Smart and Sustainable Built Environment

Interactions and connections of safe egress factors in hospital designs

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Abstract

Purpose – This study examines fire safety design in hospitals, aiming to identify and understand the factors that influence its effectiveness through control and evacuation while addressing challenges related to patient mobility.

Design/methodology/approach – The study employs a qualitative narrative approach, systematically reviewing 130 relevant articles and research papers. Conducting a systematic literature review identified 10 key factors of safe egress in hospitals that affect patient evacuation. Then, through semi-structured interviews, 25 field experts confirmed those findings and added two more key factors.

Findings – This study found patient mobility rate and conditions as the most crucial key factor influencing safe egress apart from the other 12 factors which are occupant types, occupant behaviour, exit characteristics, interior layout, fire spread and fire cells, building fire-rated materials, required safe egress time/available safe egress time, fire detection and suppression systems, signs and evacuation elevators, building model simulation and staff training.

Research limitations/implications – This study's limitations include the non-inclusion of the most recent fire incident reports due to their unavailability to the public. Additionally, reliance on secondary data sources in some areas introduces the potential for inaccuracies. The scope of the literature review was also limited by language (English only). The robustness of the methodology followed mitigates the limitations of the study.

Practical implications – This study assists field professionals – including architects, fire engineers, consultants, medical staff and firefighters – as well as the general public, by providing critical design information to ensure the safe evacuation of all hospital occupants, particularly patients, thus participating in achieving the United Nation's goals of creating safe environments and fostering sustainable, resilient infrastructure while ensuring the safety of people of all ages. Moreover, the new factor of patient mobility conditions is an addition to the body of knowledge that would interest academics.

Originality/value – The novelty of the study identified patient mobility conditions as the key influencer for safe fire egress at hospitals while discussing the interrelations between the 12 critical factors.

Keywords Fire safety, Fire egress, Hospital architectural design, Hospital evacuation, Patient evacuation, Safe egress

Paper type Research article

1. Introduction

The primary goal of a hospital is to offer a comprehensive and fulfilling care system to all patients (Gabay and Ben-Asher, 2022). However, Charlier *et al.* (2021) explain that hospitals are inherently at risk for potentially dangerous fire incidents due to their high concentration of chemicals like sterilising agents, disinfectants, solvents, heavy metals, hazardous drugs and anaesthetic gases. Equipment failure is also a leading cause of fires in the United States, with the National Fire Protection Association (NFPA, 2016) attributing 2% of these to malfunctions in medical equipment. According to the NFPA (2016), 20% of

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the estimated 5,700 yearly structure fires in healthcare facilities in the United States occur in hospitals or hospices. Similarly, the National Health Service (2009) reported that 16% of all fires in the United Kingdom occurred in hospitals and medical centres. The United Kingdom has witnessed five major hospital fires, such as the 2008 Royal Marsden Hospital fire, which evacuated approximately 40,000 patients, excluding staff and visitors (Wapling *et al.*, 2009). In India, between 2016 and 2019, multiple hospital fires were reported, including at AIIMS in New Delhi, SAL Hospital in Ahmedabad, SMS Hospital in Jaipur, LNJP Hospital in 2019, SIC Kamgar Hospital in Mumbai, Kakinada Government General Hospital in 2018, RML Hospital in Farrukhabad, BRD Medical College in Gorakhpur in 2017 and SSKM Hospital and Medical College Hospital in Kolkata in 2016 (Sharma *et al.*, 2020). These fires, according to Sharma *et al.* (2020), are the result of various internal and external factors, such as chemical combustion, accidents, arson or natural events. New Zealand has also faced significant hospital fires, such as the 2020 surgical fire caused by faulty medical equipment (Martin *et al.*, 2021) and the 2002 fire at Waitakere Hospital's operating theatre (Waitemata District Health, 2002). One of New Zealand's deadliest incidents was the 1942 fire at Seacliff Mental Hospital, which killed 37 of 39 female patients in Ward 5 (Otago Daily Times, 2018). If large hospitals with poorly designed emergency exits experience major fires, the fatality rate could reach 95%, similar to the Seacliff tragedy (Sahebi *et al.*, 2021). The consequences of hospital fires are severe, especially considering the size and typical occupancy of these facilities. Sharma *et al.* (2020) noted that many major hospitals remain inadequately prepared for safe evacuation. Their interior layouts often do not support safe egress, with issues like patients being trapped on upper floors, inadequate smoke re-channelling due to centralised ventilation systems, malfunctioning announcement systems, insufficiently trained staff and challenges firefighters face in breaking windows or relocating patients with various medical conditions to safety. Though countries like New Zealand, Australia and the United Kingdom have codes and standards for fire safety, they do not address the safe egress of all patients in hospitals. Therefore, it is crucial to identify the key factors that impact safe egress design in hospitals during fire emergencies and understand how they affect each other to improve fire safety and ensure successful patient evacuations. This study addresses the research question: What are the key interacting factors affecting safe egress in hospitals and their interconnections?

2. Literature review

The following paragraphs display information found in the literature review on some of the factors affecting safe egress in hospitals. Among those articles, Fahmi *et al.* (2022) have summarised the key factors into 10. These include emergency interior layout, exit characteristics, occupants' flow rate, the required safe egress time (RSET)/available safe egress time (ASET) factor, fire control elements, building construction materials, software simulation, fire spread, elevators/signs and human behaviour during fire emergencies.

2.1 Interior layout

Hospitals are complex facilities with intricate interior layouts that pose unique challenges for fire safety and evacuation. Othman *et al.* (2024) highlight that hospital evacuations are particularly demanding for facility managers due to compartmentalised designs, long corridors and multiple departments. These features, along with reliance on specialised medical equipment, often obstruct evacuation routes and delay emergency responses (Fang *et al.*, 2022). The presence of immobile or vulnerable patients further complicates evacuation, making accessible exits and direct pathways essential. Poorly planned layouts can also accelerate smoke spread and hinder staff coordination. This underscores the need for fire-resistant compartmentation, intuitive wayfinding and designated refuge areas to support patient safety. Koo *et al.* (2013) emphasise that hospital designs must balance medical functionality with stringent fire safety standards.

Furthermore, reports indicate that nurses and staff may delay evacuation unless fire poses an immediate threat, particularly during critical care or surgical procedures. To mitigate such risks, hospitals incorporate fire cells to contain hazards. According to the *NZ Building Regulation C/AS3 (2014)*, escape route lengths must not exceed 20 m in dead-end paths and 50 m in open paths, with adjustments for intermediate floors and vertical transitions, as outlined in the regulations (Table 1).

2.2 Exit characteristics

Emergency exit routes are vital in ensuring safe and timely evacuation during emergencies, serving both as escape paths for occupants and access points for first responders like firefighters and police officers (OSHA, 2013). In hospitals, exits must support a diverse range of users – including non-ambulatory patients, staff and visitors – requiring wider doorways, clear access and features like ramps or evacuation lifts. Poorly marked exits, blocked paths or insufficient lighting can significantly impede evacuation, particularly during high-stress fire scenarios (Wurzer *et al.*, 2009). Effective exit design includes not only quantity but strategic distribution and capacity to prevent congestion and enable phased evacuations suited to different hospital zones (Kobes *et al.*, 2010). Clear signage and regular maintenance are essential to uphold functionality and support a smooth evacuation flow. According to the National Health Service (2015), every staircase in a healthcare facility must serve as an emergency escape route, not merely as accommodation access, and only staircases within atriums are exempt. This ensures that vertical evacuation remains possible under all conditions. Supporting this, New Zealand building regulations require a minimum of two stairways in healthcare facilities to maintain safety and ensure compliance with evacuation standards.

2.3 Occupants flow rate

The movement rates within a hospital vary depending on the individuals present and their specific speed of movement. According to Di Francesco *et al.* (2005), certain areas within a hospital experience significantly higher foot traffic than others. Di Francesco *et al.* (2005) elaborates that these spaces include the reception area, waiting rooms, outbound patient areas, the emergency room (ER) and the cafeteria (if available), as these spaces typically accommodate a high flow of people compared to other hospital departments. The ER, in particular, has the highest and most complex flow of movement due to the urgency and unpredictability of patient conditions (Forster *et al.*, 2003).

Table 1. A guidance on path dimensions to facilitate assisted patient evacuation

Minimum clear landing width (mm)	Minimum clear stair width (mm)	Minimum clear landing depth (mm)	Remarks
2800	1100	1950	Allows assisted patient evacuation only
2800	1200	1925	
2800	1300	1850	Allows assisted patient evacuation and restricted ambulant passing
3000	1400	1750	
3200	1500	1550	
3400	1600	1600*	Allows assisted patient evacuation plus ambulant passing
3800	1800	1800*	

Source(s): Authors' own work inferred from NZ building regulation C/AS3

2.4 The RSET/ASET factor

Choi *et al.* (2022a, b) define the RSET as the total duration, beginning at the moment of fire ignition, that occupants require to either fully evacuate a building or reach a protected exit enclosure. In contrast, the ASET refers to the duration between fire ignition and the onset of untenable conditions, with ASET typically being longer than RSET (Fleischmann, 2009). According to Schröder *et al.* (2020), ASET is determined by factors such as temperature, visibility and smoke toxicity within the escape routes. Various elements can influence or extend ASET, including the type and quantity of combustible materials (fire load), ceiling height, smoke ventilation systems, physical barriers such as downstands or smoke curtains and the geometry of the room where the fire originates.

2.5 Fire spread

O'Connor (2016) states that fire spreads rapidly in open spaces with simple interiors compared to areas with a denser sectional layout. Buildings with minimal interior structures burn faster than those with hallways and closed doors, as walls and doors act as barriers, trapping the fire and delaying the spread of flames and smoke that, if left unchecked, the fire will eventually burn through these structures and continue to spread, O'Connor (2016) elaborates. However, if left unchecked, the fire will eventually burn through these structures and continue to spread. Cheng and Hadjisophocleous (2011) explain that the characteristics of barriers between adjacent compartments determine the type of fire spread, directly influencing both fire severity and duration, and the fire resistance of these barriers plays a crucial role in containing the spread. According to Wu *et al.* (2024), temperature variations depend on the fire phase that has developed.

The *New Zealand Building Regulation (C/AS3, 2014)* requires at least two exits for every 50 occupants, each with a minimum width of 1200 mm, and allocates 10 mm of exit width per person. While this regulation assumes adequate capacity, it does not account for hospital-specific challenges. A standard hospital bed, roughly 980 mm wide (Active Health Care, 2025), fits tightly within these exits, allowing only one bed to pass through at a time. Additionally, with 50 occupants requiring an average space between 232 and 500 m^2 according to the *NZ Building Regulation C/AS3 (2014)*, the exit capacity becomes insufficient, particularly as exits are often dispersed across a broader floor area. Morse *et al.* (2015) note that this space could hold no more than 25 patient beds under realistic hospital conditions, suggesting overcrowding risks when regulations are applied generically. Moreover, the *NZ Building Regulation C/AS3 (2014)* permits only a 50% increase in exits for a 200% increase in occupancy, revealing a non-linear correlation.

In contrast, UK regulations adopt a more proportional approach. For example, doubling patient numbers requires a 1.5-fold increase in exit provisions. This more accurately reflects the escalating demands during evacuations. Time is another critical factor. Tinaburri (2022) recommend an RSET of approximately three minutes; however, Country Fire Authority Australia (2023) warns that fire and smoke can spread rapidly – flames advancing at 0.27 m/s and smoke at 36.5 m/min – especially through weak points such as windows and stairwells. While healthy individuals may evacuate at 1.4 m/s (Bejek *et al.*, 2006), most hospital patients are significantly slower. In large compartments, evacuation for immobile or assisted patients can take up to 25 min, depending on their condition and the availability of assistance, which greatly exceeds safe thresholds and increases the risk of smoke inhalation (Koo *et al.*, 2013).

This analysis highlights that New Zealand's regulations insufficiently address the realities of hospital evacuations as design teams often work only to the minimal code requirements (D'Orazio *et al.*, 2020). In addition, relying on general fire safety systems like sprinklers is inadequate (Poon, 2013). This indicates the presence of additional factors that influence the other factors, thereby providing a safer evacuation for all patient types during a fire.

2.6 Critical analysis of current practices

Current international practices in hospital fire evacuation demonstrate a growing recognition of the complex challenges posed by patient mobility and building design; yet, substantial variability remains across regions and regulatory frameworks (Bagaria *et al.*, 2009). While New Zealand's standards emphasise compartmentalisation and fire-rated materials within the C/AS3 acceptable solutions, leading countries like the United States (NFPA 101) and the United Kingdom (Health Technical Memoranda HTM guidance) have adopted more nuanced approaches as have global entities such as the Pan American Health Organization (PAHO). For instance, PAHO's "Hospitals Don't Burn!" guide prioritises horizontal evacuation and patient-centred drills, highlighting the importance of adaptive strategies tailored to vulnerable occupants (PAHO, 2014). The United Kingdom's intensive care unit (ICU) evacuation protocols further integrate clinician insights into emergency planning, demonstrating best practice in aligning clinical and fire safety considerations (Kelly *et al.*, 2021).

Despite these advances, many frameworks still rely heavily on prescriptive rules rather than performance-based methods, limiting their ability to accommodate dynamic evacuation scenarios, particularly involving mobility-impaired patients (Wu *et al.*, 2024). This gap is increasingly addressed by simulation tools such as Pathfinder and Fire Dynamics Simulator (FDS), which model both occupant movement and fire/smoke spread. Recent international studies utilising these tools reveal critical bottlenecks and evacuation delays related to patient mobility and staff assistance needs; yet, their integration into design codes remains limited. Moreover, empirical research employing virtual reality and real-world drills uncovers complex human behaviour patterns that challenge simplified assumptions in many simulation models.

Critically, most international standards lack harmonisation, with limited cross-jurisdictional adoption of best practices or simulation-informed policy. Non-English literature and region-specific constraints are often underrepresented, restricting the global applicability of findings. Therefore, there is a pressing need for broader international collaboration to refine patient-centred, simulation-backed evacuation frameworks that address diverse healthcare contexts and mobility profiles. This study's emphasis on patient mobility as a core design parameter fills a vital gap and aligns with emerging global trends towards inclusive, adaptive hospital fire safety design.

3. Research methodology

This study follows a systematic literature review (SLR) and analysis as well as expert confirmation through semi-structured interviews to achieve its aim. The study conducts a three-step process to produce its conclusion. The first step is to conduct an SLR to identify key factors from various articles globally, sourced from different research engines (Google Scholar, Research Gate, Scopus and Web of Science) as well as what is recognised and currently practised in New Zealand, as per the New Zealand's building regulations. A Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram is used to screen the articles reviewed to determine the articles that relate to/address the study topic directly. While a PRISMA diagram may sometimes lack detailed explanations for the exclusion of certain studies, offering only brief categorical reasons, it nonetheless provides transparency, reproducibility, visual clarity and structured reporting, thereby supporting the credibility and auditability of the systematic review process (Sohrabi *et al.*, 2021). The second step involves presenting the results from the reviewed articles to experts in the field through semi-structured interviews. This approach allows them to share their expertise, confirm the findings and add to them if necessary. The third step involves analysing the findings from both the literature review and expert confirmation to identify key factors, understand their connections and assess their impact on the safe evacuation of all patients in the event of fire.

The following paragraphs will reflect on the method of this study, expanding further into each of the steps mentioned.

3.1 Data collection

3.1.1 Systematic literature review. As previously outlined, the first step of data collection for this study is through a SLR of previously published research articles. It is helpful to understand the factors that influence patient safety in hospitals during a fire emergency. A SLR is a valuable tool allowing a methodical and transparent approach to aggregating information (Shittu, 2020). Furthermore, Webster and Watson (2002) note that a SLR fosters theory development, pinpointing areas saturated with research and highlighting gaps where further investigation is essential. The information needed for this study manifests qualitative value. This is due to the experiment-based research articles reviewed, as opposed to the qualitative ones found in the SLR. The SLR of this study includes addressing the New Zealand's building regulations for fire safety design in hospitals, as they are considered the fundamental guide to designing evacuations in buildings in New Zealand. Therefore, its predetermined measures for safe egress were vital to the SLR. The second part of the literature review is the previously published research articles. Figure 1 explains the screening steps undertaken to identify the articles relevant to the subject, which will be included for review and analysis in this study. The chart resulted in a review of a total of 130 research articles published between 1995 and 2024, all in the English language. The search string is ("hospital evacuation" OR "patient egress") AND ("fire safety Design" OR "Hospital layout" OR "fire protection") AND ("patient mobility" OR "mobility impairment")

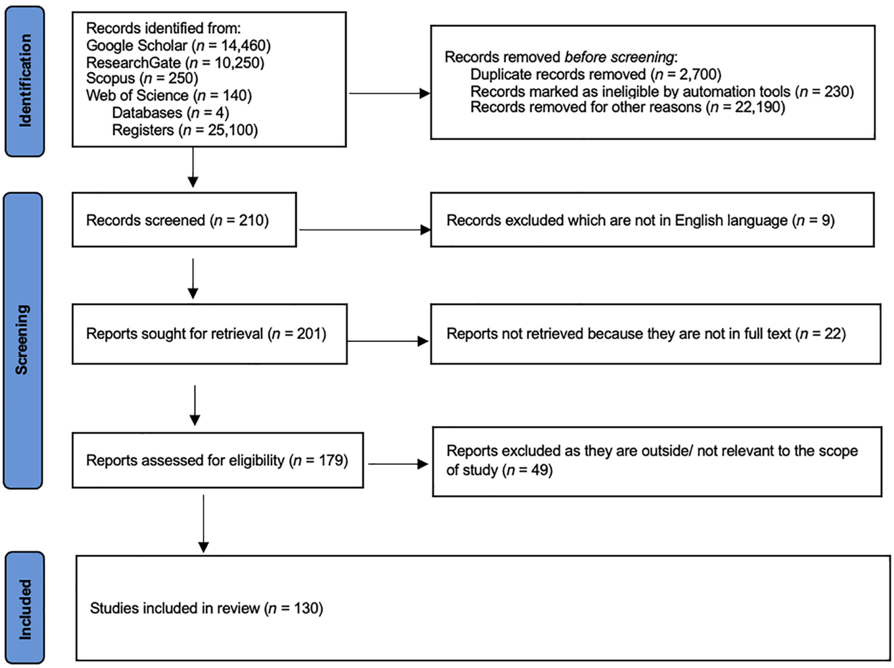

Figure 1. Research PRISMA diagram. Source(s): Authors' own work based on PRISMA guideline

3.1.1.1 Articles exclusion criteria.

(1) Articles that are not in the English language (no country exclusions followed)

(2) Articles that concern medical information and not architectural/engineering/building design information (irrelevant to this research topic)

(3) Articles that are not complete

(4) Articles that fall before 1995

3.1.2 Semi-structured interviews. Interviews give the most direct and straightforward approach to gathering detailed and rich data regarding a phenomenon (Barrett and Twycross, 2018). Therefore, the study follows a semi-structured interview path as its primary source of gathering information on evacuation in hospitals in the event of fire emergencies. It used purposive sampling to develop insight into the study question (Campbell *et al.*, 2020), reaching a total number of interviews determined by saturation at 22. Three more interviews were conducted for quality assurance, bringing the total number of interviews in this study to 25 experts in the field. The participants' professions fall under safety design consultants, engineers, doctors and nurses with 5+ years of experience across New Zealand. The semi-structured interviews follow a predetermined questionnaire form derived from the key factors of the safe egress process in hospitals, as identified through a SLR. Table 2 shows demographic and summary data of the professions of interviewees. Data are obtained using the narrative analysis (analysis of the experience shared by the participant to decode factors and connections) of semi-structured

Table 2. Semi-structured interviews – participants' demographic statistics

Participant code	Profession	Years of experience	City
P1	Hospital evacuation specialist consultant	10+	Auckland
P2	Evacuation consultant	5	Auckland
P3	Evacuation consultant	10+	Dunedin
P4	Fire protection officer	10+	Auckland
P5	ICU department head, medical doctor	10+	New Plymouth
P6	Senior architect	10+	Auckland
P7	Fire engineer	5	Wellington
P8	Fire engineer	5	Wellington
P9	Technical director – fire engineering	10+	Dunedin
P10	Head nurse	10+	Auckland
P11	Nurse	5	Wellington
P12	Building compliance manager/consultant	10+	Dunedin
P13	Medical staff	5	Wellington
P14	Architect	5	Auckland
P15	Medical staff	5	Wellington
P16	Medical staff	5	Wellington
P17	Medical staff	10+	Wellington
P18	Architect	10+	Auckland
P19	Medical staff	5	Wellington
P20	Engineer	10+	Auckland
P21	Engineer	5	Auckland
P22	Senior fire engineer	10+	Dunedin
P23	Senior fire engineer	10+	Christchurch
P24	Senior architect	10+	Christchurch
P25	Fire engineer	5	Auckland

Source(s): Authors' own work

interviews. Thematic analysis was used to identify recurring themes from interview transcripts. This is done through transcribing the interviews and then reading through the transcripts multiple times to familiarise oneself with the data. Next, recurring themes and patterns are identified and categorised through thematic analysis and coding of each interview segment using Excel. These themes, then, are reviewed and refined, ensuring that they accurately reflect the data through visual representation. A structured part of the interviews, requesting experts to rate factors of safe egress, was tabulated and statistically plotted on a Likert scale chart. This was done to showcase, describe the data variation and confirm the critical exit factors by comparing their identification in the SLR. This study employs the Likert Scale to facilitate the quantification of part of the qualitative data collected, resulting in a more statistically comprehensive analysis of opinions and attitudes (Joshi *et al.*, 2015). The Likert scale has been assigned a 5-point scale ranging from −2 to 2, indicating a scale from "strongly disagree" to "strongly agree", respectively. The mean value of each factor will be calculated based on the total score against the total number of interviews to determine which of the key factors has the highest effect on the safety of the patient during evacuation. Finally, the study acquires expert validation through re-examining the results of the interviews post-analysis, requesting confirmation of data presentation. This is to ensure the quality of the analysis process.

3.2 Quality control

The trustworthiness of this study was enhanced through careful design and execution. According to Petty *et al*. (2012), engaging a substantial number of experts strengthens research credibility, while Palinkas *et al*. (2015) highlight that validity stems from robust processes rather than post-hoc validation. In this study, validity was ensured by consistently applying a semi-structured interview protocol to 25 experts across New Zealand's healthcare, fire engineering and architectural sectors, each with over five years of experience. Participants were purposively selected, with snowball sampling ensuring diversity. Although geographically limited to New Zealand, their varied expertise offered rich, transferable insights. Ethical approval was granted by the Auckland University of Technology Ethics Committee (approval no. 23/279).

Triangulation enhanced reliability, combining a SLR, semi-structured interviews and expert validation. The review incorporated 130 peer-reviewed articles, official reports and numerical data, reinforcing credibility through diverse, high-quality sources. Although coding and thematic synthesis were conducted by the lead researcher, inter-rater reliability was strengthened through supervisory reviews of sample coding outputs, which refined the thematic framework and minimised subjectivity. A transparent audit trail documented literature selection, coding evolution and analytic decisions, ensuring traceability and reproducibility.

Likert-scale data from expert validation were the results of descriptive analysis to reveal consensus patterns, consistent with qualitative-dominant mixed-methods research where interpretation is prioritised over prediction. While inferential tests were not applied, descriptive analysis adequately supported thematic findings; future research could strengthen robustness through non-parametric analyses. The study acknowledges limitations, including the exclusive use of English-language sources and the absence of simulation validation. However, triangulation, peer review and rigorous documentation underpin the study's credibility, transparency and reliability. Collectively, these measures ensure that the methodological design is robust and provides a sound foundation for advancing the understanding of patient-centred fire safety in hospitals.

For consistency, fire spread was calculated using a speed of 2.4 m/s, and smoke spread was calculated using a speed of 6.25 m/s, representing a conservative estimate typical for confined hospital corridors based on NFPA data. Where other speeds were mentioned, these reflect scenario-specific variations documented in prior studies but do not alter the overall conclusions.

4. Results

The following diagrams highlight important information as concluded from a literature review of previous research articles and expert interviews. They show common themes, connections between factors and confirmation of key factors.

4.1 Systematic literature review

As previously explained, this study reviewed 130 articles addressing the subject of fire safety design in hospitals to identify key players. The summary of the most common themes/factors concluded from this systematic review, along with the total number of articles addressing those themes, as indicated by bar charts, is plotted in Figure 2. Tables 3 and 4 also *outline the expected foot traffic levels in different hospital departments and* deduce key elements that contribute to fire progression in different scenarios. The data in these tables help understand how fire spreads in different situations based on the occupancy levels of each affected department, which aids in fire risk analysis that is used for fire safety designs and evacuation procedures (Cheng and Hadjisophocleous, 2011).

4.2 Semi-structured interviews

One of the results of the semi-structured interview questions was that each participant rated the importance of safe egress factors in hospitals on a 5-point scale. This is done to provide statistical data aiming to answer the study question (Joshi *et al.*, 2015). Figure 3 displays the mean values of the Likert scale scores given by each of the 25 participants for each factor, highlighting the addition of two important factors marked in orange. For example, "Exit characteristics" factor is showing at 2, indicating that 100% of the 25 interviewed participants have given the highest score for this particular factor, meaning that it is unanimously acknowledged as a key factor of safe evacuation design in hospitals.

Another result of the semi-structured interviews is presented in Figure 4. Narrative analysis of the acquired data, where participants explained fundamental connections between key safe egress factors, has resulted in the presentation of factor categorisation and connectivity in Figure 4. Connectivity charts offer a visual representation of relationships and connections

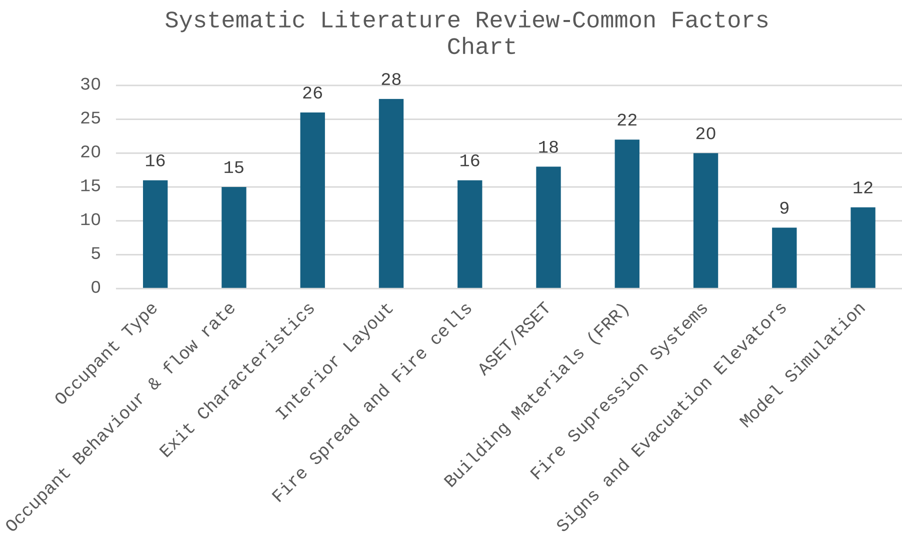

Figure 2. Identified common themes/factors in reviewed literature and the total number of articles addressing each theme. Source(s): Authors' own work

Table 3. Expected foot traffic in different departments within a typical hospital building

Departments in a typical hospital	Expected foot traffic (heavy, mid-heavy, light)
Reception	High
Waiting areas and cafeterias	High
Outbound patients	Mid-high
Radiology	Low
Physiotherapy	Mid-high
General surgery/operating rooms	Mid-high
Specialised surgery rooms	Low
Psychiatric	Low
Blood testing department	Mid-high
Podiatry	Mid-high
Emergency department	High
ICU department	Low
Cancer treatment department	Low
Dialysis	Mid-high to low
Pharmacy	High

<50 people = high foot traffic zones, 20–50 people = mid-high foot traffic, >15 people = low foot traffic zones

Source(s): Authors' own work

Table 4. Possible pathways of fire spread vertically and horizontally

Fire spread horizontally	Severity of spread	Fire spread vertically	Severity of spread
Through a wall connecting two compartments	Low	Through a ceiling connecting two compartments	Low
Through a closed door connecting two compartments	High	Through an opening, such as a stairwell connecting two compartments	Highest
Through an open door connecting two compartments	Highest	Outside flames projecting out of windows in the fire compartment, entering windows above	Highest
Fire spread horizontally	Severity of spread	Fire spread vertically	Severity of spread
Through a window connecting two compartments	Highest	–	–
From one compartment to another compartment, separated by a corridor	Lower	–	–

Source(s): Authors' own work

between key factors of safe egress, making complex information easier to understand and interpret (Divecha *et al.*, 2023). The figure displays the connections of each building-related factor to the three-occupant related factor, showing how each of them affects the occupants and their safety positively or negatively. For example, a hospital's interior layout, which can accommodate different types of patients (i.e. positive), negatively affects the patient mobility rate during evacuation (i.e. negative).

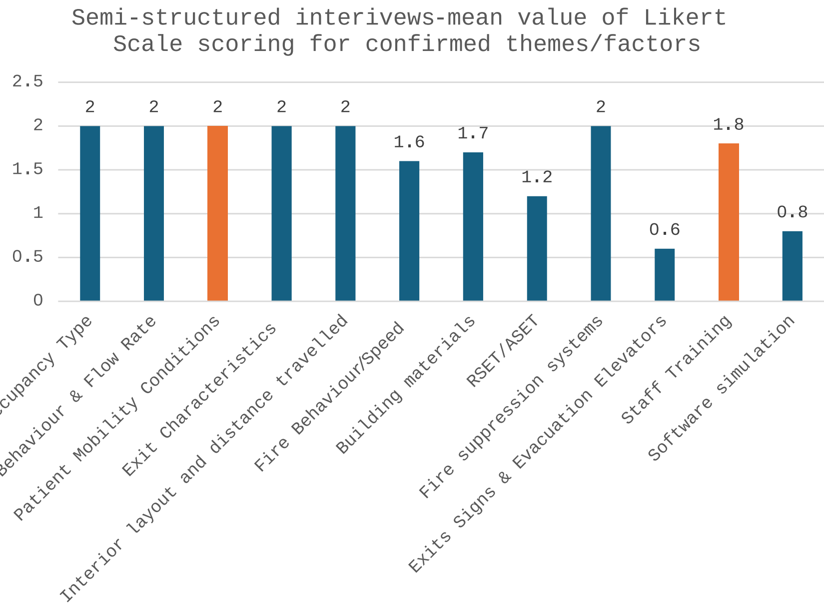

Figure 3. Semi-structured interviews – mean value of Likert scale scoring for confirmed themes/factors.
Source(s): Authors' own work

5. Discussion

The study identifies the key factors that influence safe egress in hospitals and addresses challenges. Thus, the key factors of safe egress design could be categorised into three sections: factors relating to people/hospital occupancy, factors relating to the hospital building itself and factors relating to technology and training. The following paragraphs delve into the key components under each section and their sub-categorisation, discussing how each key factor affects the others and, consequently, the safety of the patient evacuation process in hospitals.

5.1 Factors relating to people/hospital occupancy

5.1.1 Hospital occupancy types. Identifying occupancy types and their levels is determined as a vital factor of safe egress design in hospitals by 16 of the reviewed 130 articles and 100% of the interviewed experts, as shown in Figures 2 and 3, respectively. Hospital occupancy consists of three main categories: patients, staff members and visitors. Patients are the core of any hospital's care system. They can be categorised into fully mobile patients usually in the hospital as outbound patients, partially mobile patients who use crutches or another form of assisting device to move independently, conscious entirely immobile patients (completely bed-bound), unconscious entirely immobile patients (completely bed-bound) and psychiatric and paediatric patients (including toddlers and new-born babies). Staff are categorised into two groups: those dealing with patients and visitors, including nurses, orderlies, doctors, technicians and administrators/reception staff, and business staff, including administrators, hospital wardens and service workers (cleaners, shop and cafe operators, construction members etc.). The last category of hospital occupant types is the visitors who are identified as the general public (Rahouti *et al.*, 2020a, b). A typical "pre-COVID" hospital comprises 50%–60% of staff (including doctors, nurses, administrative staff, technicians and support staff), 20%–30% patients (including inpatients and outpatients) and 10%–20% visitors. This distribution is dependent on several factors, such as the size, type (Speciality hospital or teaching hospital), location of the hospital and the time of day (Foster *et al.*, 2003). However,

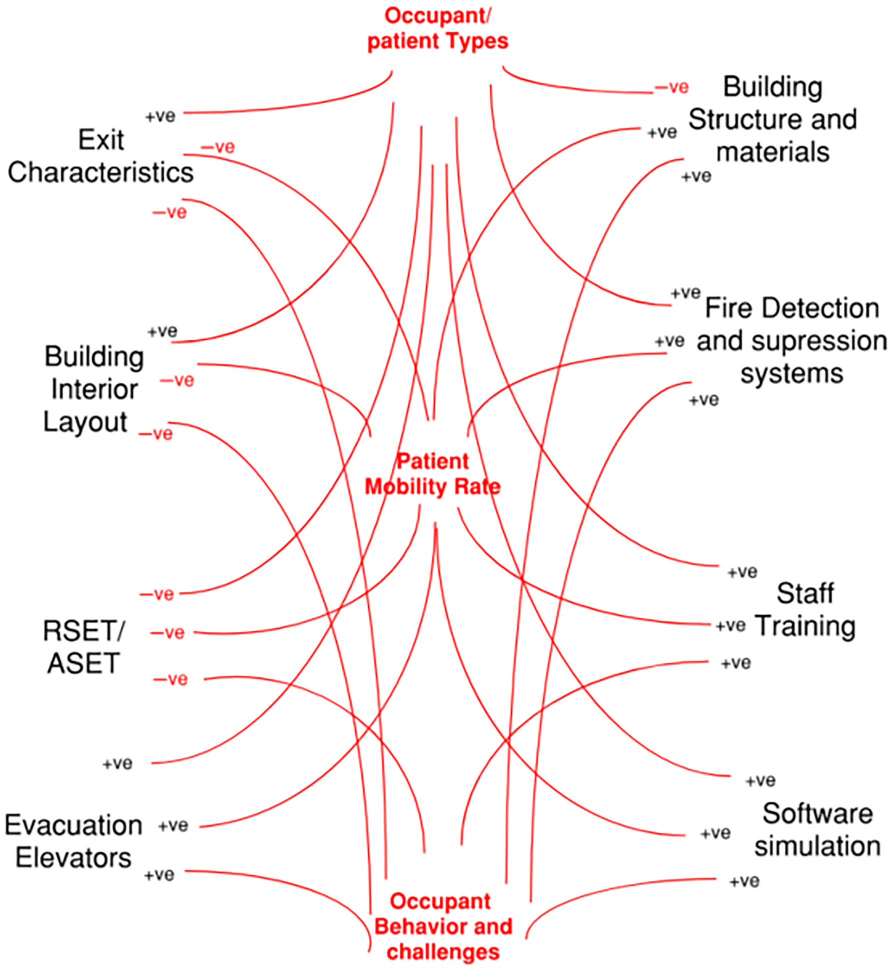

Figure 4. Connectivity Chart between factors. Source(s): Authors' own work

according to one of the experts interviewed, emergency department use and acute hospital admissions are growing "more than twice the rate of population growth", which has changed the typical nurse-to-patient ratio that was once 1:3, respectively, into 1:6 or more in terms of patients.

5.1.2 Occupant behaviour. Occupant behaviour has been identified as a key factor in safe egress design in hospitals, according to 15 research articles and 82% of the experts interviewed, as illustrated in Figures 2 and 3. In fire emergencies, occupant behaviour significantly impacts the safety and efficiency of hospital evacuations (Gerges *et al.*, 2017). According to one of the interviewed experts, hospitals present unique challenges due to the diversity of occupants, including staff, patients with varying levels of mobility and visitors unfamiliar with the environment. Staff behaviour is critical in such situations, as they are responsible for coordinating the evacuation, managing patients and ensuring that emergency protocols are followed. Trained healthcare staff play a dual role as they must protect themselves while assisting vulnerable patients, such as those in intensive care, surgery or unable to move independently. Therefore, pre-emergency planning is critical, and ensuring the staff is vastly knowledgeable of all emergency evacuation routes (main and alternative); moreover, emergency procedures cannot be overstated (Chien and Korikanthimath, 2007). According to Kuligowski *et al.* (2017), patients, especially those with limited mobility or cognitive impairments, pose a significant challenge during evacuations. Some individuals may require wheelchairs, stretchers or medical devices, which can slow down the process. In high-acuity settings like ICUs, relocating patients without jeopardising their health requires additional time and coordination. Patients may also experience heightened anxiety or confusion, which can impede their ability to follow instructions and may require personalised evacuation strategies. Table 5 displays some of the possible challenges faced by patients and staff as acquired from the interviews conducted. D'Orazo *et al.* (2020) explain that visitors can further complicate evacuations as, unlike staff, they may be unfamiliar with the hospital layout, fire exits or emergency procedures. In a panic, visitors might inadvertently obstruct hallways or delay the evacuation by attempting to remain with their loved ones. This behaviour can hinder staff's ability to move patients and access critical areas efficiently. Therefore, the behaviour of each occupant group in a hospital influences the speed and safety.

5.1.3 Patient mobility rate and patient mobility conditions. Patient mobility rate and condition are confirmed as the most critical considerations in the safe egress design of hospitals, according to experts interviewed. This factor significantly influences evacuation strategies during emergencies. While the literature has yet to examine this factor, 100% of experts interviewed have confirmed its significance and how it influences all other key factors discussed in the following paragraphs of this study. Hospitals house diverse populations with varying mobility levels, ranging from fully ambulatory individuals to those requiring assistance or specialised equipment for movement. According to one of the interviewed experts, this diversity necessitates an inclusive approach to egress planning, ensuring the safety of all occupants, particularly those with restricted mobility, as they require specialised evacuation measures such as those confined to beds, wheelchairs or undergoing critical care. Table 5 shows examples of mobility rates for different hospital occupants, especially patients, as well as potential issues encountered because of their medical condition. The design of exit routes, staircases and corridors must accommodate these needs, as explained by another interviewed expert. "For instance, stairways should be wide enough to facilitate the use of evacuation chairs, and landing areas should provide sufficient space for caregivers to manoeuvre equipment or assist patients. Similarly, elevators designated for evacuation must be fire-rated and equipped with backup power to ensure functionality during emergencies" *P4.* Eighteen out of the 25 interviewed experts have not only identified patient mobility rate and condition as a key factor, but they have also indicated that this factor alone can affect the performance and calculations of all other key factors. "It is the vital factor that dictates the success of the evacuation process of patients", *P12*.

Evacuating hospital occupants during a fire presents severe challenges, particularly for those with mobility impairments or requiring assistance. The data presented in Table 5 clearly show that many assisted or non-mobile patients move significantly slower than the rate at which fire and smoke spread at 2.47 m/s and 6.25 m/s (Qin *et al.*, 2024), meaning that they are at risk of being overtaken long before reaching safety. For instance, fire in unobstructed spaces can cover 20 m in approximately 10 s. In stark contrast, a fully mobile patient with no impairment moves at 0.93 m/s, requiring 10.75 s to cover 10 m and 32.26 s to cover 30 m (Rahouti *et al.*, 2020a, b), already slower than the rates of fire and smoke spread, as shown in Figure 5. The risk escalates for impaired patients: two-crutch users travel at 0.78 m/s, taking almost 13 s to reach 10 m (Jiang *et al.*, 2012), while a two-crutch user who is already 30 m away from the fire will be caught by it after 17 s, as shown in Figure 6. Evacuating assisted hearing and visually impaired patients is even slower at only 0.52 m/s, needing 19.23 s for 10 m (Rahouti *et al.*, 2020a, b). Immobile and unconscious patients are far worse as they move at 0.86 m/s when handled by male staff and 0.80 m/s when handled by female staff (Kwak *et al.*, 2021). This is due to the movement challenges met during evacuation, as shown in Table 5.

Table 5. Mobility rate and conditions of different types of hospital occupants and reaction times during fire and smoke spread

			Distance (in metres)	10	20	30	40	50
			Fire will cover set distance (in seconds)	4.05	8.10	12.15	16.19	20.24
			Smoke will cover set distance (in seconds)	1.60	3.20	4.80	6.40	8.00
Source	Occupant types	Occupant mobility conditions	Occupant speed (metres/second)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)
Rahouti *et al.* (2020)	Fully mobile patients/no impairment (unassisted)	Possible panic and falling over due to crowd evacuation	0.93	10.75	21.51	32.26	43.01	53.76
Boyce *et al.* (1999)	Fully mobile patients/No Impairment (Assisted)	Possible panic and falling over due to crowd evacuation	0.78	12.82	25.64	38.46	51.28	64.10
	Partially mobile patients							
Jiang *et al.* (2012)	One-crutch user	Possible issues with crutches, falling over while evacuating as well as patient behaviour (panic)	0.87	11.49	22.99	34.48	45.98	57.47
Jiang *et al.* (2012)	Two-crutch user	Possible issues with crutches, falling over while evacuating as well as patient behaviour (panic)	0.78	12.82	25.64	38.46	51.28	64.10
Brand *et al.* (2001)	Manual wheelchair (unassisted)	Possible issues with the wheelchair, patient fatigue from forced fast paced movement as well as patient behaviour (panic)	1.35	7.41	14.81	22.22	29.63	37.04
Brand *et al.* (2001)	Electric wheelchair (unassisted)	Possible issues with the wheelchair, equipment mechanism failure as well as patient behaviour (panic)	1.85	5.41	10.81	16.22	21.62	27.03

(*continued*)

Table 5. Continued

			Distance (in metres)	10	20	30	40	50
			Fire will cover set distance (in seconds)	4.05	8.10	12.15	16.19	20.24
			Smoke will cover set distance (in seconds)	1.60	3.20	4.80	6.40	8.00
Source	Occupant types	Occupant mobility conditions	Occupant speed (metres/second)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)
Boyce *et al.* (1999)	Wheelchair (assisted)	Possible issues with the wheelchair, patient fatigue from forced fast paced movement, as well as patient behaviour (panic)	1.30	7.69	15.38	23.08	30.77	38.46
Boyce *et al.* (1999)	Walking frame	Possible issues with the walking frame, falling over while evacuating as well as patient behaviour (panic)	0.81	12.35	24.69	37.04	49.38	61.73
Boyce *et al.* (1999)	Walking stick	Possible issues with the walking stick, falling over while evacuating, as well as patient behaviour (panic)	0.57	17.54	35.09	52.63	70.18	87.72
Sorensen and Dederichs (2015)	Audible and visual impairment	Possible issues with patient behaviour (panic), and patient miscommunication and errors during evacuation	0.9	11.11	22.22	33.33	44.44	55.56
Rahouti *et al.* (2020)	Audible and visual impairment (unassisted)	Possible issues with patient behaviour (panic), and patient miscommunication and errors during evacuation	0.52	19.23	38.46	57.69	76.92	96.15
	Immobile patients (conscious)							

(*continued*)

Table 5. Continued

Source	Occupant types	Occupant mobility conditions	Distance (in metres)	10	20	30	40	50
			Fire will cover set distance (in seconds)	4.05	8.10	12.15	16.19	20.24
			Smoke will cover set distance (in seconds)	1.60	3.20	4.80	6.40	8.00
Source	Occupant types	Occupant mobility conditions	Occupant speed (metres/ second)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)
Hunt *et al.* (2013 and 2016)	Evacuation chair	Possible issues with chair movement and mechanism, attached equipment (e.g. oxygen feed) and patient behaviour (e.g. panic). Patient may require monitoring after transfer	1.46	6.85	13.70	20.55	27.40	34.25
Hunt *et al.* (2013 and 2016)	Stretcher	Possible issues with stretcher movement and mechanism, attached equipment (e.g. oxygen feed) and patient behaviour (e.g. panic). Assisting staff may face difficulty in crowd management in the path of the stretcher. Patient may require monitoring after transfer	1.04	9.62	19.23	28.85	38.46	48.08
Hunt *et al.* (2013 and 2016)	Carry chair	Possible issues with chair movement and mechanism, attached equipment (e.g. oxygen feed) and patient behaviour (e.g. panic). Patient may require monitoring after transfer	1.50	6.67	13.33	20.00	26.67	33.33
Hunt *et al.* (2013 and 2016)	Rescue sheet	Possible issues patient condition and safety during handling, and patient behaviour (e.g. panic). Patient may require monitoring after transfer	0.89	11.24	22.47	33.71	44.94	56.18

(*continued*)

Table 5. Continued

			Distance (in metres)	10	20	30	40	50
			Fire will cover set distance (in seconds)	4.05	8.10	12.15	16.19	20.24
			Smoke will cover set distance (in seconds)	1.60	3.20	4.80	6.40	8.00
Source	Occupant types	Occupant mobility conditions	Occupant speed (metres/second)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)
Hunt and Weigh (2018)	Ski mat (with 2 handlers)	Possible issues with patient behaviour (e.g. panic). Patient may require monitoring after transfer	0.58	17.24	34.48	51.72	68.97	86.21
Hunt and Weigh (2018)	Ski mat (with 3 handlers)	Possible issues with patient behaviour (e.g. panic). Patient may require monitoring after transfer	0.95	10.53	21.05	31.58	42.11	52.63
	Immobile patients (unconscious)							
Kwak *et al.* (2021)	Handled by male	Possible issues with bed conditions (maintenance and operation), attached equipment (e.g. oxygen feed), patient health condition complications during transfer to safety and patient monitoring after transfer	0.97	10.31	20.62	30.93	41.24	51.55
Kwak *et al.* (2021)	Handled by female	Possible issues with bed conditions (maintenance and operation), attached equipment (e.g. oxygen feed), patient health condition complications during transfer to safety and patient monitoring after transfer	0.86	11.63	23.26	34.88	46.51	58.14
	Other assisted patients							

(*continued*)

Table 5. Continued

			Distance (in metres)	10	20	30	40	50
			Fire will cover set distance (in seconds)	4.05	8.10	12.15	16.19	20.24
			Smoke will cover set distance (in seconds)	1.60	3.20	4.80	6.40	8.00
Source	Occupant types	Occupant mobility conditions	Occupant speed (metres/second)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)	Occupant will clear set distance (in seconds)
Tomas and Lackey (2008)	Psychiatric patients (assisted)	Possible issues with patient behaviour (panic and self/others harm), patient health condition complications during transfer to safety and patient monitoring after transfer	0.40	25.00	50.00	75.00	100.00	125.00
Yao *et al.* (2023)	Paediatric patients (assisted)	Possible issues with patient behaviour of panic. Possible challenges and delays due to accompanying guardians. patient might require monitoring after transfer	0.55	18.18	36.36	54.55	72.73	90.91
Rahouti *et al.* (2020)	Staff Assisting (partially mobile patients)	Possible issues with human behaviour (e.g. panic), non-patient wheelchair users	0.52	19.23	38.46	57.69	76.92	96.15
Kwak *et al.* (2021)	Staff (assisting fully immobile patients)	Possible issues with human behaviour (e.g. panic), non-patient wheelchair users	0.93	10.75	21.51	32.26	43.01	53.76
Rahouti *et al.* (2020)	Staff (non-dealing with patients)	Possible panic and falling over due to crowd evacuation	1.06	9.43	18.87	28.30	37.74	47.17
Rahouti *et al.* (2020)	Visitors and general public	Possible panic and falling over due to crowd evacuation	1.06	9.43	18.87	28.30	37.74	47.17

Source(s): Authors' own work

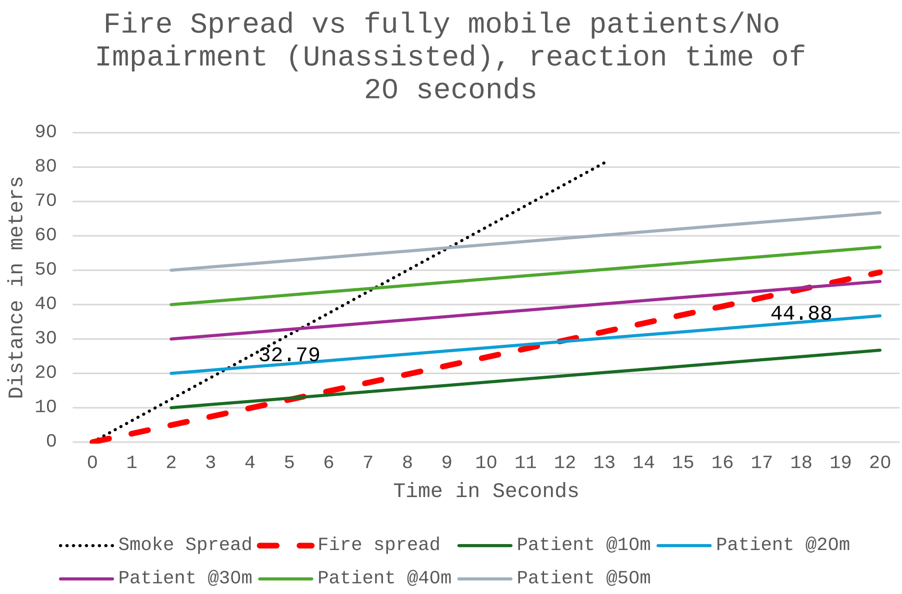

Figure 5. Fire spread versus fully mobile patients/no impairment (unassisted), reaction time of 20 s. Source(s): Authors' own work

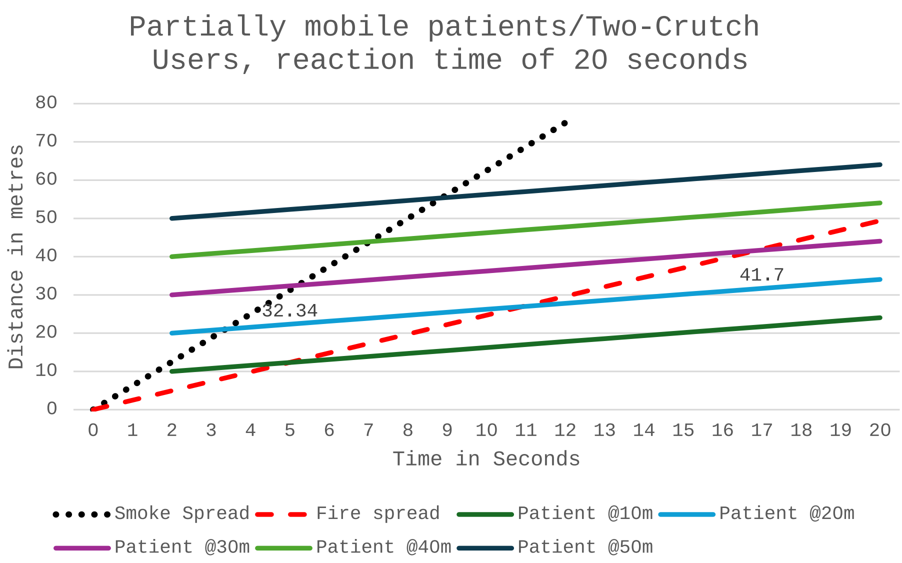

Figure 6. Partially mobile patients/two-crutch users, reaction time of 20 s. Source(s): Authors' own work

This means that if the fire ignited 30 m away from a ward of unconscious immobile patients, flames would still catch up to them after 8 s of evacuation initiation, as shown in Figure 7. Other vulnerable groups include psychiatric patients evacuating at 0.54 m/s, resulting in 18.52 s for 10 m (Tomas and Lackey, 2008), and paediatric patients (assisted) at just 0.55 m/s,

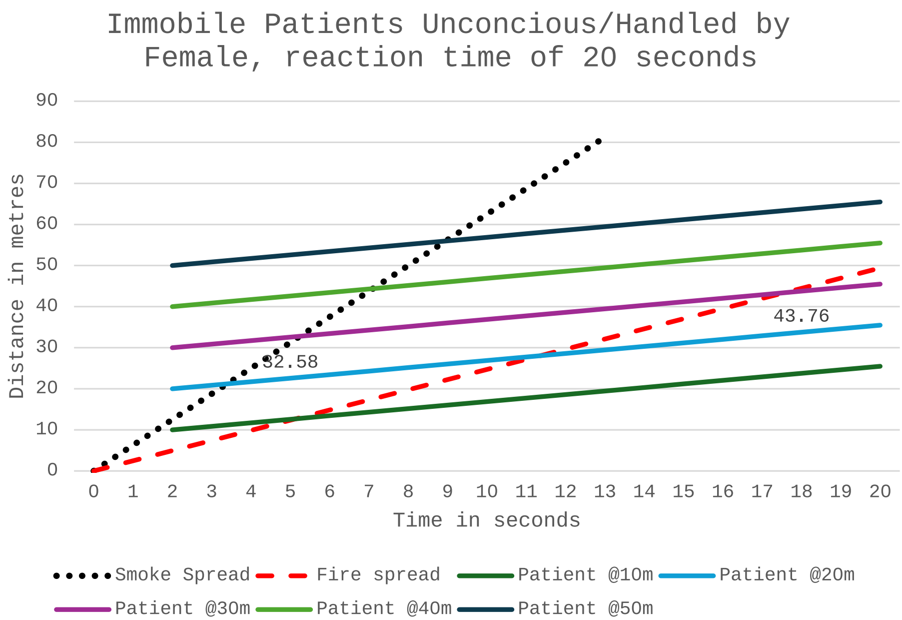

Figure 7. Immobile patients unconscious/handled by female, reaction time of 20 s. Source(s): Authors' own work

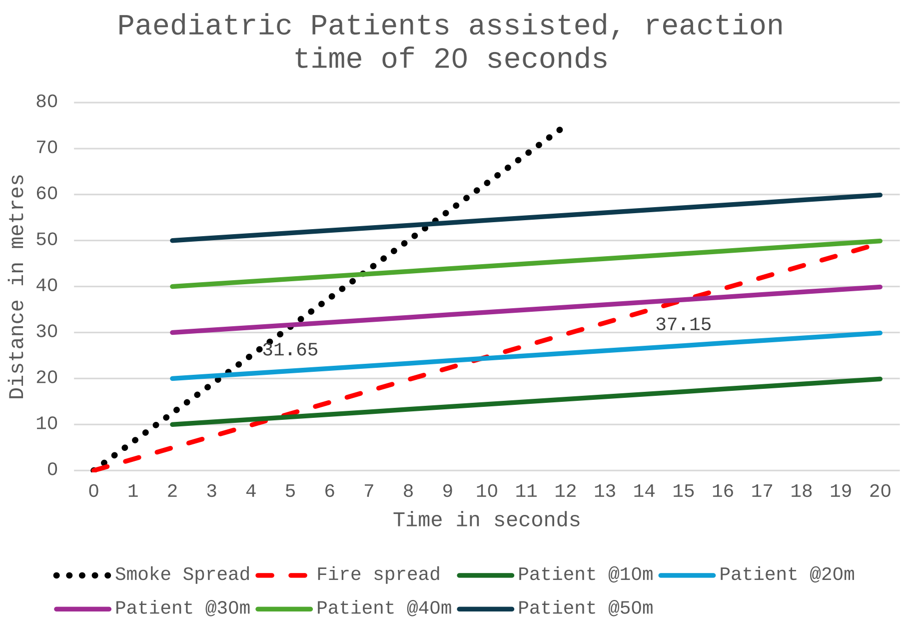

Figure 8. Paediatric patients assisted, reaction time of 20 s. Source(s): Authors' own work

evacuating 10 m in 18.18 s (Yao *et al*., 2023), as shown in Table 5. This means that with fire igniting 30 m away, it will catch up to them after 5 s of evacuating, while smoke will catch up to them in only 5 s, as shown in Figure 8.

This stark speed differential reveals a critical issue: in an unobstructed environment without smoke control or suppression systems, many patients, especially those who are assisted or immobile, cannot physically move to safety before smoke engulfs their path as shown in Figure 9. Even under optimal staffing and without obstacles, the slowest groups take three to four times longer than smoke to traverse short distances. This means that in situations where sprinkler or smoke extraction systems fail, or where fire growth is rapid, mortality risk escalates sharply. The overreliance on suppression systems in hospital design compounds this vulnerability. While sprinklers and compartmentation can delay smoke spread, system failures – whether due to mechanical malfunction, inadequate maintenance or a fire load exceeding system capacity – remove the only buffer these patients have. In such cases, evacuation times vastly exceed ASET, making fatalities almost inevitable. The data underscore that current fire safety strategies often presume ideal system performance, which is unrealistic in every incident. Without integrating design measures that reduce travel distances, enable vertical and horizontal refuge areas and improve assisted patient transport speeds, hospital fire safety will remain dangerously contingent on suppression systems functioning perfectly, a gamble that history shows is too often lost.

5.2 Factors relating to the hospital building itself

5.2.1 Emergency exit characteristics. Twenty-six reviewed articles identify emergency exits and routes as vital factors for successful emergency evacuation. Furthermore, 100% of interviewed experts strongly agree and validate that this factor is crucial in designing fire safety in hospitals, as illustrated in Figures 2 and 3, respectively. Emergency exit doors and routes are essential for providing a clear, safe way to evacuate any building in crisis or disaster, including hospitals, which is crucial for staff, patients, visitors and firefighters (Charlier *et al.*, 2021*)*. As previously explained, the current New Zealand's regulation requires a minimum requirement of two exit routes for 50 patients and a minimum of three for 150 patients, and a minimum height of 2,100 mm. However, according to one of the experts interviewed and as previously noted in Section 5.1.3, patient mobility rate and the conditions associated would require a change in these dimensions to ensure safe evacuation. Many of the hospital departments have different types of occupancy, from fully mobile staff and visitors to different

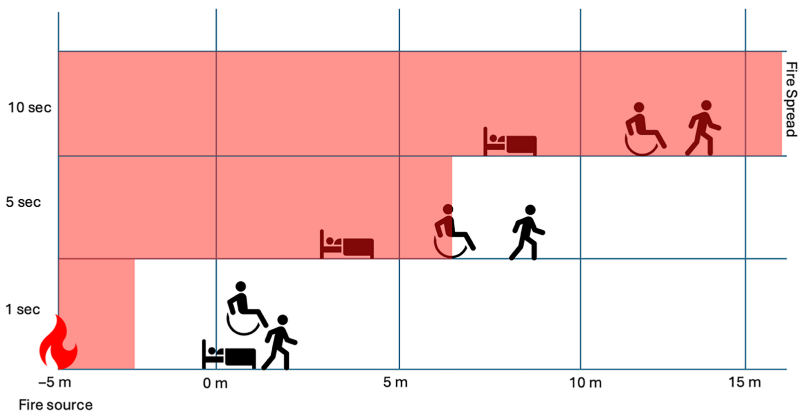

Figure 9. Fire spread versus patients with different mobility rates when the fire source is 5 m away. Source(s): Authors' own work

levels of assistance requiring patients (including bedridden ones). An efficient architectural design for evacuation routes should accommodate all types at the same time, allowing them to safely evacuate with no obstructions. External dimensions of the biggest hospital bed (for bariatric patients), according to Active Healthcare New Zealand (2025), are 1,100 mm in width and 2,200 mm in length. Therefore, experts suggest that the exit route width should be a minimum of 1,910 mm, allowing all types of hospital beds to be evacuated (including bariatric patient beds at 1100 mm) as well as maintaining enough space to evacuate fully mobile personnel in the departments (added 810 mm) without being held back by blocked routes when moving beds. Distance travelled should be the shortest to the nearest safe fire cell (avoiding the fire cell adjacent to the source of fire) to shorten the time that the patient is in transition and to ensure the ability to evacuate the rest of the patients in danger promptly.

5.2.2 Building interior layout. Internal layout of any structural building heavily influences its safety performance during fire evacuations, especially in hospitals (Notake *et al.*, 2001). Twenty-eight articles out of 130 identified building interior layout as vital for emergency evacuation success, and all of the interviewed participants strongly agreed and validated that this factor is key in fire safety designing in hospitals, as shown in Figures 2 and 3, respectively. *New Zealand Building Regulation C/AS3 (2014)* identifies that fire cells can either enclose a single space of one horizontal level or a space containing an intermediate floor in between, stating that vertical paths shall have minimum widths at any point determined only by the largest total occupant load passing that point in the direction of escape from. The design guide then specifies that the maximum travel distance before choosing escape routes should be no more than 15 m for inpatient accommodation or 18 m for all other parts of healthcare buildings. However, interviewed experts have confirmed that the routes would alter in the design phase when patient mobility conditions are considered as a key factor of evacuation planning. The recommended evacuation time for a fully immobile (bedridden) patient ward is 25–30 min, given that the fire suppression systems and smoke control are activated (Participant 3). They continue to explain that a full dependency on these systems is not recommended; thus, horizontal evacuation should take less than 25 min for an immobile patient. Therefore, the size of the fire cell should be determined based on the occupancy mobility rate, allowing for the least number of fully immobile patients per fire cell (calculated total number of patients that hospital staff can successfully evacuate in 25–30 min). Wards with fully immobile patients (conscious and unconscious ones) should open to a total open path exit route, avoiding vertical movement through stairs as much as possible (Fang *et al.*, 2022). Interviewed experts explained that the layout should allow for fire cells with fully immobile patients to evacuate to the nearest second safe fire cell and not the one adjacent to it. This issue reduces the number of staged evacuations in one department if the fire is deemed more dangerous or reduces the evaluation to a single stage only. Hence, this reduces the load of evacuated patients in each stage. According to the experts, the length/distance travelled of the path should be inversely proportional to the types of patients and their care conditions, meaning that the more the patient's health was dependent on portable support (i.e. oxygen tanks), the distance travelled should become shorter. Hospital evacuation routes, according to the experts, shall be free of all obstructing elements such as businesses (e.g. cafes and retail), bed parks or other elements of furniture that might cause a bottleneck effect during evacuation. The evacuation route layout shall be distributed for different routes around the common hospital streets.

5.2.3 Fire spread and fire cells. Fire spread is identified as a critical factor influencing safe egress design in hospitals by 16 articles reviewed, as shown in Figure 2, and confirmed by 80% of experts, as shown in Figure 3. Hospitals house diverse populations, including non-ambulatory patients, staff and visitors, requiring tailored fire safety strategies. Effective egress design must minimise fire spread to protect occupants during evacuation and ensure sufficient time for all to reach safety (Bag and Ganguly, 2023). Thus, containment strategies and fire cells play a vital role in limiting fire spread. A fire cell is a designated area within a building/hospital that is designed to contain a fire and prevent it from spreading to other parts of the structure. It is enclosed by fire-resistant barriers, such as walls, floors and doors, that have a specific fire resistance rating (FRR) designed to delay the spread of fire or prevent it entirely (BRANZ, 2022). Fire spread is categorised into three types: *Internal Horizontal Fire Spread*, which occurs across floors; *Internal Vertical Fire Spread*, which takes place via stairwells, elevator shafts, service ducts or structural breaches, allowing flames and smoke to travel between floors; and *External Façade Fire Spread*, which propagates through external cladding or materials on a building's exterior, often ignited by an internal fire breaking out through windows or gaps (Rahmani and Salem, 2020). Table 5 shows different scenarios of fire spread. Therefore, fire cells, including stairwells and corridors, as primary evacuation paths, must be designed to be fully enclosed and resist fire and smoke infiltration. For instance, smoke-sealed doors, pressurised stairwells and adequate landing spaces facilitate both horizontal and vertical movements, crucial in hospitals with high-rise configurations. These measures prevent bottlenecks and accommodate assisted evacuation devices, such as wheelchairs and stretchers.

5.2.4 Building fire-rated materials/elements. Hospitals employ fire-resistant construction materials and compartmentalisation strategies, dividing buildings into discrete zones using fire-rated walls and doors. This approach aligns with established fire safety principles as it significantly slows fire propagation and creates temporary refuge areas for patients who cannot be evacuated immediately (O'Connor 2016). Twenty two out of 130 reviewed studies emphasise its role, as shown in Figure 2, and 85% of interviewed experts confirmed its practical importance as a key factor of safe egress. The importance of fire resistance level (FRL) or FRR in managing the spread of fire, smoke and heat is well supported. FRL defines the duration for which structural elements can withstand fire, offering critical time for evacuation and fire-fighting interventions (Nyman, 2002). There is alignment in the literature regarding the significance of tailoring fire cell design and passive fire protection strategies to the specific occupancy types and evacuation challenges present within each zone of the hospital. For instance, *New Zealand's Building Regulation C/AS3 (2014)* stipulates a standard FRR of –/60/60 for hospital occupancy, including walls and glazed components. However, a point of contention raised by several experts in this study is that these minimum standards may be insufficient for high-dependency areas like ICUs, where patient mobility is significantly restricted. Interviewees advocated for increasing life safety ratings to 120 min in such wards, highlighting a gap between regulation and practical evacuation needs.

Additionally, regulations mandate that all components forming the fire cell envelope – including doors and HVAC mechanical dampers – must meet the same fire rating to ensure a fully enclosed space capable of containing smoke and flame for the designated time (*New Zealand Building Regulation, C/AS3, 2014*). This is particularly important in hospitals, where adjacent fire-safe compartments are relied upon for phased evacuation strategies. The integration of automatic fire dampers in HVAC systems helps to restrict the lateral and vertical spread of smoke through ductwork, a practice supported by both empirical findings and regulatory standards (Cheung *et al.*, 2006). Proper fire-stopping in service shafts and routine maintenance are similarly essential in preventing structural vulnerabilities, which could enable fire spread, including fire-resistant glazing, automatic shutters and adequate separation between façade cladding and internal combustible materials (De-Ching *et al.*, 2011).

5.2.5 RSET/ASET. Another factor identified as a key player in the success of egress performance on buildings, through 18 articles reviewed, is RSET/ASET, as well as being confirmed by 85% of interviewed experts. RSET is the amount of time (also measured from fire ignition) that is required for occupants to evacuate a building to the exterior of the building/fire cell. At the same time, ASET is the amount of time that elapses between fire ignition and the development of untenable conditions, and it is usually greater in value than the RSET (Horasan, 2002; Guanquan and Jinhua, 2006). Tinaburri (2022) indicate an average of 3 min as an ideal time to reach the exterior of the building in case of fire or hazards taking place inside the building in a fully able-bodied escapee situation. According to Babrauskas *et al.* (2010), the ASET's criteria are temperature, visibility and toxicity of smoke within the fire escape routes. The ASET can be altered or extended based on many factors, such as the type and amount of combustible material/fire load, ceiling height, smoke ventilation systems, physical barriers like down-stands/smoke curtains and the geometry of the room of fire origin. Babrauskas *et al*. (2010) explains that these factors are embedded into modelling software (a fire engineering approach) that utilises the layout of the building in the early stages of architecture to identify the proper ASET considering the design in question. This helps provide adequate fire safety factors in the early design of the hospital. Egressing the building in less than 5 min in case of emergencies is optimal, according to interviewed experts. However, smoke spread is the most dangerous element to look out for, especially with the different mobility conditions of the patients, which, if not factored in, "would cause a delay in the actual evacuation time of patients, decreasing the ASET coefficient" *P3*. Therefore, as previously stated in Section 5.1.3, factoring patient mobility rate and condition into early calculations can affect ASET value and, therefore, the evacuation plan to ensure the safety of all patients.

5.2.6 Fire detection and suppression systems. Fire detection and suppression systems are a key factor in safe fire egress in hospitals, as they aid in early detection and alert staff/ appropriate authorities (firefighters) to the danger, enabling them to respond quickly and protect the building and its occupants. Twenty articles out of 130 reviewed identify fire detection and suppression systems as vital for emergency evacuation success as well, and 100% of interviewed experts confirmed this key factor. Fire detection and suppression systems, such as sprinklers and alarms, are equally vital. Early detection systems provide critical lead time for initiating evacuations, while sprinklers help suppress fire spread, ensuring that evacuation routes remain accessible (Sahebi *et al*., 2021). *New Zealand Building Regulation C/AS3 (2014)* requires the installation of a Type 7 automatic fire protection system to comply with the NZS 4541 standard (latest update: NZS:2013). The system must consist of two independent supplies, one of which is not dependent on the town mains (alternative reservoir). Fire sprinklers should be laid out in each room with a distribution of 1.5–2 m in between in a grid form, depending on the design of the department, and one detection sensor should be placed per room (disregarding rooms experiencing certain high temperatures to operate adequately). An interviewed expert explains that all under-ceiling obstructions for these systems, such as curtains or other installed devices, must be lowered or removed, if possible, to ensure that these sensors can detect and activate when needed without delay. "One of the obstructions that is usually overlooked is the existence of full-length curtains used around patient beds" *(P14, 2024)*. The expert continues to explain that lowered curtain rails should be used to avoid obstructing heat/smoke detection as well as sprinklers. Patient mobility rate and condition affect the number of fire suppression systems to increase ASET value and, therefore, ensure patient safety (Poon, 2014).

5.2.7 Exit signs and evacuation elevators. Exit signs and specialised evacuation elevators are critical components of safe egress design in hospitals, as identified in nine reviewed articles and 65% of interviewed experts in the field, as they enhance visibility, guidance and accessibility during emergencies. Exit signs are essential for guiding occupants to safety during emergencies, particularly in smoke-filled or low-visibility conditions (Jung *et al.*, 2017). In hospitals, these signs are strategically placed at critical junctions, corridors and doorways to direct patients, staff and visitors towards the nearest exits. Illuminated or photoluminescent exit signs ensure visibility even during power failures, often supported by backup generators. Compliance with standards such as NFPA 101 ensures uniformity and effectiveness (Luh *et al.*, 2012). In addition, hospitals often employ dynamic signage systems that adapt to the nature of the emergency, such as directing occupants away from blocked routes or areas of higher risk. Conventional elevators are typically deactivated during fires due to the risk of shaft fire spread and power failures; however, specialised evacuation elevators are designed to operate safely during emergencies, providing a critical evacuation solution for non-ambulatory patients and those requiring medical equipment (Boonngam and Patvichaichod, 2020). These elevators are equipped with fire-resistant shafts, dedicated power supplies and emergency ventilation systems to ensure safe operation under extreme conditions. Access control prioritises operation for emergency elevators and can designate selected elevators for trauma units and hygiene-sensitive transport (Choi, 2022). Interviewed experts as well as literature have agreed that when evacuation elevators are paired with clearly marked staging areas, it is easier for hospital staff to prioritise patient evacuation into safety efficiently based on their mobility rate and conditions of movement (Koo *et al.*, 2013).

5.3 Factors relating to design and training

5.3.1 Staff training. Staff training is a crucial component of the safe egress process in hospitals, as confirmed by 100% of interviewed experts (Figure 3), ensuring that employees can respond effectively during emergencies (Sahebi *et al.*, 2021). "It plays an immensely important role in the overall success of the evacuation procedure, and its full potential has not been realised yet in current hospital protocols", *P21, elaborating that there is still room for development to improve evacuation training effectiveness in hospitals*. General effective training programs equip staff with the knowledge and skills needed to execute evacuation protocols confidently, including familiarising them with fire safety systems, such as alarm triggers, fire suppression systems and smoke compartmentalisation features (Jung, 2022). *Thus, hospital* training should also cover the use of specialised fire control systems, evacuation equipment and crowd control and management. Interviewed experts insist that regular fire drills reinforce skills needed in these situations, helping staff practice coordination and communication under simulated emergency conditions. When assessing patient needs, it is essential to determine the most efficient evacuation strategies, such as horizontal evacuation to adjacent smoke compartments or vertical evacuation using fire-rated stairwells or evacuation elevators. Interviewed experts explain that this will be achieved through identifying patient mobility conditions at an early stage and training the staff accordingly. Comprehensive staff training is indispensable for hospital fire safety. Training empowers employees to respond swiftly and effectively, minimises risks during evacuations and enhances overall resilience in life-critical situations (Farra *et al.*, 2019).

5.3.2 Model simulation. Model simulation is a critical component in designing safe egress systems for hospitals during fire emergencies. By using advanced computational tools, fire safety engineers can analyse evacuation dynamics, predict potential hazards and optimise egress strategies to ensure the safety of all occupants (Klüpfel *et al.*, 2005). Twelve articles and 50% of experts have confirmed this as a key factor to safe egress design in hospitals. Interviewed experts explain that building models allows for a detailed examination of various fire scenarios, including fire spread, smoke movement and the behaviour of occupants, without endangering lives during this process of exploration. These models account for the diverse needs of hospital occupants, such as non-ambulatory patients, staff and visitors, each with different evacuation capabilities. For example, programs like Pathfinder and FDS simulate how smoke might fill corridors or stairwells, enabling designers to identify bottlenecks and ensure that evacuation routes remain clear (Klüpfel *et al.*, 2005). Building modelling also helps determine the optimal size and placement of stairwells, fire doors and evacuation elevators based on real-world usage patterns and the hospital's occupant load (Zhang *et al.*, 2017). Moreover, simulations provide valuable insights into evacuation timeframes, enabling designers to assess compliance with safety standards. By modelling worst-case scenarios, hospitals can identify potential vulnerabilities stemming from patients' varying mobility conditions and develop effective contingency plans. Building model simulation is an indispensable tool in hospital fire safety planning, which improves egress design by identifying and mitigating risks (Zhang *et al.*, 2017).

5.4 Study practicality

In practical design terms, the findings indicate that hospital projects – particularly those housing high proportions of bed-bound patients – should incorporate protected horizontal evacuation routes, adequately sized refuge areas and dedicated evacuation lifts from the earliest design stage. Such provisions can be integrated into architectural workflows by requiring evacuation simulations (e.g. Pathfinder or equivalent) at each design milestone to verify that mobility-related evacuation needs are met. From a policy perspective, these insights could be embedded into national building regulations, such as amendments to the New Zealand Building Code's C/AS3 Acceptable Solutions for Sleeping, institutional risk groups, to mandate performance-based evacuation assessments for healthcare facilities. Economically, early integration of these design measures can minimise costly retrofits, improve operational continuity during emergencies and potentially reduce insurance premiums through demonstrable risk mitigation. This targeted approach provides a clear and actionable pathway for translating theoretical contributions into measurable, real-world outcomes.

While the study provides practical guidance for architects, engineers and emergency planners – including mobility-aware cell sizing, horizontal compartmentation and reduced travel distances – translating these recommendations into policy or code-level standards requires further validation. Future work could model these design strategies under varied patient mobility scenarios using simulation tools such as Pathfinder or FDS, or assess them through post-occupancy case studies of hospital projects. Practically, embedding these findings into early design stages can reduce retrofit costs, improve insurance outcomes, and strengthen operational resilience. The study also offers a valuable teaching tool for integrating patient mobility into fire safety curricula and a foundation for future academic exploration into predictive evacuation modelling. At a societal level, the proposed strategies advance safety and equity by addressing the needs of the most vulnerable populations, contributing to sustainable development goals related to health, infrastructure and sustainable communities.

5.5 Research replication

This study can be replicated through a qualitative approach combining a SLR and semi-structured expert interviews. The SLR involves searching key academic databases – Google Scholar, ResearchGate, Scopus and Web of Science – using the search string: ("hospital evacuation" OR "patient egress") AND ("fire safety Design" OR "Hospital layout" OR "fire protection") AND ("patient mobility" OR "mobility impairment"). Retrieved papers are screened to exclude duplicates, studies published before 1995 and non-English language papers, yielding a final sample of 130 relevant articles. For the qualitative component, semi-structured interviews are conducted with approximately 25 experts across New Zealand, selected via purposive sampling and expanded through snowballing until thematic saturation is achieved. Interview transcripts are analysed using narrative and thematic coding techniques facilitated through Excel, involving multiple readings to identify and refine recurring themes. Following these steps allows other researchers to replicate the methodology, adapt the search strategy for different contexts or expand upon the thematic analysis framework.

6. Conclusions

This study set out to identify and validate the key factors that influence safe egress design in hospitals, with particular attention to the role of patient mobility and its impact on evacuation effectiveness. To achieve this objective, a comprehensive qualitative research approach was employed, involving a SLR of 130 research papers and semi-structured interviews with 25 experts in New Zealand's healthcare and fire safety fields. These experts, each with over five years of relevant experience, provided valuable insights that confirmed and expanded upon the literature findings. The study identified a total of 12 critical factors essential to hospital evacuation safety. Ten factors were initially established through the literature review, covering occupant characteristics, building layout and materials, fire spread mechanisms, fire safety systems, evacuation signage and elevators and evacuation modelling tools. The expert interviews further highlighted two vital additional factors: (1) patient mobility rate and condition and (2) staff training. Experts emphasised that patient mobility is the most influential factor throughout all design and evacuation stages, as it directly affects other evacuation components and overall success. Furthermore, the study demonstrated the interconnectedness of occupant-related factors, such as patient types and behaviour, with building-related factors, reinforcing the need for integrated, holistic design and planning approaches.

Theoretically, this study contributes significantly to the field of fire safety and hospital evacuation planning by repositioning patient mobility as a central consideration in safe egress system design. Traditionally, evacuation models have treated occupant mobility generically, but this study advances theory by incorporating detailed patient mobility categorisation into early architectural and engineering planning stages. This patient-centred approach encourages professionals to move beyond standard, generalised egress models towards more nuanced strategies that accommodate the vulnerabilities inherent in healthcare populations. By doing so, the study paves the way for developing predictive evacuation models tailored to mobility classifications, which can enhance the accuracy of risk assessment and safety design in complex, high-occupancy healthcare facilities.

From a practical perspective, the findings provide actionable recommendations for hospital architects, engineers, emergency planners and policymakers. Design strategies should prioritise protected horizontal evacuation routes, appropriately sized refuge areas and dedicated evacuation lifts, integrated from the earliest stages of hospital planning. Performance-based evacuation simulations, utilising tools such as Pathfinder or FDS, should be mandated to verify that these mobility-related needs are met at key design milestones. On the policy front, this study supports amendments to regulatory frameworks like *New Zealand's Building Code C/AS3*, advocating for mandatory simulation-based evacuation assessments that reflect diverse patient mobility profiles. Economically, early implementation of these adaptive design features can reduce costly retrofits, ensure operational continuity during emergencies and potentially decrease insurance premiums through demonstrable risk mitigation. Moreover, the study emphasises the importance of after-evacuation care, including continuity of medical treatment in designated safe zones or triage areas, which is vital for patient outcomes and aligns with global safety and humanitarian standards. Collectively, these practical recommendations contribute to achieving several United Nations sustainable development goals, including Goal 3 (good health and well-being), Goal 9 (industry, innovation and infrastructure) and Goal 11 (sustainable cities and communities), thereby fostering safer, more resilient healthcare environments.

Despite its contributions, this study has several limitations. Access to the most recent and detailed fire incident reports was restricted, potentially limiting the comprehensiveness and timeliness of the data. The reliance on secondary data and English-language literature may have narrowed the breadth of perspectives, while the qualitative focus and purposive sampling limit the generalisability of findings beyond the New Zealand context. Assumptions regarding fire and smoke spread were standardised at 2.4 m/s and 6.25 m/s based on conservative international estimates, enhancing internal consistency but warranting further validation. Additionally, the proposed evacuation thresholds, while grounded in empirical data, were not tested through computational fluid dynamics or evacuation simulations, which future studies could employ using tools such as Pathfinder or FDS. Likert-scale results were analysed descriptively, without confidence intervals or variability measures, limiting inferential strength. Future research should broaden linguistic and geographic scope, incorporate empirical data from diverse hospital contexts and validate findings through modelling, case studies or evacuation drills. Greater interdisciplinary collaboration among fire engineers, healthcare professionals, behavioural scientists and policymakers will further strengthen the evidence base and support the translation of these insights into best practices and policy frameworks.

This study bridges a critical gap between theory and practice by emphasising the pivotal role of patient mobility in hospital fire evacuation planning. Its 12 identified factors, especially the newly foregrounded patient mobility and staff training, offer a comprehensive framework for improving evacuation safety. By integrating these insights into design, policy and research, the healthcare sector can better protect vulnerable populations and enhance resilience against fire emergencies.

7. Future research

Future research could build upon these findings by conducting experimental studies and test trials to more precisely examine how patient mobility levels and medical conditions affect hospital evacuation procedures and influence design considerations. Additionally, further investigation into technologically innovative interior layout solutions, such as adaptive spatial configurations or smart navigation systems, could offer new strategies for enhancing the safe and efficient evacuation of critically ill patients.

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Glossary of Abbreviations

ASET	Available Safe Egress Time
CFA Australia	Country Fire Authority Australia
CFD	computational fluid dynamics
FDS	Fire Dynamics Simulator
FRL	Fire Resistance Level
FRR	Fire Resistance Rating
ICU	Intensive Care Unit
NFPA	National Fire Protection Association
NZ	New Zealand
PAHO	The Pan American Health Organization
PRISMA	A Preferred Reporting Items for Systematic reviews and Meta-Analyses diagram
RSET	Required Safe Egress Time
SASBE	Smart and Sustainable Built Environment Journal
SLR	Systematic Literature Review
UK	United Kingdom
UN Goals	United Nations Goals
USA	United States of America

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