

Human Behavior and Circulation Efficiency in High-Rise Residential Buildings: A Review

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Abstract

The vertical expansion of cities through high-rise residential buildings addresses urban land scarcity but presents complex challenges in circulation efficiency and human behavior. Adopting a Systematic Literature Review methodology and guided by PRISMA protocols, 23 peer-reviewed articles published between 2010 and 2024 were critically evaluated using defined inclusion and exclusion criteria. Thematic synthesis of the selected literature revealed key domains: human behavior, circulation design, user satisfaction, emergency egress, typology and density, smart technological interventions, sustainability, and research gaps. Findings show that human behavior during emergencies is often marked by delay, verification of alarms, and reliance on social cues, which can critically hinder evacuation. Psychological concepts such as “psychonomics” and stress-induced cognitive inertia were found to play major roles in movement decisions. Circulation efficiency was shown to be dependent on spatial configurations, with strategic placement of stairwells, corridor geometry, and stair rotation influencing both routine flow and evacuation speed. Moreover, user satisfaction is tied not just to safety and accessibility but also to social interaction zones and environmental comfort. Smart technologies were demonstrated to improve movement efficiency and energy use. Gaps remain in behavioral modeling, post-occupancy evaluations, and region-specific data, particularly within African urban contexts like Nigeria. Contradictions were also noted in areas such as the use of refuge floors and elevators during emergencies, where traditional codes diverge from empirical performance data. The study concludes with policy-oriented recommendations for Nigerian building code revisions, advocating for behavior-informed design standards, mandatory POE processes, and the formalization of fire safety engineering as a discipline.

Keywords: Circulation, High-Rise, Human Behavior, Movement, Residential Building.

Introduction

The rapid urbanization of cities worldwide has led to a significant increase in the development of high-rise residential buildings, especially in densely populated urban centers (Eynullayeva, 2023). These vertical structures are not only a response to limited land availability but also serve as a means of accommodating growing populations in compact spaces. High-rise buildings offer spatial efficiency, they also introduce complex challenges related to circulation systems and human behavior, particularly during routine use and emergency situations (Soltanzadeh, Mazaherian & Heidari, 2021). The way occupants move

within and interact with circulation spaces such as staircases, elevators, corridors, and lobbies is influenced by psychological, social, and physical factors. Efficient circulation design is therefore critical in ensuring user safety, comfort, and satisfaction in residential high-rises (Purnami, 2021). An in-depth understanding of human behavior within these vertical environments is necessary for creating safer, more user-friendly, and sustainable living spaces.

Despite the growing prevalence of high-rise residential developments, many of these buildings still suffer from inefficient circulation systems that do not adequately consider the behavioral patterns of users. Challenges such as bottlenecks during peak hours, poor wayfinding, insufficient escape routes, and psychological discomfort in vertical transit spaces can compromise user safety and well-being. In emergency situations, especially fires or earthquakes, delays in evacuation due to design flaws or behavioral inertia can have fatal consequences (Salankar, S. (2021).

Research Gap

Although significant studies have addressed architectural and engineering aspects of circulation design, there remains a clear lack of integration between behavioral science and spatial design in high-rise residential contexts. This gap is particularly pronounced in rapidly developing urban environments, such as those in Africa, where population density, infrastructure constraints, and cultural factors present unique challenges.

The study aims to examine the relationship between human behavior and circulation efficiency in high-rise residential buildings, with the goal of identifying design strategies that improve user experience and safety. To achieve this aim, the study will:

- i. Critically evaluate existing literature on human behavior and circulation design in high-rise residences.
- ii. Identify key behavioral patterns that affect circulation efficiency during routine use and emergencies.
- iii. Analyze design elements that enhance or hinder occupant mobility and safety.
- iv. Examine the role of technological interventions in improving circulation performance.
- v. Highlight research gaps and contextual challenges in African high-rise residential environments.

The scope of this study is limited to high-rise residential buildings, focusing on both daily circulation and emergency egress. The research will explore occupant behavior, spatial design elements, and circulation efficiency, using a combination of literature review, case studies, and observational data where available. The study will not cover commercial or mixed-use high-rises in depth. This study is significant for architects, urban designers, and policy makers involved in the design and regulation of high-rise residential buildings. By exploring the intersection of human behavior and circulation design, the research provides critical insights that can inform safer, more efficient, and user-centered building layouts.

The findings are particularly relevant in the context of growing urban populations and the increased need for vertical housing solutions. Furthermore, incorporating behavioral science into design practice promotes a holistic approach to architecture that enhances both functionality and occupant well-being.

Literature Review

This literature review is organized thematically using a framework that draws on three key dimensions: (i) behavioral theories and psychological models of movement; (ii) architectural design factors affecting circulation and egress; and (iii) technological and sustainable interventions that enhance efficiency and safety. These dimensions collectively guide the interpretation of empirical and theoretical insights across reviewed studies.

Concept of Human Behavior in High-Rise Buildings

Human behavior in high-rise buildings is shaped by a combination of individual psychology, social influences, and environmental factors (Ghorbani & Naseri, 2024). Occupants develop routines and spatial awareness over time, which affects how they navigate circulation spaces. Behavioral patterns are often influenced by stress levels, perceived safety, familiarity with the building layout, and even cultural norms. In high-rise residential settings, behaviors may differ from commercial buildings due to personal attachment, family responsibilities, and the presence of vulnerable users like children and the elderly (Brognoli Goularte, 2025). In emergency situations, human behavior can become unpredictable. Studies by Sefidari (2025) and Wolfberg (2025) have shown that individuals often delay evacuation due to skepticism about alarms, reliance on others' actions, and a tendency to verify threats before reacting. These behavioral tendencies can critically influence evacuation timelines and outcomes. Thus, understanding human behavior in these vertical environments is essential for designing effective circulation systems that accommodate both routine and emergency use.

Theories of Evacuation and Movement Patterns

Evacuation theories provide a framework for understanding how people respond to threats and how they physically move through space during emergencies. Theories such as the Protective Action Decision Model (PADM) and Affordance Theory help explain the decision-making processes behind evacuation behaviors (Saini, 2025). These models emphasize how cognitive interpretation of environmental cues (e.g., alarm sounds, signage, and peer actions) guides movement decisions during crises. Movement pattern studies also rely on pedestrian dynamics and crowd simulation models such as Pathfinder, SIMULEX, and agent-based simulations. These tools replicate real-time evacuation scenarios to identify patterns, predict bottlenecks, and assess the effectiveness of circulation design. Findings from these simulations show that variables such as walking speed, crowd density, and exit visibility significantly influence evacuation outcomes. Together, these theories and tools

inform behavioral modeling and help designers create safer and more efficient circulation pathways (Khan & Deng, 2024).

Circulation Efficiency: Definitions and Metrics

Circulation efficiency refers to the optimal flow of people through a building, minimizing time, effort, and congestion (Zadobrischi, 2025). In high-rise residential buildings, it encompasses both horizontal and vertical movements via corridors, staircases, and elevators. Efficient circulation ensures that residents can move smoothly during peak periods and evacuate quickly during emergencies (Bae & Choi, 2025). Key performance indicators (KPIs) for circulation efficiency include travel time, flow rate, congestion levels, and waiting times at critical nodes. Metrics used to evaluate circulation efficiency often stem from traffic engineering and architectural standards (Hosseinian & Mirzahosseini, 2024). For instance, stair width, elevator speed, and corridor length are commonly measured against national building codes and international guidelines. Simulation software allows for the modeling of these metrics under various occupancy scenarios. When analyzed in conjunction with human behavior, these metrics provide a more accurate picture of how design decisions impact both every day and emergency movement.

Design Factors Influencing Circulation in High-Rise Residential Settings

Several architectural design elements directly affect circulation efficiency in high-rise buildings. Vertical access points such as staircases and elevators must be strategically located to ensure balanced foot traffic and reduce travel distance. Studies like Liu & Zou, (2024). demonstrate that placing vertical cores at opposite ends of a building significantly improves evacuation speed and reduces crowding. Similarly, corridor width, turning radii, and visibility lines all influence how comfortably and safely occupants can move. Beyond spatial geometry, the configuration of refuge floors, access control systems, and lighting conditions also play crucial roles (Gurcan Bahadir & Tong, 2025). Poorly lit corridors or complex layouts may discourage usage or disorient residents during emergencies. Incorporating intuitive wayfinding, open sightlines, and ergonomic stair designs can foster positive behavioral responses and enhance the user experience. These design choices should be guided by an understanding of occupant demographics and mobility requirements.

User Satisfaction and Perception of Circulation

User satisfaction in high-rise residential buildings is heavily linked to perceptions of safety, accessibility, and comfort within circulation spaces. Studies by Dash & Shetty, (2024) show that residents value circulation areas that are well-lit, thermally comfortable, and socially interactive. Green spaces, communal zones near circulation nodes, and adequate ventilation contribute to both psychological well-being and navigational ease. Perception also includes the subjective experience of vertical travel. Long wait times for elevators,

narrow stairwells, and confusing signage can generate frustration, especially in taller buildings. Bou Kalfouni, (2025) found that inadequate circulation designs can lead to feelings of isolation and stress among residents, particularly in high-density environments. Understanding user feedback through post-occupancy evaluations is crucial for refining circulation systems in future developments.

Emergency Egress and Behavioral Response

Emergency egress planning is a critical aspect of circulation design, especially in high-rise settings where vertical distance and congestion can hinder rapid evacuation. Research by Ma, Van Coile, & Gernay, (2024) highlights the need for performance-based design that accounts for human behavior under stress. Many occupants instinctively choose the nearest exit or familiar routes, often leading to congestion in certain areas. Behavioral responses to emergencies are influenced by alarm credibility, social cues, and physical exertion. Dash et al., (2024) found that even the direction of staircase rotation (e.g., counterclockwise vs. clockwise) can affect evacuation speed and user fatigue. Simulation tools and sensor-based data collection enable better predictions of these behavioral tendencies, allowing architects to design egress routes that facilitate faster and safer exits, particularly for vulnerable populations.

Sustainability Considerations in Circulation Design

Sustainability in circulation systems involves reducing environmental impact while enhancing user comfort and mobility. This includes energy-efficient elevators, promoting stair usage, and incorporating passive design strategies like natural ventilation in stairwells. Metwally, Ismail, & Farid, (2024) argue that sustainable design must be aligned with user behavior, encouraging occupants to participate in energy-saving practices. Sustainable circulation also extends to material choices, maintenance efficiency, and adaptability over time. Kompauer, (2025) found that optimizing elevator traffic not only saves energy but also reduces long-term operational costs. Incorporating renewable energy sources, smart lighting, and user-responsive climate control in circulation zones can improve building performance without compromising functionality or safety.

Identified Gaps and Future Research Directions

While substantial progress has been made in understanding circulation in high-rises, several research gaps remain. Current models often oversimplify human behavior, failing to account for cognitive factors like stress, fatigue, and decision-making under uncertainty. Gurcan, (2025) call for more nuanced simulation models that reflect behavioral realism, especially for diverse occupant groups such as the elderly and physically impaired. Moreover, there is a lack of localized studies, particularly in African urban contexts, where infrastructural limitations and cultural factors may influence circulation differently. Sefidari, (2025) stress the need for integrating cognitive science with fire safety engineering to

better predict behavior. Future research should focus on cross-disciplinary approaches that merge architecture, psychology, data analytics, and user experience to design more adaptive and inclusive circulation systems.

Local Context Reflection: Why African High-Rises Matter

In many African cities, high-rise buildings are rapidly replacing low-density housing due to land scarcity and migration pressures. However, African high-rises often suffer from infrastructure deficits, intermittent electricity, poor maintenance, and informal occupancy. These factors may alter evacuation behavior significantly. For instance, malfunctioning elevators and overcrowding could reduce trust in mechanical systems, leading to overuse of staircases even during non-emergencies. Additionally, cultural behaviors such as communal child-rearing or social reliance could influence movement patterns, especially in emergencies. These nuances suggest that findings from Western or East Asian contexts may not fully apply. Future research must integrate localized POEs, simulation, and behavioral studies in African urban housing estates.

Methodology

This study adopted a systematic literature review (SLR) approach to collate, evaluate, and synthesize existing research on the relationship between human behavior and circulation efficiency in high-rise residential buildings. To ensure relevance and rigor, a set of inclusion and exclusion criteria as shown in Table 1.0 was applied to journal articles, conference papers, and reputable reports published between 2010 and 2024 with contemporary relevance.

The screening process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines:

- i. Title and abstract screening: Articles were reviewed for relevance to the research questions and inclusion criteria.
- ii. Full-text review: Eligible articles underwent detailed analysis to assess their methodological quality and thematic relevance.
- iii. Data extraction: Key information from each study was recorded, including Author(s) & Year, Key Findings and Contribution to Knowledge.

Table 1.0: Inclusion Criteria and Exclusion Criteria for Literature Selection

Criteria Category	Inclusion Criteria	Exclusion Criteria
Publication Type	Peer-reviewed journal articles, conference papers, and scholarly reviews	Non-scholarly sources (blogs, magazines, newsletters), theses not peer-reviewed
Language	English	Non-English publications
Time Frame	Publications from 2010 to present	Publications before 2010 (unless foundational or seminal)
Building Type	Studies focused on high-rise residential buildings	Studies on low-rise buildings, commercial buildings, or institutional facilities
Focus Area	Studies addressing human behavior, movement patterns, circulation design, wayfinding, or space efficiency in high-rise residences	Studies that focus solely on structural, mechanical, or unrelated architectural systems
Population Studied	Residents or users of high-rise residential buildings	Construction workers, maintenance staff, or populations not relevant to user behavior
Methodology	Empirical studies (qualitative, quantitative, or mixed-methods), simulation-based studies, and systematic reviews	Opinion pieces, editorials, or purely theoretical discussions without evidence
Geographical Relevance	Global studies with applicable urban residential contexts	Studies in rural, non-residential, or contextually irrelevant areas
Accessibility	Full-text available through institutional access or open-source platforms	Abstract-only publications or restricted-access documents

Source: Author (2025)

Ultimately, 23 articles met all criteria and were included in the final synthesis. The extracted data were analyzed using a thematic synthesis approach. This involved: Coding key findings from each article into thematic categories, Human Behavior, Design & Circulation Efficiency, User Satisfaction, Safety & Egress, Typology & Density, Smart Solutions, Sustainability & Energy, and Gaps & Future Research.

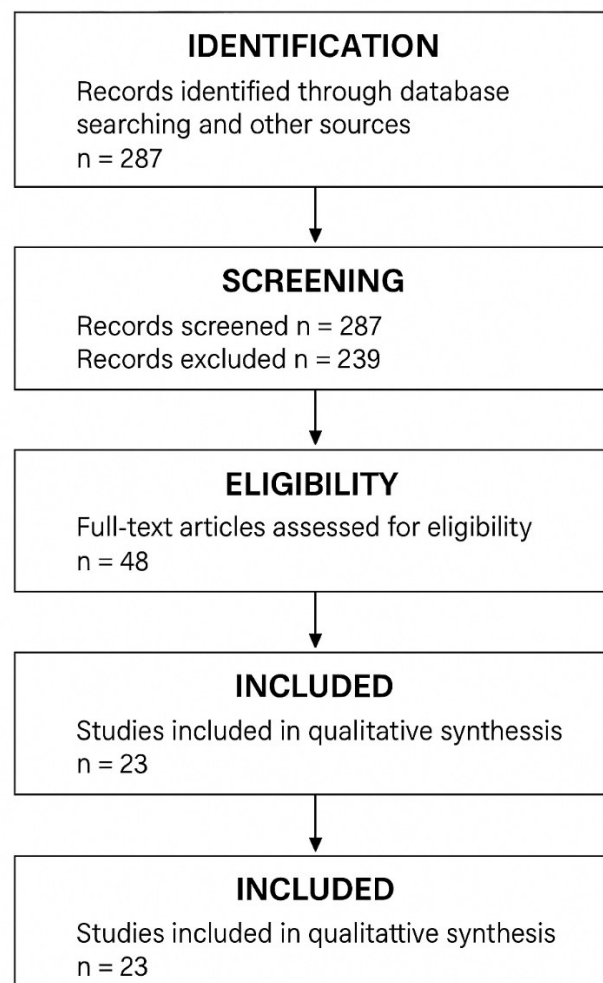


Figure 1.0: PRISMA diagram of study

Source: Author (2025)

Results and Discussion

A synthesis table was developed to summarize and compare the contributions of each study, enabling cross-case insights and the identification of recurring trends and gaps. This table formed the backbone of the discussion and helped guide the structure of the literature review. Table 2.0 shows the Key Findings from the selected literature in a synthesis table.

Table 2.o: Synthesis Table

S/N	Theme	Author(s) & Year	Key Findings	Contribution to Knowledge
1.	Human Behavior	Gerges et al. (2017)	Occupants delay evacuation, rely on others, and investigate alarms	Highlights behavioral inertia and social cues in evacuation
		Kobes et al. (2010)	Psychological factors like risk perception and decision-making are critical	Introduces “psychonomics” as essential to understanding evacuation behavior
		Ronchi & Nilsson (2013)	Behavior varies by population/building; fatigue and group dynamics matter	Advocates for more nuanced, multi-agent simulation modeling
2.	Design & Circulation Efficiency	Soltanzadeh et al. (2021)	Stair placement at opposite sides reduces evacuation time by 20%	Demonstrates the importance of vertical access placement
		Ma et al. (2012)	Refuge floors can create bottlenecks in stair-based evacuation	Reveals the importance of transitional space configuration
		Huo et al. (2016)	Merging flows and stair geometry impact descending speed and congestion	Emphasizes flow dynamics in circulation design
		Zhang (2017)	Spiral slideway evacuation system enhances speed, supports disabled users	Suggests alternative emergency egress mechanisms
3.	User Satisfaction	Lee et al. (2011)	Health, safety, and functionality rank highest in well-being index	Connects design to user satisfaction and health
		Hussein & Uzunoğlu (2020)	Residents prefer secure, green, and socially interactive circulation areas	Evaluates post-occupancy satisfaction with physical layout
		Kalantari & Shepley (2021)	Poor design linked to isolation and psychological stress	Stresses social implications of circulation design
4.	Safety & Egress	Gerges, Demian & Adamu (2021)	BIM + smartphone guidance reduces evacuation time by ~50%	Validates tech-enabled personalized evacuation strategies
		Konbr & Maher (2022)	Counter-clockwise staircases resulted in lower heart rates and improved evacuation efficiency. Cultural and medical factors influence architectural preferences and lack of guidelines on staircase rotation in building codes	Empirical evidence linking staircase rotation to evacuation efficiency and highlights the need for building code revisions to incorporate staircase rotation considerations
		Chow (2017)	Fire egress time is often insufficient in tall buildings	Argues for rethinking prescriptive codes in supertall design
		Yatim (2012)	SIMULEX modeling shows stair layout and corridor design critical to safety	Supports design-based safety planning with simulation tools

5.	Typology & Density	Mansouri & Zarghami (2025)	Solitary and combined arrangements influence wind, heat, and comfort differently	Links architectural form to climate and circulation performance
		Wang & Chien (1998)	Environmental Behavior Analysis helps mitigate density-related challenges	Introduces planning strategies for safe, dense environments
6.	Smart Solutions	Gerges, Demian & Adamu (2021)	Agent-based BIM simulations improve evacuation efficiency	Advocates for digital integration in emergency planning
		Marsong et al. (2022)	Elevator traffic data can optimize energy use and vertical transport efficiency	Connects energy modeling with real-time circulation flow
7.	Sustainability & Energy	Wener & Carmalt (2006)	Behavior-responsive green design is key to achieving sustainability goals	Proposes aligning green features with occupant psychology
		Marsong et al. (2022)	Elevators consume significant energy; load balancing improves efficiency	Reinforces energy-conscious design in vertical circulation
8.	Gaps & Future Research	Ronchi & Nilsson (2013)	Need for fatigue and vulnerability modeling in evacuations	Encourages deeper behavioral modeling
		Kobes et al. (2008)	Traditional safety codes misalign with actual behavior	Recommends integrating cognitive science in safety protocols
		Quiquero et al. (2018)	Fire safety engineering should be its own profession to meet modern challenges	Promotes disciplinary expansion to meet complex safety demands

Source: Author's Compilation (2025)

Patterns of Human Behavior in High-Rise Residential Settings

Human behavior in high-rise residential buildings is deeply influenced by individual perception, environmental cues, and collective action. Gerges et al. (2017) highlighted that many occupants exhibit delayed response to fire alarms, often choosing to verify the situation independently before evacuating. This behavior stems from a lack of fire safety awareness, previous false alarms, and dependence on others' reactions, which can significantly delay the initiation of evacuation and increase risk during actual emergencies. Kobes et al. (2010) emphasized the psychological dimension of evacuation, identifying factors such as stress response, prior knowledge, familiarity with the building layout, and trust in alarm systems as determinants of evacuation efficiency. They argued that psychological and cognitive processes, collectively termed "psychonomics", play a crucial role in influencing how individuals respond to emergency situations. Ronchi and Nilsson (2013) broadened the discussion by comparing behavioral differences across building types, noting that high-rise residential settings uniquely require customized evacuation modeling due to the presence of vulnerable populations, such as children and the elderly. Their work

stressed the importance of simulating human movement under stress and fatigue, and emphasized the utility of multi-model approaches to capture varied behavioral outcomes.

Design Elements Affecting Circulation Efficiency

The spatial configuration of vertical and horizontal circulation spaces, such as staircases, corridors, and elevator shafts, directly affects evacuation efficiency and daily mobility. Soltanzadeh et al. (2021) conducted simulations to compare different vertical access placements in 60-story residential towers and found that positioning staircases and elevators at opposite ends of the building plan led to a 20% reduction in total evacuation time. This arrangement distributed foot traffic more evenly and minimized congestion during emergencies. Ma et al. (2012) explored vertical circulation through experiments in the Shanghai World Financial Center. Their study involved both individual and group evacuations across staircases and elevators, emphasizing the complexity of transitional zones, such as refuge floors, where flow bottlenecks frequently occurred. The authors underlined the significance of maintaining consistent walking speed and minimizing delays at merging points.

Complementing these findings, Huo et al. (2016) conducted experiments comparing phased and total evacuation strategies. Their data revealed that merging flows at stair landings can decelerate descending participants and amplify evacuation time. The study's fundamental diagrams of movement speeds illustrated how pedestrian behavior changes under crowding, underscoring the need for thoughtful stair geometry and flow management. Innovatively, Zhang (2017) introduced a mechanical slideway evacuation device, designed for use during fires in high-rise buildings. This device enables rapid vertical descent without reliance on electricity, accommodating mobility-impaired individuals. Simulation tests demonstrated significantly faster evacuation times compared to traditional stairs, proposing a supplementary escape system for extreme scenarios.

User Perception and Satisfaction with Circulation

Perceptions of safety, comfort, and accessibility heavily influence how users experience circulation spaces. Lee et al. (2011) proposed a well-being index for residents of super-tall buildings in Korea, ranking health, safety, ecological environment, and functionality as key components of satisfaction. The study used Analytic Hierarchy Process (AHP) to derive weighted indices, revealing that health and safety overwhelmingly shape residents' evaluations of circulation systems. In Erbil, Iraq, Hussein and Uzunoğlu (2020) assessed user satisfaction through post-occupancy evaluation of a gated high-rise community. Residents expressed concerns about insufficient green and communal spaces and indicated that building orientation and corridor design influenced thermal comfort and navigation. Their study reinforced the need for circulation areas to serve not only utilitarian but also social and environmental functions. Kalantari and Shepley (2021) reviewed post-occupancy literature and found that poor circulation design in high-rises often contributes to

psychological stress, especially among economically disadvantaged populations. The lack of social interaction spaces, long corridors, and enclosed vertical access points can amplify feelings of isolation and reduce overall well-being.

Safety, Accessibility, and Emergency Egress

Evacuation during emergencies is a major challenge in high-rise design. Gerges, Demian, and Adamu (2021) demonstrated that custom-tailored evacuation instructions, delivered to residents via smartphones and generated using BIM and Pathfinder simulations, could reduce average evacuation time by nearly 50%. The study revealed that occupants often default to the nearest exit, leading to congestion, but customized routing dispersed flow and improved overall efficiency. Chow (2017) discussed critical issues in fire safety for buildings over 300 meters tall in the Asia-Oceania region. Key concerns included wind-driven fires due to open windows, short available safe egress time versus long required egress time, and novel architectural layouts like open kitchens that exacerbate fire spread. Chow argued for revising traditional codes and adopting performance-based safety systems. Yatim (2012) conducted an evaluation of escape route designs in Malaysian high-rise buildings, using simulations to assess optimal configurations. The research found that factors such as stair width, corridor length, and door swing direction significantly affect evacuation speed. The study recommended integrating simulation tools like SIMULEX during the design phase to better anticipate real-world evacuation challenges.

Adding to this growing body of research, Konbr and Maher (2022) investigated how the rotational direction of staircases influences evacuation efficiency and occupant exertion. Through a combination of architect surveys and controlled field experiments with 53 participants, the study revealed that counter-clockwise staircases consistently outperformed clockwise ones, reducing heart pulse rates during ascent and descent by up to 21.5%. This suggests lower physical effort and faster movement in emergency scenarios. The authors attributed these results to ergonomic and possibly cognitive factors influencing user comfort and spatial orientation. Importantly, the study also highlighted a critical oversight in building regulations, which currently do not address staircase rotation despite its measurable impact on evacuation performance. This underscores the need to reconsider egress design holistically, including directional geometry, and supports the broader call for evidence-based and performance-driven safety codes in high-rise environments.

Influence of Building Typology and Density

Building form and density impact both environmental conditions and circulation dynamics. Mansouri and Zarghami (2025) investigated the relationship between block arrangements, solitary, environmental, combined, and row, and their effects on urban heat islands (UHIs), wind patterns, and thermal comfort. Their findings showed that solitary patterns facilitated better air circulation but increased temperature variance, while combined and environmental patterns struck a balance between structural density and climate control,

indirectly improving circulation efficiency. Wang and Chien (1998) applied Environmental Behavior Analysis (EBA) to assess circulation patterns in Taiwanese high-rise zones. By integrating growth management principles and AHP techniques, they devised strategic planning tools for enhancing urban safety and environmental quality. Their study provided a foundation for reconciling human behavior with physical planning constraints in dense urban developments.

Technological Interventions and Smart Solutions

Emerging technologies offer new ways to manage circulation and emergency response. Gerges et al. (2021) illustrated how BIM-based simulations and real-time routing apps could improve wayfinding, reduce congestion, and assist in tailoring evacuation strategies for each occupant. Their case study in Cairo demonstrated how agent-based modeling could guide better architectural decisions during early design stages. Marsong et al. (2022) conducted a comprehensive study on elevator power usage in Bangkok's high-rise buildings. By analyzing traffic load profiles and real-time elevator data, they identified inefficiencies in vertical transport and proposed adjustments in scheduling and load balancing to enhance performance and reduce energy consumption. This study underscores the critical link between technology, energy use, and circulation efficacy.

Sustainability and Energy Implications of Circulation Design

Sustainability in circulation systems extends beyond energy-saving technologies to include behavioral compatibility and long-term usability. Wener and Carmalt (2006) emphasized that sustainable design must account for user behavior, noting that occupant participation in energy-saving practices (e.g., using stairs over elevators) is vital for realizing design goals. Their review stressed the need for buildings to align architectural intent with psychological motivation. Marsong et al. (2022) corroborated this by demonstrating that elevators are among the highest energy consumers in high-rise buildings. Their empirical findings suggested that optimizing elevator traffic through smarter control algorithms could significantly reduce operational costs and environmental footprints, thereby contributing to both sustainability and improved vertical circulation.

Challenges, Gaps, and Future Research Directions

Despite significant progress in modeling and designing for circulation efficiency, gaps remain. Ronchi and Nilsson (2013) called for advanced evacuation models that incorporate behavioral realism, especially for vulnerable groups like the elderly and disabled. They emphasized the need to simulate fatigue, social behavior, and delayed responses for a more holistic understanding of evacuation dynamics. Kobes et al. (2008) argued that prevailing fire safety paradigms rely too heavily on regulatory assumptions and fail to consider actual human behavior during crises. They recommended integrating findings from cognitive science into fire safety engineering to better predict and manage real-world evacuation

behavior. Quiquero et al. (2018) further advocated for formalizing fire safety engineering as a distinct professional discipline in Canada, drawing on international practices. They stressed the need for interdisciplinary collaboration and performance-based design to meet the growing complexity of high-rise environments.

Table 3.0: Evidence Strength Overview

S/N	Theme	Evidence Strength	Remarks
1.	Human behavior in evacuation	Strong	Supported by multiple empirical and simulation-based studies
2.	Circulation layout/design	Strong	Repeated confirmation from simulations and real-life studies
3.	Technology use (BIM, apps)	Strong	Growing empirical support and reproducibility
4.	Staircase rotation	Weak/Emerging	Limited studies; promising but untested in multiple contexts
5.	Building typology/density	Moderate	Simulation-based; lacks field validation in tropical/high-density settings
6.	User satisfaction/POE	Moderate	Based on subjective feedback; context-sensitive
7.	Elevator in emergency use	Contradictory	Conflict between traditional codes and smart tech findings
8.	Refuge floors	Contradictory	Design intent vs. empirical evacuation bottleneck findings

Source: Author's Compilation (2025)

Implications of Findings on policy in Nigeria

The findings from this systematic literature review provide critical insights that can directly inform and enhance building design regulations, emergency planning frameworks, and urban development policies in Nigeria, particularly in the context of high-rise residential buildings. With increasing urban densification in Nigerian cities like Lagos, Abuja, and Port Harcourt, the adoption of evidence-based policies becomes imperative to ensure occupant safety, circulation efficiency, and sustainable living environments.

- i. **Need for Behavior-Informed Safety Codes:** The consistent observation across studies that human behavior, especially delay in response, social reliance, and stress, affects evacuation success implies that Nigerian building codes must go beyond structural requirements to integrate behavioral science. Current National Building Code (NBC) provisions do not sufficiently consider psychonomic factors during emergencies. Lessons from Kobes et al. (2010) and Ronchi & Nilsson (2013) call for revisions to incorporate simulations that factor fatigue, social grouping, and vulnerability, particularly for children, the elderly, and the disabled.

- ii. Revision of Circulation Design Standards: Design-focused findings (e.g., Soltanzadeh et al., 2021; Huo et al., 2016) emphasize how the layout of stairwells, refuge floors, and merging points influence evacuation time and safety. Nigerian codes should mandate circulation strategies that minimize bottlenecks and incorporate flexible layouts tailored to the local urban context. Incorporating features like slideways (Zhang, 2017) or directional staircase design (Konbr & Maher, 2022) could improve evacuation performance, especially in Lagos where high-rise developments are rapidly expanding.
- iii. Incorporation of Post-Occupancy Evaluation (POE) in Planning Approvals: Studies by Lee et al. (2011) and Hussein & Uzunoğlu (2020) demonstrate that user satisfaction with circulation spaces hinges on comfort, social interaction, and ecological features. Nigerian policies should make POEs a mandatory component of building performance assessment, particularly for public and multi-family housing projects. This would ensure that design quality aligns with resident needs, including thermal comfort, security, and mental well-being.
- iv. Smart Technologies in Emergency and Energy Policy: Technological solutions such as BIM-based evacuation modeling and smart elevator systems (Gerges et al., 2021; Marsong et al., 2022) demonstrate how digital tools can optimize circulation and energy use. Nigerian urban policies and energy codes should incentivize the adoption of smart building systems, especially in high-rise projects financed by government or private-public partnerships. Encouraging digital simulation tools in the architectural design process would significantly enhance building performance and emergency preparedness.
- v. Climate-Sensitive Typology Guidelines: Research on building form and typology (Mansouri & Zarghami, 2025; Wang & Chien, 1998) shows that circulation efficiency is affected by the way buildings are arranged in relation to environmental factors. Nigerian urban development policies should guide high-rise residential developments with typologies that mitigate heat stress and improve natural ventilation, thereby reducing reliance on mechanical systems. This aligns with broader goals for energy efficiency and climate adaptation in rapidly growing urban areas.
- vi. Professionalization of Fire Safety Engineering: The call by Quiquero et al. (2018) for fire safety to evolve into a distinct profession has resonance in Nigeria, where fire emergencies in residential towers are often poorly managed. Nigerian policy should support the institutionalization of fire safety engineering education and certification, backed by national councils such as COREN and ARCON. This will foster a new generation of professionals skilled in integrating safety with circulation and behavioral modeling.
- vii. Evidence-Based Code Development and Research Integration: The cumulative evidence reinforces the need for Nigerian policymakers to adopt a performance-

based approach in future revisions of the National Building Code. Rather than relying solely on prescriptive norms, policies should incorporate international best practices, simulation results, and behavioral insights from both local and global research. The Nigerian Building and Road Research Institute (NBRRI) and academic institutions should be empowered to conduct longitudinal studies on circulation and user behavior in urban housing estates to generate context-specific data.

Conclusion and Recommendations

This study explored the critical intersection between human behavior and circulation efficiency in high-rise residential buildings through a comprehensive review of existing literature. The findings reveal that circulation systems in vertical housing are not merely functional pathways but complex social and psychological environments that deeply influence user behavior, safety, and satisfaction. Human responses especially during emergencies are shaped by a variety of factors including prior knowledge, environmental cues, design layout, and collective behavior. From delays in evacuation caused by alarm skepticism to the role of psychological comfort in routine movement, the literature emphasizes the need to integrate behavioral science into architectural design.

Moreover, circulation efficiency is influenced by the spatial configuration of vertical and horizontal movement systems such as stairwells, elevators, corridors, and refuge areas. Studies consistently show that the strategic placement of these elements such as positioning staircases at opposite ends of a building can significantly reduce congestion and evacuation time. Other findings stress the importance of stair geometry, lighting, signage, and even stair rotation direction in enhancing both movement speed and occupant exertion. Beyond technical configurations, user satisfaction with circulation spaces is also linked to thermal comfort, social interaction zones, and perceived safety. Technological interventions such as BIM-based simulations, smartphone-guided evacuation tools, and smart elevator algorithms were highlighted as effective innovations for improving circulation performance.

However, the study is limited by its reliance on secondary literature and the absence of primary empirical data. While the review includes simulation-based and international case studies, it lacks field-based validation in African high-rise settings, where infrastructural, cultural, and regulatory conditions may differ significantly. This limitation suggests that findings should be interpreted with caution when applied to regional contexts. To improve circulation efficiency and user safety in high-rise residential buildings, especially in African urban contexts, the following actions are recommended:

- i Adopt behavior-informed design practices: Architects and planners should simulate human movement under normal and emergency scenarios and incorporate findings into the spatial configuration of staircases, corridors, and vertical cores.

- ii Revise national building codes: Regulatory bodies should integrate emerging evidence on stair rotation direction, crowd behavior, and spatial psychology into circulation and egress standards.
- iii Mandate post-occupancy evaluations (POE): Policy frameworks should require POEs in high-rise residential projects to assess user satisfaction, circulation efficiency, and behavioral fit, ensuring continuous feedback for future designs.
- iv Promote technological integration: Encourage the use of agent-based simulations, BIM tools, and smart systems (e.g., adaptive elevators and evacuation apps) from the design stage to operational use, particularly in dense, high-risk environments.

This study concludes that achieving circulation efficiency in high-rise housing goes beyond compliance with spatial standards it requires an empathetic, science-informed approach that considers the lived experiences, behaviors, and safety of occupants. Future research should focus on fieldwork in African high-rise developments, combining observational studies, user interviews, and local case analyses to contextualize global knowledge in regional practice.

References

- Bae, Y. S., & Choi, M. (2025). Optimizing Key Evacuation Features for Safer Egress in Complex Buildings with Underground Connections: A Simulation-Based Approach to Resilient and Sustainable Design. *Sustainability*, 17(8), 3731.
- Bou Kalfouni, B. (2025). Design for well-being: from disadvantaged to satisfactory built environment, building places for vulnerable communities. *Open House International*.
- Brognoli Goularte, N. (2025). Searching for Home: Exploring the relationship between living in apartment buildings and newcomers' sense of belonging.
- Chow, W. K. (2017). A discussion on tall building fire safety in the Asia-Oceania regions. In *Fire Science and Technology 2015: The Proceedings of 10th Asia-Oceania Symposium on Fire Science and Technology* (pp. 61-72). Springer Singapore.
- Dash, S. P., & Shetty, A. (2024). Transitional Spaces as an Integrated Design Approach Enhancing Social Cohesion in High-Rise Dwellings. In *SDGs in the Asia and Pacific Region* (pp. 1-18). Cham: Springer International Publishing.
- Eynullayeva, M. (2023). Architecture of high-rise residential buildings in Baku: evolution, challenges and innovative solutions. *Architecture and Modern Information Technologies*, (3 (64)), 168-181.
- Gerges, M., Demian, P., & Adamu, Z. (2021). Customising Evacuation Instructions for High-Rise Residential Occupants.
- Gerges, M., Mayouf, M., Rumley, P., & Moore, D. (2017). Human behaviour under fire situations in high-rise residential building. *International Journal of Building Pathology and Adaptation*, 35(1), 90-106.
- Ghorbani, M., & Naseri, G. (2024). Identifying the psychological and behavioral principles in developing social interactions in the design of high-rise residential complexes. *Journal of Psychological Science*, 23(135), 607-624.
- Gurcan Bahadir, C. G., & Tong, T. (2025). Computational approaches to space planning: A systematic review of enhancing architectural layouts. *International Journal of Architectural Computing*, 14780771241310215.

- Hosseinian, S. M., & Mirzahosseini, H. (2024). Efficiency and safety of traffic networks under the effect of autonomous vehicles. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 48(4), 1861-1885.
- Huo, F., Song, W., Chen, L., Liu, C., & Liew, K. M. (2016). Experimental study on characteristics of pedestrian evacuation on stairs in a high-rise building. *Safety science*, 86, 165-173.
- Hussein, Z. A., & Uzunoğlu, K. (2020). Evaluation of the residents' satisfaction with high rise housing in new Eskişehir/Izmir-Iraq as a gated community. *International Journal of Advanced and Applied Science*, 7(11), 25-36.
- Kalantari, S., & Shepley, M. (2021). Psychological and social impacts of high-rise buildings: A review of the post-occupancy evaluation literature. *Housing studies*, 36(8), 1147-1176.
- Khan, S., & Deng, Z. (2024). Agent-based crowd simulation: an in-depth survey of determining factors for heterogeneous behavior. *The Visual Computer*, 40(7), 4993-5004.
- Kobes, M., Helsloot, I., De Vries, B., & Post, J. G. (2010). Building safety and human behaviour in fire: A literature review. *Fire Safety Journal*, 45(1), 1-11.
- Kobes, M., Post, J., Helsloot, I., & Vries, B. D. (2008, May). Fire risk of high-rise buildings based on human behavior in fires. In *Conference Proceedings FSHB* (pp. 07-09).
- Kompauer, J. (2025). *Optimizing Elevator Control with a Destination Registration System* (Doctoral dissertation, Technische Universität Wien).
- Konbr, U., & Maher, E. (2022). Investigating the impact of staircases rotation on the evacuation efficiency. *Civil Engineering and Architecture*, 10(6), 2524-2540.
- Lee, J., Je, H., & Byun, J. (2011). Well-being index of super tall residential buildings in Korea. *Building and Environment*, 46(5), 1184-1194.
- Liu, Z., & Zou, R. (2024). Dynamic evacuation path planning for subway station fire based on IACO. *Journal of Building Engineering*, 86, 108828.
- Ma, C., Van Coile, R., & Gernay, T. (2024). A user interface to compare the lifetime costs of prescriptive and performance-based fire designs of composite buildings. In *13th International Conference on Structures in Fire*.
- Ma, J., Song, W. G., Tian, W., Lo, S. M., & Liao, G. X. (2012). Experimental study on an ultra high-rise building evacuation in China. *Safety science*, 50(8), 1665-1674.
- Mansouri, S. T., & Zarghami, E. (2025). Investigating the effect of the physical layout of the architecture of high-rise buildings, residential complexes, and urban heat islands. *Energy and Built Environment*, 6(1), 1-17.
- Marsong, S., Kongjeen, Y., & Plangklang, B. (2022). Vertical Transportation System Power Usage: Behavioural Case Study of Regulated Buildings in Bangkok. *Sustainability*, 14(20), 13267.
- Metwally, E. A., Ismail, M. R., & Farid, A. A. (2024). Advancing Building Assessment Tools: Achieving Sustainable Development Goals through the Fusion of Internet of Things Occupant-Centric Principles and Sustainable Practices. *Buildings*, 14(6), 1798.
- Purnami, S. (2021). *A Study on the Facilities-Related Issues in High-Rise Residential Building* (Doctoral dissertation, UTAR).
- Quiquero, H., Smith, M., & Gales, J. (2018). Developing fire safety engineering as a practice in Canada. *Canadian Journal of Civil Engineering*, 45(7), 527-536.
- Ronchi, E., & Nilsson, D. (2013). Fire evacuation in high-rise buildings: a review of human behaviour and modelling research. *Fire science reviews*, 2, 1-21.
- Saini, N. (2025). *Understanding Elderly Mitigation Strategies for Indoor Smoke During Wildfire Events* (Doctoral dissertation, WORCESTER POLYTECHNIC INSTITUTE).
- Salankar, S. (2021). Study of critical fire safety parameters and development of an evacuation strategy for high rise buildings (Doctoral dissertation, College of Engineering, UPES, Dehradun).

- Sefidari, N. (2025). L'Influenza dell'Esperienza Precedente di Inondazioni sulla Percezione del Rischio e sui Comportamenti di Preparazione: Uno Studio con Metodo Misto nella Provincia del Belucistan, Iran.
- Soltanzadeh, A., Mazaherian, H., & Heidari, S. (2021). Optimal solutions to vertical access placement design in residential high-rise buildings based on human behavior. *Journal of Building Engineering*, 43, 102856.
- Soltanzadeh, A., Mazaherian, H., & Heidari, S. (2021). Optimal solutions to vertical access placement design in residential high-rise buildings based on human behavior. *Journal of Building Engineering*, 43, 102856.
- Wang, M. S., & Chien, H. T. (1998). Environmental behaviour analysis of high-rise building areas in Taiwan. *Building and Environment*, 34(1), 85-93.
- Wener, R., & Carmalt, H. (2006). Environmental psychology and sustainability in high-rise structures. *Technology in Society*, 28(1-2), 157-167.
- Wolfberg, A. (2025). Different Kinds of Threat. In *Climate Security Intelligence* (pp. 107-125). Springer, Cham.
- Yatim, Y. M. (2012). Optimum escape routes designs and specification for high-rise buildings. In *Proceedings of the 3rd International Conference in Construction Industry, Indonesia*.
- Zadobrischi, E. (2025). Traffic and Vehicle Management in Roundabouts Through Systems Based on Dedicated Short-Range Communications and Visible Light Communications. *Electronics*, 14(2), 317.
- Zhang, X. (2017). Study on rapid evacuation in high-rise buildings. *Engineering science and technology, an international journal*, 20(3), 1203-1210.