-emergency use.

4.2 The risk of "panic" during evacuation via elevators

"Panic" is a rare event in an evacuation during a fire emergency. However, evacuation behavior is often falsely labelled as panic [97]; so-called panic has been reported from various catastrophic events, such as earthquakes, fires, or manmade disasters during mass events or terrorist attacks [97-100]. Given that media coverage of emergencies often uses the term *panic* when large numbers of occupants evacuate, it seems necessary to address this topic with regard to evacuation via elevators [101]. As strategies for evacuation via elevators may lead to crowding or bottlenecks in certain locations, such as elevator lobbies, one might expect occupants to "panic" in such situations. Kobes gives a concise overview of reported panic, actual events, as well as empirical research and definitions of the term [87]. However, as Fritz and Keating pointed out as early as 1957:

"According to a pervasive popular conception, they [occupants] panic, trampling each other and losing all sense of concern for their fellow human beings. After panic has subsided – so the image indicates – they turn to looting and exploitation, while the community is rent with conflict. Large numbers of people are left permanently deranged mentally. This grim picture, with its many thematic variations, is continually reinforced by novels, movies, radio and television programs, and journalistic accounts of disaster. [102]"

Current definitions describe panic as basic fear reactions that occur in situations of danger which are associated with fight-or-flight responses [103]. Symptoms of panic include strong and abrupt cognitive and somatic reactions [104]. Another definition identified four elements of panic: 1) hope to escape through dwindling resources; 2) contagious behavior; 3) anti-social behavior; and 4) irrational, illogical responses [105] (cited from [87]). In reality, however, occupants mostly show adequate, rational, and controlled reactions in emergency situations [106].

Clark and other authors summarize that over fifty years of research showed that during such crisis situations people hardly lose control, even if they experience extreme fear. Moreover, survivors of catastrophes report that occupants support each other during evacuations [87, 107, 108]. Even in the extreme case of a so-called mass panic, it is reported that people try to help others who, for example, have fallen to the ground and are in danger of being trampled [97, 101].

4.3 Methodological aspects and open questions for empirical evacuation research

The previous sections sought to shed light on what is known about occupant use of elevators for evacuation. This knowledge is still limited and there are several important pending research questions on evacuation strategies for *mobility impaired occupants* which require empirical research:

1. Are *mobility impaired occupants* aware of the possibility of using elevators for evacuation during a fire emergency?
2. What are *mobility impaired occupants*' attitudes towards the use of elevators for evacuation during a fire?
3. How willing are *mobility impaired occupants* to use elevators for evacuation during a fire?
4. What are *mobility impaired occupants*' decisions and behaviors during evacuation from a fire emergency?
5. Are there concerns of *mobility impaired occupants* using elevators during fire evacuation? If so, what are these concerns?

So far, there are no satisfactory answers to these questions. Future research is necessary to address these questions, as only a better understanding of the human factors during the evacuation of buildings will ultimately lead to research-based safety improvements in building codes and designs, as well as improvements in building evacuation procedures for all building occupants.

Various methods are available to study the use of elevators for evacuation: observation from real events and drills, field studies, laboratory experiments, simulation studies, and all forms of subjective data collection (interviews, questionnaires, etc.). Social roles [66, 109], personality traits (such as trait anxiety), observational powers [87], beliefs [110], and appraisal processes [111] may influence decision-making and ultimately occupants use of elevators for evacuation.

Unfortunately, there are massive ethical and methodological challenges for each of the aforementioned methods, as it is very difficult to obtain objective, reliable and valid data for human behavior in fire. All available research methods have to trade-off between external validity and experimental control. Data from unannounced drills and real events may have high external validity, as occupants/participants may be convinced that they are in a real emergency, but experimental control, and thus the possibility to detect causal relations between variables is not without limitations. The reason for this problem lies mainly in the difficulty to control potentially confounding variables (e.g., the behavior of other occupants or external conditions such as daylight or temperature, etc.). For example, it may be difficult to identify why occupants start to evacuate if there are multiple cues (e.g., fire alarm announcements and other occupants evacuating). Furthermore, certain variables of interest cannot be measured objectively in an unannounced drill (e.g., orientation behavior, psychological or physiological parameters) and have to be coded by observers from video material (which is prone to observation biases).

The goal of laboratory studies is to create an experimentally controlled space in which single parameters can be manipulated and objectively and reliably measured while keeping other potentially confounding factors constant [112]. Laboratory experiments have satisfying relative external validity [e.g., 113].

Qualitative approaches, such as questionnaire studies and interviews give an understanding of why occupants decide to take a specific action but are prone to bias (e.g., social desirability) as well as memory and mood effects [114]. Simulation studies of evacuation behavior are very powerful tests of different design options. However, these rely heavily on the validity of underlying assumptions on occupant behavior, which in turn require a sound empirical basis. To date, the knowledge on human factors in elevator use during a fire evacuation is almost entirely based on questionnaire or simulator studies (See previous section). Future research needs to develop behavioral paradigms to validate these results, specifically on occupants' readiness to use elevators for evacuation and what may be acceptable waiting times to use such elevators.

4.4 Potentially beneficial measures for occupant evacuation via elevators

Based on the literature, a number of measures to improve occupant elevator evacuation can be considered. These measures can affect several of the aforementioned human factors aspects. Occupants need to know which of the possible strategies identified are available and accessible for evacuation. Fahy states that "information is the key to a successful building evacuation during an emergency" [p.10, 115]. The overall goal of these measures is to help occupants (including *mobility impaired occupants*) making the right decisions (i.e., are elevators safe for evacuation?) in less time.

1. *Education*: Educational campaigns informing people about the possibilities of occupant elevator evacuation are necessary. This information should be disseminated to the general public. However, special focus should be set on high-risk groups, such as *mobility impaired occupants*. A recent study on refuge areas found that awareness of these installations had been raised through education and training (See below) [15]. These findings may be transferred to occupant evacuation elevators, but should be validated in separate studies.
2. *Signage*: Clear, standardized, and self-explicatory signage needs to be designed and tested for occupant evacuation via elevators. Well-designed signage systems inform occupants of the available evacuation routes and the closest occupant evacuation elevator. Improved signage reduced egress time from World Trade Center 1 on September 11, 2001 compared with the 1993 bombing of the same building [116, 117].
3. *Real-time information:* Real-time information about estimated evacuation time should be made available at exit stairs and occupant evacuation elevator lobbies. This could help

the participants make informed decisions about the quickest and safest evacuation route [48, 82].

4. *Training*: Regular drills and training help to establish procedural knowledge about occupant evacuation via elevators. The effectiveness of practical training on evacuation behavior has been demonstrated in other fields of evacuation [e.g., 118]. However, there are no studies to date which test training of evacuation via elevators.

Heyes and Spearpoint as well as Kuligowski and Hoskins give additional recommendations for occupant evacuation elevators [48, 82, 117]. The authors recommend evacuation modeling for buildings in which occupant evacuation elevators are available. In addition, on each floor, information should be provided to occupants on timing for evacuation. For example, real time information should be provided on how quickly occupants can evacuate the building using the exit stairs from that floor level and when the next evacuation elevator would arrive.

5 Summary and conclusions

Overall, elevators have become an important part of evacuation concepts for high-rise buildings. Particularly, occupant evacuation elevators may be a significant contribution for safe egress of *mobility impaired occupants*. This is reflected in buildings codes, such as the IBC and NFPA. Many of the technical challenges of occupant use of elevators for evacuation have been overcome so that elevators can be considered as a safe method to evacuate a building during a fire emergency. Strategies for evacuation using elevators have already been established in a variety of high-rise buildings around the world.

The aim of the present report was to give an overview of evacuation procedures using occupant elevators during fire emergencies in international buildings. A special focus was given to evacuation of *mobility impaired occupants*, building codes, and organizational challenges. Evacuation procedures were featured for six selected buildings and building complexes from the Middle East, Asia, Great Britain, and Australia. The information provided on these buildings included general building information, evacuation procedures for occupants during fire emergencies, and evacuation procedures for occupants with mobility impairments during fire emergencies. Additionally, a literature review gave an overview of the human factors aspects of evacuation via elevators. The findings from the aforementioned sections were used to identify research gaps.

Given the relatively recent advances in occupant evacuation elevator technology and the aforementioned difficulties to study human behavior in fire, it is not surprising that there is still a considerable knowledge gap with regard to performance issues associated with *mobility impaired occupants*' evacuation via elevators. In particular, there is little knowledge about awareness and behaviors performed by occupants before proceeding to an exit stair, behavior and route choice during evacuation movement, including the use of either exit stairs or elevators, and background information about the occupant and experience with building evacuations. It is also important to understand the underlying behaviors during occupant evacuation. Analysis of occupant movement is incomplete without an understanding of the decision-making and behavioral processes that prompt occupants to move, as movement is the result of behavioral decisions.

As the introduction of the use of elevators is a major change in a building's evacuation strategy, it is important that all aspects of elevators usage are perceived, attract attention, and are comprehended by building occupants before and during evacuation conditions. In addition, information needs to be clear, unambiguous, easy to understand, and accessible for *mobility impaired occupants*. Evacuation strategies which allow different means of egress for specific occupant populations may be difficult to comprehend. For example, if only *mobility impaired occupants* are to use elevators for evacuation, both mobility impaired and able-bodied occupants need to be aware of that differentiation and understand that associates may have to split up during an evacuation.

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