Enhancing Emergency Evacuation Routes through Integration of Safety and Adaptive Characteristics in the Architectural Design of Educational Buildings

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Abstract:
Education has been and remains one of the most important components of the progress of all nations. However, disasters and crises have a significant negative impact, especially on children and the extent to which appropriate educational buildings can be provided to ensure their safe evacuation during disasters. Schools must take responsibility for the ability to support demand in the face of natural disasters. The research encompasses an analysis of distinct challenges presented by natural disasters, incorporating insights derived from fire safety models that align with diverse safety protocols in disaster scenarios. Leveraging the guidelines outlined in the British Code for fire safety, this study aims to augment the suitability standards of building designs specified by the General Authority for Egyptian Educational Buildings. It allows proposed modifications to existing models to mitigate the impact of damage during disaster evacuations. Therefore, this research provides Improving safety features and resilience during disaster evacuation especially in the design of escape routes in school buildings and proposes implementable recommendations for adapting architectural designs, by shortening travel distances in corridors, providing safe fire escape stairs, and providing assembly areas to prevent crowding during evacuation form School buildings. These are factors that play a pivotal role in mitigating the risks posed by natural disasters in educational buildings, and the study supports the idea that effective evacuation strategies in schools depend on an accurate understanding of the challenges posed by different types of natural disasters, to ensure the safety of students during critical circumstances.

Keywords:
Disasters, School buildings, Safe design, Escape routes, Safe evacuation

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1. Introduction

Education stands as the cornerstone of societal progress, yet its continuity faces significant challenges during disasters. Natural calamities disrupt educational systems and pose severe threats, especially to children. School infrastructures, therefore, hold a crucial responsibility to fortify their capacity to safeguard students during such crises. This study delves into the unique challenges presented by natural disasters within educational settings, drawing insights from fire safety models, and national and international regulations, and proposing adaptations to existing safety protocols to mitigate disaster impact during evacuations. Emphasizing the pivotal role of well-designed escape routes, this research aims to enhance safety features and resilience in school buildings, crucial for ensuring student safety during critical circumstances.

While the education sector is not generally recognized as a priority in emergencies. No other sector consistently ranks as the least funded or has a lower share of funded humanitarian appeals. (Partnership, 2012). In addition, the international community spends only 1% of aid on disaster preparedness, even though it is an essential investment against the effects of natural hazards. (UNDP, 2012)

In scrutinizing the distinctive challenges posed by earthquakes, floods, hurricanes, and analogous disasters, the research additionally consults local and international fire safety models. Incorporating the insights gleaned from these models, the primary objective of the research is to augment students' capacity to evacuate safely during disasters. Consequently, the study assumes modifications to the architectural designs of schools, with the aim of mitigating the impact of damage caused by the disaster during the evacuation of students.

The research culminates in actionable recommendations for the adaptation of both current and prospective architectural designs. These

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recommendations are expressly formulated to engender appropriate safety measures for the evacuation process during natural disasters. Strengthening the nexus between architectural design and student safety, this research aligns with the assertion that, Architectural decisions play a pivotal role in mitigating the risks posed by natural disasters in educational settings. Effective evacuation strategies in schools are contingent upon a nuanced understanding of the specific challenges posed by different types of natural disasters. (Erica D. Kuligowski, 2005). Thus, architectural considerations must be not merely aesthetic but are intrinsically linked to the overarching goal of ensuring the safety and well-being of students during exigent circumstances.

1.1. Research Goal

The research aims to augment the adaptability of architectural designs in educational buildings, focusing on enabling safe student evacuation in the face of natural disasters. This initiative strives to minimize potential damage while prioritizing safety aspects throughout student evacuation processes.

1.2. Research Methodology

The research methodology in this context is grounded in the fundamental rights of children to swift recovery from the adverse impacts of disasters and crises, while ensuring access to quality education in conducive environments. Aligned with the Universal Declaration of Human Rights and the Convention on the Rights of the Child, it recognizes the entitlement of all individuals—children, youth, and adults—to an education that comprehensively fulfills their fundamental learning needs. This encompasses the acquisition of knowledge, practical skills, communal integration, and personal development. (UNESCO, 2000). This will only be possible in a safe educational environment that provides appropriate safety measures during the evacuation of students in disaster situations. The research approach is based on formulating a methodology through which the research objectives can be achieved on three levels:

- First. Initial focus involves introducing the concept of disasters and fundamental requisites in architectural design to ensure security and safety, with particular emphasis on evacuation necessities during natural disasters..
- Second. An examination of fundamental safety concepts crucial for evacuating students during diverse catastrophic incidents, especially the most common fire safety requirements, which also include safe evacuation requirements in most disasters.
- Third. By conducting a comparative analysis between existing real-models pre and post the proposed enhancements, the research develops specific design elements that establish resilient security and safety measures, enabling swift and secure evacuations. It aims to derive recommendations that aid in the advancement of adaptable architectural solutions prepared to effectively tackle disasters, with a primary focus on ensuring the safety of evacuating students during critical periods.

2. An Overview of Disasters and Crises Effects

A disaster refers to a sudden and overwhelming event or series of events that cause severe damage, destruction, loss of life and property, displacement of populations, destruction of infrastructure, disruption of basic services such as water and electricity supplies, and in the long run. Social and economic influences. Disasters and Crises can be natural, or they can be man-made, and they can be identified in the following points:

2.1. Literature Review of the Concept of Disasters and Crises

2.1.1. Disaster Definition

Many literatures define the concept of disasters, and it will suffice to include a simplified definition according to the United Nations International Strategy for Disaster Reduction, which states the following: “A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its resources”. It also illustrates that “Impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.” (UNISDR, 2009)

2.1.2. Crisis Definition

Much literature defines the concept of Crisis, it can be defined as “A situation faced by an individual, group or organization which they are unable to cope with by the use of normal routine procedures and in which stress is created by sudden change". (Booth, 1993) (Moe, 2006)

2.2. Types of Disasters and Crises and their Impact on Schools

Disasters and Crises, whether natural or man-made, have significant implications for educational infrastructure. Understanding the effects of various types of disasters and Crises on schools is essential for developing resilient school designs, disaster preparedness plans, and effective response strategies. This overview examines different disaster types and their specific impacts on educational infrastructure. (Setiadi, 2014) (FEMA, 2023)

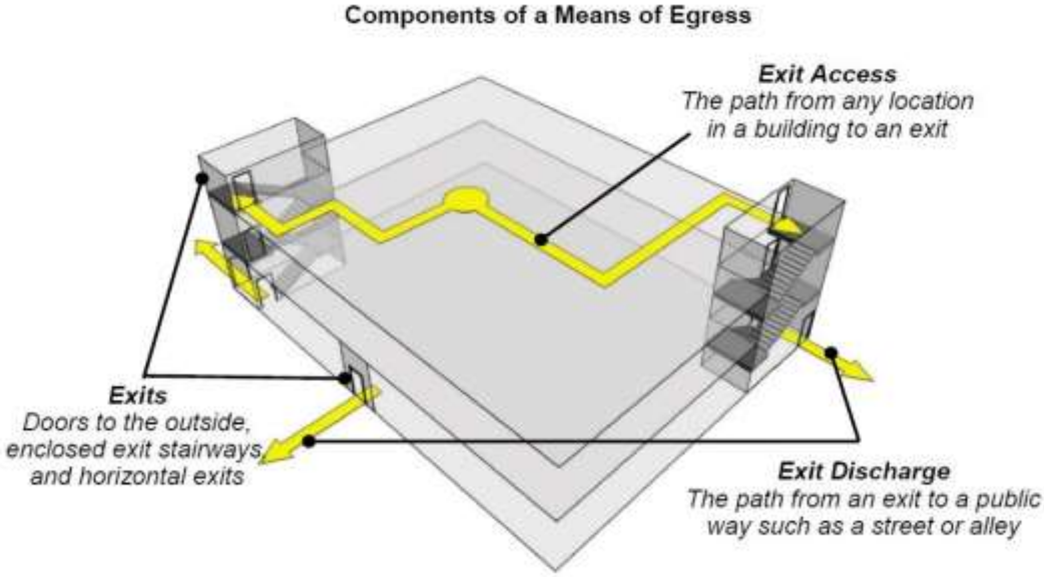


Fig. 2. Components of a means of Egress. (Guide, 2003)

- Earthquakes: Earthquakes represent a substantial threat in seismically active regions. Architectural designs should incorporate seismic-resistant structures, flexible building materials, and clear evacuation routes to mitigate the impact of seismic activities on school buildings.
- Floods: In flood-prone areas, schools must be elevated or fortified to resist water ingress. Additionally, designing multiple evacuation routes, safe assembly points, and emergency shelters within the school premises is imperative for addressing these challenges.
- Hurricanes and Tornadoes: High-wind events such as hurricanes and tornadoes require specific architectural considerations, including reinforced roofing systems, impact-resistant windows, and designated safe zones within the school. Evacuation routes must be designed to account for the rapid onset of these disasters.
- Wildfires: In regions susceptible to wildfires, architectural designs should focus on creating fire-resistant structures, maintaining defensible spaces around school buildings, and establishing clear evacuation plans that prioritize student safety. This is in addition to a group of disasters that rarely occur and may not occur at all in the Middle East region, which are as follows: Avalanches, cold waves, hail, blizzards, tsunamis, volcanic activity, coastal flooding, and drought.

3. Overview of Safety Design for School Disaster Evacuation

Evacuation requirements in fire incidents represent a comprehensive set of protocols applicable across diverse natural disaster scenarios. Consequently, this research focuses on examining the necessary design criteria crucial for ensuring the safe evacuation of students in such circumstances. The primary objective is to swiftly attain safety through the provision of sufficient exit routes and appropriately sized doors, enabling simultaneous evacuation—a minimal requirement for effective means of escape. Fig. 1

These guidelines operate under the premise that during emergencies, occupants should be able to independently evacuate from any section of the building without external assistance. Ideally, these escape routes should align with regular circulation pathways, eliminating the need for emergency-exclusive alternatives. This alignment aids in familiarizing all students, particularly younger ones, with evacuation procedures, thereby mitigating anxiety during emergencies and fire alarms.

Efforts are made to minimize travel distances within corridors and implement necessary measures to prevent bottlenecks or congestion in both horizontal and vertical movement pathways until reaching a safe exterior location.

3.1. Attributes of Safety Design for School Disaster Evacuation

The safety and protection of students within educational institutions stand as a primary concern in the architectural blueprint of schools. This comprehensive approach goes beyond providing a conducive learning environment, extending to preparedness for natural calamities. The subsequent are generalized architectural measures for disaster evacuation exits in school infrastructures: (Publications, 2006)

- The safety and protection of students within educational institutions stand as a primary concern in the architectural blueprint of schools. This comprehensive approach goes beyond providing a conducive learning environment, extending to preparedness for natural calamities. The subsequent are generalized architectural measures for disaster evacuation exits in school infrastructures (Publications, 2006):
- Regulatory Compliance: Adherence to Building Regulations, particularly emphasizing fire safety protocols.
- Multiple Exit Points: Provision of multiple escape pathways to ensure occupants have varied avenues for evacuating the building during emergencies.
- Accessibility: Ensuring accessibility of escape routes for all individuals, including those with disabilities, through features like ramps and handrails.
- Fire-Resistant Doors: Use of self-closing fire-resistant doors along escape routes to contain and impede the spread of fire.
- Clear Signage: Installation of conspicuous and understandable signs delineating escape routes and exit locations, catering to the comprehension of all occupants, including children.
- Emergency Lighting: Installation of emergency lighting systems to illuminate escape routes during power outages, ensuring safe navigation.
- Fire Alarms: Integration of robust fire alarm systems compliant with Standards, promptly detecting and alerting occupants to potential fires.
- Fire Suppression Systems: Consideration of fire suppression systems like sprinklers based on the building's size and usage.
- Safe Gathering Points: Designation of safe assembly areas outside the building accessible to all, including those with disabilities, along with clear indicators guiding occupants to these zones.
- Emergency Services Access: Ensuring unhindered access for emergency vehicles and personnel through clear designated routes.
- Construction Materials: Employing fire-resistant and disaster-resilient materials in the building's construction, particularly close to escape routes.
- Route Width: Ensuring escape routes possess adequate width to accommodate the anticipated number of occupants for a swift and organized evacuation.
- Evacuation Plans: Development and prominent display of clear and concise evacuation plans throughout the building, coupled with regular drills to familiarize occupants with escape routes and procedures.
- Routine Inspections: Regular assessments of escape routes and associated safety features to verify their operational integrity.

4. Basic elements of disaster evacuation: Meeting security and safety standards by local and international standards

In light of the urgent needs imposed by natural disasters and the necessity of ensuring safe evacuation operations for schools, it has become necessary to support the safety procedures applied locally with safety protocols in the field of fire safety design for schools according to international models to achieve the greatest efficiency in the performance of safe evacuation routes in disaster situations. Therefore, Building Bulletin 100 (Revised) was used in the British Fire Code, which details the basic requirements for rapid evacuations, specifically targeting the protection of occupants within educational institutions. In light of adhering to the standards set by the General Authority for Educational Buildings regarding the suitability of sites and the structural integrity of school buildings, this study highlights the pivotal areas that require improvement to strengthen evacuation procedures within local educational institutions.

4.1. Security and safety standards for escape routes according to the British Fire Code in Schools

The number of escape routes and exits to be provided depends on the number of occupants in the room, tier, or floor in question and the limits on travel distance to the nearest exit given in Table 1 (Education, 2021),

Table 2 gives the minimum number of escape routes and exits from a room or store according to the number of occupants. The number of exits may have to be increased to comply with the limits on travel distances given in Table 1.

Table 1: Maximum travel distances

	Where travel is possible in one direction only (m)	Where travel is possible in more than one direction (m)
Places of special fire hazard	9	18
Areas with seating in rows	15	32
Areas not listed above	18	45
Ground floor of small premises with a single exit	27	N/A

Table 2: Minimum number of escape routes and exits from a room, tier, or floor

Maximum number of persons	Minimum number of escape routes/exits
60	1
600	2
more than 600	3

For escape routes and exits for escape purposes, the minimum corridor width of 1200mm recommended by AD M is sufficient if the corridor is not expected to serve as a means of escape for more than 250 people. If the number of people is greater than this, the minimum width should be increased by an additional 50mm for each additional 10 persons.

Table 3: Escape route width and exit capacity

Maximum number of persons	Minimum width mm(1)
60	750
110	850
220	1050
More than 220	50mm for each additional 10 persons

An important aspect of means of escape in multi-floor buildings is the availability of adequately sized and protected escape stairs. Helical stairs, spiral stairs, and fixed stairs cannot be used as part of an escape route for pupils in schools, or for members of the public, and single steps should be avoided

The dimensions of the exit sizes for escape stairs are determined by considering the width and capacity required for simultaneous evacuation, wherein all individuals exit the building upon the activation of the fire alarm. Many schools adhere to this simultaneous evacuation protocol, even in cases where the school includes multiple buildings, as it simplifies the process and ensures swift accountability of all occupants at the designated assembly point. Table. 4

Table 4: Capacity of a stair for simultaneous evacuation of the building according to the width of stairs and number of floors served

Number of floors served	1100 mm wide	1200	1300	1400	1500	1600	1700	1800
1	220	240	260	280	300	320	340	360
2	260	285	310	335	360	385	410	435
3	300	330	360	390	420	450	480	510
4	340	375	410	445	480	515	550	585

4.2. Requirements for horizontal and vertical communication elements according to the General Authority for Educational Buildings

The criteria outlined by the General Authority for Educational Buildings for vertical and horizontal movement components can be concisely summarized: (Department, 2011)

1st. Horizontal Connectivity (Corridors):

Ensure the absence of dead-end paths

Minimum width for single-direction aisles is 2.4 m; for double loads, it's 3.0 m

Keep walking distance to the nearest staircase under 18.0 m from any space

Maintain a corridor width equal to or greater than the distance between study spaces and the nearest stairwell

2nd. Vertical Connectivity (Stairs):

Provide more than one stair for an emergency, considering security and safety aspects. The minimum number of stairs should not be fewer than two, with a minimum width of 1.4 m for both straight and spiral staircases.

4.3. Aspects in Formulating Proposed Safe Evacuation Requirements: Leveraging Preceding Standards

By evaluating the fire safety components incorporated into safe evacuation parameters, especially in fire-related disaster scenarios, as described in previous safety codes, the safe evacuation of students from buildings can be enhanced and to achieve this goal through the following elements: (Department for children, 2007), (Guide, 2003)

1st. Reducing Corridor Travel Distances: The reduction of travel distances within corridors assumes paramount importance in expediting and ensuring the safety of evacuations during emergencies. The design configuration of educational environments significantly influences the duration for occupants to reach safety during crises. Altering the layout to favor a closer alignment to a square design rather than a rectangular one reduces the distance between classroom exits and assembly points, facilitates a faster exit of students, reduces the risk of overcrowding, and improves the evacuation process.

2nd. Establishment of Pre-Stair Gathering Areas for Students: Designating areas for student congregation before accessing the stairs represents a strategic architectural adaptation to alleviate overcrowding issues and streamline orderly evacuations. During emergency evacuations, staircases often encounter congestion, leading to potential bottlenecks and safety risks. Introducing gathering spaces preceding the stairs disperses the flow of individuals, alleviating congestion at critical exit points.

3rd. Installation of Secure Fire Escape Stairs: The incorporation of secure fire escape stairs stands as a pivotal element in school architecture to facilitate safe evacuations, particularly in scenarios involving fires or situations where ground-level exits are inaccessible. These staircases provide alternative escape routes, serving as egress options for individuals on upper floors or areas where conventional exit pathways might be compromised.

4.4. Documentation of the Study Sample Models.

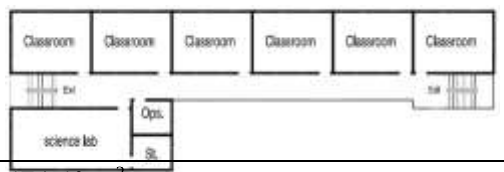
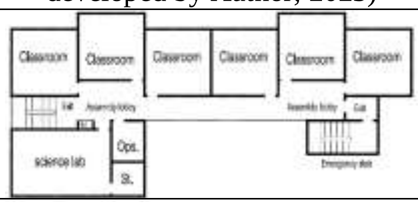
The configuration of school designs exhibits variance based on ownership . Public schools adhere to standardized models provided by the General Authority for Educational Buildings, while private institutions employ engineering offices authorized by the same authority to ensure alignment with technical specifications. These designs generally fall into distinct classifications based on the arrangement of classrooms along corridors. In the following comparison model, for each type, two models are considered: one representing the typical model outlined by the General Authority for Educational Buildings, and the other representing an existing school:

1st. The pattern of grouping classrooms on a corridor in “Single Loaded” grouping.
   a. “Typical model of 15 classes School”. As a basic stereotype. Table. 4
   b. “Mahmoud Shukry School”. As a Current case. Table. 5

2nd. Classroom grouping pattern on a corridor in “Double Loaded” grouping.
   a. “Typical model of 20 classes School “. As a basic stereotype. Table. 6
   b. “Amr bin Al-Aas School”. It was the same previous design. Table. 6

3rd. Cluster Group Classroom Arrangement around a Central Space: The study sample and proposed modifications showcased no fundamental disparities; hence, they were disregarded in the analysis.

Table 4: Documentation of “Model 15 class” school (Current and Proposed)

Status	Current (Department A. D., 2021)	Proposed (A design model developed by Author, 2023)
Floor Plan		
Bld. area	474.40 m^2	476.00 m^2
Bild. Total ength	45.00 m	39.00 m
Bild. Total width	14.80 m	17.80 m
Hallways area	98.00 m^2	81.90 m^2

Hallways length	36.20 m	26.00 m

Table 5: Documentation of Mahmoud Shukry School (Current and Proposed)

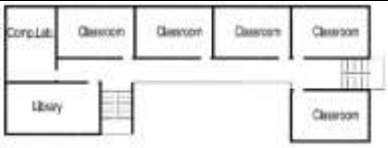
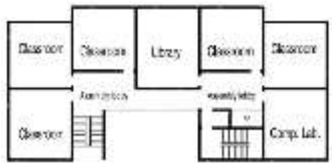
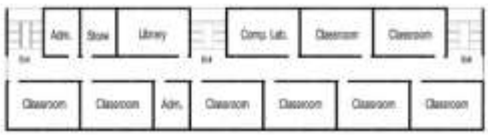
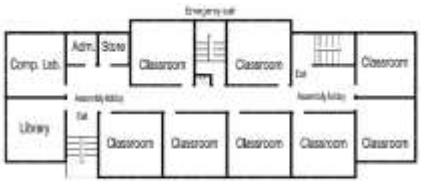
Status	Current (Author, Field documentation of the study area, 2022)	Proposed (Author, A design model developed by Author, 2023)
Floor Plan		
Bld. area	424.30 m^2	414.50 m^2
Bild. Total length	39.00 m	32.50 m
Bild. Total width	13.30 m	15.50 m
Hallways area	68.90 m^2	64.70 m^2
Hallways length	29.30 m	19.50 m

Table 6: Documentation of "Model 20" class school and Amr bin Al-Aas School (Current and the Proposed)

Status	Current (Department A. D., 2021)	Proposed (Author, A design model developed by Author, 2023)
Floor Plan		
Bld. area	705.40 m^2	597.00 m^2
Bild. Total length	52.30 m	41.10 m
Bild. Total width	13.50 m	15.80 m
Hallways area	153.20 m^2	106.00 m^2
Hallways length	52.00 m	29.10 m

Upon examining the comparison models presented in the previous tables, several key observations come to light regarding the optimization of safety measures and evacuation protocols within the premises:

1st. Classroom Layout and Travel Distances: Travel distances within designated corridors have been curtailed, aiming to enhance both the speed and safety of evacuations during emergency cases. This was achieved by implementing a more square-shaped classroom design, which effectively reduces the spatial footprint occupied by each classroom within the hallways. As a result, the proximity between classrooms, emergency exits, and assembly points has been significantly decreased, fostering a more efficient evacuation route. Table1. This is evident from the percentages of reducing traveling distances, which ranged between 28.2% - 44.0%, Fig. 2, which are large percentages, about a third of the walking distance.

2nd. Emergency Stair Provision: To address potential challenges posed by fires or situations where conventional ground-level exits might be inaccessible, an emergency stair has been installed. This addition serves as a crucial means of egress, particularly for individuals located on upper floors or areas where conventional evacuation routes may be compromised. The provision of this alternative exit pathway bolsters overall evacuation capabilities and ensures safer outcomes in critical scenarios.

3th. Creation of Student Assembly Areas: A student assembly areas preceding staircases has been implemented to mitigate congestion and promote orderly evacuations. Recognizing that staircases often become congested during emergency evacuations, leading to potential bottlenecks and safety hazards, the establishment of designated assembly zones before stairwells aim to alleviate these issues. This approach not only minimizes crowding but also streamlines the evacuation process, enhancing overall safety protocols within the premises.

4th. A specific area was Designated within the stair zone that is safeguarded against fire hazards to house the fire-fighting connections. This secured space is intended to protect crucial fire-related connections and installations, ensuring their preservation and functionality in the event of a fire emergency.

5th. Although more space was provided for students before and in front of the stairs to alleviate congestion, there was no increase in the overall area of the corridors. Instead, due to a reduction in the total length of the corridor path, there was a substantial decrease ranging from 6.1% to 30.8%. Fig. 2. This discrepancy in savings stems from the difference in space allocation between single and double loading of corridors, where single loading allows for a greater share of space in corresponding aisles compared to double loading.

6th. By minimizing the presence of underutilized spaces in corridors, the impact on the overall area of school buildings varied from a marginal decrease to considerable savings. This resulted in a range of -0.3% to 15.4% Fig. 2, in terms of space reduction, significantly impacting the total construction expenses. This emphasis on optimizing space not only meets safety and security standards but also presents a distinct advantage in terms of cost-effectiveness within the realm of school education.

7th. The comparison models vividly demonstrate that by curtailing the length of corridors, the total building length experienced a notable reduction, ranging between 16.7% to 21.4%. Fig. 2. This adjustment proves immensely beneficial in accommodating school structures within limited spaces, particularly in densely populated areas. Although there was an uptick in the building's depth, ranging from 16.5% to 20.3%, Fig. 2, the actual increment are within the range of 2.3 meters to 6.5 meters. This increase remains within acceptable limits and is manageable in terms of practical implementation.

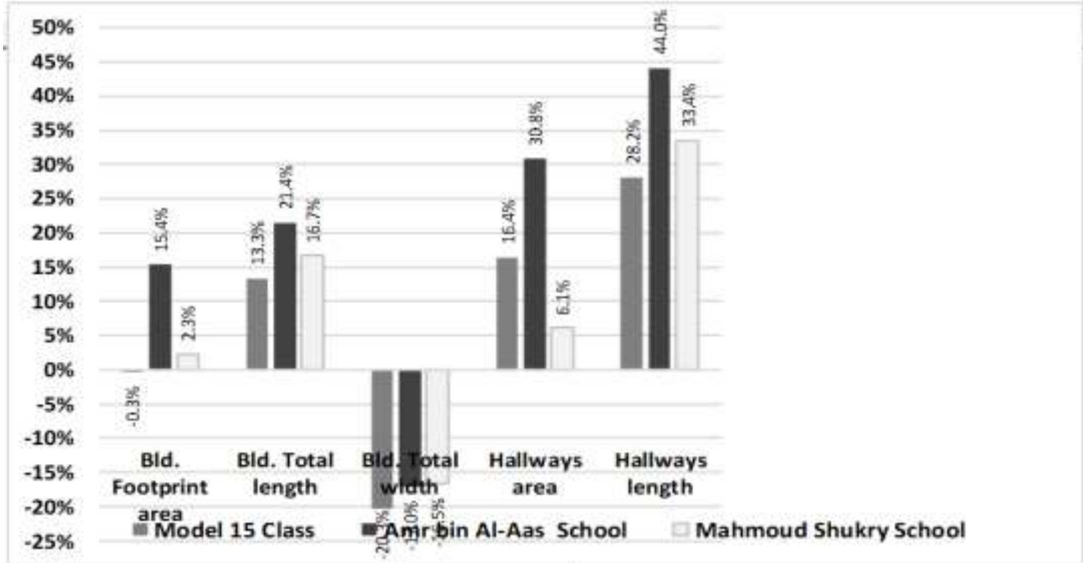


Fig. 1. The ratio of savings between the current situation and the proposed one. (Author, Data analysis using Excel program by Author, 2023)

5. Conclusion

In summary, ensuring the safety of students during natural disasters remains a crucial aspect of educational infrastructure. Advancing safety measures within school buildings, particularly emphasizing well-designed evacuation pathways, emerges as a key priority. Incorporating insights from fire safety models and adhering to both national and international regulations presents a comprehensive framework for adapting existing safety protocols. By fortifying safety features and resilience during disaster evacuations, educational institutions can actively mitigate risks and ensure both the safety and continuity of education.

Typically, educational buildings are constructed using fire-resistant materials that meet the requirements for safe evacuation. The structural system often involves reinforced concrete, while walls are commonly made of brick blocks, either solid or hollow. Wall finishes consist of cement and paint, and floors predominantly comprise tiles. These materials exhibit reduced flammability and possess adequate fire resistance. Windows are typically glass with aluminum frames, while doors are wooden, although treated paints can be recommended to slow down the spread of fire.

Recommendations include the include the importance of providing and placement of guidance signs and fire extinguishers, directing emergency stair exits toward courtyards and open areas. Emphasizing clear escape paths and utilizing regular movement routes can reduce confusion and hesitation during rapid evacuations in disaster situations.

Key elements derived from the study of fire safety code requirements related to swift evacuations in disaster scenarios can be summarized as follows:

- Shortening Travel Distances: Reducing the distance between the last room door and the nearest staircase by adopting classroom designs closer to squares, thereby minimizing corridor lengths. This aids in reducing evacuation time, enhancing evacuation flow, and simplifying routes for better coordination during emergencies.
- Providing Gathering Areas: Establishing gathering zones in front of stairs to accommodate students transitioning from corridors, facilitating smoother movement, managing flow, and ensuring organized evacuations. These areas act as staging points for instructions and orderly ascent, improving communication and coordination among occupants.
- Safe Fire Escape Stairs: Installing fire-safe stairwells with doors to prevent smoke flow between floors and offer secure evacuation options from elevated spaces. These stairs serve as reliable evacuation routes, regardless of proximity to ground exits, adhering to safety standards and enhancing safety measures within educational premises.
- It is imperative to calculate the widths of horizontal corridors and staircases based on the maximum anticipated student occupancy on eatch floor, aligning with the specifications outlined in the British Fire Code. This calculation should not follow the method of grouping spaces Which is based on imposing a constant dimension 2.4 meters for single assembly or 3.0 meters for double assembly around the hallwayes, as indicated in the building suitability standards of the General Authority for Educational Buildings. Neglecting to consider potential overcrowding could pose a serious life-threatening risk in emergency situations.
- Fire-Fighting Connections: Allocating space for fire-fighting connections within secure stair enclosures to safeguard fire-related installations.

These modifications—shortening corridor travel distances, implementing safe fire escape stairs, and creating assembly areas—represent pivotal components of school architecture design aimed at enhancing safety measures during evacuations. Their roles encompass improving evacuation routes, providing alternative egress, and managing passenger flow, ultimately fostering a safer environment for students, faculty, and staff during emergencies.

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