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ABSTRACT: Many office buildings encounter various problems with their fire safety evacuation designs. The Chamber of Commerce, Industry and Agriculture Tripoli - North Lebanon (CCIAT) is considered the only modern office building in its context that lacks fire escape elements and emergency plans. This paper presents an analysis and proposals for an optimal evacuation scenario for the case of the CCIAT building, and develop solutions for similar office buildings. The problem is interpreted with reference to the positions of existing staircases and lifts and their connectivity with occupants' offices and other facilities on the floors, in order to provide a comprehensive scenario for a fire escape safety design in the building. This paper relies on the Lebanese Building Regulations to evaluate the case of the CCIAT's fire safety, along with the simulation software Pathfinder 2018 to evaluate the evacuation process of the existing design and the proposed solutions.

KEYWORDS: Fire safety, escape route, egress, simulation, evacuation

1. INTRODUCTION

In cases of emergency, once a fire alarm rings or a fire signal is detected, evacuation of the building becomes essential. Before 11 September 2001, however, it was not fully understood whether or not to evacuate: "High-rise residential building has been hotly debated in all sectors of the fire protection industry." (MacLennan, 2001) MacDonald (1985) and Proulx (2001) suggested the "stay-in-place" approach as the most appropriate behaviour during building fires, essential for dormitory buildings, but after the 11 September 2001 disaster, the procedure of not evacuating has been shown to cause further problems. Buildings can collapse if a fire breaks out, as exhibited in the World Trade Center tragedy, especially if it is a steel structure building similar to that found in the Chamber of Commerce, Industry and Agriculture (CCIAT). The Canadian Wood Council (2000) states that fire safety in buildings is improved by using sufficient fire-resistant material and through verified building design features deliberately put in place to assure fire safety in the building and minimize the risk of people being harmed by fire to the greatest extent possible.

Proulx (2001) states that recent reports show that most people who died during the evacuation process were found in stairwells or in corridors, which were often far away from the site of the fire (Fahy and Proulx, 2001). Investigation shows that many of these incidents noted obstacles in the escape route, such as encroached objects, occupants' belongings or furniture placed in the staircase or passageway, causing congestion by reducing the staircase width and resulting in a bottleneck effect. In order to attain optimal results, the orientation of escape routes, including fire doors, corridors and staircases, is essential to achieve the safe and smooth evacuation of people from the building in the case of fire. There are several key factors that influence the means of egress of a building, which include the architectural design, the characteristics of the populace, the level of education, culture and training of the population, the staff available, the fire safety installations and other variables (Hall, 2000). A study of the different features of a building is critical to understand the conceivable evacuation strategies that could be accepted. For example, the occupants on the upper floors may have a very long distance to reach the ground level. This causes a rest periods in the evacuation, resulting in a consequent increase in the evacuation time (Proulx, 2001).

Generally, in the office buildings there exists an open work space (on most floors), which limits the probability of containing the fire within a compartment. Occupants are generally better arranged to evacuate the building, since they are typically skilled through evacuation drills, are dressed, alert and mainly responsible for themselves, and are more familiar with the egress elements such as the staircases and corridors (Peacock and Bukowski, 2009). According to the National Fire Protection Association (NFPA, 2012), high-rise buildings are defined as "Buildings greater than 75 feet (approximately 23 m) in height where the building height is measured from the lowest level of fire department vehicle access to the floor of the highest occupiable story".

2. FIRE SAFETY GOALS

Commonly, the fire safety goals focus on life preservation and the defence of the building's skeleton, property, continuity and the running of the business, as well as environmental safety (Buchanan and Abu, 2017). Moreover, this philosophy claims that "any design which does not cause traffic congestion at any level, and allows people to be smoothly evacuated from the building with the minimum time taken, is the safest", further exemplifying the need to be aware of the escape routes provided and planned (Yatim, 2012). It is important to note that the objective of fire safety emphasizes the need for people to be able to use the building under safe conditions. To achieve this, it is essential to alert occupiers in the case of fire provide a safe escape route and ensure that people are not exposed to burns or harmed by smoke while attempting their escape to a secure and safe place.

3. FIRE RISKS TO AN OFFICE BUILDING

The potential fire hazards for an office building typically include the following:

a- Quick spread of fire and smoke: Under the "chimney effect" in an office building, fire and smoke can spread to the upper floors very rapidly through staircases, elevator shafts and ducts, especially in certain places such as machinery rooms, copying and printing rooms and computer centres, if the fire and smoke control measures are not adequate or are missing.

b- Difficult firefighting process due to the following factors:

- Inadequate firefighting equipment in these buildings certainly increases the difficulties of maintenance and repair, leading to a conversation regarding financial issues.
- The existing wall cladding systems of all building facades are made of combustible materials, which contributes to the spread of fire and increases the difficulties for firefighters and rescue teams.
- The safe evacuation of occupants also faces a problem when there is a missing evacuation plan or signs and a lack of training for employees, as well as the absence of fire safety sense and the capability of escaping safely from the building in case of fire; all together, such factors cause an increase in evacuation time (Ma and Guo, 2012).

4. EGRESS STRATEGIES

There is undoubtedly that efficacious evacuation is an arrangement of moderate speed and reasonable densities (Pauls, 1994). Generally, a building's characteristics define which strategies could possibly be applied to the building, such as the exit items available, compartmentation, the inheritance, the staff/rescue workers, the nature of the scenario and the threat(s) involved. Moreover, in attempting to achieve evacuation, main egress strategies can be summarized into the following types: (1) total evacuation, (2) phased evacuation, (3) defend-in-place and (4) delayed evacuation.

(1) Total evacuation: The 9/11 terroristic attack on the World Trade Center is one of the famous events representing a case of total evacuation (Averill et al.., 2005). This strategy is followed based on the building use, occupant load, and the behaviours of the occupants and the probability of direct exposure to hazards due to fire spreading along the building structure.

(2) Phased evacuation: The phased evacuation strategy is depend on the priority of evacuating occupants on critical floors that exhibit the highest potential of being exposed to the fire. This strategy is recommended with the purpose of decreasing queuing time and reducing occupant congestion during escape. In this case, occupants may be moved to a "temporary refuge floor" and wait for directive according to the development of the status.

(3) Defend-in-place: The defend-in-place strategy can be a possible solution in some cases. It is the most appropriate behaviour in the case of residential buildings, simply because occupants can close the doors and wait for rescue. Many fatalities may be avoided if this strategy is approved (Proulx, 2001). As Proulx (2001) mentions, during fires in high-rise buildings, the defend-in-place strategy is the most appropriate behaviour in the case of residential buildings, and promises a high success rate if occupants and designers have the same perspective and follow the following main characteristics: (1) the evacuation of low-rise buildings is faster relative to the under six floors; (2) residential buildings differ from enclosed apartments, where apparatuses for defend-in-place functions are accessible; (3) most building materials are non-combustible; (4) in case of fire, occupants are informed using an alarm system; and (5) a voice-over communication system

affords occupants with data about the evolution of the fire and guides occupants on the defend-in-place actions to perform.

5. EGRESS COMPONENTS

The evacuation process of office buildings is generally influenced by the features of the vertical egress components. Recently, office buildings have become very complicated through the addition of contemporary computer laboratories, copy and printing centres, sophisticated networks and advanced technical installations and services. These increase the complexity of dealing with firefighting and evacuation and create a greater challenge for firefighters. As a result, modern egress designs should take into consideration many variables, including the variation of inhabitant demographics (Spearpoint and MacLennan, 2012) and occupant activities (Nilsson and Jönsson, 2011).

5.1 Staircases

In office buildings, the traditional method of evacuation is using the staircase, generally designed with an adequate capacity to provide safe and easy evacuation relative to the full capacity of occupant load on the floor (Peacock et al.. 2012). Taking into consideration the number and location of staircases in the building plan, stair width and length (Pauls, 2002), this method allows for a rudimentary understanding of the number of people that it can accommodate (Pauls and Jones, 1980). In addition, the staircase's specific features, such as the stair slope (Blair and Milke, 2011; Peacock and Averill, 2011), and behaviour aspects, such as gender, motivation levels, evacuation performance, group behaviours and the physical abilities of occupants (Pauls et al., 2007), can determine the speed of exit and, consequently, affect the total evacuation time (Galea et al., 2009).

5.2 Evacuation elevators

In general, the concept of using the elevators in emergency cases is not accepted, but after the incident of 9/11 (the terrorist tack on the World Trade Center) (Galea and Blake, 2004; Kuligowski, 2011; Ronchi and Nilsson, 2013), evacuation processes and details have been raised and have pushed researchers also regulators to consider the problem of rapid vertical departure in typical cases. There are several issues that need to be considered from an evacuation design perspective, such as the limited speed and sequence of using elevators and the consequence of people squeezing into limited spaces and high-density situations (Harding et al., 2010). Fire, heat and smoke may spread in the elevator shaft, especially when smoke is sucked into the shaft due to the elevator movement creating negative pressure (Chien and Wen, 2011). In addition, certain aspects related to earthquake protection, emergency power supply and communication systems, and water protection should further be taken into consideration (Klote et al., 1993). The American Society for Mechanical Engineers have paid particular attention to human factors and investigated these behavioural issues and their influence on the effectiveness of evacuation concepts. Another reason for using evacuation elevators as an extra fire - exit item is that they can help people with evacuation issues without external aid (British Standards Institution, 2004).

5.3 Sky-bridges

Sky-bridges are one of the alternative methods of providing horizontal evacuation between parts of the building (similar to the CCIAT case study). The concept has already been executed in several buildings round the world (Ariff, 2003). The main benefit of using sky-bridges is to increase the available options for evacuation and reduce vertical evacuation travel distance (Wood, 2007). Choosing the location for sky-bridges is very important in order to achieve maximum efficiency of the egress circulation in case of evacuation, keeping in mind the expected occupant load on various floors. However, recently a lack of information on the efficiency of sky-bridges during evacuation is exist, and studies addressing their procedure in combination with other exit items are needed (Ronchi and Nilsson, 2013).

5.4 Refuge floors

From an evacuation perspective, especially in high-rise buildings, refuge floors provide many advantages: (1) they are a space of repose for the occupants; (2) they reduce the risk of staircases or lift shafts filling with smoke; (3) firefighters or even employees can protect and provide help for disabled people or injured evacuees (Williamson and Demirbilek, 2010); and (4) they allow a rescue team to assist evacuation and use it as a firefighting base (Wood, 2007). Furthermore, there are many factors that may result in the failure of the refuge floor thought with regard to human behaviour in the case of fire or emergency, such as less utilization, overcrowding, fear of remaining in the building in a fire, the actions of evacuees, cost usefulness, sustainability and alternative strategy solutions (Clawson and O'Connor, 2011).

6. METHODOLOGY

According to current local fire code (referring to the National Fire Protection Association – NFPA), the Chamber of Commerce, Industry and Agriculture building (CCIAT) is considered to have been designed as a Type 2: non-combustible – a fire-resistant building (non-combustible construction uses materials that do not ignite or support combustion). Therefore, to ensure that everyone in the building can safely evacuate during an emergency case, it is vital to strategize and implement an optimal specified escape route according to the NFPA. This can be done via two approaches within this research:

a. Building observation: In an emergency situation, there are certain complications in the evacuation process that need to be observed with regard to human behaviour, attitude and willingness to proceed during the evacuation process, as well as obstacles related to the building's features, represented in escape route performance and egress components such as escape stairs, corridors, fire doors and fire lobby. All of these should be discussed and put down in writing to demonstrate and establish any drawbacks, in order to overcome them.

b. Computer simulation: By using Pathfinder 2018, it is possible to simulate people evacuating from the existing building and clarify any problems in the evacuation process. This then allows for suggestions in order to enhance and test the evacuation process in buildings.

7. MODEL DETERMINATION

For the evacuation case study (CCIAT) or a similar office building, there are a few key points that have been identified for the analysis of an evacuation process using modelling studies (Ronchi and Nilsson, 2012):

-Using evacuation models to study the evacuation process in similar office buildings can be effective.

-Using evacuation models can provide an acceptable alternative, in order to present different features and characteristics in similar buildings.

-The interactions between the occupants inside the building and the infrastructure can be represented either indirectly or clearly by using evacuation models, but human attitude data for the calibration of the model input is scarce.

-Reviewing a set of evacuation model features stresses their ability to simulate multiple evacuation egress components.

- Some evacuation models present and provide adequate flexibility to characterize human behaviour in these types of buildings.

Data collected using observations, notes, occupants and visitors' attitudes can be studied and analysed to provide a base for the study model used. Moreover, this reflects the five main components in the study models developed, i.e. (a) offices, (b) corridors, (c) staircases, (d) fire doors, and (e) people, to help refine the fire safety goals and the time needed for evacuation by choosing the best scenario.

8. CASE STUDY: THE CHAMBER OF COMMERCE, INDUSTRY AND AGRICULTURE (CCIAT) REALIZATION AND APPROACH

The Chamber of Commerce in Tripoli is one of the oldest chambers and businesses in the Arab countries. The old port of Tripoli boomed through export and import across the roads towards Beirut and Palestine in the south, Syria and Turkey in the north, Iraq in the east and the European countries via the Mediterranean Sea in the west. The Chamber building (Boulevard Bechara El Khoury St. El-Tall – Tripoli), constructed in 1980 in a prominent and prestigious location, expresses the civilized and social aspects of the area, serving heads and memberships of foreign chambers and businessmen who visit to gather essential facts and data relating to the economy. Recently, in 2004, the expansion of the old building with new glass extensions and a steel structure, to hold innovative projects, received funding from international funders not only the EU and the US Agency for International Development, but also other international associations, agencies and non- profitable governmental organizations.

8.1 Problems in escape route design for Chamber of Commerce, Industry and Agriculture in Tripoli – North Lebanon (CCIAT)

By observing and analysing fire evacuation plans and fire escape safety designs for CCIAT, the following problems have been found:

A- Fourth floor (laboratory; a corridor and a set of separated rooms, using glass partitions and glass doors), as shown in figure 1: There is only one direction of escape route for the occupants on the fourth floor, more than 36.6m of travel distance for those occupants who work in the room on the left side of the building to get to the only staircase existing on that floor. Around 28.9m from the last room on the right side to the same staircase, there is only one escape route.

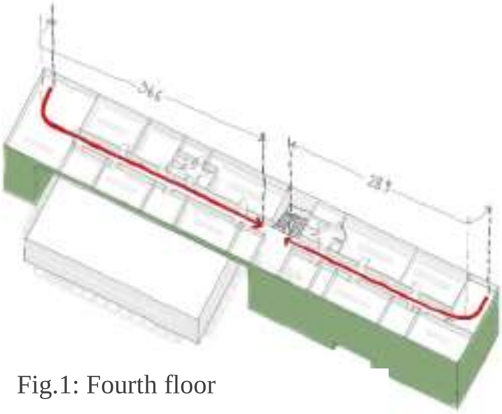


Fig.1: Fourth floor

B- Third floor (open-area offices, rented for company), as shown in figure 2: There are no escape routes for the people in the room on the left side of the building except for a small circular iron staircase with a diameter of 2m connecting to the second floor. The National Fire Protection Association (NFPA) does not accept spiral stairs as emergency stairs. Moreover, there remains the same problem on the right side (28.9m in a one-way escape route).

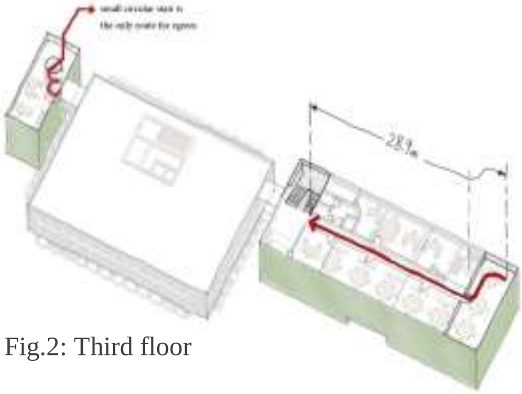


Fig.2: Third floor

C- Second floor (open-area offices, rented for the company), as shown in figure 3: The only escape route in the old building for the occupants on the left side of the room passes through many offices and a small bridge to reach the nearest ladder, while facing many obstacles in the escape route to evacuate from the building. Furthermore, there are many doors through the winding path to reach the staircase in the new building (none of these doors open in the evacuation direction and they do not have a fire range of more than 20 minutes). Furthermore, there still exists the same problem on the right side (28.9m in a one-way escape route).

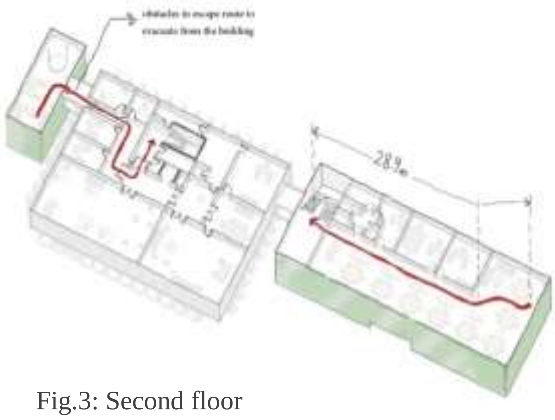


Fig.3: Second floor

D- First floor (under renovation to be an educational centre), as shown in figure 4: Similar to the second floor, the first floor also faces the problem of finding an escape route (especially for people who are non-employees in the building).

E- Ground floor (the exit floor), as shown in figure 5.

F- Basement floor (-1; auditorium hall), as shown in figure 6.

Fig.4: First floor

The auditorium capacity of 150 people and the audiences who attend events in the auditorium have two escape routes in the case of evacuation. However, both routes are more than 30m in distance, and none of the doors in the escape routes open in the proper evacuation direction. With no more than a 20-minute range and an inadequate width, the escape route is not sufficient to evacuate 150 people or more (also bearing in mind that some of them will have special needs) in the case of emergency. Furthermore, fire and smoke can spread feast to the upper floors quickly through staircases, elevator shafts and ducts in a very short period, especially if there are no overhead sprinklers or smoke control measures installed.

Fig.5: Ground floor

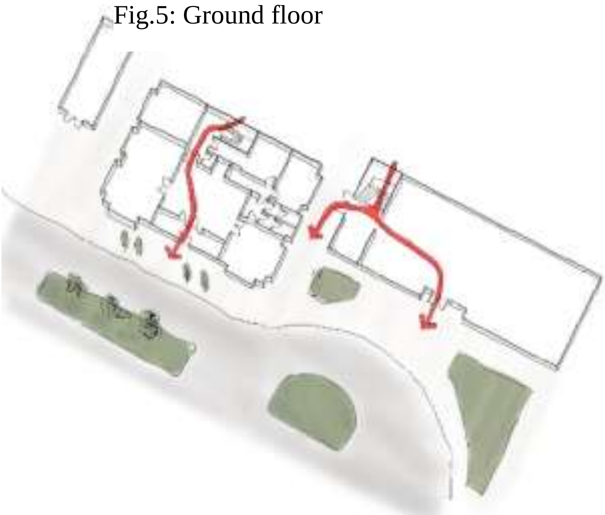
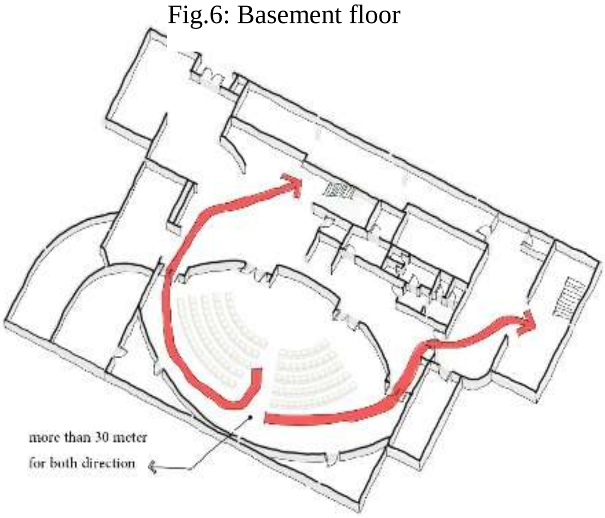


Fig.6: Basement floor



G- Basement floors (-2 and -3; parking): There are no comments, except that there is a lack of overhead sprinklers and adequate smoke control measures installed.

8.2 General notes

- No doors in the building classify as emergency fire doors and their fire rate is no more than 20 minutes.
- Most escape routes in the building are in only one direction and are not adequate to ensure safe evacuation for four main reasons:

a) Long evacuation distance (around 30m)
b) No fire doors to provide safe transfer from one part of the building to another
c) No complete partitions (with more that 25cm width) with two hours to separate the inner spaces of the building to clear fire zones
d) No installation to remove smoke in case of fire

8.3 Suggested solutions

Referring to the previous notes and analysing the observations, the research studied many alternatives and concluded with a series of scenarios, which were compiled and summarized into three main scenarios, along with a group of recommendations to enhance the evacuation process performance.

These recommendations are as follows:

a- Construct staircases on both sides of the building to provide another route for evacuation on all floors to decrease the distance of travel. These staircases: (a) can be external (if authorized by the regulatory authority – municipality) or internal by subtracting parts of the space attached to the outer facade; (b) should be provided with emergency 1.5 hour (class B) fire-rated doors and with a self-closing tool; (c) should use suitable material providing a 2- hour fire rate; and (d) should be extended from the roof to the basement floors (-1, -2 and -3), with adequate smoke control measures to provide positive pressure in staircase shafts.

b- Change all main corridor doors to enable them to be opened by either pushing or pulling and in the direction of the escape flow.

c- Re-divide the plans of the building using completed firewalls (one hour) for the open-plan areas and around staircases (1.5 hour – class B), to provide separated fire zones and to obstruct fire or smoke from seeping (in the case of fire) to the upper floors via staircases or elevator shafts. In terms of the first floor, it is recommended that the partitions for the old and new buildings are modified in regard to providing safe, easy and direct escape routes to the staircases.

d- Construct two new staircases in the basement (-1) to provide safe and fast evacuation for the audience in the auditorium, with the addition of fire walls and emergency 1.5-hour (class B) fire-rated doors with a self-closing tool, and fitting sprinklers and adequate smoke control measures.

In order to fulfil the above fire safety points and notes, the following solutions have been suggested.

After applying all these recommendations, as shown in the drawing of the building without adding any new staircases as shown in figure 7, and by modifying and editing the original drawing to be compatible with and recognized by the simulation software Pathfinder 2018, running the program concludes the following below.

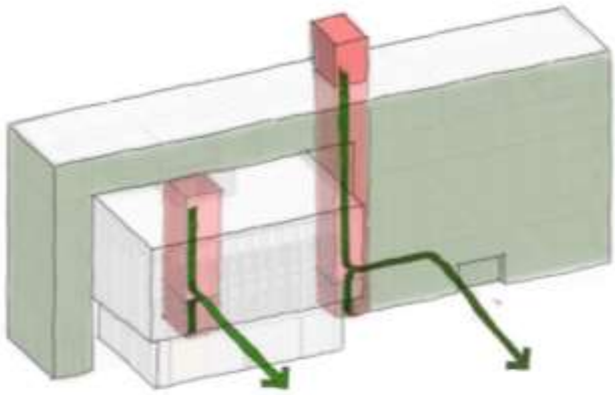
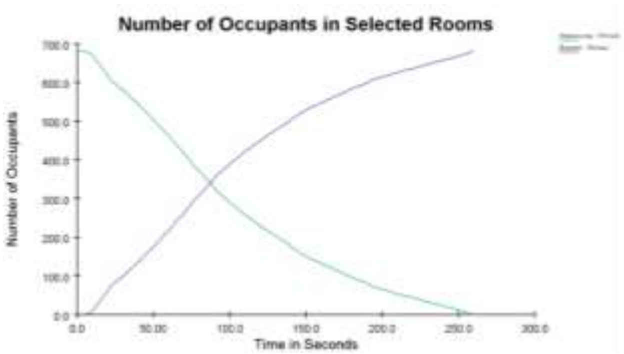


Fig.7: Existing staircases

After three minutes (the time allowed to complete evacuation), shown in Figures (8) and (9), only 583/680 persons will be evacuated. For the complete evacuation of everyone in the building, 4:19.3 minutes are needed, referring to the final report of the simulation software.



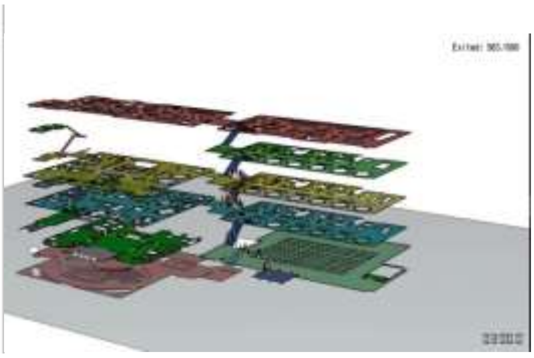


Fig.8: Time for complete evacuation 4:19s

Fig. 9: Evacuation diagram

Furthermore, referring to the previous plans, the study concludes the following possible solution scenarios:

A- Scenario one is to increase the flow rate of evacuation and decrease the distance of escape on the left side of the building. Moreover, this provides an acceptable staircase instead of the circular iron staircase, which is not accepted as an escape route (as previously mentioned), resulting in a block in running the simulation software Pathfinder, as shown in figures 10 and 11.

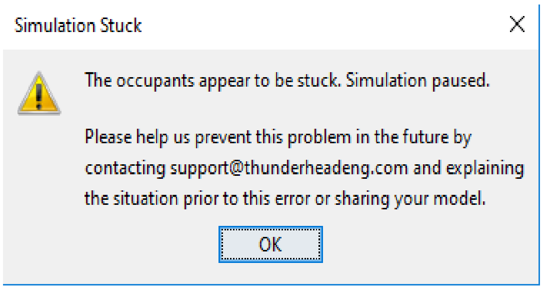


Fig.10: Message of occupants stuck

Fig.11: Block running the software

In the proposal, there should be one staircase added on the left side of the building, as shown in figure 12. The results in figures 13 and 14 show that in the third minute, only 628/680 persons will be evacuated, and the time taken for the complete evacuation of the building decreases to 3:47.3 minutes, referring to the final report of the simulation software. This time is unacceptable.

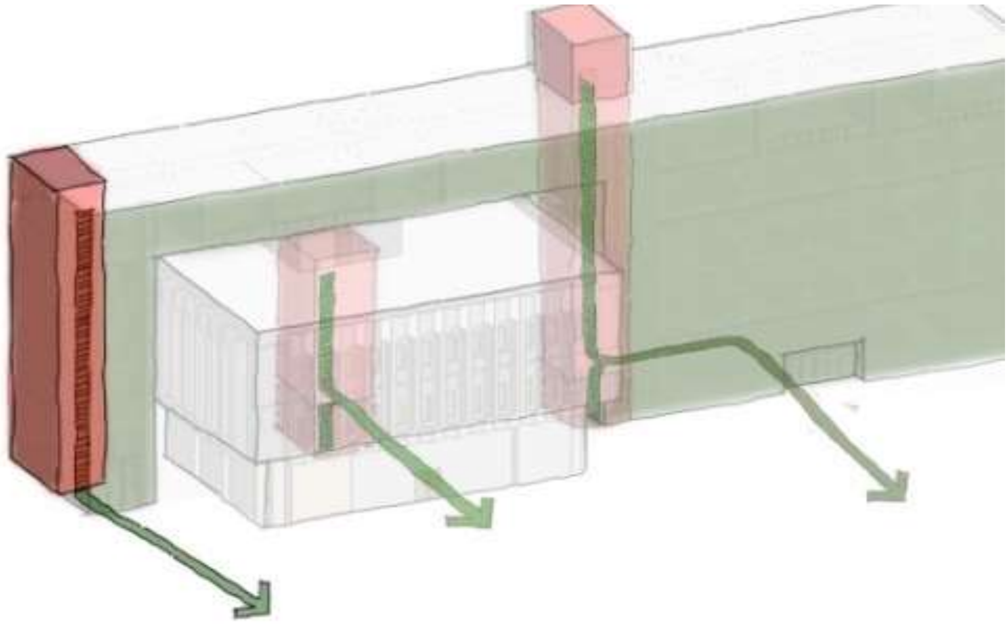
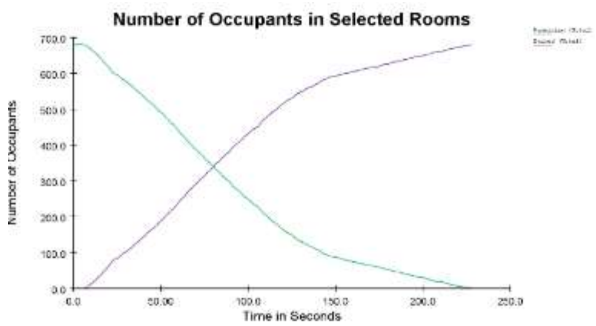


Fig.12: New staircase- left side



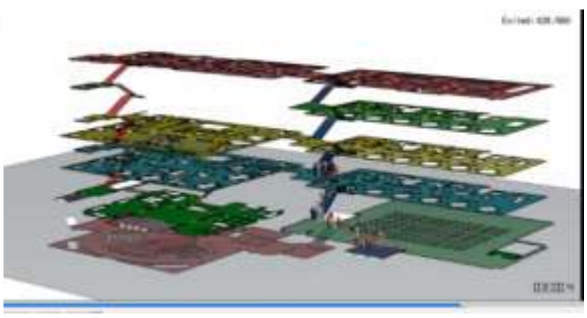


Fig. (13) Time for complete evacuation 3:47

Fig. (14) Evacuation diagram-Scenario 1

B- Scenario two is in reference to many experiments using the simulation software tool (Pathfinder 2018). In addition to the staircase in scenario one, adding two staircases to increase the flow rate of the evacuation of the audience in the auditorium is shown in figure 15. The results in figures 16 and 17 show that in the third minute, only 631/680 persons will be evacuated, and the time for the complete evacuation of the building decreases to 3:41.5 minutes, referring to the final report of the simulation software. Once more, this time is still unacceptable.

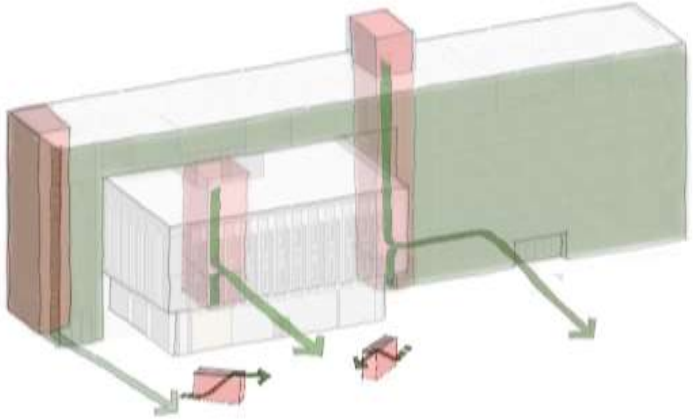


Fig.15: New two staircase in basement

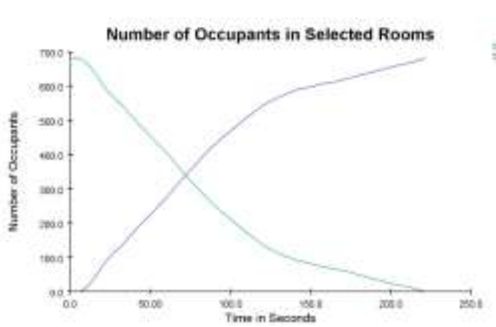


Fig.16: Time for complete evacuation 3:41

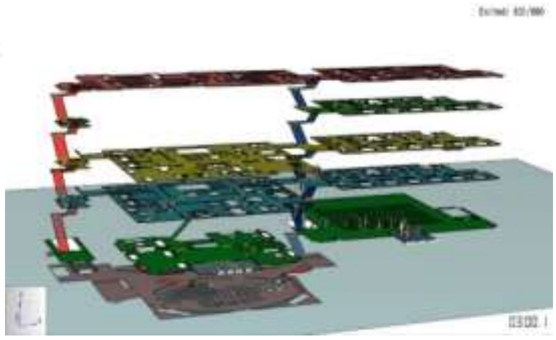


Fig.17: Evacuation diagram-Scenarios 2

C- Scenario three is developed by the means of many additional experiments using the simulation software tool (Pathfinder 2018). In this scenario, another staircase is added on the right side of the building, as shown in figure 18. The results shown in figures 19 and 20 are that the time taken for the complete evacuation of the building decreases to 2:49.5 minutes, referring to the final report of the simulation software. This time is considered acceptable.

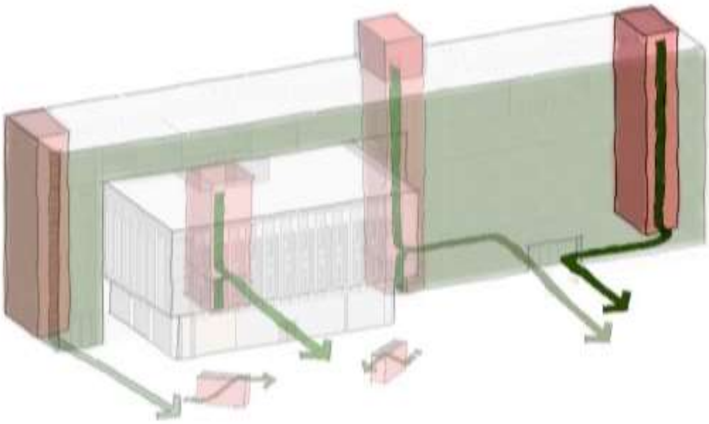


Fig.18: Right side

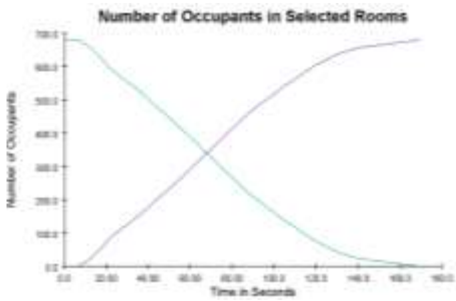


Fig.19: Time for complete evacuation 2:49

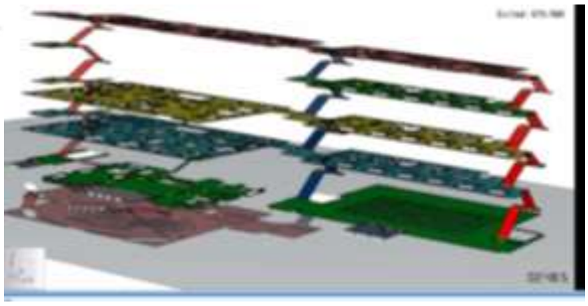


Fig.20: Evacuation diagram-Scenario 3

9. FEASIBILITY ANALYSIS

The effectiveness of scenario three has been examined with regard to three aspects (based on fire safety goals) to secure safety: (a) providing safe evacuation of occupants, (b) controlling the fire in the early phase, and (c) controlling the spread of smoke.

(a) Providing safe evacuation of occupants:

High temperatures and toxicity, as a result of fire and smoke, cause excessive hazards to human life. It is essential to consider how to stop fire and smoke from spreading away from the fire source. Therefore, effective fire separation is required. For example, as previously mentioned, using fire doors for each side of the lobby, staircases and private offices can successfully prevent fire and smoke from spreading to the corridors. Using two staircases on the basement floor for the audience in the auditorium and on each side of the building provides a different evacuation path so that if there is a problem with or obstacles in one staircase, inhabitants on the upper floors can evacuate through the other side. This can guarantee the safe evacuation of the occupants and better conditions for firefighting practices.

(b) Early-stage fire control:

Since CCIAT is a traditional office building, the main fire tools of the office building are furniture, office equipment and supplies. Sprinklers, fire hydrant systems and fire extinguishers also aid in putting out the early stages of a fire.

(c) Controlling the spread of smoke:

Smoke-protected staircases are the best way for occupants to evacuate. Therefore, sensible and effective smoke-control measures are essential to stop smoke and heat from spreading to staircases or elevator shafts. Pressurization facilities create positive pressure in the staircases, which can help to prevent smoke from spreading to the lobby.

According to the above study and scenario three, there is a guarantee that the fire safety plan of the CCIAT building is safe enough for occupant evacuation and firefighting if it is renovated in consideration with the suggested scenario.

10. CONCLUSION

In emergency cases, the design of escape routes in any building could save many lives. According to studies and research, many of the deaths that have taken place in building fires happen in escape routes quite far away from the fire origin. This confirms the high probability that the deaths occurred due to traffic congestion during the evacuation process. Those who were unable to make it out alive might have been obstructed by other occupants, who desperately wanted to evacuate the building. Basic design principles for safety plans and evacuation processes should be required when designing an escape route, including egress components, staircase numbers and locations, exit and entrance positions, corridor patterns and widths and so on.

In this paper, based on fire safety goals and in relation to the CCIAT building's design features and occupancy observations, countermeasure office safety designs have been suggested and their feasibility has been analysed and discussed. In addition, this paper presents the conclusions of a literature review conducted on the existing building egress components, human behaviour and modelling simulations for evacuations in office buildings. Using egress components has been thoroughly examined. The study shows that the importance, capacity and efficiency of emergency exits components are associated with the building's use and the occupants involved. The evacuation simulation software models are useful tools for simulating different relocation strategies, but their predictive capabilities are connected to their flexibility and adaptability in representing emergency exits components and the complexity of human behaviour in emergencies and their actions in the evacuation process.

Simulation software model development and future studies should focus on the staff's actions, attitudes, impact and group dynamics in the case of the evacuation of existing buildings, with more emphasis on people with disabilities and the effects of fatigue. Hopefully, this study of improved evacuation processes and design techniques provides a valuable reference for the fire safety design of similar existing buildings.

REFERENCES

- Ariff, A. (2003). Review of evacuation procedures for the Petronas Twin Towers. CIB REPORT, 35–42.
- Averill, J., Mileti, D., Peacock, R., Kuligowski, E., Groner, N., Proulx, G., . . . Nelson, H. (2005). Final report on the collapse of the world trade center towers. NIST NCSTAR, 1(7).
- Blair, A. & Milke, J. (2011). The effect of stair width on occupant speed and flow rate for egress of high rise buildings. In Peacock, R. D. & Averill, J. D. (eds.) Pedestrian and Evacuation Dynamics: Springer, pp. 747–750.
- BSI, British Standards Institution PD 7974–6 (2004) The application of fire safety engineering principles to fire safety design of buildings. Human factors. Life safety strategies. Occupant evacuation, behavior and condition (Sub-system 6). BSI Group, London, UK.
- Buchanan, A. H. & Abu, A. K. (2017). Structural Design for Fire Safety (second edition).
- Canadian Wood Council (2000). Fire safety in Residential Buildings, Building Performance Bulletin, series 2.
- Chien, S.-W. & Wen, W.-J. (2011). A research of the elevator evacuation performance and strategies for Taipei 101 Financial Center. Journal of Disaster Research, 6(6), 581–590.
- Clawson, K. & O'Connor, D. (2011). Considerations and challenges for refuge areas in tall buildings. Paper presented at the Proceedings of the CTBUH 2011 World Conference, Seoul, 332–338.
- Fahy, R. F. & Proulx, G. (2001). Toward creating a database on delay times to start evacuation and walking speeds for use in evacuation modeling. Paper presented at the 2nd International Symposium on Human Behaviour in Fire.
- Galea, E. & Blake, S. (2004). Collection and analysis of human behaviour data appearing in the mass media relating to the evacuation of the World Trade Centre towers of 11 September 2001: Office of the Deputy Prime Minister, London.
- Galea, E., Hulse, L., Day, R., Siddiqui, A. & Sharp, G. (2009). The UK WTC 9/11 evacuation study: an overview of the methodologies employed and some analysis relating to fatigue, stair travel speeds and occupant response times. Paper presented at the 4th International Symposium on Human Behaviour in Fire.
- Hall, J. R. (2000). High-rise building fires. Nation Fire Protection Association.
- Harding, P. J., Amos, M. & Gwynne, S. (2010). Prediction and mitigation of crush conditions in emergency evacuations. In Peacock, R. D. & Averill, J. D. (eds.) Pedestrian and Evacuation Dynamics: Springer, pp. 233–246.
- Klote, J., Deal, S., Donoghue, B., Levin, B. & Groner, N. (1993). Fire evacuation by elevators. National Institute of Standards and Technology. Elevator World. Special Publication, 983, 66–70.
- Kuligowski, E. D. (2011). Terror defeated: occupant sensemaking, decision-making and protective action in the 2001 World Trade Center disaster. Thesis, University of Colorado.
- Ma, Q. & Guo, W. (2012). Discussion on the fire safety design of a high-rise building. Procedia Engineering, 45, 685–689.
- Macdonald, J. N. (1985). Non-evacuation in compartmented fire resistive buildings can save lives and it makes sense. National Bureau of Standards Special Publication, 694, 117–130.
- MacLennan, H. (2001). To evacuate or not to evacuate: which is the safer option? Paper presented at the 2nd International Symposium on Human Behaviour in Fire, Interscience Communication, pp. 477–487.
- Nilsson, D. & Jönsson, A. (2011). Design of evacuation systems for elevator evacuation in high-rise buildings. Journal of Disaster Research, 6(6), 600–609.
- Pauls, J. (1994). Vertical evacuation in large buildings: missed opportunities for research. Disaster Management – Redhill, 6, 128–128.
- Pauls, J. (2002). Evacuation of large high-rise buildings: reassessing procedures and exit stairway requirements in codes and standards. Paper presented at the Proceedings of the 7th Conference of the Council of Tall Buildings and Urban Habitat.
- Pauls, J. L., Fruin, J. J. & Zupan, J. M. (2007). Minimum stair width for evacuation, overtaking movement and counterflow – technical bases and suggestions for the past, present and future. In Peacock, R. D. & Averill, J. D. (eds.) Pedestrian and Evacuation Dynamics: Springer, pp. 57–69.
- Pauls, J. & Jones, B. (1980). Building evacuation: research methods and case studies. In Canter, D. (ed.) Fires and Human Behavior, John Wiley & Sons, Ltd., London, UK, pp. 251–275.
- Peacock, R. D. & Averill, J. D. (2011). Pedestrian and Evacuation Dynamics: Springer Science & Business Media.
- Peacock, R. D. & Bukowski, R. W. (2009). Summary of NIST/GSA cooperative research on the use of elevators during fire emergencies. Retrieved from

- Peacock, R. D., Kuligowski, E. D. & Averill, J. D. (2012). Building occupant safety research 2012. Retrieved from
- Proulx, G. (2001). Highrise evacuation: a questionable concept. Paper presented at the 2nd International Symposium on Human Behaviour in Fire.
- Ronchi, E. & Nilsson, D. (2012). Fire evacuation in high-rise buildings: a review on human behaviour and modelling research. Lund University, Department of Fire Safety Engineering and Systems Safety.
- Ronchi, E. & Nilsson, D. (2013). Fire evacuation in high-rise buildings: a review of human behaviour and modelling research. Fire Science Reviews, 2(1), 7.
- Spearpoint, M. & MacLennan, H. A. (2012). The effect of an ageing and less fit population on the ability of people to egress buildings. Safety Science, 50(8), 1675–1684.
- Williamson, B. J. & Demirbilek, N. (2010). Use of lifts and refuge floors for fire evacuation in high rise apartment buildings. Paper presented at the Proceedings of the 44th Annual Conference of the Australian and New Zealand Architectural Science Association.
- Wood, A. (2007). Alternative forms of tall building evacuation. Paper presented at the AEI, Architectural Engineering Institute/NIST, National Institute of Standards and Technology Conference, Symposium on High-Rise Building Egress, McGraw-Hill Auditorium, New York, NY.
- Yatim, Y. M. (2012). Optimum escape routes designs and specification for high-rise buildings. Paper presented at the Proceedings of the 3rd International Conference in Construction Industry, Indonesia.