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Characterizing Disability in Fire: A Progressive Review

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Abstract

People with disabilities are one of the most vulnerable groups involved in building fires. According to U.S. Fire Administration, an estimated 700 home fires involve people with physical disabilities each year, while over 1700 involve those with mental health disorders. Despite this, there is very little evacuation research for the disabled population, resulting in high injury and death rates. Thus, this work presents a comprehensive literature review of fire evacuation research focused on various forms of disability. This is first explored through a brief introduction to disability rights history, where research gaps, significant accessibility legislation, and key disasters are identified. These are summarized in the four-part *Disability Evacuation Framework,* which facilitates the retrieval and review of articles by identifying key components of the evacuation process. Studies were then categorized into the framework by type of disability, and a lack of research focused on chronic illnesses and mental health disorders were identified. This is mainly due to little behavioral understanding among fire safety officials and engineers, even in studies involving only non-disabled individuals. Based on these findings, a new definition of disability in relation to evacuation is defined for use by building professionals. This flexible definition places disabilities and structural evacuation components (stairwells, fire alarms, etc.) side-by-side in order to effectively categorize needs and evacuation routes for those with disabilities. It is the hope that this definition may be used to improve the building design process and development of egress routes, resulting in decreased evacuation times, injuries, and deaths for the disabled population.

Keywords: Disability; Fire; Evacuation; Human Behavior; Review; Disability History; Human Rights.

Introduction

A Brief Look into Disability Rights History

Beginning with classical philosophers such as Aristotle labeling impairments as "abnormalities" and evolving into 19th century scientific thinking of *survival of the fittest*, people with disabilities (PWD) have been marginalized for centuries (3,4). It was not until the 20th century that people with functional limitations[1] became more interested in advocating for equal rights. In the United States, the Disability Rights Movement transformed treatments and perceptions of disability starting in the mid-1900s (2). Organizations for people with disabilities existed well before the

[1] Functional limitation is defined as "the restriction or lack of ability to perform an action or activity in the manner or within the range considered normal that results from impairment" (1).

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movement began, but it was not until the Great Depression that they gained significant popularity. In the 1930s, the *League of Physically Handicapped* was created to fight for equal employment (2). The 1940s through 1960s saw an increase in organizations for people with mental health conditions and cognitive impairments with *We Are Not Alone* and the *National Association for Retarded Children.* Also, during this time, President Harry Truman formed the *National Institute of Mental Health* (NIMH), now the leading federal agency for research on mental health disorders in America (2, 5). In Europe and elsewhere, disability advocacy is more recent and mainly focused only on the last few decades (6). In 1996, the *European Disability Forum* (EDF) was founded to represent the 50 million disabled people in the European Union (7). Just three years later, the *International Disability Alliance* (IDA) was established as a network of global and regional disability organizations and was essential in the development of the *International Disability Caucus* (IDC), now a key negotiator of the *United Nations Convention on the Rights of Persons with Disabilities* (UN CRPD) (8). In India, the Decade of Disabled Persons (1983-1992) marked one of the first shifts in advocacy for PWD (9). Much like the Disability Rights Movement in the United States, this period saw an explosion of interest and development of local, national, and international non-governmental organizations (NGOs) related to disability.

Nearly all disability rights movements worldwide began with a push for social justice and an end to classical views, oppression, and traditional cultural ideas of disability. In the west, the root of this push was the emergence of the social model of the disability first introduced by the *Union of Physically Impaired Against Segregation* (UPIAS) in the 1970s (10). According to their policy statement, the goal of the organization was to adapt inaccessible facilities so that PWD could fully participate in society and live and work independently. This was perhaps the first connection to disability and the built environment. By the social model's viewpoint, impairment and disability are not individual deficits, nor do they need to be cured by medical intervention. Instead, a modified society and environment can reduce the burden of disability.

The development and acceptance of the social model of disability were, in many ways, a form of liberation for disabled people. It no longer placed a burden on the individual and their impairment but instead transferred the responsibility to society to produce a change in accessibility and perceptions of disability. Additionally, the social model rejected the medical model of disability at its most fundamental level. This approach understands disability as an inherent quality of the individual, assuming that an impairment is a physiological issue rather than caused by societal views or expectations (11). The medical model approach also characterizes PWD as requiring assistance in the form of rehabilitation or medical effort and treatment to overcome the impairment. Thus, disabilities are purely individual, and society retains no responsibility for the disadvantages they may cause. While scholars today rarely defend this model due to its suggestion that disability rights are "special", it continues to be the prominent paradigm of disability across much of western culture (11). This has resulted in public perceptions of disability based on media and local culture, which largely misrepresent both the number of people with disabilities and the extent to which someone's disability is affected by daily life.

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Disability Legislation and Accessibility

While certain aspects of the medical model remain important, its narrow focus means that many issues concerning disabled people are overlooked or ignored (12). Clearly, one's impairment is an important aspect of their daily life; but encounters with societal barriers—whether physical, institutional, or attitudinal—only further prevent full participation in society (11). For this reason, scholarly and professional adoption of the social model of disability has been fundamental in advancing equal rights legislation for people with disabilities.

In Europe, this began just 20-25 years ago, when not a single state had national protections against disability discrimination. Statutes emerged quickly in the regions where the social model of the disability first took hold. For example, the United Kingdom (UK) *Disability Discrimination Act* was passed in 1995 and was the location where UPIAS first introduced the social model. Other initial disability statutes included the *Hungarian Equalization Opportunity Law* (1998) and the *Cypriot People with Disabilities Law* (2000), both related to employment discrimination (6). Later, legislation emerged in Latvia, Denmark, Luxembourg, Poland, and FYR Macedonia. Now, more than thirty countries have some form of anti-discrimination law, and the European Union (EU) has signed and ratified the United Nations CRPD (6).

In the United States, more than 50 laws on civil rights and disability were passed between the years 1960 and 1990. The *1973 Rehabilitation Act* addressed items ranging from disability discrimination in the federal workplace to equal access to technological information. The *1975 Education for All Handicapped Children Act* guaranteed children with disabilities the right to a public-school education. Before this, the *1968 Architectural Barriers Act* became the first federal accessibility law in the world (13). In 1990, the movement's greatest legal achievement—the Americans with Disabilities Act (ADA)—was passed nationally, prohibiting the discrimination of disabled people in many aspects of daily life (2). This marked a clear transition away from the medical model in America by highlighting the social dimension of disability. However, continued adherence to viewing impairments through the medical lens created several interpretive issues with the legislation. The key component of the ADA was to provide equal accommodations for people with disabilities (in terms of public access, employment opportunity, and much more); however, its failure to clearly define disability has resulted in several Supreme Court decisions labeling individuals as either "too disabled" or "not disabled" enough (11). Without clear definitions and requirements, accommodations under the ADA have had mixed results, sometimes not properly benefitting those who need them. Additionally, resistance among designers and construction professionals has resulted in more negative attitudes toward people with disabilities.

In other countries, anti-discrimination laws for PWD came later. 1993-2002 was declared the Asian and Pacific Decade of Disabled Persons (14). In Hong Kong, this was heralded by one of the most far-reaching anti-discrimination laws for disabled people: the *Disability Discrimination Ordinance of 1995*. This is only one of three pieces of anti-discrimination legislation in the region but covers both the public and private sectors in a variety of areas ranging from education to housing to sports. In India, the *Persons with Disability Act* was passed in 1995 (9). This law was strengthened by the initiation of the *National Centre for Promotion of Employment for Disabled People* (NCPEDP) in 2000, a national campaign that collaborated with NGOs, local governments, and other advocacy groups to form the National Disability Network. In South Africa, disability legislation came with the political transformation of the country in the early 1990s. The *Disability Programme* and the *White Paper on Integrated National Disability Strategy* were developed in 1997 (15). This paper aimed to create equal opportunities and an enabling environment for PWD. The Office of the Status of Disabled Persons also worked to integrate disability resolutions into the changing government at the local, regional, and national levels (15).

The Complexity of the Disability Definition

Disability has yet to be consistently defined (16). In the United States, most of the inconsistencies in creating a single disability definition have been focused on the vague definition created by the original Americans with Disabilities Act. The Act presented disability as a "*physical or mental impairment that substantially limits one or more of the major life activities of such individuals"* (17). With many disagreements over the Act's range of applicability in its first 20 years of existence, one scholar noted that the "overarching disagreement…can rightly be characterized as a 'clash of perspectives' about the meaning of disability" (11). In 2008, the development of the ADA Amendments Act aimed to fix this issue by emphasizing that the definition of disability be extended to include a larger range of individuals with impairments and reduce the amount of scrutiny placed on the decision of whether someone is disabled or not (17). While this reduced the burden on PWD to prove their "disabled-ness," it only created another new definition with room for interpretation.

As seen with the ADA and its Amendments Act, any attempt to create a single, universal definition is met with conceptual issues of applicability and vagueness as well as backlash from both public and scholarly communities. This is partly due to the transition away from the medical model and toward the social model of disability, as definitions must also transition away from descriptions of impairments and toward social discrimination and components of restriction. This is a compounding issue among scholars and researchers, many of whom have already accepted the social model of disability because their definition must also appeal to their own field and the public. With much of the public still entrenched in the medical viewpoint, many researchers and organizations have resulted in creating their own definitions for personal application. For example, criteria from the *American Psychiatric Association's* (APA) Diagnostic and Statistical Manual are often adopted among mental health researchers (18).

Other organizations have attempted to define disability from a more inclusive standpoint. In the United States, the *Federal Emergency Management Agency* (FEMA) adopted the functional needs approach as a way to define disability in relation to the disaster. Published in both their Comprehensive Preparedness Guide 101 in 2010 and their National Response Framework (2019), this definition does not create a single description of disability but instead specifies five areas of potential need in the event of a disaster: *communication, medical health, functional independence, supervision,* and *transportation* (18-20). Internationally, the most widely recognized definition of disability is the *World Health Organization's* (WHO) *International Classification of Functioning, Disability, and Health* (ICF). Written in 2001, it considers disability as "*neither purely a biological nor a social construct, but the result of interactions between health conditions and environmental and personal factors"* (21). More generally, under WHO, disability is defined as an umbrella term that covers impairments, activity limitations, and participation restrictions (22). It is a complex entity resulting from interactions between one's own self and their environment. Other international organizational definitions can be found in (23).

Disability cannot and will not remain the same over cultures and time. Not only does it represent a wide range of physical, mental, sensory, and medical impairments, it can also include a combination of them and a broad range of effects. Additionally, the acceptance of disability as a social construct means that it will also change with developing environments as well as communities, generations, and politics. With the emergence of disability studies as a working field, the continued presence of disability rights activism, and the push for cross-cultural information exchange through research and technological advances, the creation of a universally accepted disability definition is all too important in order to shape the changing world landscape and policy (15).

Disability, Disaster, and the Built Environment

More than 15% of the world's population is estimated to live with a disability today, and this number is only expected to grow due to the aging population, obesity epidemic, and push for equality (24, 25, 36). However, despite the increasing number of PWD and actions taken during disability rights movements around the world, many disabilities continue to be thought of as abnormal, limiting, and different. Perhaps one of the most significant limiting factors in the push for equality for people with disabilities is accessibility in the built environment. Often defined as all buildings, spaces, and products created or modified by people, the built environment has recently been the focus of a growing body of research related to disability and public health (26-28). For example, in a recent study conducted in England (37), people with disabilities were asked to describe their experience in public spaces. Almost all participants noted that it was easier for them to remain at home than to attempt to venture into public. Broken sidewalks, poor lighting, narrow doorways, a lack of ramps and elevators, and inaccessible bathrooms were all items that consistently prevented disabled people from entering or using buildings (37). According to studies (29-32), the proper design of these features has been associated with preventing mobility disability, encouraging independence in those with underlying health conditions, and increasing physical activity.

Other related studies show similar results and highlight the inefficiency of functional accommodations for PWD, especially those with mental health conditions or cognitive impairments. Several forms of legislation have aimed to improve this in public environments, but they continue to show a lack of concern and awareness among designers and policymakers toward disabled people. For example, the amended *1968 Architectural Barriers Act* (ABA) specified that all buildings financed by the federal government in the US, intended for use by the public or which may be a home or workplace for physically handicapped persons, be designed and continuously inspected for accessibility barriers (11). However, the legislation describes only minimums that must be taken by engineers and architects as they design and retrofit structures. With this mindset, few designers work toward truly accessible design; aesthetics, budgets, and timelines are often deemed more important.

The inaccessible design of structures, transportation services, and functional aids (ramps, handrails, etc.) is not the only problem people with disabilities experience in the built environment. People with disabilities are also disproportionately affected by disasters (33-35). For example, people in wheelchairs cannot take refuge under desks or tables during earthquakes. They also cannot quickly descend stairs in the event of a fire, as seen in the 9/11 attacks on the World Trade Center (WTC) buildings. Several accounts of the event point to coworkers attempting to carry wheelchair users down flights of stairs that were only 44 inches wide—enough for two non-disabled people side by side (38). Few used the over 100 "stair chairs" purchased following the 1993 bombing of the towers (38). Those with visual or hearing impairments may not hear or see evacuation cues, warnings, or other indicators of disaster either, and people with learning difficulties or mental health conditions may not be able to interpret social or physical cues of dangerous events. Additionally, PWD who rely on electricity to treat or assist with medical conditions (dialysis, ventilators, communication devices) may not have access to these following disasters. After the 2008 Sichuan earthquake in China, people with disabilities were reported to search for their radios among the debris for information (33).

Unfortunately, this type of discrimination among disaster relief services and practices is all too common. The University of Kansas *Nobody Left Behind project* attempted to identify what disaster managers know and understand about people with disabilities during natural and human-influenced disasters. From a survey of 30 randomly selected FEMA disaster sites between the years 1998 and 2003, it was found that 66% of counties did not plan on updating their disaster management plans to better include those with disabilities because of costs, limited staffing, lack of awareness, and other demands (39). In their study on natural hazards and human vulnerability, Hemingway and Priestley (41) also noted a lack of inclusion of people with disabilities in disaster planning and management. For example, the *Tsunami Evaluation Coalition* (TEC), created in response to the December 2004 Asian earthquake and tsunamis, was a collaboration of over 50 agencies (40). These included members of the United Nations, Red Cross, and NGOs. Yet in the eleven broad evaluation reports published immediately following the disasters, only "two" referenced those with disabilities. Additionally, they only mentioned accessible restrooms in shelters and more generally stated that they had "not taken this (disability) onboard" (41).

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Current Fire Evacuation Research

Methodology

The first section of this review has focused on the past and present inequalities regarding people with disabilities. After reviewing this information, it became clear that one of the most persistent issues for PWD is accessibility in the built environment. While efforts have been made to reduce this burden through legislation and equality movements, there is still a lack of information regarding the safe *egress* of people with disabilities from public buildings. Inherently related to building design, physical accessibility, and disaster management, the ability of people with disabilities to safely egress and evacuate from a structure has only loosely been explored. Thus, a categorization of disability from a fire evacuation perspective was developed in order to identify research gaps. Presented in **Figure 1,** the *Disability Evacuation Framework* facilitated in the retrieval of articles and other reviews by identifying key components of the evacuation process for various types of disabilities. The questions and categories facilitated in the identification of the following keywords and phrases for the retrieval of existing articles and reviews on evacuation for PWD: "disability evacuation", "fire evacuation", "fire safety for people with disabilities", "functional independence", "evacuation assistance", "visual impairment with evacuation", "smoke effects on evacuation", "behavioral effect on evacuation." Papers were selected from the Elsevier and Science Direct Databases over a period of six months (January 2021 through June 2021), with additional searches for new work from July 2021 through December 2021.

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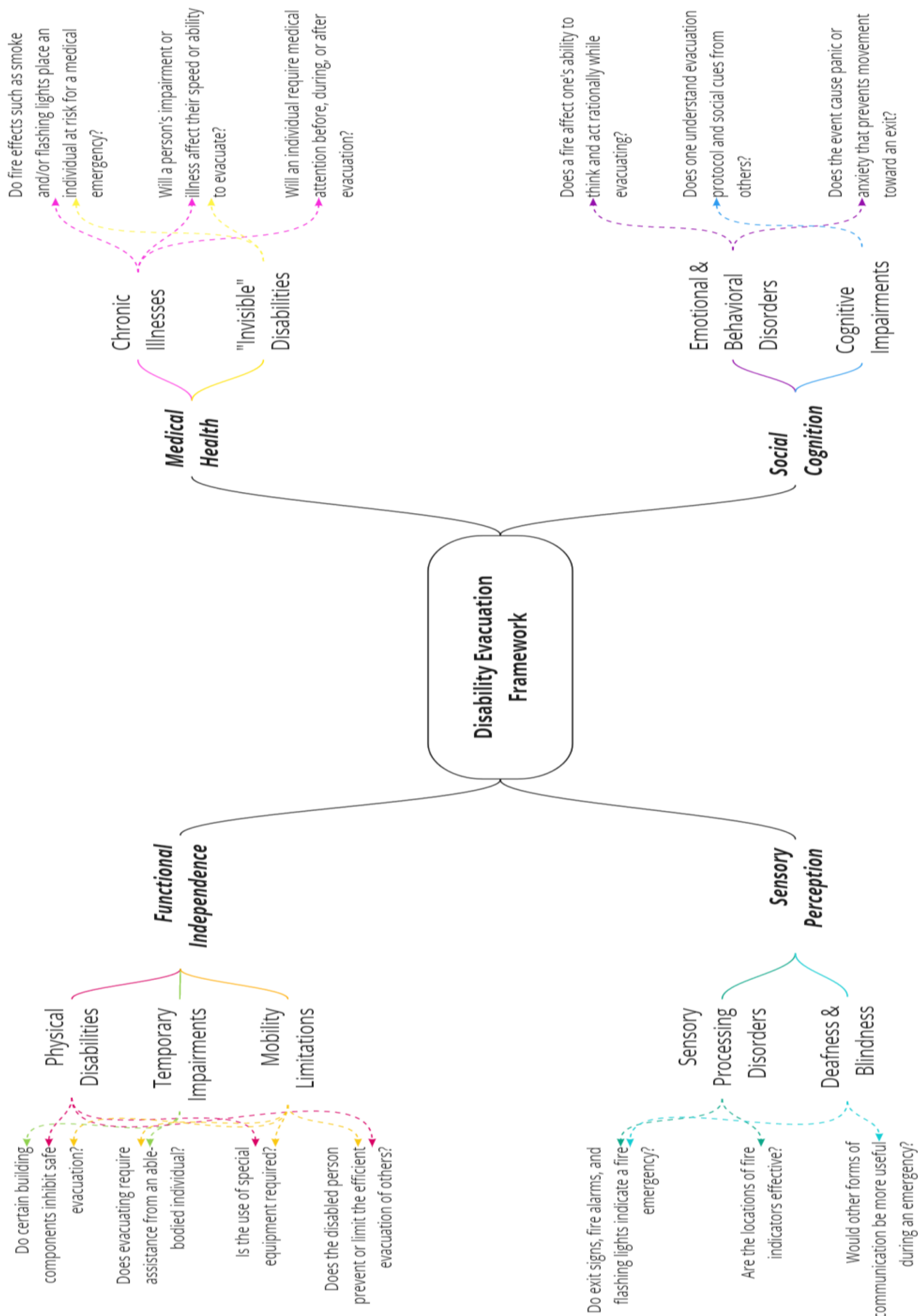

Figure 1: Disability Evacuation Framework

For papers to be included in this study, they had to address fire evacuation from buildings (public or private) and refer to people with functional limitations or diagnosed disabilities. Note that studies including non-disabled building occupants were also included in the following section in order to address the contrast between available research for both population segments. Both journal articles and reviews were included with an emphasis on evacuation studies and experiments—either real or simulated. Papers were excluded if they only focused on policy or legislation relating to fire safety, modelling development and methods, or buildings where assisted evacuation is expected (hospitals, nursing homes, etc.). The main focus of this study is on buildings where self-evacuation is expected, although papers were included if they mentioned help from otherwise "untrained" but non-disabled evacuees (i.e., coworkers assisting a wheelchair user downstairs). After gathering papers, information was extracted and sorted based on the four main categories in **Figure 1:** *functional independence, sensory perception, medical health, and social cognition.* Linking each paper to a category resulted in the identification of research gaps for certain disabilities and the identification of a baseline disability definition for fire evacuation.

Non-Disabled

Although the focus of this research is on those with disabilities, it is necessary to address the vast number of studies that have been completed for those without impairments. Following the terrorist attacks on the World Trade Centers (New York, USA) in 2001, researchers across the world became increasingly aware of the complex nature of building evacuations, especially high-rise evacuations. In fact, in the two decades following the event, over 15,000 studies, reviews, and experiments have been completed, according to the search engine Google Scholar. One of the most prominent studies produced during this time frame was the multi-year investigation into 9/11 performed by the *National Institute of Standards and Technology* (NIST) (60). While it mainly focused on structural reasons for the towers' collapse, the organization also produced a 298-page report on occupant egress, behavior, and emergency communication.

The NIST investigation made it clear that occupant survival was a direct result of both efficient structural design and social and environmental cues. For example, each affected tower (WTC1 and WTC2) had three interior stairwells: two of width 44 inches and one of width 56 inches (60). These stairwells combined for a total of 6.5 units[2] of exit width—just enough to meet the minimum requirements of the New York City (NYC) Building Code under office occupancy (61). Additionally, impending changes to the NYC code in 1965 resulted in the elimination and/or reduction of several egresses aids in the final design of both WTC1 and WTC2. Fire towers[3] were eliminated, reducing the total number of stairwells from 6 to 3, the size of exit doors was reduced by eight inches, and elevator and stair shafts were changed from a three-hour fire rating to a two-hour rating (60). These changes, although they met code requirements from NYC and the International Building Code (IBC), undoubtedly resulted in several issues during the evacuation effort on September 11.

[2] One unit is equal to 22 inches of exit width per the 1968 NYC Building Code (60)

[3] Fire towers are exterior fire-rated stairwells that terminate at ground level and are designed to ensure that smoke and fire conditions from the building do not infiltrate the tower (61)

Social and environmental cues also played a large role in the evacuation of both towers on 9/11. The overall size of the buildings (110 stories) made it difficult for occupants located more than a few stories from the impact regions to understand the gravity of the situation; smoke, fire, and other emergency cues were undetectable. Thus, emergency communication was of the utmost importance for efficient evacuation. Unfortunately, this was an issue in both WTC1 and 2. In the North Tower (WTC1), NIST found no evidence that evacuation announcements were heard or understood by building occupants, despite several attempts by the lobby fire command station. In the South Tower (WTC2), there were 16 minutes after the attack on the first tower but before the attack on the second tower. Before the second impact, occupants of WTC2 were instructed to return to their offices. However, just a few moments later, another announcement was made to evacuate. Both created issues in situational awareness that resulted in the deaths of approximately 100 people (60).

The NIST investigation wasn't the only study produced on the World Trade Center following 9/11. Several others aimed to study the evacuation from a variety of fronts. The first analysis of the event came from a collection of first-person accounts published either in the media or online (44). While the over 700 accounts collected do not provide the same opportunity for analysis as other scientific studies, they did provide insight into occupant experiences, emotions, and behaviors that explained the complexity of human interactions and reactions to the event. Another study of 9/11 was performed by the Mailman School of Public Health at Columbia University under a grant from the Centers for Disease Control and Injury Prevention (CDC) (45). This study was performed from an epidemiological perspective, and it aimed to identify risk factors and to facilitate factors in evacuation time. Using a Participatory Action Research (PAR) framework and qualitative survey, the evacuation study found that factors associated with effective evacuation included disaster preparedness training, building familiarity, physical conditions, medical health status, footwear, and occupant behavior (social and sensory cues) (46). The final 9/11 study was international—a collaboration between the Universities of Greenwich, Ulster, and Liverpool in the United Kingdom called Project HEED, or the High-rise Evacuation Evaluation Database. Its goal was to create a database of information on the towers and their evacuation on September 11 by tying occupant experiences to specific times and locations, thus allowing other researchers to estimate information such as response and evacuation times. Interviews with 271 WTC survivors gave an average travel speed of 0.29 m/s with the lowest recorded speed of 0.17 m/s, likely resulting from high levels of congestion and not physical ability (47). Additionally, the study produced a large amount of data on response times and observed that Body Mass Index (BMI) and fitness do not appear to significantly affect the need for rest time or slower travel speeds (47).

The diverse and alarming findings from each of the 9/11 evacuation studies resulted in a large influx of evacuation studies focused on high-rise buildings, human behavior, structural components, crowding tendencies, and much more. Perhaps most prominent are those focused on high-rise buildings (43, 48-54, 56-59, 62, 70), as a recent study showed that vertical evacuation could take up to 70% of the total evacuation time in large structures (55). Recent real-time experiments for tall buildings have focused on parameters such as downward/upward movement speed (49, 53, 56-59), crowd density or bottlenecking (49, 62-64), the effect of visibility conditions (65-68, 72, 75), and combined elevator/stairwell evacuation times (57, 69, 70), all of which aim to quantify values for determination of efficient evacuation strategies. Another category of evacuation experiments is focused on evacuee characteristics, including gender (71, 72, 74), age (50, 73), and weight/BMI (71). Of these studies, none mentioned building occupants with disabilities or impairments.

The studies mentioned previously all represent the leading edge of real-time research related to fire evacuation of buildings. They surfaced mainly due to the diverse issues discovered following 9/11, but they are far from the first studies on fire evacuation. Prior to the World Trade Center attacks, evacuation studies were mainly performed in response to other fire incidents. For example, an analysis of behavioral cues was performed following a hotel fire that occurred in Tokyo, Japan, on February 8, 1982. The study gathered information on guests' recognition of emergency exits as well as their pre-evacuation behavior and found that people were mainly concerned with finding information about the severity of the fire threat before evacuating. Guests also evacuated quicker if they sought out emergency exits prior to the fire (76). Similarly, an analysis of human behavior in the MGM Grand Fire (1980) also found information-seeking behavior among evacuees. Individuals were found to congregate together in refuge areas to gather information and communicate, resulting in as many as 35 people in a single room at once (77). These groups, called "convergence clusters" by the authors, were documented on as many as 17 floors of the hotel. Other behavioral studies were common prior to 9/11 as well. Sources (78-80) studied reactions to various fire alarms and/or exit choice, finding that evacuees tend to choose the most familiar exit (usually the main exit), regardless of the time it takes to get there. They also found that people react the most quickly to spoken alarms rather than simple sounds or bells.

It is clear from the discussion above that evacuation research is diverse in topic and scope. Studies have been performed on human behavior, evacuee characteristics, building components, and much more. However, studying fire evacuation is difficult and sometimes unattainable. Real fires cannot be used in experiments because they present hazards to participants. Additionally, it can be hard to obtain people willing to participate in research studies, especially those requiring diverse populations (studies related to age, gender, people with disabilities, etc.). They can also be expensive, and selected building types and components may not be available (investigated high-rise buildings in rural locations, tunnel studies in locations without metro or subway systems, etc.). For these reasons, recent research has moved toward studying evacuation through simulation and modeling. This has created an entirely new realm of information and data on fire evacuation. Beginning around 1980, simulation modeling was introduced as a viable option for dealing with complex issues in the fields of safety and health (81). In 1987, one of the first reviews on available computer models for evacuation analysis was published on network models[4] and algorithms using

[4] Network models are graphic representations of paths or routes by which objects or energy may move from one point to another (82).

an early form of EVACNET+ as an example (82). By 2010, there were 26 models recognized by NIST's Fire Research Division, all containing a vast number of special features (151). More recently, independent models have been created to explore special problems usually not capable of being analyzed by those available for public use. For example, very few models can simulate the interaction between a building environment, occupants, and combustion materials. Since environmental conditions and smoke distributions can significantly influence human behavior and capabilities during fires, Chinese researchers Tang and Ren (90) developed a GIS-based model to incorporate all essential interacting variables using rule-based behavioral modeling and dynamic fire features. Other recent independent models have focused on combining several complex dynamic phenomena associated with building fires, thus working toward more realistic simulations. Nguyen, Ho, and Zucker (83). integrated smoke effect and blind evacuation strategies within their model, confirming that a reduction in vision has a significant impact on the number of casualties in a fire. Filippidis et. al. (84) introduced occupant interaction with signage systems in their evacuation model, thus incorporating physical obstructions and some behavioral concepts. Sources (85-95) also incorporated human behavior in their evacuation models, studying everything from stress variation to decision making and group effects.

Evacuation research has progressed significantly in recent decades. From simple experiments to quantify walking speeds and evacuation times to current simulation and modelling practices that include complex decision-making capabilities and occupant characteristics, researchers are all in agreement that evacuation is a complex phenomenon including a wide variety of dynamic interactions between people and their environment. However, people with disabilities are still neglected. Nguyen, Ho, and Zucker studied reduced visibility due to smoke, but they did not incorporate blindness or those with other disabilities. The simulation and modelling studies incorporating human behavior are wide in scope, and all agree that occupant behavior plays a large role in how, when, and why someone chooses to evacuate, but they fail to include heterogeneous populations and those who make decisions differently than the neurotypical population. Similarly, case studies and investigations do not typically recognize those with disabilities and their evacuation strategies. The exception to this is the NIST 9/11 investigation, which recognized the roughly 1,000 people with mobility impairments that evacuated from the towers during the event. This mention was only in passing, however, as NIST explained that over one-half of people interviewed from WTC1 and one-third of those from WTC2 reported injured and/or disabled occupants as a constraint to their own evacuation in the stairwells (60). As the number of impaired and disabled people continues to grow due to an aging population, the obesity epidemic, and the push for equality, a more concerted effort needs to be made to include them in evacuation studies and experiments.

Disability

The wide number of evacuation studies focused on homogenous populations of non-disabled occupants suggests a significant push to improve fire safety and knowledge regarding building fires. But while there have been many studies focused on quantifying evacuation times, studying human behavior and decision-making, and the effects of smoke or low visibility for those without impairments, there is still a lack of research focused on those with disabilities. This is surprising for a number of reasons. First, PWD accounts for over 15% of the world's population (over one billion people) (96). Additionally, 2-4% of those with disabilities experience significant difficulties functioning; and the number of PWD will only continue to grow due to population aging, the rapid spread of chronic illnesses, and improvements in medical care (96). Second, the push for equality (both during the Disability Rights Movements and today) means an increased number of people with disabilities are working to reclaim their freedom in society. More PWD in all building types directly results in a more diverse building population with more complicated needs during disasters. Finally, researchers have already shown increased interest in human behavior during fire, proving that decision-making and development of inclusive evacuation procedures for the neurotypical and non-disabled population is difficult. With these reasons, as well as examples such as the NIST 9/11 study citing people with disabilities as a constraint to evacuation due to lack of inclusive evacuation procedures, an increased effort needs to be made to introduce those with impairments into fire research.

Despite the underdeveloped field of evacuation research for those with disabilities, several researchers have made an effort to include PWD in their reviews. Boyce et. al. (97) considered mixed populations as they reviewed design provisions and historical fires, noting that design guidance (mostly on exit and stair widths) is determined almost exclusively from largely non-disabled populations. Additionally, the authors stated that there is no international requirement to provide lifts as a means of evacuation despite being the preferred method in the UK (98). Narrow stair and exit widths combined with a lack of evacuation lifts can lead to congestion, blockages, and much more. Additionally, those who cannot evacuate via stairs are left waiting for help from colleagues or emergency personnel rather than evacuating on their own. Another recent study has focused on existing egress datasets with the goal of updating them based on changing demographics (99). The authors explain that existing datasets (for walking speeds, evacuation times, etc.) are outdated and based mainly on limited populations. Changing demographics and heterogeneous populations make the evacuation process more complex by changing rescue requirements for emergency personnel, increasing social pressures for help and assistance among other building occupants, changing overall evacuation performance, and producing a discrepancy between the required safe egress time (RSET) and available safe egress time (ASET) (99). In a final recent review, authors Bukvic et. al. (100) highlights the lack of research for those with cognitive impairments through a categorization of evacuation actions. Using a variety of case studies and experiments, common evacuation activities and procedures were identified (walking downstairs, crawling, information-seeking) and paired with a classification from the ICF, thus creating a database of evacuation activities and evacuee behavior.

The majority of evacuation research, including PWD is focused on physical impairments and easily quantifiable data, as shown from the previously mentioned reviews. However, those pertaining to wheelchair users are the most abundant. Studies (101-104, 110) performed evacuation experiments to determine how flow rates change as the number of wheelchair users increases. They each noted a significant decrease in flow coefficient as the number of wheelchair users increased, thus showing a clear difference between homogeneous and heterogeneous population dynamics in a fire. Other studies using wheelchairs are mostly based in hospitals in order to isolate as many physically disabled occupants as possible (105-106, 109). Still, others have focused on disaster preparedness and guidance for more efficient evacuation strategies (106-108, 111). Overall, experiments and simulations with wheelchair users at the forefront claim that they present the most challenges and barriers to safe evacuation for all because they take up more space, move slower on average than those without disabilities, and cannot navigate some building components.

Other studies, including people with physical disabilities, typically refer to one's limitation as a *mobility impairment*. They focus more on building components than the type of disability. For example, there are many experiments and simulations that study stair evacuation (107, 112-118). Several have gathered local movement speeds with average values ranging between 0.30-0.50 m/s, although individual speeds vary tremendously due to surface changes, congestion, aid or lack thereof, and assistance. Additional structural components studied include elevators or lifts. Occupant emergency elevators (OEEs) have long been suggested to benefit evacuation for all populations, as they were first introduced by NIST in 1914 (126). Now proven to aid in the evacuation of mobility-impaired occupants by allowing them to self-evacuate, studies using OEEs have shown a significant reduction in evacuation time as well as fatigue and exhaustion (107, 119-126). Additionally, they reduce the problems that arise with stair evacuations and devices. For example, when an evacuee is transferred to a stair chair, they give up their own independence and the ability to use their mobility aids. Furthermore, they must rely on other individuals to keep them safe. In much the same way, waiting for help in refuge areas also forces disabled occupants to relinquish their independence. One study found that people were uncomfortable with waiting for moderate periods of time for fear of being forgotten or isolated (127). Others have noted factors such as crowding, under-utilization, and a lack of understanding of refuge areas (131). Source (128) studied several combinations of structural components to determine the optimal number of stairwells, OEEs, and refuge floors. Using simulation, results showed that providing one refuge floor in combination with six OEEs and three stairwells allowed for 25% more people to evacuate. However, increasing the number of refuge floors resulted in congestion and long queues in the refuge area. Despite the clear disadvantages, refuge areas have been commonly implemented in the design of ultra high-rise buildings. In Hong Kong, they have been in use since 1996 (128). In the United States, the IBC requires all new construction to include an area of refuge unless the building is single-story, has a supervised automated sprinkler system, and has a wheelchair-friendly route out of the building (129). Elsewhere, refuge areas may be required every seven floors (130). This is because they can provide a temporary resting area for those with low stamina, act as a place of assembly for all occupants, and provide a safe waiting area for those requiring assistance to navigate stairs (97).

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Apart from physical disabilities, there has been some interest in sensory disabilities among evacuation researchers. This includes the blind and deaf communities as well as those with sensory processing disorders. For the blind and visually impaired, walking speeds both horizontally and downstairs were explored by authors Sorensen and Dederichs in 2013 (132). Their evacuation drill included 40 participants with different degrees of vision loss and found that recommended horizontal walking speeds present in the literature are typically much higher than results showed for the visually impaired (1.19-1.34 m/s compared to 0.75-1.18 m/s) (132). Experiments and case studies (133-135, 138-140) also explored occupants with visual impairments. Many of them noted that orientation (familiarity) and surrounding sounds are the most significant factors of evacuation. Loud fire alarms can prevent visually impaired evacuees from hearing ambient noise, thus depriving them of necessary cues to orient themselves (135-137). Auditory disabilities are wide in range and scope and can impede perceptions of fire alarms and other hearing emergency cues (135). For example, at a Russian boarding school for deaf children in 2003, 28 were killed, and 17 more were injured in a fire because auditory alarms were not heard (141-142). In another instance, a deaf teacher and her students were left in a classroom during a fire drill because the school issued only audible alarms (141). Thus, the ability to alert the deaf community of an emergency has been of great concern among researchers, and several studies have focused on alerting devices such as shaker beds and visual alarms (143-146). In a research study (143), a new vibratory device to wake sleeping occupants was proven to be up to 93% for the hard of hearing. Additional studies discussed in (145) show similar effectiveness for shaker beds.

Chronic medical health disorders and cognitive impairments or mental health disorders are by far the least studied forms of disability in evacuation research. This is likely because these disabilities are largely considered "invisible" and hard to quantify. However, one study evaluating evacuation performance of a variety of occupants (elderly, visually/hearing impaired, cognitively impaired, etc.) found that those with cognitive or intellectual disabilities required the longest time to make evacuation decisions, but their response (movement) time was the shortest (147). Another study suggests that long-term training and reminders seem to be the best approach to evacuating people with mental impairments (135). However, many trials are needed, and training must be repeated at regular intervals to ensure building occupants do not forget evacuation procedures. For people with chronic health conditions, evacuation can be challenging for a number of reasons. First, this group is diverse and complex, ranging from people with asthma to those with heart disease, cancer, or diabetes. Additionally, people with medical health disorders may require additional equipment, some of which must be powered by electricity. Finally, as mentioned, people in this group are hard to easily identify. All of these factors make it hard for researchers to study anonymously or without knowing individual characteristics. Thus, an unannounced evacuation drill or a non-biased experiment toward building occupants may be nearly impossible to achieve. No experiments or case studies for fire evacuation were found among those with chronic health disorders during this literature review. Studies primarily focused on disaster preparedness and the needs or development of impairments following disasters.

Simulation and modelling is also an important aspect of evacuation research for people with disabilities. However, to current knowledge, there has only been one model developed with the initial goal of studying PWD. The BUMMPEE model: *Bottom-Up Modeling of Mass Pedestrian flows—implications for Effective Egress of individuals with disabilities* was developed as a "platform for evaluating the environmental characteristics and population criteria used to include the diversity and prevalence of disabilities in the population" (153). BUMMPEE can incorporate the blind and deaf communities, the physically disabled, and some cognitive disabilities. Additionally, modified environmental characteristics such as routes, exits, and obstacles are included as they have been shown to have behavioral effects on disabled populations (153). While this model is a step in the right direction for the safe evacuation of people with all forms of disability, most, if not all, features can be simulated in other evacuation software such as Pathfinder (148), which do not have the main goal of simulating people with disabilities.

Discussion

Overview of Key Findings

Throughout history, people with disabilities have generally been overlooked in the social, economic, and legislative realms. This has only recently changed with disability rights movements around the world; and a push for equality in the public environment has created the need for updated building components and accessibility requirements. Legislation such as the ADA in the United States, the *Disability Discrimination Ordinance of 1995* in Hong Kong, and many more have allowed PWD to re-enter society and gain much of the freedom they lacked for so long. However, their needs are still often neglected in disasters. This is clear from the comprehensive review of existing literature for fire evacuation presented herein. Research is abundant for homogeneous populations of non-disabled building occupants, focusing on everything from high-rise buildings to human behavior and even boat or aircraft evacuation. For disabled occupants, much less information is available. Additionally, evacuation research for PWD is primarily focused on physical disabilities. There are few studies focused on cognitive impairments or chronic health conditions.

The unbalanced number of studies available between the disabled and non-disabled communities has identified a clear set of issues. First, many people with disabilities are neglected or altogether forgotten about in the fire. From the unwillingness of the non-disabled to assist those with impairments during the evacuation of the World Trade Center towers during 9/11 to the lack of studies focused on all forms of disability in disaster, those who need the most help are usually unable to get it. This includes those with chronic health conditions such as asthma, cystic fibrosis, or cancer. No studies devoted to these impairments were identified in the literature, despite several focused on smoke and toxic gases for the non-disabled. Of those for the non-disabled population, many have identified problems with smoke impairing vision and creating breathing issues that hinder safe evacuation. In fact, smoke inhalation has been considered as the number one cause of fire fatalities for many years (149-150). From this, one can only assume that for those with respiratory health conditions, the effects would be compounded.

Similar to chronic health conditions, mental health disorders are also rarely found in the literature. This is surprising due to the recent push among evacuation researchers to study human behavior in fire, as it can vary greatly among different people and populations. In the non-disabled population, for example, significant information-seeking behavior has been identified. People regularly look for signs of danger (smoke, other people evacuating, etc.) before attempting to evacuate. This leads to increased evacuation times and alterations in route choice, stairwell use, and other choices during the evacuation process. People have also been found to evacuate in groups, often called convergence clusters in the literature. While these groups may reduce stress for evacuees because they bond over shared experiences, they only increase queuing and congestion in buildings. These behaviors among evacuees are consistent and easy to identify. However, they continue to be difficult to quantify, especially for the disabled population. This may be why there are few studies focused on those with cognitive disabilities. Neurodiverse populations make decisions and find information differently than those without disabilities. However, because there are a limited number of current studies, it is unclear if they are consistent in their evacuation behaviors, choose exit routes in the same way as non-disabled populations, or even evacuate in the same time frame. Thus, it is all too important to begin studying those with cognitive impairments in fire.

This work also brought to light the need to identify structural aids and barriers to evacuation for all populations. For those without disabilities, stairs and elevators have widely been considered to assist in the evacuation. However, there are significant issues with overcrowding in stairwells, bottlenecks around corners and within doorways, and long waiting times for elevators. Additionally, fire signals such as alarms and lights have been proven to save lives during nighttime fires. However, they do not work for all populations. Those with sensory impairments require unique fire signals so that the visually impaired are not disoriented, and those with auditory impairments are alerted to the issue. Correct alarms may also ease decision-making issues for the sensory impaired by leading them to the most efficient exit rather than the most familiar exit. These issues have shown that the need for self-evacuation among PWD is imperative. Researchers have published several accounts of evacuees struggling to find help downstairs or afraid to wait in refuge areas for fear of being forgotten. If structural components can be tied to various categories of building populations, designers and fire safety engineers may be better able to plan for a variety of fire scenarios. This may also be better tackled if PWD are included in the building planning and construction phases. All too often, legislation and planning focused on helping people with disabilities is finished without ever consulting someone with a disability. This results in building designs that aim to reduce the difficulty of PWD to traverse public buildings but actually fail to provide an environment that benefits impaired occupants.

Finally, evacuation modeling and simulation have been consistently shown as one of the most effective ways to study and improve life safety in the built environment. Low cost, study efficiency, and ease of use are attractive features of most models, and they reduce the need for willing participants and desirable locations. Researching the evacuation of people with disabilities is a challenge in any fashion, but evacuation models give the ability to incorporate a wide range of impairments without seeking a study group in real life. With the introduction of virtual reality and artificial intelligence, using simulations to study evacuation has become even easier. Serious gaming has been implemented in several evacuation studies recently (154-157). These give researchers the ability to study human behavior with real evacuees but without the possible danger associated with a fire evacuation. Additionally, they present a more accurate representation of building fires for study participants, which in turn gives better results compared to real-time experiments that cannot use fire or simulations that only estimate behavior. Currently, many evacuation models do not incorporate the complexity of all human behavior in a fire scenario. However, their continued development and the implementation of virtual reality results may improve these significantly in the near future. Including heterogenous populations in these studies will only further improve evacuation models, allowing the research community to gain a better understanding of how to improve the future safety of everyone in the ever-evolving built environment.

Defining Disability

Also discussed in this review is the broad and long history of disability. Centuries of overlooked disabled populations and their societal needs have created a world in which many people do not understand disability, and it has ultimately resulted in the lack of a comprehensive definition of the term. This is apparent by the wide range of definitions adopted by organizations around the world. For example, FEMA's functional needs approach attempts to define the needs of people with disabilities following a disaster. The World Health Organization has also defined disability through the ICF by recognizing it as a complex entity resulting from both society and the environment. While these definitions provide an inclusive and overarching view of impairments for the general population, they fail to identify qualities that affect their safety in a fire. Thus, it is imperative that a new definition be introduced from an engineering and evacuation background. Divided into four parts, the following definition of disability was produced based on the available research for disabled populations in a fire as well as historical categorizations of disability (see **Figure 1**). Disability in relation to evacuation is therefore defined as follows:

1. *Functional Independence*: Related to the physical ability of one to evacuate a structure and inherently includes a building's organization and design components (stairwells, hallways, elevators, etc.) This part also encompasses any assistive technology required by an evacuee and in their daily life.

2. *Sensory Perception:* Related to the detection, interpretation, and response of an individual to environmental stimuli. This section of the framework involves the ability of one to understand and respond to exit signs, fire alarms, smoke, and other protective fire components and can be interpreted by an individual's requirement of alternative communication.

3. *Medical Health:* Related to an individual's personal medical needs and how they change due to a fire. This section includes the effects of smoke, flashing lights, and the evacuation process on someone's health.

4. *Social Cognition:* Related to rational thinking and the ability of one to make proper decisions during an emergency. The part includes mental health disorders and the interaction between building occupants.

None of the four items specify "applicable" forms of disability, leaving room for researcher interpretation. However, each can be generally applied to a group of disabilities if desired. The review of existing literature clearly identified physical disabilities as the most widely studied among evacuation researchers. Thus, *functional independence* loosely refers to physical and mobility impairments. This includes wheelchair-bound individuals, those with other gait irregularities, and those requiring assistive technology (oxygen, service animals, canes, etc.). The second most frequently studied were sensory impairments. *Sensory perception* refers to the deaf and blind communities but can include any sensory difficulties previously acquired or obtained during a fire event. Third, the *medical health* category can be applied to those with chronic illnesses and "invisible" disabilities such as seizure disorders or multiple sclerosis. Finally, *social cognition* is applicable to many mental health and cognitive disorders. Each section requires different actions during an emergency, but there is room for overlap as well. Many people with disabilities who require assistance evacuating may also need medical intervention during a fire event. Just as each individual's impairment or disability is unique, so is their safe evacuation path and procedure. Furthermore, each is inherently associated with structural components that restrict movement during emergencies. Identifying each part in future studies will allow engineers to extract the main element preventing an individual's safe evacuation.

The hope behind introducing a new definition of disability is for researchers and non-disabled occupants to be able to effectively categorize the needs of various disabilities in fire. If building components and evacuation aids can be placed alongside each section of disability, one can easily pair disability with the most effective method of evacuation. This may result in a more efficient evacuation for all populations, even when some are uneducated on disability needs in the built environment. This can also be extended to building designers and fire safety professionals. As mentioned, people with disabilities are rarely consulted in design processes. Referencing this definition (and a future tie to structural components) will help ensure the proper facilities are included in each new building. Finally, the ultimate goal of this research on PWD in fire is to allow everyone to self-evacuate during an emergency rather than waiting for help, which may never arrive. Providing the most beneficial structural evacuation aids for each person's disability is key to achieving this, and a new definition is just the beginning for evacuation researchers and professionals.

Limiting Factors and Research Challenges

Research on PWD can sometimes create an ethical dilemma. This may be why they have generally been overlooked in evacuation research. Regardless, very little is known by the general population about the majority of disabilities identified by the ADA and other organizations. This alone creates several challenges for professionals outside the fields of health and disability studies. The following points identify challenges that must be overcome by evacuation researchers, fire safety professionals, and engineers in order to achieve the main goals of this research.

- Inclusivity of all disabilities may not be possible for targeted research studies and time frames.

  While PWD forms a large portion of the world population, they are still small in number in some locations and buildings. This is due to the long and difficult history of disability which has historically not accepted them into society. Additionally, some forms of disabilities are rare, and others may not be willing to participate in research studies. With an already limited population-focused upon in this research, recruiting people of a wide range of backgrounds and disabilities is not always possible. Using simulation and modelling to reduce this challenge is a viable option, but as noted, many models do not accurately address behavioral components, diverse populations, and disabilities.

- Consultation with social science experts may be required for accuracy.

  Human behavior is often not the expertise of engineers and fire safety officials. This may be one of the reasons it is rarely explored in fire research. Evacuation research in itself is also multi-disciplinary. In order to fully appreciate the wide range of disabilities and behavior possible during a fire evacuation, consultation with experts is required. This increases the time frame and cost of research projects, but it will undoubtedly increase the accuracy and knowledge of building officials and design engineers as well.

- Extensive modification of evacuation and structural models may be necessary.

  As noted, many evacuation models and experiments lack the ability to fully represent the disabled population and their needs in a fire. This results in studies that only represent a small part of the population (typically wheelchair users and those with other mobility impairments) when in reality, the disabled population includes thousands of unique impairments. Additionally, behavioral aspects of evacuation (route choice, groups, etc.) are not extensively explored in evacuation models. Both of these points combined mean that evacuation simulations for PWD are not often accurate. Improving models requires the addition of more disabilities as well as behaviors through statistical analysis of building populations. Human behavior is also rarely predictable, requiring the use of stochastic capabilities in order to produce results based on probabilistic random distributions.

- Questionnaires and small-scale real-time experiments may be needed in order to assess current population views.

  Small-scale experiments involving real people produce the most precise results and opinions. With changing societal views of disability, they are even more important for fire research. Current population views and thoughts about evacuation are outdated in comparison to technological updates and building designs and, therefore, cannot be used to address the efficiency of evacuation procedures and components.

- "New" views on disability may be required as research findings develop and evolve.
  Only disability experts, social scientists, and people with disabilities understand the true extent of disabilities in society. This means that buildings, evacuation routes, and accessible features are often not designed with PWD in mind. The disabled population and field experts must be consulted in order to improve current designs, and educational efforts must be made among engineers and designers to better understand PWD.

Conclusion

This review has first provided a historical look at disability around the world. From traditional societal views of impairment to disability rights movements, and recent equality legislation, it is clear that the inclusion of people with disabilities in everyday life has progressed greatly in the past decades. However, building safety is still behind this trend. This has resulted in an increased risk of further injury and even fatality for PWD during disasters. Additional evacuation research of highly heterogenous populations is required to reduce this risk, and a comprehensive definition of disability for disaster researchers and engineers is the first step to achieving this. Based on this definition, a series of suggestions for future research is presented as follows.

- Identify accurately and quantifiable representations of all forms of disability in evacuation models.
  A connection between structural components and different types of disability is proposed. For example, people with physical disabilities often have difficulty traversing stairs. If researchers can accurately quantify how these evacuees use the structural component (time of use, method of use), they can be implemented into current evacuation models.

- Re-assess the widely accepted walking speeds of both the able-bodied and disabled populations as studied via real-time evacuation experiments.
  Currently, there are significant variations between published walking speeds of both the disabled and non-disabled populations. To more accurately address occupant needs during the evacuation process, a consensus must be drawn between published values. This may be done through new studies that focus on heterogenous populations and current building components, as some building codes and commonly used structural components have been updated in recent decades.

- Identify physical aids and barriers to the evacuation process.
  As drawn from this review, elevators are beneficial for people with physical disabilities, while stairwells present several challenges to self-evacuation. It is necessary to develop a more exhaustive list of aids and barriers such as these for all populations so that they may be identified as challenges during fires. By reducing the

level of challenge associated with certain disabilities and building components, a more efficient method of egress may be identified.

- Work to form engineering conditions that ensure the continued availability of required materials for people with disabilities during a fire and subsequent evacuation.
  From stair lifts to sufficient alarm systems and even ventilation systems, building systems that specifically address the needs of PWD are often not included. If engineers can better identify helpful evacuation systems and fire suppression systems, they can become the norm in public buildings around the world, thus reducing injury and fatality risks in building fires.

- Determine how to accurately model highly-heterogenous populations for fire evacuation.
  To date, there has only been one evacuation model produced with the specific goal of simulating the evacuation of PWD—BUMMPEE. Even so, it fails to include many forms of disability and even to simulate a combination of building populations. This is all too common in other models, which often only include homogenous populations of non-disabled evacuees. Thus, it is unknown how to properly include more representative views of building occupants in evacuation simulations. This may be explored through real-time observations of building populations or even virtual reality experiments.

It is the hope that by successfully fulfilling these research requirements, true equality may be achieved for people with disabilities in fires.

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Conflict of Interest
The authors declare no conflict of interest.

List of Acronyms and Abbreviations
ABA: Architectural Barriers Act (1968)
ADA: Americans with Disabilities Act (1990)
APA: American Psychiatric Association
ASET: Available Safe Egress Time
BMI: Body Mass Index
CDC: Centers for Disease Control and Injury Prevention
CRPD: Convention on the Rights of Persons with Disabilities
EDF: European Disability Forum
EU: European Union
FEMA: Federal Emergency Management Agency
HEED: High-rise Evacuation Evaluation Database

IBC: International Building Code
ICF: International Classification of Functioning, Disability, and Health
IDA: International Disability Alliance
IDC: International Disability Caucus
NCPEDP: National Centre for Promotion of Employment for Disabled People
NIMH: National Institute of Mental Health
NIST: National Institute of Standards and Technology
NYC: New York City
OEE: Occupant Emergency Elevator
PAR: Participatory Action Research
PWD: People/Person with Disability/Disabilities
RSET: Required Safe Egress Time
TEC: Tsunami Evaluation Coalition
UK: United Kingdom
UN: United Nations
UPIAS: Union of Physically Impaired Against Segregation
WHO: World Health Organization
WTC1: World Trade Center North Tower, Building I
WTC 2: World Trade Center South Tower, Building II

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