Relation between The Architectural Design and Fire safety Evacuation: The case of High-rise Residential Buildings-Bengaluru, India

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KEYWORDS

Evacuation, Prescriptive codes, Architectural Design, Fire safety, Residents Behaviour.

ABSTRACT

The safety of those who reside in tall residential buildings has become a crucial concern, particularly in considering incidents including the London Grenfell Tower disaster. The primary focus of current research is to evaluate the qualitative elements of fire safety measures and escape routes in Bengaluru's high-rise residential complexes, which are marked by a steady increase in urbanization and distinctive fire safety issues. Although the National Building Code (NBC) offers a theoretical framework for building structures free from significant fire hazards, the research found that this is more of a wish than a reality because of increasing gap between providers and end users. This result adheres with even the most basic NBC regulations, making buildings extremely vulnerable to fire incidents. Five high-rise residential structures in Bengaluru are subject of research. To identify particular shortcomings in operational and architectural integrity of fire safety, research utilizes conventional methods and questionnaire evaluation. The researcher employed a variety of research tools, including checklists that had been developed especially for the research, observational checklists that utilized while researcher was on site, "and qualitative analysis of the residents behavior during fire incidents. These issues include" inadequate exits, insufficient fire safety precautions, and inattention and blindness in public spaces. Additionally, architectural flaws include faulty placement of fire suppression equipment, inadequate or nonexistent maintenance of fire safety amenities, and the lack of suitable labeling indicating exit locations. Given that many residents prioritize their belongings over evacuation, their actions add layers to the evacuation procedures. The research in concern emphasizes the necessity of a comprehensive approach to fire safety management, which takes into account elements like resident training, legislative actions, and upgraded architectural solutions. High-rise residential structures can be made fire-safe through improved adherence to current codes, shared knowledge of fire hazards, and the main roles of "building owner, architect, fire safety engineer, and occupants". These issues must be addressed to reduce fire disasters and protect citizens' lives and property.

Introduction:

Tall apartment buildings have become an indicator of modernization in architectural construction globally, particularly in regions with expanding populations, including Bangalore, India. Given that the population of these cities continues to grow, fire safety in those buildings is crucial. However, fire incidents in high-rise structures remain an issue despite safety precautions and governing standards, especially NBC-2016. These incidents have far-reaching consequences, including loss of life and property, that emphasize the significance it is to putting forth suitable fire safety measures.

Numerous high-rise building fire disasters have happened throughout time, including London Grenfell Tower fire, which brought attention to the risks hidden in construction safety precautions. High-rise building safety requires several preventive measures including hall

protection plans, extinguishing equipment, and structurally protective layers. However, there have always been and continue to be certain flaws in these policies, in addition to issues with their execution and enforcement, particularly in emerging urban contexts.

Due to Bengaluru's rapid urbanization and dense population, high-rise building fire issues are particularly complex. These include factors residential architecture, fire safety regulations and how they function, and difficulties with firefighting, evacuation, and rescue efforts.

Problem Definition

Although formal regulations for bush fire safety are present, especially NBC-2016, as previously mentioned, it is often observed that there may be a significant difference amongst "legal and policy provisions and their actual application. Problem has several critical issues:

1. **Regulatory Compliance**: Due to" inadequate regulation enforcement or noncompliance, buildings often violate fire safety standards.
2. **Design and Infrastructure**: Iron grilles on balconies, supposed to improve security, might trap inhabitants in fire.
3. **Evacuation Challenges**: Overcrowding, poor escape routes, and lack of signage restrict evacuation, especially for the elderly and disabled.

Gap in the Literature

Although numerous research addresses fire safety generally, there is lack of investigations concerning challenges "and limitations encountered by individuals and evacuation protocols in high-rise residential buildings in urban areas, particularly in Bengaluru. Most of previous research is predominantly associated with theoretical fire safety ideas or case studies from other geographical regions, resulting in a scarcity of specific data concerning implementation of fire safety measures in specified area.

This research attempts to enhance the current literature by conducting a comprehensive evaluation of evacuation measures and fire safety techniques in high-rise residential buildings in Bengaluru". Results of current research's, derived from photographic evidence, observational case studies, and detailed descriptions, will identify gaps and provide specific recommendations for improving fire safety initiatives.

Research results, about "fire safety and evacuation planning", "should enhance comprehension of challenges faced by high-rise residential buildings in expanding locations. The results will focus on the development of enhanced fire safety measures that reduce the risks encountered by residents of high-rise buildings.

Literature Review

The fire safety and evacuation protocols for high-rise residential buildings have" received increased attention recently, due to rising population density and the proliferation of these structures. Therefore, effective fire safety management is crucial for protecting occupants and reducing risks associated with fire incidents. This literature review concentrates on recent advancements in fire safety research about tall structures, specifically regarding "architectural design, codes and standards, human behavior, and technology".

Current research examines that architectural design affects fire occupant safety. Contemporary research recommends including fire safety in building design. As stated by [16], "multiple exits, fire-resistant materials, and well-lit exit signage aid evacuation". According to [24], fire safety systems must be tailored to certain construction types and resident behavior.

High-rise building fires may be prevented by following construction and fire safety requirements. NBC of India rules provide fire safety and protection, including "egress, fire protection, and emergency lights". Although, [22] illustrates that violations of these norms continue due to insufficient compliance and knowledge of rules among stakeholders in building sector. Increased regulatory inspections and sanctions for offenders are required to improve fire safety.

This research investigates fire emergency human behavior to improve evacuation techniques. Based on [20], residents' initial responses to fire alarms getting information, and collecting belongings endanger their lives [19]. Fire drills and emergency education raise citizens' alertness, according to research. According to [21], it is crucial to communicate evacuation instructions to residents while making exit signs visible.

Technological advances have improved high-rise fire safety. Smart fire detection, automated sprinklers, and real-time monitoring promote early fire suppression. Research conducted by [18] examines the applications of AI and ML in evaluating fire threats and determining the optimal evacuation routes based on prevailing fire conditions. Furthermore, [17] argues that VR technology may be employed to educate inhabitants and first responders about fire evacuation procedures.

Recent real-life case studies reveal high-rise fire safety difficulties and solutions. In their research of Hong Kong high-rise residential buildings, [23] highlighted significance of fire safety maintenance in addition to inspection. Similarly, [15] research on skyscrapers in New York City underscores the imperative for continuous improvements in fire safety protocols, including the amendment of regulations and the integration of data from live-fire incidents.

Literature indicates "fire safety in high-rise residential buildings" varies by architectural design, laws, human behavior, and technology. Fire safety management systems are interconnected, thus recent studies recommend a systems approach for protecting people. By addressing the identified issues while employing modern technology and design, stakeholders could enhance high-rise building fire performance and reduce fire accident risks.

Case study of high-rise Residential Buildings

Bengaluru's "30 high-rise residential buildings were surveyed for compliance with NBC-2016 fire safety regulations. To understand how architectural design affects fire safety evacuation, five buildings were evaluated. The complete examination buildings have different designs, locations, and architectural spatial analysis materials.

The criteria for choosing the case study buildings:

- High-rise residential" selection is dependent on city corporations and greater Bangalore.
- Select buildings within 30mt and 120mt in height.
- Selected buildings with Building Byelaws and Fire NOCs.
- Selected campuses are residential only.

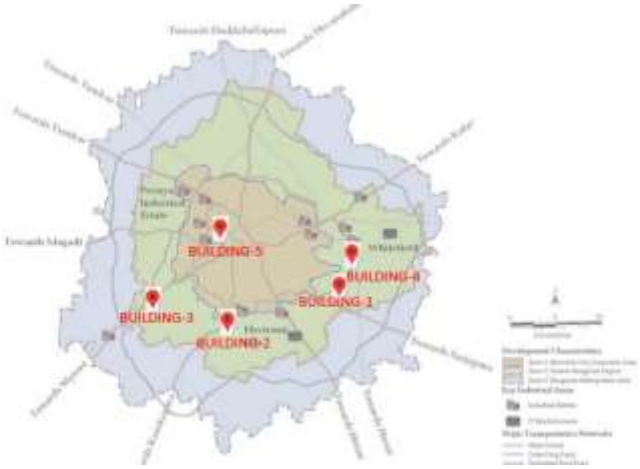


Figure1.1 Bangalore map illustrating case study buildings **"Source: CDP Bangalore Master Plan -2015"**

The urban structure of a city that includes Bangalore significantly impacts fire safety protocols and results. The urban landscape, comprising structures, avenues, infrastructure, and public places. Various elements within the urban environment might influence fire safety. The density and type of urban structures impact fire spread. High-density, tightly arranged establishes are inclined to catch fire. Rapidly urbanizing locations including High-rise structures and dense communities in Bangalore pose fire safety risks due to space constraints.

Table:1: "Details of Buildings selected for Case studies

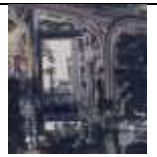
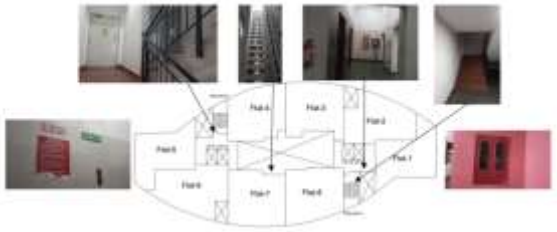
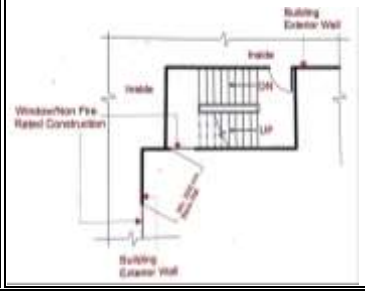
Sl.no	Description	Location	Facade	Site area	No of blocks	No of units	No of floors	Nearest fire station	Estimated time for fire brigade to reach fire origin	Year of construction	Compliance with NBC
1	Building-1			8.5 Acres	7	236	15	5km	15 min at peak hour	2016	65%
2	Building-2			9 Acres	10	309	14	6km	12 min at peak hour	2010	85%
3	Building-3			5 Acres	1	412	12	8km	12 min at peak hour	2016	75%
4	Building-4			4.6 Acres	3	356	15	8 km	15 min at peak hour	2012	75%
5	Building-5			10 Acres	1	356	36	4 km	14 min at peak hour	2013	78%"

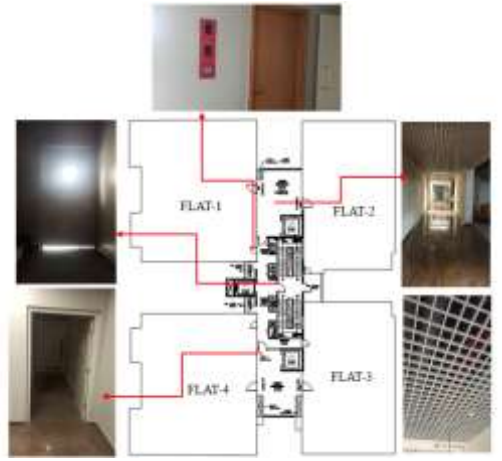
Table:1: highlights the fire safety issues with relevant figures.

Building	Details	Fire Safety Issues	Relevant Figures
Building-1	- 7blocks, 236units, 15floors. - "Two emergency staircases, four lifts. - 2016construction, 65%NBC compliance".	- With missing keys, FHC is not operational. - absence of signs and obvious entry/exit locations. - There are no fire-rated barriers separating flats and staircases. - slippery flooring on staircase.	 - Fig. 1.2: Schematic floor plan  Fig. 1.3: Typical floor plan demonstrating openings on external wall, not fire-rated. 

Building	Details	Fire Safety Issues	Relevant Figures
			Fig. 1.4 a) Typical floor plan   b)3D isometric view c)3D perspective view
Building-2	- 10blocks, 309units, 14floors. - Two emergency staircases and interconnected corridors. - 2010construction, 85%NBC compliance.	- Firefighters' access is hampered by grilled balconies. - No sprinklers in corridors, and FHC is locked. - exceeding safe evacuation travel distances.	 Fig. 1.5: Schematic floor plan

Building	Details	Fire Safety Issues	Relevant Figures
			 Fig.1.6 Floor plan of Building-2 with the Travel distances  Fig.1.7: a) Grilled balconies b) Locked FHC with Key missing

Building	Details	Fire Safety Issues	Relevant Figures
Building-3	- 1block, 412units, 12floors. - "Single staircase for emergency and daily use. - 2016construction, 75%NBC compliance".	- The options for evacuation are limited by a single stairway. - corridors are crowded with furniture and lack sufficient lighting. - Missing keys disable FHC.	-  Fig. 1.8: Schematic floor plan  - Fig. 1.9: Typical floor plan of Tower-2

Building	Details	Fire Safety Issues	Relevant Figures
Building-4	- 3blocks, 356units, 15floors. - "Two staircases for emergency and daily use. - 2012construction, 75%NBC compliance".	- Exceeding NBC travel limitations. - Missing signs and dark stairs. - Furniture obstructing corridors, preventing evacuation.	 Fig. 1.10: Schematic floor plan  - Fig.1.11: Core of Tower-1 and blocked corridors.

Building	Details	Fire Safety Issues	Relevant Figures
Building-5	- 1 block, 356units, 36floors. - Helipad, fire escape stairs, 2013construction. - 78%NBC compliance.	- Garbage "in fire exits blocked helipad access. - Fire escape floor plans and signage missing. - Locked helipad" entrance.	 Fig. 1.12: Schematic floor plan [9]. - Fig. 1.13: Fire exits and signage.

Common Issues Across Buildings: FHCs, emergency signage, and travel distances are lacking in all buildings.

Signage requirement in FES as per NBC

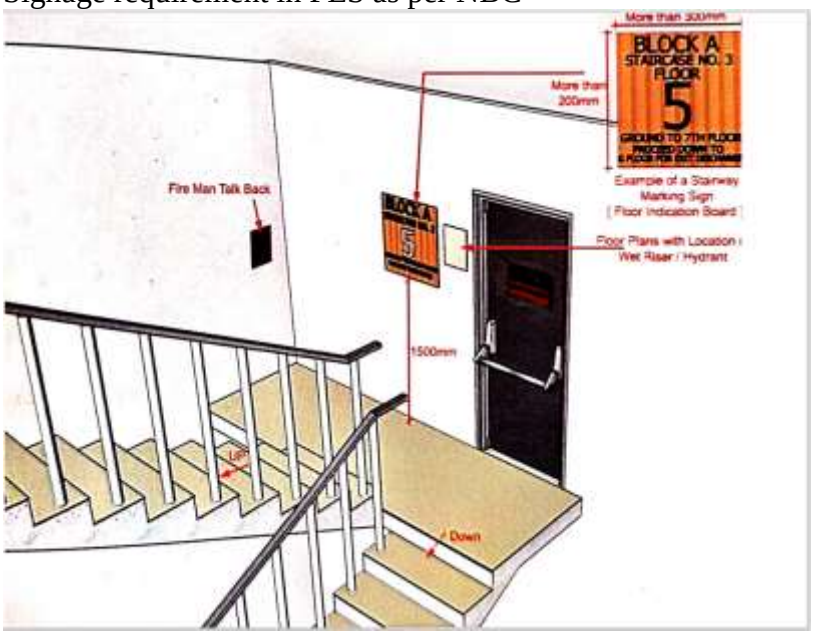


Fig.: "1.13 a) Sign Marking and Requirement in Exit b) Fire exit of Building-1 b) Fire exit of Building-2 c) Fire exit of Building-3 d) Fire exit of Building-4 e) Fire exit" of "Building-5[2]

Staircase Identification: Install indication boards inside staircase on wall nearest fir door and face it on each floor. Mount boards 1500mm above floor. Floor indicator boards should include block/wing/building name, staircase number, floor number, and exit direction". Indicator board should exceed 300X200mm [2].

Questionnaire survey conducted for the Residents:

Online and offline interviews have been conducted with occupants of high-rise residential complexes in Bangalore, India, for case studies. Given the incomplete responses, 171 samples have been analyzed from 181 respondents. Data collected from residents of three high-rise buildings (33-45m height) with the following age distribution: "36% aged 15-30, 28% aged 30-50, 21% aged 50-60, and 15% aged above 60". Out of total samples, "98 male and 73 female". As illustrated in Fig 1.14, women had lower educational attainment than men.

Survey participants' fire safety evacuation and drill experiences in high-rise buildings were assessed. From Mar-Dec 2023, respondents understood research objectives and questionnaire. The questionnaire had three sections: assessing occupants' fire safety knowledge, examining their behavior during evacuations, and assessing their opinions on egress components.

Microsoft Excel has been employed for collecting and evaluating qualitative data. Multiple verifications have been performed to verify accuracy and input error.

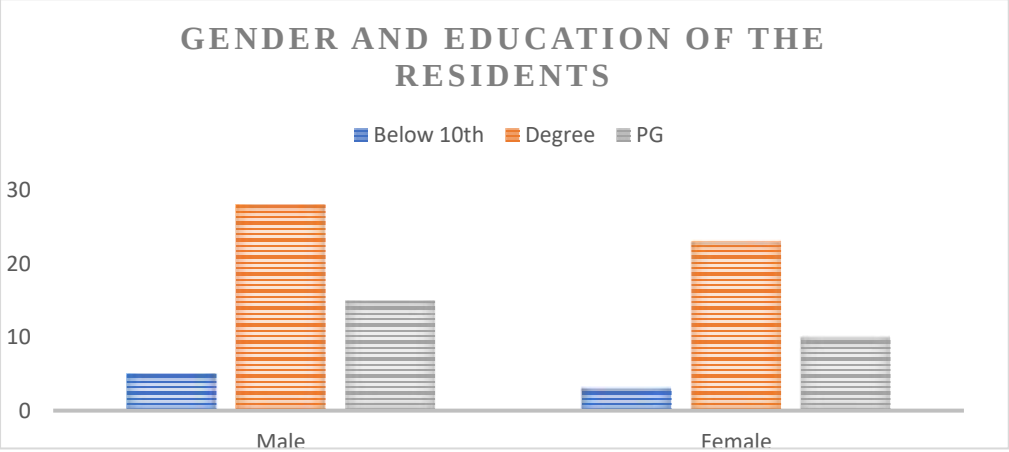


Figure:1.14 Resident Gender and Education

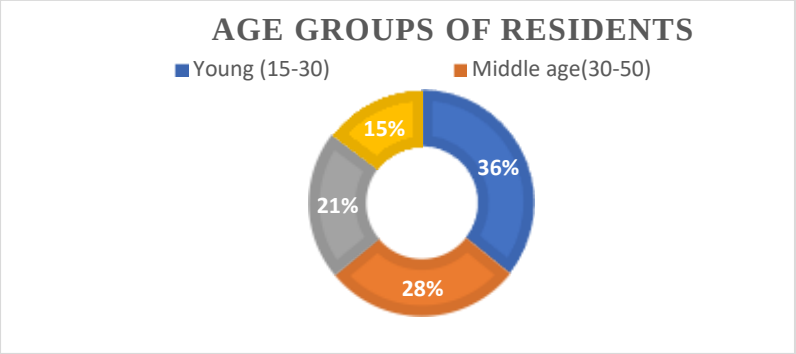


Figure:1.15 Resident age group

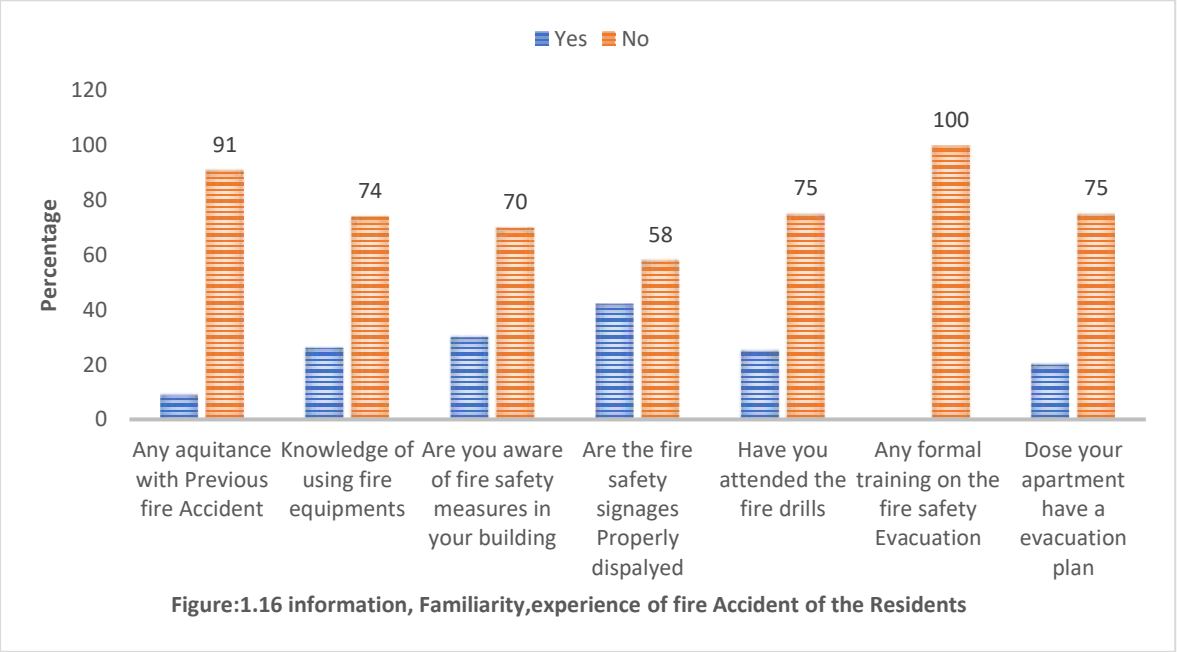
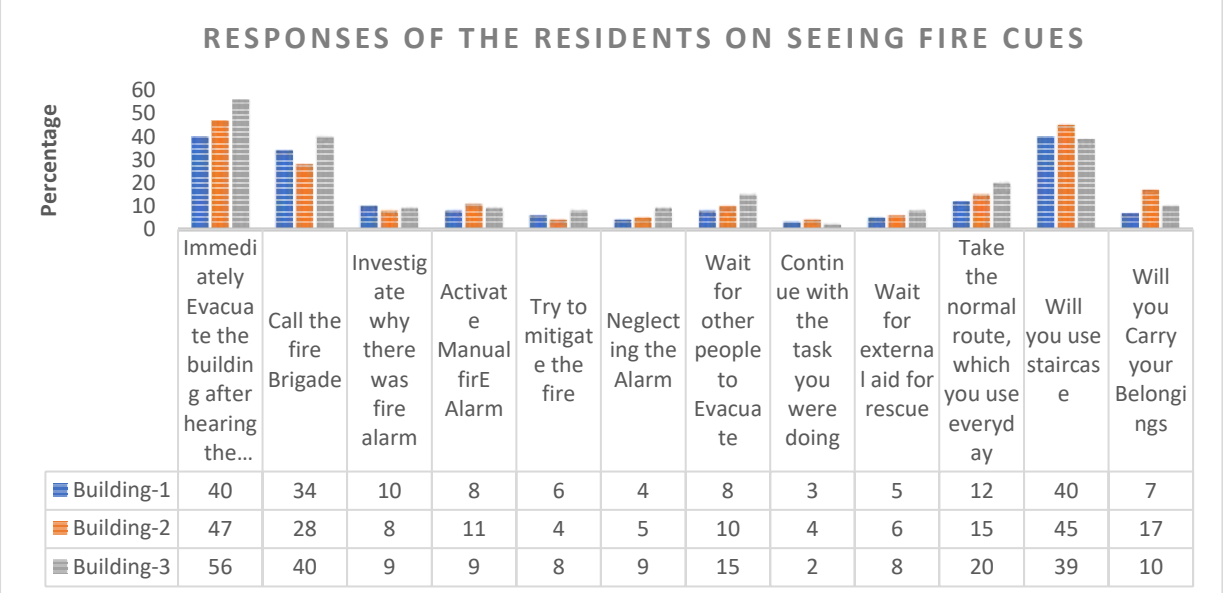


Figure:1.16 information, Familiarity,experience of fire Accident of the Residents

This aspect of the research revealed that residents remained skeptical of fire safety evacuation routes and equipment due to inadequate guidance. Despite their lack of familiarity with fire safety devices, residents appeared to be unconcerned. The absence of exit signage in structures is illustrated in Fig. 1.15. Essential information relating to fire safety protocols, that includes evacuation plans, recommended actions during fires, and exit signals, is inadequate, despite the presence of fire safety equipment. Due to this restriction, less educated individuals experience trouble reacting to fires. Numerous inhabitants recognized the deficiency of accurate information across the buildings. Signage location and legibility are concerns. Therefore, all signage must be appropriately positioned and residents must be informed of exit routes.



	Immediately Evacuate the building after hearing the...	Call the fire Brigade	Investigate why there was fire alarm	Activate Manual firE Alarm	Try to mitigate the fire	Neglecting the Alarm	Wait for other people to Evacuate	Continue with the task you were doing	Wait for external aid for rescue	Take the normal route, which you use everyday	Will you use staircase	Will you Carry your Belongings
Building-1	40	34	10	8	6	4	8	3	5	12	40	7
Building-2	47	28	8	11	4	5	10	4	6	15	45	17
Building-3	56	40	9	9	8	9	15	2	8	20	39	10

Figure:1.17 Residents' reactions to presence of fire cues

This research interviewed locals about initial reactions to fire indicators. Fig 1.17 displays that 15% of respondents received fire information prior to evacuating. 35% would contact the fire station or security for clarification. Some preferred autonomous fire extinguishing, while others preferred collecting valuables comprising jewels and money preceding evacuation. Residents

often prioritize property over personal safety during fire evacuations. It appears that tension has an impact on their decision-making. Similar research conducted on a diverse range of age groups demonstrated that more than 65% of the initial responses were centered on the acquisition of information prior to evacuation [31]. These results indicate that occupants hesitate to leave the building when they encounter fire "warnings.

Table:2 Overall Ranking of Residents Responses

Item	Residents Responses	Overall Ranking from Residents	
		Ranking	Importance"
1	Leave building immediately when fire alarm	I	High
2	Fire brigade called	II	
3	Would you take stairs?	III	
4	Take the standard route that you use daily.	IV	
5	Are you going to carry your possessions?	V	Medium
6	Be patient and wait for others to evacuate.	VI	
7	Enable manual fire alarm.	VII	
8	Examine cause of fire alarm.	VIII	Low
9	Failure to Respond to Alarm	IX	
10	Attempt to extinguish fire.	X	
11	Waiting for external assistance to be provided for rescue.	XI	
12	Remain engaged with work you were previously engaged in.	XII	

Architectural Design

Architects must balance practical and aesthetic aspects with client, stakeholder, and regulatory obligations while making design decisions. Fire safety is essential, however, it may be overlooked in favor of other design goals due to its apparent lack of significance and immediate benefits that include comfort or aesthetic appeal. Fire safety considerations can occur since architects value aesthetics and artistic expression. All buildings must provide fire safety as a public good. Building codes and standards mandate fire prevention measures, imposing diverse restrictions on architects. Although design concepts frequently arise from visual and aesthetic aspects, architects might require modifications in their designs following these standards. The disparity between design objectives and regulatory requirements may cause architects to consider code restrictions as creative restraints. [3, 4].

With assistance from the design team, architects prioritize design objectives while developing an optimal solution. Figure 1 describes principal building design goals from numerous sources [5-6].

Fig.1.18 Numerous design objectives of architects [25]

Building fire safety performance

Fire safety measures efficacy has a significant relationship with building's features, its inhabitants, and the nature of the fire. Large exit signs may assist persons escape a fire safely, improving life safety. Fire suppression systems, detectors, and egress improve fire safety. The occupants' familiarity with a building's layout is a critical factor affecting fire safety. Individuals familiar with the building's configuration can swiftly identify the most efficient departure pathways during emergencies, resulting in expedited evacuation durations. An effectively designed floor plan can improve inhabitants' spatial awareness, especially in complex buildings that include hospitals or commercial centers. The association between building characteristics, particularly architecture function, and occupant characteristics including familiarity, significantly influences fire safety drills. In a fire, occupants can choose an established exit route over another due to frequent building operations.

Building, human variables, and fire characteristics interact in complicated manners. Integrating human elements into fire safety design and planning is crucial as residents' building layout expertise influences their behavior during emergencies [15].

Relationship between Architectural Design and Fire Safety Performance

"Prescriptive building regulations and design" can't completely manage the interaction involving "architectural design, human behavior, fire dynamics, and fire safety evacuation". Comprehensive building system and component requirements are easily investigated for code compliance under these standards. The numerous relationships that impact fire safety performance weren't adequately captured.

Prescriptive laws recognize human attributes, fire behavior, and building design, but they rarely describe fire safety performance. Building height, size, construction type, occupancy classification, and sprinkler system presence often determine regulation-recommended choices for design. These standards might not, however, adequately take into consideration the wide variety of building layouts and occupancy situations, which could result in disparities in fire safety performance. Thus, few building fire signs cause unacceptable damage and loss, emphasizing on demand for more prescriptive regulations. Architectural design is increasingly recognized as a fire safety evacuation tool. In fire safety planning and design, clear exit signage, accessible escape, and human behavior considerations may reduce fire risks. By examining building elements, occupant behavior patterns, and fire dynamics, Performance Based Design (PBD) evaluation improves fire safety. This method allows designers to customize fire safety protocols to specific characteristics of subsequent building, thereby enhancing evacuation efficiency and diminishing fire-related injuries and deaths. Although prescriptive requirements provide framework for fire safety design, architectural design aspects are becoming recognized as necessary for fire safety evacuation strategies. Buildings may more effectively protect residents during fire crises by combining legal requirements and architectural design principles.

Table-3: "Summary of issues and repercussions identified in high-rise residential buildings based on observations and questionnaire results from the three building case studies in Bangalore

SL. No	Categories	Challenges Identified	Issues Identified	Implications"
1.	**Architectural Design and building construction**	No alternate staircase provided in Buiding-1 and Building-3	Single staircase provided	Residents might become trapped
		Building-1 lacks the 3000mm blank wall that NBC specifies be located between apartment opening and stairway window at an inclination of less than 180º.	Fire escape stairs have non-fire-rated windows.	Heat and smoke may reach fire escape staircase, making evacuation difficult.
		Travel distance exceeding allowed limit in Building-2	Lacking sprinklers, NBC-2016 recommended travel distance of 22.5 m is exceeded by all units.	This will result in an extended evacuation period.
		In Building-1, flooring of fire escape stairs is slippery.	It has a very smooth finish	It could injure residents in evacuation.
		Building-3 corridors lack enough lighting and ventilation.	There is only one window available at end of corridor.	Reduces rate that residents are evacuated
		Missing Refuge area	Despite having 36 floors, Building 5 lacks refuge area.	Elderly people and those with physical disabilities could find it challenging to evacuate during a fire.
2.	**Fire safety measures in the building**	Buildings-1&3 have improperly installed ventilation systems.	There is insufficient room for natural ventilation in stairwell.	Smoke and fume accumulation in corridors and stairwells
		Not installing illumination system properly.	Corridor's artificial lighting is inadequate.	Impaired visibility Impeded mobility Increased risk of slipping
		Lack of sufficient fire-extinguishers	There is only one type of fire extinguisher and they have not been placed properly.	Fire mitigation takes time.
		Inadequate exit signage installation	No corridor exit signs Lack of exit sign illumination	Fire victims may have trouble accessing evacuation routes.
3	**Maintenance**	Maintaining the condition of fire suppression systems remained inadequate.	Missing keys and broken/no glass at key holder	Not operational in an emergency, evacuation may be difficult.

		Insufficiently maintained lighting systems	Regular light replacement and inspection aren't checked.	Reduce the intensity of light.
		Poorly maintained fire doors	The fire doors are unpainted and challenging to operate.	Slows down the evacuation process
		Inadequate staircase maintenance	Garbage and dust clutter stairs.	It might cause accidents during evacuation.
		Torn fire notices	When fire notices are damaged, they have not been replaced, therefore they fail to convey message.	Unclear Messages may mislead residents.
4.	**"Management**	No regular inspection	Corridor furniture & garbage bins	This will add up to the fire-ignited
		Lack of control and enforcement	Railings on balconies	Difficulty for the firefighters to access building
		No fire drills conducted	Residents are unaware of building's fire safety features.	Residents will lack evacuation information.
		Fire audits are not regular	Building management isn't serious about fire audits.	The fire safety provisions will be checked"
5.	**People's Attitude**	Not interested in Attending fire drills	Reported to be insignificant	Residents unfamiliar with evacuation routes may struggle to escape.
		Vandalism	Torn fire notices Improper fire suppression system Improper fire door	Residents aren't guided System failure could allow smoke entering staircase.
		Dumping in fire escape	Furniture/ garbage in Stairwell	It ignites fires and delays evacuation.
		Furniture placement in corridor	Furniture/flower, pot/bicycles in corridor	Traffic congestion may cause delays in evacuation, trapping occupants, and reducing corridor width and stairs.

Conclusion:

Current research analyzes fire safety evacuation processes in high-rise residential buildings in Bengaluru, India, and highlights gaps in current methods. Research indicates inadequate compliance with NBC guidelines, particularly for egress route design and preventing fires. Poor evacuation routes, obstructed exits, and damaged firefighting apparatus are architectural and operational issues. These shortcomings increase fire emergency risks and emphasize the requirement for improvement. Moreover, results indicate that residents are predominantly ignorant and ill-prepared for fire incidents due to insufficient awareness and training. This research recommends strict NBC requirements, better architecture, and maintenance. It additionally emphasizes the significance of instructing residents, particularly through training and drills related to fire safety. Additional research is necessary for a follow-up period to evaluate the effectiveness of the new fire safety measures, compare results with other cities, and implement novel technology in fire safety and evacuation procedures. According to results and proposed methods, fire safety standards could be improved to avoid fires in Bengaluru's high-rise residential buildings and protect residents.

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