Journal of Engineering Research (ERJ)
ISSN: 2356-9441 Vol. 8 – No. 1, 2024 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

Building for safety: Design considerations for refuge areas in tall buildings from Quality Management Perspective

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Abstract*- New El Alamein City is one of the largest urban projects in Egypt, and the largest project on the north coast. Tall buildings (super high-rise buildings) are considered the prevailing trend by architectural designers to obtain the maximum view of the Mediterranean Sea. The provision of safety evacuation in emergencies for these buildings' occupants is a crucial challenge from the Quality management point of view. In contrast, there are no sufficient architectural design guidelines for the tall buildings provided by the Egyptian code for protecting buildings from fire, especially the design of the refuge areas. This study aims to investigate the design considerations of refuge areas in promoting safe evacuation for tall buildings. (Thirty) design considerations were derived from the extensive literature and international codes. An expert interview was conducted to assess these considerations by multidisciplinary stakeholders involved in making a key decision on this subject. Based on the quantitative analysis by using Failure Mode and Effects Analysis (FMEA) analytical approach, the design considerations were ranked. Therefore, the most important considerations and rules influencing the design of refuge areas were determined. Then, a sequential operational model consisting of seven steps, and a proposal for refuge area were concluded to improve the lifecycle, and safety procedures of the tall buildings.

***Keywords*- Tall buildings, Design considerations, Safety evacuation, FEMA, Quality management.**

I. INTRODUCTION

Tall buildings have become an integral part of modern urban landscapes, symbolizing human ambition and technological advancement [1]. Tall buildings are usually designed for multiple uses, such as residential, commercial, or mixed-use purposes. They often incorporate advanced technologies and materials in their construction, such as high-strength concrete, steel, and glass [2]. The design of tall buildings must take into account various factors such as structural integrity, wind resistance, elevator efficiency, and safety measures like fire protection systems and evacuation strategies [3]. Quality management is a collection of processes and procedures that aims to ensure that the quality of products, functions, and services meets the users' expectation [4]. The Failure Mode and Effects Analysis (FMEA) tool is an effective tool used to evaluate and improve functions during Quality management processes. In this respect, the (FMEA) tool is a powerful methodology that plays a vital role in identifying and mitigating functions' weaknesses. It systematically examines potential failure modes, their causes, and the potential effects associated with safety, and processes to enable stakeholders to proactively address vulnerabilities [5]. This study investigates the refuge area design considerations in tall buildings and its rules to provide safe evacuation and achieve quality measures for these types of buildings. The importance of this study lies in filling the gap in Egyptian code for protecting buildings from fire in this regard. By using the inductive method, the design considerations were summarized from the previous literature and the international codes, and classified under three categories. Then, the design considerations were ranked using Failure Mode and Effects Analysis (FMEA) analytical approach through its three paths. Finally, the most important considerations were derived by using the deductive method and a sequential operational model consists of seven steps was concluded to improve the lifecycle of the tall buildings.

II. BACKGROUND

1.1 TALL BUILDINGS

Tall building serves as iconic architectural landmarks and symbols of urban progress, defining the skylines of modern cities worldwide. A common benchmark for tall buildings is a height exceeding 150 meters (approximately 492 feet) [6]. In recent years, the average height of newly completed tall buildings has steadily increased. In 2023, the average completion height reached 242.7 meters, marking a 2.7 percent rise from the world's tallest buildings to 409.7 meters in 2023 [7]. An essential consideration for both building designers and governmental authorities is the implementation of effective evacuation strategies to enhance occupant safety in tall buildings. consequently, there is a pressing need to address potential risks associated with tall buildings, particularly concerning fire incidents [8]. Therefore, comprehensive measures must be implemented to mitigate these risks and safeguard the lives and well-being of building occupants, staff, and emergency responders. such measures may include the integration of advanced fire suppression systems, and enhanced evacuation protocols.

1.2 REFUGE AREA

Refuge area is a fire safe area playing a crucial role in ensuring the safety and well-being of individuals during

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emergencies [9]. Where occupants can briefly rest before continuing their escape from a high-rise building, while also serving as a place of temporary refuge for occupants with disabilities and young children awaiting rescue by fire authorities [10]. The importance of refuge areas in tall buildings has become increasingly recognized, as concentrating occupants onto refuge floors during emergencies has gained traction. However, this concept presents challenges to efficiency, and life safety goals [11].

1.2.1 Classification of refuge area in tall buildings

The classification of refuge spaces in tall buildings includes three types: concentrated refuge space, dispersed refuge space, and multifunctional refuge space [12]. The dispersed approach considers all floors as potential refuge areas [13]. The consolidated approach considers that only selected floors will serve the refuge function, while the multifunctional refuge area is a combination of both concentrated and dispersed refuge areas [14]. The description and advantages of the Approaches to refuge areas in tall buildings can be summarized as shown in (Table 1).

Table 1: Approaches to refuge areas in tall buildings [15]

Type	Description	Advantages
Dispersed	Areas of Rescue Assistance" or horizontal exits for disabled occupants who cannot use stairs. Horizontal exits are constructed using continuous fire barriers and self/automatic-closing fire doors to divide a floor area into independent fire/smoke-protected zones.	Provides a safe means of egress for disabled occupants.
Consolidated	Refuge floors provide a safe holding area for occupants during evacuation. Exit stairs are interrupted to make occupants aware of the availability of the refuge floor.	Provide refuge space that serve as a safe holding area for occupants during evacuations. Occupants can pause and rest at the refuge floor until they feel ready to continue descending the exit stairs. Interrupting the exit stairs can mitigate stack effect and improve stair pressurization systems.
Multifunctional	serve a dual purpose by incorporating other functionalities in addition to their role as refuge areas. For example, a refuge space could be designed to also function as a meeting room, break area, or amenity space or also the roof of a building during normal building operations.	Maximizes utilization of space and provides added value beyond emergency situations.

1.2.2 Refuge area challenges

The challenges of life safety in refuge areas are multifaceted and require careful considerations. In fact, evacuating a refuge floor can present crowd management issues, as a large number of occupants compete for limited evacuation routes [16]. Additionally, from a security perspective, it's necessitating special considerations for security precautions and access during non-use periods. So that it must consider these factors when designing and implementing refuge areas [17].

1.2.3 Refuge area design considerations

The actual utilization of a refuge floor during an emergency is unpredictable and depends on various design considerations, such as the location and spread of the fire, characteristics of the occupants, and effectiveness of emergency communications [18]. It is noteworthy, assuming a large number of occupants gather on a refuge floor, there are several issues to consider for their comfort and safety: including provisions for toilets and drinking water, seating or standing accommodations, emergency power, protection from fire effects, and reliable ventilation/HVAC design [19]. As well as, significant attention has been given to ensuring that all areas of refuge are located near stairwells or elevator lobbies [20]. Furthermore, areas of refuge must be strategically positioned to avoid obstructing the evacuation routes of others. Where these areas, are equipped with communication systems to connect occupants with building managers or emergency personnel, and are clearly identified with accessible signs and featured in emergency-evacuation procedures to ensure widespread awareness among building occupants [21]. More specifically, the refuge area fire safety and architectural design considerations can be summarized from the revised literature as illustrated in (Table 2).

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Table 2: The refuge area fire safety and architectural design considerations

N	Design considerations	The most effective rules
Fire safety design considerations [22, 23]		
1	Fire resistance finishing martials	Walls, ceiling, floors, and furniture must be 90 minutes fire resistant.
2	Smoke control	To prevent spread smoke and toxic gases.
3	Emergency lighting	Must be connected with a standalone electric source.
4	Suppression systems (firefighting systems)	Should be equipped with fire
5	Communication systems	Reliable communication system connected with emergency responders.
6	Fire detection and alarm system	Must be integrated with the building overall fire alarm system.
7	Emergency power supply	Must be supplied with dependent power supply.
8	Connectivity with firemen elevators	It must have direct access for firefighters and paramedics.
Architectural design considerations [24, 25,26]		
9	Location and accessibility	Strategic location: closed to emergency staircase, near key gathering points, in low fire risk floors, easily accessible for occupants, clear and direct routes.
10	Size and capacity	0.30 m^2 per person, 1.2m^2 per wheelchair, and space for emergency responders must be provided.
11	Number of refuge areas	After 24 stories (90 m height)- Every 16-floor interval.
12	Structural integrity	The structure must withstand fire and emergency hazards (2 hours at least).
13	Ventilation system	maintaining air quality and preventing smoke buildup are essential, natural ventilation is preferred.
14	signage	Should be visible and easy to understand.
15	Usability	It should be designed with user experience in mind.
16	Adaptability and flexibility	Able to future extension and upgrades to fire safety systems.
17	Furnishing and amenities	Provide seating option for occupants, and consider first aid supplies.
18	Capacity for special needs	Must be to wheelchair accessible with ramps or lifts.
19	Evacuation time	Ensuring that the refuge area contributes the achievement of the required safe evacuation time (maximum 2 hours).

1.3 Quality Management System (QMS)

Implementing a quality management system (QMS) is crucial in the construction industry to ensure precise project execution, adherence to specifications, and regulatory compliance [27]. Similarly, in the field of architecture, a well-implemented QMS is essential to deliver exceptional design and construction services [28]. By providing a comprehensive QMS framework throughout the construction process, which includes quality planning, assurance, control, and continuous improvement, architectural firms can establish clear quality objectives and standards to meet or exceed client expectations [29]. The QMS plays a crucial role in minimizing defects, rework, and delays by implementing robust quality control procedures, ultimately improving project outcomes. Moreover, a robust QMS enhances client satisfaction and contributes to long-term success in the construction industry [30].

1.3.1 Quality management system in tall buildings

Applying a Quality management system approach in tall building construction projects is essential to avoid defects in design, and maintenance processes, as illustrated in (Table 3). It involves ensuring compliance with codes standards of materials and fire safety design considerations. Ultimately, contributing to the overall safety and reliability of tall buildings. Therefore, it is a critical aspect of tall buildings' safety to prevent accidents, and fires that may have a negative impact on the building and the occupants during and after the construction process [31]. Indeed, there are several tools in quality management systems can be used to evaluate and improve the design rules of refuge areas in tall buildings to provide safe evacuation. Failure Mode and Effects Analysis (FMEA) is one such tool, it can provide a operational model by assembling a multidisciplinary team to analyze identified factors (design rules of refuge areas), quantifying their severity, and detectability to arrive at an integrated approach [32].

Table 3: The refuge area Quality management considerations [33, 34]

N	Design considerations	The most effective rules
Quality management considerations		
20	Construction quality	Must be resistant to high temperature, smoke and toxic gases.
21	System integration	Must be integrated with fire alarm, and sprinklers systems.
22	Regular inspection and maintenance	Routine inspections must be established to ensure the functionality.
23	Emergency response planning	It must be incorporated in the building emergency response plan.
24	Innovation and Technology	Incorporating with intelligent sensors for fire detection.
25	Durability and sustainability	It can withstand the rigors of use.
26	Training and awareness	Drills and training must be conducted for the occupants and building staff to be familiar with the refuge area.
27	Evacuation coordination	Coordinating the evacuation routes to guide occupants to refuge area.
28	Time efficiency (emergency response time)	Must not exceed 60 second after fire alarm detecting.
29	Compliance with building codes	Respecting the country code, IBC, and NFPA as possible.
30	Appling Failure Mode and Effects (FMEA)	Following FEMA 3 paths

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Journal of Engineering Research (ERJ)
ISSN: 2356-9441 Vol. 8 – No. 1, 2024 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

1.3.2 Failure Mode and Effects Analysis (FMEA) in tall buildings

The origins of Failure Mode Effect Analysis can be traced back to its initial adoption by the U.S. Army in 1949, where it was utilized to enhance military operations. Subsequently, NASA embraced this technique in the early 1960s to improve reliability and optimize safety analysis. Since then, FMEA has been continuously refined and has gained widespread application across diverse industries, including aerospace, mechanical engineering, and construction sectors [35].
Failure Mode Effect Analysis (FMEA) is a valuable tool for identifying and prioritizing potential failure modes and errors in various processes, systems, and projects. Its main purpose is to generate multiple problem-solving ideas, ensuring comprehensive identification and justification of possible errors or failures [36]. Meanwhile, FMEA is not only a tool for identifying and mitigating potential failures but also serves to enhance good engineering practices through the utilization of a cross-functional team's knowledge and experience. This team plays a crucial role in reviewing the design progress of a project or process and assessing its probability of failure [37]. Following paths in (Figure 1) can be conducted to undertake the FMEA tool in tall buildings projects to enhance its design process and maintenance procedures.

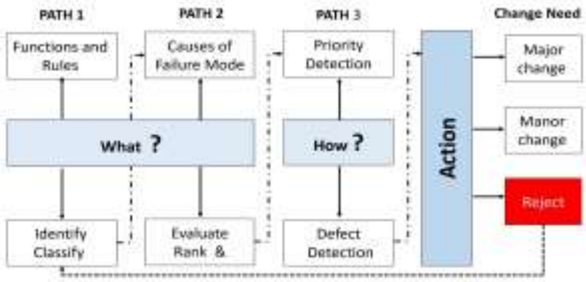

Figure 1: FEMA paths

III. .METHODOLOGY

This study uses Failure Mode and Effects (FEMA) Analytical approach to evaluate and rank the design considerations for refuge in tall buildings. Therefore, this study methodology consists of three sections or three paths as follows below:

a-The first section (path1), thirty design considerations (functions) were gathered from the scrutinized literature and classified under three categories as; Fire safety, architectural, and quality management design considerations.

b-In the second section (path2), the most important rules (causes of failure modes) for the design considerations were identified.

c-The third section (path3), expert interviews were conducted to assess the thirty design considerations (priority detection) through a professional team (experts) was assembled comprising (8) architects, (4) academics, (6) civil defense, (4) electromechanical engineers, and (3) QC engineers. For each category and its subset considerations, the experts evaluate the design considerations on 5-Likert scale, from “extremely important” to “extremely not important” as illustrated in (Table 4). Subsequently, Standard Deviation (α), the mean value (μ), and the Coefficient of Variance (CV) were calculated. Finaly, the relative importance index (RII) was concluded and the design considerations were ranked by the following equations:

$$(\mu) = n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5 \;/\; \text{Total number of samples} \qquad \text{eq (1) [38]}$$

$$(CV) = (\alpha / \mu) * 100 \qquad \text{eq (2)}$$

Where:

- CV< 10 = Excellent sample
- CV (between 10-20) = Very good
- CV (between 20-30) = Acceptable
- CV (between 30-40) = Low
- CV> 40 = Unacceptable

$$(RII) = n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5 / 5(n_1 + n_2 + n_3 + n_4 + n_5) \qquad \text{eq (3) [39]}$$

Where:
(n_5) the number of experts scored (EI), (n_4) the number of experts scored (I), (n_3) the number of experts scored (A), (n_2) the number of experts scored (NI), and (n) the number of experts scored (ENI).

Therefore:

- RII = 0: 0.20 = Importance level (Low = L)
- RII = 0.21: 0.40 = Importance level (Medium low = M-L)
- RII = 0.41: 0.60 = Importance level (Medium = M)
- RII = 0.61: 0.80 = Importance level (Medium high = M-H)
- RII = 0.81: 1.00 = Importance level (High = H)

In conjunction with (detecting/determining) the priority of the refuge area design considerations through ranking it in the third section (path 3), the detection controls were established. Therefore, designers and decision-makers in the tall buildings design processes can ensure that the design meets the necessary requirements or to prevent failure modes from reaching the customer undetected (in the context of the FMEA process). This particular step guarantees the validation of design or process enhancements and the attainment of proportional improvement.

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Table 4: The experts' evaluation for the design considerations

	No	Design considerations	Extremely important EI	important I	Average A	Not important NI	Extremely not important ENI
Fire safety design considerations	1	Fire resistance finishing materials	14	8	2	1	0
	2	Smoke control	10	8	6	1	0
	3	Emergency lighting	8	11	4	2	0
	4	Suppression systems (firefighting systems)	13	5	4	3	0
	5	Communication systems	3	7	8	5	2
	6	Fire detection and alarm system	16	6	3	0	0
	7	Emergency power supply	13	9	2	1	0
	8	Connectivity with firemen elevators	5	14	1	2	3
Architecture design considerations	9	Location and accessibility	18	5	2	0	0
	10	Size and capacity	2	8	8	2	5
	11	Number of refuge areas	7	12	6	0	0
	12	Structural integrity	6	13	6	0	0
	13	Ventilation system	16	8	0	1	0
	14	signage	5	5	5	5	5
	15	Usability	2	13	9	0	1
	16	Adaptability and flexibility	3	9	10	3	0
	17	Furnishing and amenities	5	8	11	1	0
	18	Capacity for special needs	13	9	3	0	0
	19	Evacuation time	10	10	5	0	0
Quality management considerations	20	Construction quality	8	13	3	1	0
	21	System integration	15	8	2	0	0
	22	Regular inspection and maintenance	6	10	8	1	0
	23	Emergency response planning	9	14	2	0	0
	24	Innovation and Technology	2	2	2	7	12
	25	Durability and sustainability	11	10	4	0	0
	26	Training and awareness	12	12	1	0	0
	27	Evacuation coordination	8	14	2	1	0
	28	Time efficiency (emergency response time)	5	6	8	6	0
	29	Compliance with building codes	13	9	2	1	0
	30	Appling Failure Mode and Effects (FMEA)	17	5	3	0	0

IV. RESULTS

Regarding the average coefficient of variance (CV) for the experts' interviews. The (CV) value was 15.65, thus the sample is homogeneous and accepted. Meanwhile, seventeen design considerations were ranked "High", ten were ranked "Medium-High", two were ranked "Medium", and one was ranked "Medium-low" as shown in (Table 5).

Likewise, the most important design considerations which ranked from (1 to 10) were fifteen design considerations as; location and accessibility (R1), applying Failure Mode and Effects Analysis (FMEA) (R2), ventilation system (R2), system integration (R3), fire detection and alarm system (R3), training and awareness (R4), fire resistance finishing materials (R5), capacity for special needs (R5), emergency power supply (R6), compliance with building codes (R6), emergency response planning (R7), durability and sustainability (R7), evacuation time (R8), evacuation coordination (R9), and construction quality (R10) respectively.

More specifically, the design considerations (the top 10) were classified as follows, three considerations out of eight were in the fire safety category, four considerations out of eleven were in architectural, and eight considerations out of eleven were in the quality management design category as demonstrated in (Figure 2). In this respect, 53% of (the top 10) deign considerations were under quality management design category, 27% were under architectural, and 20% were under fire safety category.

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Table 5: The design considerations (RII)

No		Mean	Standard Deviation	Coefficient of Variance	RII		Ranking (R)
		µ	α	cv			
Fire safety design considerations	**1**	4.400	0.816	18.557	0.880	**High**	**5**
	2	4.080	0.909	22.285	0.816	**High**	**11**
	3	4.000	0.913	22.822	0.800	**Medium High**	**13**
	4	4.120	1.092	26.515	0.824	**High**	**10**
	5	3.160	1.143	36.174	0.632	**Medium High**	**20**
	6	4.520	0.714	15.800	0.904	**High**	**3**
	7	4.360	0.810	18.586	0.872	**High**	**6**
	8	3.640	1.254	34.460	0.728	**Medium High**	**16**
Architecture design considerations	**9**	4.640	0.638	13.744	0.928	**High**	**1**
	10	3.000	1.258	41.944	0.600	**Medium**	**21**
	11	4.040	0.735	18.189	0.808	**Medium High**	**12**
	12	4.000	0.707	17.678	0.800	**Medium High**	**13**
	13	4.560	0.712	15.610	0.912	**High**	**2**
	14	3.000	1.443	48.113	0.600	**Medium**	**21**
	15	3.600	0.816	22.680	0.720	**Medium High**	**17**
	16	3.480	0.872	25.051	0.696	**Medium High**	**18**
	17	3.680	0.852	23.164	0.736	**Medium High**	**15**
	18	4.400	0.707	16.071	0.880	**High**	**5**
	19	4.200	0.764	18.185	0.840	**High**	**8**
Quality management considerations	**20**	4.120	0.781	18.957	0.824	**High**	**10**
	21	4.520	0.653	14.451	0.904	**High**	**3**
	22	3.840	0.850	22.148	0.768	**Medium High**	**14**
	23	4.280	0.614	14.340	0.856	**High**	**7**
	24	2.000	1.291	64.550	0.400	**Medium Low**	**22**
	25	4.280	0.737	17.222	0.856	**High**	**7**
	26	4.440	0.583	13.133	0.888	**High**	**4**
	27	4.160	0.746	17.935	0.832	**High**	**9**
	28	3.400	1.080	31.768	0.680	**Medium High**	**19**
	29	4.360	0.810	18.586	0.872	**High**	**6**
	30	4.560	0.712	15.610	0.912	**High**	**2**
Average (CV)				**15.652**	**Accepted sample**		

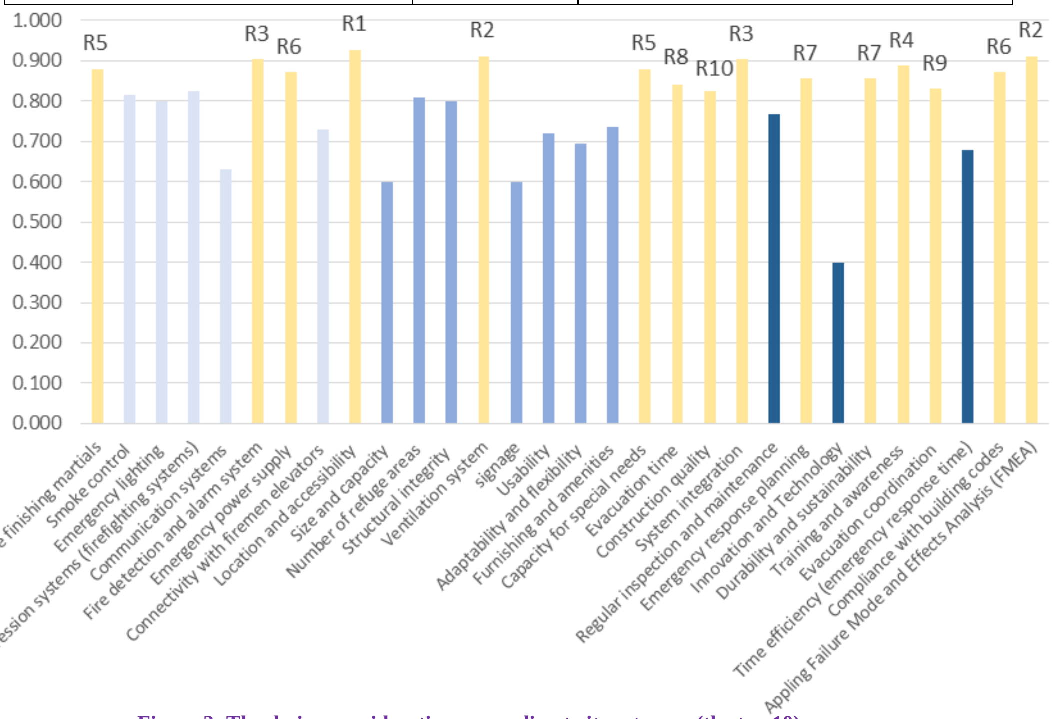

Figure 2: The design considerations according to its category (the top 10)

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Journal of Engineering Research (ERJ)
ISSN: 2356-9441 Vol. 8 – No. 1, 2024 ©Tanta University, Faculty of Engineering e ISSN: 2735-4873

VI. Discussion

With regard to the evaluation of experts' interviews, eight of eleven considerations under the quality management category were ranked "high" and classified under the most important considerations. That reflects the consensus of the experts that implementing quality management considerations on tall buildings plays a vital role in the success of these projects whether in the design, emergency evacuation, and maintenance processes. In other words, it facilitates the identification of critical areas that require attention and enables the implementation of measures to mitigate risks, enhance design quality, improve occupants' satisfaction, and ensure compliance with safety and regulatory standards.

Meanwhile, applying Failure Mode and Effects Analysis (FMEA) design consideration under the quality management category was located in second place of importance. That ensures the importance of this analytical tool in the assessment of the construction projects during their lifecycle, especially the complex buildings like the tall buildings. Moreover, the early utilization of (FMEA) tool ensures ongoing enhancement of quality and reliability. Also, it promotes continuous improvement, and helps maintain optimal performance for these types of buildings as illustrated in (Figure 3&4).

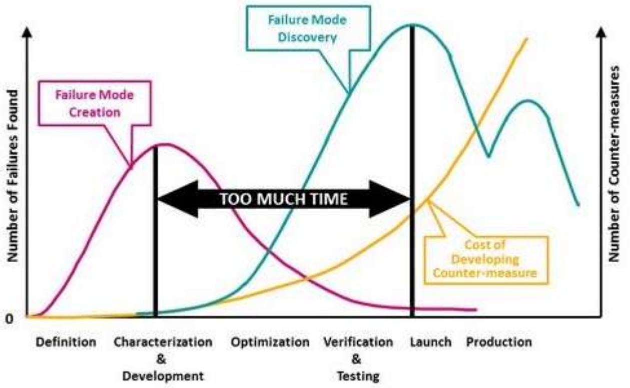

Figure 3: Late failure mode Discovery

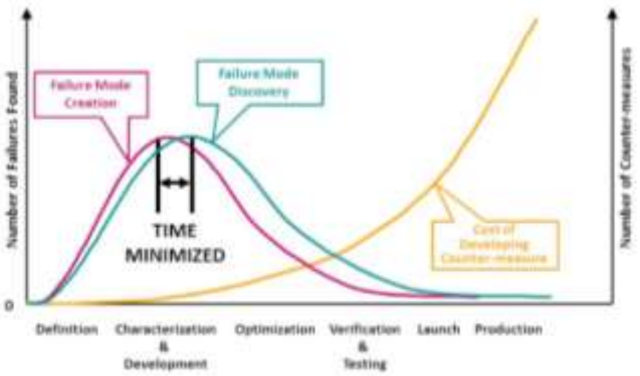

Figure 4: Early failure mode Discovery

More specifically, the application of the FMEA tool to the design and utilization of refuge areas in emergency cases involves a sequential operational model. This model consists of seven steps that aim to enhance the reliability, safety, and functionality of refuge areas as summarized in (Table 6). Thus, by following the suggested operational model, the FMEA tool effectively contributes to the design and utilization of refuge areas in the evacuation system, ensuring their reliability, safety, and functionality during emergency situations.

Table 6: The operation model steps.

Steps	Description
S1	Assemble a diverse cross-functional team comprising individuals with expertise in disciplines such as design, safety, engineering, operations, and relevant stakeholders. This team composition facilitates analysis by incorporating different perspectives and knowledge.
S2	Identify potential failure modes through brainstorming sessions. Consider factors such as structural integrity, accessibility, environmental conditions, blocked exits, faulty evacuation signs, inadequate emergency lighting, and lack of clear communication channels.
S3	Assess the severity or impact of each identified failure mode on the safety and functionality of the refuge area. Evaluate factors such as potential harm to occupants, the ability to provide shelter, and the overall effectiveness of the evacuation system.
S4	Determine the causes underlying each failure mode. Evaluate the effectiveness of existing control measures and safeguards in mitigating or preventing failures. Identify weaknesses or gaps in the current design or operational procedures, such as poor maintenance or inadequate training. Assess detection methods for timely identification of failure modes.
S5	Prioritize failure modes based on scores and develop appropriate mitigation measures. This may include design modifications, process improvements, additional safety features, or enhanced training and maintenance protocols.
S6	Regularly monitor the performance of the refuge area and the effectiveness of implemented mitigation measures. Conduct periodic reviews and update the Failure Modes and Effects Analysis (FMEA) with new information or modifications to the evacuation system or refuge area.
S7	Emphasize continuous improvement by incorporating lessons learned from previous experiences and incidents. Encourage feedback from occupants and stakeholders to identify opportunities for further enhancing the refuge area and the overall evacuation system.

On the other hand, the most important consideration was "location and accessibility" under the architectural design category. As previously emphasized, providing a strategic location close to the emergency staircase, near key gathering points, in low fire risk floors, and easily accessible for occupants through direct routes were the most important rules regarding this consideration. Similarly, as a consequence of the function of the refuge areas as a service space, and where the services in the tall buildings were located in its core, thus, the refuge area location shall be involved as a part of the service/s core. In this respect, it is essential to understand the common classifications of the service/s core to determine the expected location of the refuge to achieve efficient accessibility. It is noteworthy, services cores in the tall buildings classified as; central, peripheral split, and external cores as showed in (Figure 5) [40].

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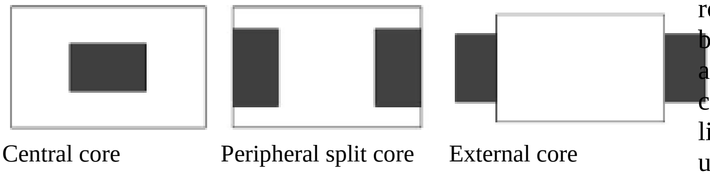

Figure 5: the classification of the srevice cores

From this point of view, a proposed refuge area zone can be suggested according to the service core location and based on the following rules [22, 23, 24, 25, 26] and as illustrated in (Figure 6):

- It shall directly connect with the emergency stair (or means of egress).
- The area provided for each person 0.30m2 with minimum total area 15m2 (50 persons).
- The minimum clear height is 2.3 m.
- Implemented immediately above the 25th floor with an additional refuge floor for every 25 floors or in each floor above (90 m height).
- it must cover 25% of the occupants' load for the floors above.
- Provided with a waiting area for disabled persons and toddlers (one places for each 100 persons).
- Supported with separated fire detectors, communications, and sprinkler system.
- Provided with separate ventilation system and exhaust fans.
- 2 Fire extinguishers (6 kg) must be supplied for each 15m2.
- Separated from the other services core functions.
- The refuge walls and floors must be fire-rated for 2 hours, and its doors must be fire-rated for 1.5 hours.
- It must be directly served by the fireman elevators with a maximum 7.5 m far.
- The minimum fireman elevators lobby area 9m2

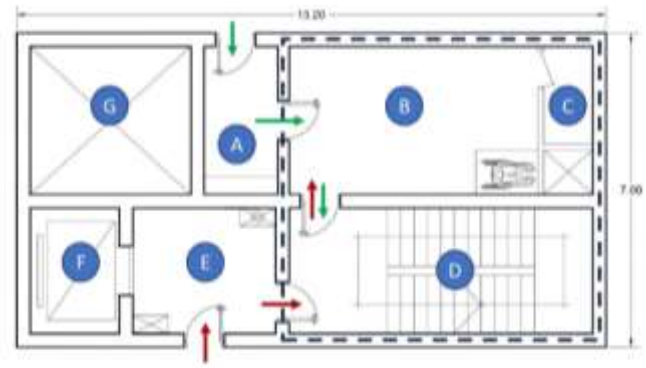

Figure 6: A proposal for refuge area zone

In this regard, the proposed refuge area expresses the functional relationships on the refuge zone and achieving all the discussed design considerations. Thus, many designs can be implemented according to the building floor design but with respect to the functional relationships.

V. CONCLUSION

Achieving safety procedures, especially in emergencies in tall buildings is a crucial challenge as a result of the high occupant load of inhabitants. This study highlighted the design considerations of the refuge area, where it plays a vital role in the emergency evacuation process for these types of buildings. The study adopted the quality management system approach and (FEMA) tool to assess thirty design considerations that were summarized from the previous literature reviews and classified under three categories by using the (FEMA) paths. The results of the evaluation indicated that the most important design consideration was "location and accessibility" under the architectural design category. Additionally, fifteen design considerations were ranked "high" where, three were under fire safety design category as; fire detection and alarm system (R3), fire resistance finishing materials (R5), emergency power supply (R6), and four were under architectural design category as; location and accessibility (R1), ventilation system (R2), capacity for special needs (R5), evacuation time (R8) as well, eight were under quality management category as; applying Failure Mode and Effects Analysis (FMEA) (R2), system integration (R3), training and awareness (R4), compliance with building codes (R6), emergency response planning (R7), durability and sustainability (R7), evacuation coordination (R9), and construction quality (R10). Moreover, based on (FEMA) tool, an operation model was suggested to enhance the reliability, safety, and functionality of refuge areas. Finally, a design of refuge area zone was suggested according to the service core location and based on the previous ranked design considerations and its rules.

REFERENCES

[1] "Council on Tall Buildings and Urban Habitat." Damping Technologies for Tall Buildings, 2019.
[2] Sung, Lee-yong. "Exterior Space Characteristics of Mixed-Use Residential Tall Buildings." Advanced Science and Technology Letters, 2015.
[3] Fu, Feng. "Typical fire safety design strategy for tall buildings." Fire Safety Design for Tall Buildings, 2021, 113-148.
[4] "Integration of Building Design and Systems." The Society of Fire Protection Engineers Series, 2021, 55-60.
[5] El-Awady, Shaymaa M. "Overview of Failure Mode and Effects Analysis (FMEA): A Patient Safety Tool." Global Journal on Quality and Safety in Healthcare 6, no. 1 (2023), 24-26.
[6] Jedwab, Remi, Jason Barr, and Jan K. Brueckner. "Cities Without Skylines: Worldwide Building-Height Gaps and Their Implications." SSRN Electronic Journal, 2020.
[7] Kerner, Amichai. "ISIDLB1769 - Do high-rise buildings influence melanoma? Tall buildings as positive externalities." 2023.
[8] Fu, Feng. "Structural fire design principles for tall buildings." Fire Safety Design for Tall Buildings, 2021, 77-112.
[9] Semin, A. A. "Estimated data for refuge area design in buildings of health care facilities." Pozharovzryvobezopasnost/Fire and Explosion Safety 28, no. 6 (2020), 52-70.
[10] Gerges, Michael, Peter Demian, and Zulfikar Adamu. "Customising Evacuation Instructions for High-Rise Residential Occupants to Expedite Fire Egress: Results from Agent-Based Simulation." Fire 4, no. 2 (2021), 21.
[11] Lau, K. W., T. K. Yue, and W. K. Chow. "Numerical analysis of the effect of external opening on fire safety of refuge floors in tall buildings." Indoor and Built Environment 30, no. 8 (2020), 1062-1075.

doi: XXXXXXXXXX

[12] Selim, Ahmed M., Enass A. Salama, and Heba M. Gaber. "Optimizing safe evacuation using pathfinder: emergency strategies in high-rise and super high-rise complex buildings in the new administrative capital." HBRC Journal 20, no. 1 (2024): 385-413.
[13] Tousi, Evgenia, Maro Sinou, and Antonia Perouli. "Urban Acupuncture as a Method of Open Space Regeneration in Greek Ex-Refugee Areas. The Case of Nikea, Piraeus." Journal of Sustainable Architecture and Civil Engineering 30, no. 1 (2022): 5-18.
[14] Lee, Byung-Hyun, and Kyung-Hee Lee. "A Study on the Improvement of the Refuge safety area in High-rise Buildings Type." Korean Journal of Air-Conditioning and Refrigeration Engineering 28, no. 7 (2016), 288-292.
[15] Ivanov, Martin Lyubomirov, and Wan-Ki Chow. "Fire safety in modern indoor and built environment." Indoor and Built Environment 32, no. 1 (2023): 3-8.
[16] Hutomo, Cahyo Septianto, and Lily Tambunan. "Study of TODs Tall Building Fire Evacuation: Refuge Floor Utilities." In IOP Conference Series: Earth and Environmental Science, vol. 532, no. 1, p. 012022. IOP Publishing, 2020.
[17] Tracy, Jerry, Jack Murphy, and James Murtagh. High-rise Buildings: Understanding the Vertical Challenges. Fire Engineering Books, 2023.
[18] Ballo, Yaroslav, Roman Yakovchuk, Victor Kovalchuk, Vadym Nizhnyk, and Roman Veselivskyi. "Investigation of the fire-preventing eaves effectiveness to prevent the fire spreading by vertical building structures of high-rise buildings." AIP Conference Proceedings, 2023.
[19] Fu, Feng. "Fundamentals of Tall Building Design." Design and Analysis of Tall and Complex Structures, 2018, 5-80.
[20] Kim Clawson, A. O. N. "Considerations and Challenges for Refuge Areas in Tall Buildings." (2011).
[21] Choi, Minji, Seulbi Lee, Sungjoo Hwang, Moonseo Park, and Hyun-Soo Lee. "Comparison of Emergency Response Abilities and Evacuation Performance Involving Vulnerable Occupants in Building Fire Situations." Sustainability 12, no. 1 (2019), 87.
[22] Dubai Building Code Board. Building Code of Dubai 2021.
[23] International Code Council, Douglas W. Thornburg, and Chris Kimball. 2021 International Building Code® Illustrated Handbook. New York: McGraw Hill Professional, 2021.
[24] Australian Building Codes Board. Building Code of Australia 2022: NCC. Volume one. 2022.
[25] Canadian Commission on Building and Fire Codes, and National Research Council of Canada. National Building Code of Canada, 2015.
[26] National Fire Protection Association. NFPA 101, Life Safety Code®. 2022.
[27] Tricker, Ray. Quality management systems: A practical guide to standards implementation. Routledge, 2019.
[28] Zoghlami, Rochdy. "Process for Implementing a Quality Management System (QMS) Adapted to Architectural Practices in Tunisia, in the Case of ISO 9001." Qeios (2024).
[29] Neyestani, Behnam. "Effectiveness of quality management system (QMS) on construction projects." Available at SSRN 2947712 (2016).
[30] Ibrahim, Alizada Shahla, and Rafiyev Asif Ceyhun. "ASSESSMENT OF QUALITY PROJECT MANAGEMENT IN CONSTRUCTION: QUALITY MANAGEMENT CHALLENGES IN AZERBAIJAN." Endless light in science ноябрь (2023): 610-617.
[31] Nayak, Chittaranjan, Snehal Walke, and Suraj Kokare. "Optimal Structural Design of Diagrid Structure for Tall Structure." ICRRM 2019 – System Reliability, Quality Control, Safety, Maintenance and Management, 2019, 263-271.
[32] Ramezani, Mehrnoosh, Mohammad R. Mohammadizadeh, and Saeed Shojaee. "A new approach for free vibration analysis of nonuniform tall building structures with axial force effects." The Structural Design of Tall and Special Buildings 28, no. 5 (2019).
[33] Poon, S. L. "Tall Building Evacuation Strategy—The Refuge Floor Concept Revisited." The Proceedings of 11th Asia-Oceania Symposium on Fire Science and Technology, 2020, 911-921.
[34] Shreya,., and K. Rajan. "Modeling & Simulating the Evacuation of a Building Based on Building Floor Plan and Evacuation Strategies." Proceedings of the 9th International Conference on Geographical Information Systems Theory, Applications and Management, 2023.
[35] Ya Mon, Thu. "HAZARDS IDENTIFICATION & RISKS ASSESSMENT FOR HIGH-RISE BUILDING CONSTRUCTION BY FAILURE MODE AND EFFECTS ANALYSIS [FMEA] & PREVENTED BY OH&S MANAGEMENT SYSTEM." Proceedings on Engineering Sciences 2, no. 4 (2020), 379-388.
[36] Ansari, Ramin, Parisa Dehghani, Mahdi Mahdikhani, and Jaewook Jeong. "A Novel Safety Risk Assessment Based on Fuzzy Set Theory and Decision Methods in High-Rise Buildings." Buildings 12, no. 12 (2022), 2126.
[37] Chen, Zhen-Song, Jun-Yang Chen, Yue-Hua Chen, Yi Yang, LeSheng Jin, Enrique Herrera-Viedma, and Witold Pedrycz. "Large-group failure mode and effects analysis for risk management of angle grinders in the construction industry." Information Fusion 97 (2023), 101803.
[38] Ankur Joshi, S. K. Likert Scale: Explored and Explained. British Journal of Applied Science & Technology. 2015.
[39] Hatkar K., Hedaoo N. delay analysis by using relative importance index method in infrastructure projects. International Journal of Civil Engineering and Concrete Structures, Vol. 1, No. 3, October. 2016.
[40] Fu, Feng. "Shear Wall, Core, Outrigger, Belt Truss, and Buttress Core System for Tall Buildings." Design and Analysis of Tall and Complex Structures, 2018, 81-107.