IMPACT OF ARCHITECTURAL LAYOUT ON EXIT PREFERENCE OF RMG WORKERS DURING FIRE EMERGENCY

by

Masrifa Ahmed

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Department of Architecture

BANGLADESH UNIVERSITY OF ENGINEERING & TECHNOLOGY

Dhaka, Bangladesh.

Department of Architecture
Bangladesh University of Engineering and Technology (BUET)
Dhaka-1000, Bangladesh.

The thesis titled "**IMPACT OF ARCHITECTURAL LAYOUT ON EXIT PREFERENCE OF RMG WORKERS DURING FIRE EMERGENCY**" submitted by **Masrifa Ahmed** (Roll No-0413012009, Session: April 2013), has been accepted as satisfactory in partial fulfillment of the requirements for the Degree of **MASTER OF ARCHITECTURE** on this day 30 October, 2021.

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Dedication

To my late parents

Minhaz Uddin Ahmad

Nazmun Nahar Ahmed

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Abstract

Fire in the Readymade Garments (RMG) sector has become a common event in recent years and causing colossal damage of lives and properties. The high density of workers in RMG results in a large number of injuries and fatalities in the event of a fire accident. Fast and effective evacuation during fire emergency depends on occupants' fast egress towards the safe area before the environment become hazardous. Performance of the evacuation highly depends on the behaviour and preference of users during an emergency event. Individuals exit choice is mostly affected by the condition of their immediate environment and the familiarity of the space. The architectural layout of RMG buildings, as well as crowd characteristics, might have an important role for fast and safe evacuation as part of hazard management, and this is needed to be considered for fire safety design.

This research aims to develop architectural planning strategies to meet the requirements and procedures of adequate crowd safety in evacuation with a focus on the exit preference of the occupants during fire emergencies in thqe context of RMG buildings of Bangladesh. The literature review has been done to understand RMG building evacuation system, current building codes, guidelines, standards and requirements for fire safety and evacuation, and to understand human behaviour in fire, the crowd dynamics, management, and communication techniques with the users in a fire emergency. Exit preferences of users in RMG buildings were studied using field observation and questionnaire survey, and by using agent-based crowd simulation and analyzing framework 'Anylogic'.

The findings from the associated questionnaires and logistic analysis of the data showed that "familiarity" and "distance" with the building and the users were the two most important factors for exit preference in RMG buildings. Frequent training for a fire drill, good audible alarm and staff intervention reduce the response phase time, as well as reduce the evacuation time of the evacuees. Imbalanced use of exit doors considerably increases the evacuation time. Simulation study emphasized the difference between evacuation assumptions in current building guidance compared with the results of real-life experiments. It is expected that the recommendations from this research will contribute in architectural layout guidelines by considering evacuees' exit preference to achieve adequate fire safety in RMG buildings of Bangladesh.

Keywords

Emergency evacuation, human behaviour, exit preference, evacuation modelling, fire safety design.

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ABBREVIATIONS OF NAMES

BUET	Bangladesh University of Engineering and Technology
BGMEA	Bangladesh Garments Manufacturers and Exporters Associations
BKMEA	Bangladesh Knitwear Manufacturers and Exporters Association
BFSCD	Bangladesh Fire Service and Civil Defence
BNBC	Bangladesh National Building Code
BigML	Big Machine Learning
DIFE	Department of Inspection for Factories and Establishments
DoA	Department of Architecture, BUET
EPB	Export Promotion Bureau, Bangladesh
EPZ	Export Promotion Zones, Bangladesh
HBRI	Housing and Building Research Institute
RMG	Ready Made Garments
NFPA	National Fire Protection Association
UGC	University Grants Commission

ABBREVIATIONS OF WORDS

m	meter
sqm	square meter
ft	feet
sft	square feet
ASET	Available Safe Egress Time
CC TV	Close Circuit Television
DXF	Drawing Exchange Format
IDE	Integrated Development Environment
PCA	Principal Component Analysis
PDP	Partial Deepnet Plot graph
REST	Required Safe Egress Time

CHAPTER 1: INTRODUCTION

1.1. Preamble

The fundamental principle for safety in a built environment is to ensure that the occupants in buildings are safe during emergency events and normal conditions. To ensure the safety and security of the built environment in a fire emergency, architects are concerned about layout design, the fulfilment of required codes and standards by suggesting appropriate building and finished materials, firefighting equipment, fire safety, and evacuation plans means of escape.

It is almost impossible to consider and satisfy the safety and security requirements of all types of extreme and emergency events for building design. Lovreglio (2016) stated that fire accidents (e.g., Tunnel 1999, Tunnel 2005) and terrorist attacks (e.g. New York 2001, Madrid 2004, London 2005, and Paris 2015) had shown that existing transportation systems and buildings might fail to provide adequate safety conditions during evacuations.

Incident evaluations and real-life experiments mainly study human behavior in fires, such as unannounced evacuation drills (Kobes, 2010). Building occupants can significantly influence building architecture as they are the ones who use and interact with space. Observation of occupants' behaviour in fire evacuation can provide some clue about faults of built environment design and the management. Requirements needs and the cognitive ability of occupants related to their vision, sound, heat, and haptic senses (Sagun, 2013), which depends on the users' characteristics and interaction with the building, need to be considered.

1.2. Problem statement

Bangladesh has qualified its RMG export levels growing progressively from its beginning in the late '70s and has become a top global exporter. According to Export Promotion Bureau (EPB, 2019), the RMG sector has contributed 84.21% to Bangladesh's total exports of $40.53 billion, growing by 10.55% in the Fiscal year 2019 (Ishaque, 2019). The RMG industries are one of the most important industrial sectors, which has earned an 11.17% share of GDP in 2017-18

(BGMEA, 2017-18). Since this is a highly labour-intensive industry, the sector is also the most significant industrial employer in the country, with 3.5 million (approx.) people who are directly working (60.8% are female, and 39.2% are male) in 3596 active RMG factories. According to the Centre for Policy Dialogue (CPD) (Akter,2019). Huda (2014) stated that fire in the RMG sector had become widespread in recent years, causing colossal damage to lives and properties. The fire is supposed to be the most significant cause of on-the-job injuries fatalities in this sector. The fire department of Bangladesh has recorded that 414 workers were killed in 213 factories due to fire hazards from the year of 2006 to 2009 (BFSCD, 2010), and at least 1304 death and 3877 injuries happened in fire and other safety incidents in Bangladesh RMG from November 2012 to April 2019 (Solidarity Center, 2019). For the improvement of the fire safety culture in the garment sector, there have been concerted efforts from the government, the industry lobby (Bangladesh Garments Manufacturers and Exporters Associations (BGMEA) and Bangladesh Knitwear Manufacturers and Exporters Association (BKMEA), and the international buyers of the apparel products and International Labour Organization (ILO). These exertion has made more cautious the owners and the design consultant for better fire safety design. Indeed, compliance with fire safety and building codes have adopted several measures to ensure safety during an emergency evacuation. No matter which way the fire is initiated, in many cases, the death and injury of the worker are caused due to an inappropriate evacuation system. According to the Bangladesh Fire Service and Civil Defence, the factories must have regular fire drills with the workers and keep all entrance/exit gates open when working in the factories (Choity, 2018). As per Code, a fire drill is exercised to practice evacuation from a building during a fire or other emergency to familiarise occupants with the plans. It helps to increase the probability of a successful evacuation and its management during an actual emergency.

In labour-intensive RMG buildings, it is essential and challenging for the architects to design adequate evacuation circulation systems for fire emergencies where safe and speedy evacuation of a large crowd is involved. During the design phase, architects are concerned about layout design, fire fighting equipment, building and finish material, fire safety, and evacuation plans, means of escape to ensure building safety in case of fire. Some RMG factories are now running in purpose-built buildings (Choity, 2018). In the present context, compliance with fire safety is the utmost requirement of the factory buildings, particularly in the production areas where many workers are employed. Indeed, Building Codes have adopted several measures to ensure safety during an emergency evacuation. Some other critical safety issues that need to be explored within this context are wayfinding, crowd flow, control and communication. Circulation and means of egress are the main areas of building layout design for such a design approach (Sagun, 2013). Therefore, this research took the initiative to investigate and consider appropriate design information and guidelines to improve safety in the RMG built environment.

A prerequisite for a successful escape from an inbuilt fire structure is to provide adequate evacuation opportunities to the occupants. If importance is given to user preferences in designing the built environment, then it becomes more interactive. An increase in the safety level and resilience of new and existing buildings in emergencies requires deep insight into how evacuees behave and the factors affecting their behaviour during such emergencies. Lovreglio (2016) mentioned that, in the last decades, several models had been introduced in research to describe and predict human behaviour during emergency evacuations. These models could have a different nature since their aim could be to provide either a quantitative estimation to assess the safety of building (i.,e. engineering models) or a qualitative description of the process characterizing human behaviour during emergencies (i.e., conceptual models). These studies can support (a) the assessment of the risk, (b) the training and preparation for future fire events, and (c) fire safety design (Canter, 1980b). Understanding how people behave in fire evacuation is essential to bring the design of buildings and infrastructures into line with evacuee needs and preferences during an incident (Kobes et al., 2010). Therefore, these studies are fundamental to developing new codes and regulations aimed at addressing this design issue. These decision-making processes are mainly based on subjective streamline design because it has to deal with the occupant's behaviour which is a complex and dynamic process (Li, 2017). These active measures can help significantly in times of emergencies by quickly connecting the environment with the users. Compliance to 'BNBC' or "Mahanagar Imarat Nirman Bidhimala – 2008", "Bangladesh Export Promotion Zone - EPZ building rules (2006)"- guidelines followed in Bangladesh for RMG should have been critically evaluated to address these active measures. These national guidelines are dominated by quantitative estimations, not in the qualitative description (Section 2.3.2).

In a fire emergency, people often use emergency exits and main or familiar exits to reach a safe place quickly. Fire accidents and evacuation experiments have shown that people often use familiar exits instead of unfamiliar emergency exits (Nilsson, 2009). A familiar exit can be, for example, the entrance of a building or the ordinary exit. Overuse of the familiar exit can be a substantial threat to safe evacuation as it increases evacuation time and congestion toward the egress path. (Nilsson, 2009). Several features need to be investigated, which could impact occupants' response and behaviour that need to be considered in building design. Research is necessary to establish the scope for enhancing the safety of building occupants through the improved built environment design to better cope with emergencies focusing on architectural layout associated with crowd behaviour in extreme events. It also needs to seek to study evacuations to develop new design guidelines to enhance occupants' safety.

1.3. Existing research gap

Many tragic events have highlighted that evacuees may not behave according to the designers' and planners' expectations during fire emergencies (Proulx, 2002). Fruin (1993) claims that building code requirements in the design process do not assure efficient functioning in actual daily use and emergency. Moreover, current building design guidance (e.g., codes and standards) includes assumptions on people's behaviour and presents static building information highlighting only some safety issues (Sagun, 2013). Furthermore, the dynamic data such as herding and panic behaviour, ignorance in guidance, or variations in route and exit preference based on the level of familiarity with the building can guide designers in their design process by reflecting real-life circumstances that need to be included (Lovreglio, 2016). In general, yet, reliable information is rare about human behaviour in fires in the context of Bangladesh. Behavioural research can raise many vital aspects that researchers need to consider fulfilling the said research gap. This research finds space characteristics and dynamic information related to building use, behaviour, and movement of occupants in various circumstances and their interaction with each other and their immediate environment in the context of Bangladesh to contribute to the present research gap.

1.4. Aim and objectives

This research aims to develop architectural design strategies to meet the requirements and procedures for effective crowd safety during evacuation, focusing on the occupants' exit preference during fire emergencies in the context of RMG buildings of Bangladesh.

The following objectives have been developed to achieve this aim,

- **Objective 1:** To observe the evacuation time; factors that affect the evacuation time; and behaviour of RMG workers during a fire alarm.
- **Objective 2:** To identify exit preferences and factors affecting the exit choice of RMG workers during evacuations.
- **Objective 3:** To compare different scenarios and crowd movement for different architectural layout of RMG buildings.

1.5. Overview of research methodology

A detailed description of the research methodology used for this thesis has been discussed in Chapter 3. This section provides a brief overview of the research methodology for the thesis. Figure 1.1 shows a flow diagram of the research process, which integrates the main research methods: literature review, field studies, questionnaire survey, statistical analysis, interview, and simulation study.

A literature review is done in two phases. Firstly, to understand the RMG building evacuation system, current building codes, guidelines, standards, and fire safety and evacuation requirements. Secondly, to understand the crowd dynamics and human behaviour in fire, management, and communication techniques with the fire emergency users. A theoretical framework is developed in research methodology to identify the factors influencing users' exit preference during an evacuation after review.

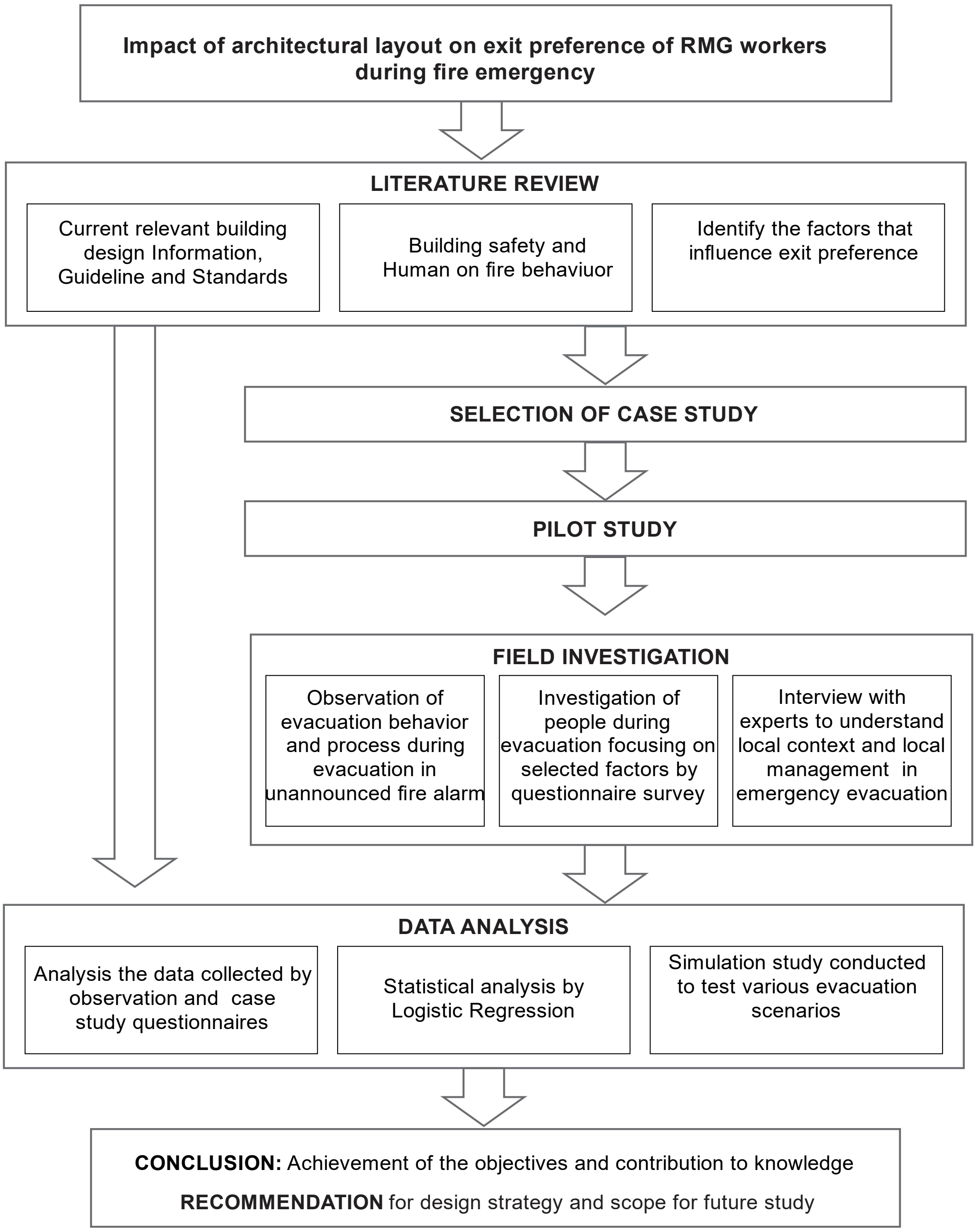


Figure 1.1: Flow diagram of the research process

Field studies were conducted on three purpose-built RMG factories. Case Studies were selected following the 'purposive non-probability sampling method' from the Dhaka region. Firstly, a pilot study was conducted to understand the requirement and deficiency in management by observing evacuation drills for the research activities such as fixing the location of the cameras or identifying the close circuit (CC) television (TV) coverage, defining some people to volunteer during the drill, and position of the volunteers for the practical design was done for the observational case study. The observational case study was done to understand the user's behaviour and exit preference in the fire emergency conducted by an unannounced fire drill.

A questionnaire survey on the fire drill participants was conducted to determine users' preference for exit doors, reasons for the choice, orientation with the fire marshal and signage, and bottleneck area. Logistic Regression Analysis was used to build a statistical model of the exit preferences of building occupants using the distance data and the factors identified in the questionnaire.

Interview with the fire personnel from each field investigation focused on the evacuation process to understand the factors affecting the pre-movement Time and the evacuation behaviour.

The simulation study was conducted to test various evaluation scenarios for the crowed movement, found from the observational case studies of RMG buildings. The purpose of the simulation studies was to investigate how factors identified in observational case studies affect the evacuation and design process using evacuation modeling techniques. It is done using 'Anylogic'– an agent-based crowd simulation and analysis framework for evaluation modeling developed by 'The Anylogic Company' to simulate people-people, people-event, and people-structure interaction. Finally, an understanding of literature review with experiences of data collection and simulation study was compiled to develop architectural design strategies to meet the requirements and procedures for adequate crowd safety during evacuation, focusing on the occupants' exit preference during fire emergencies in the context of RMG buildings of Bangladesh.

1.6. Structure of the thesis

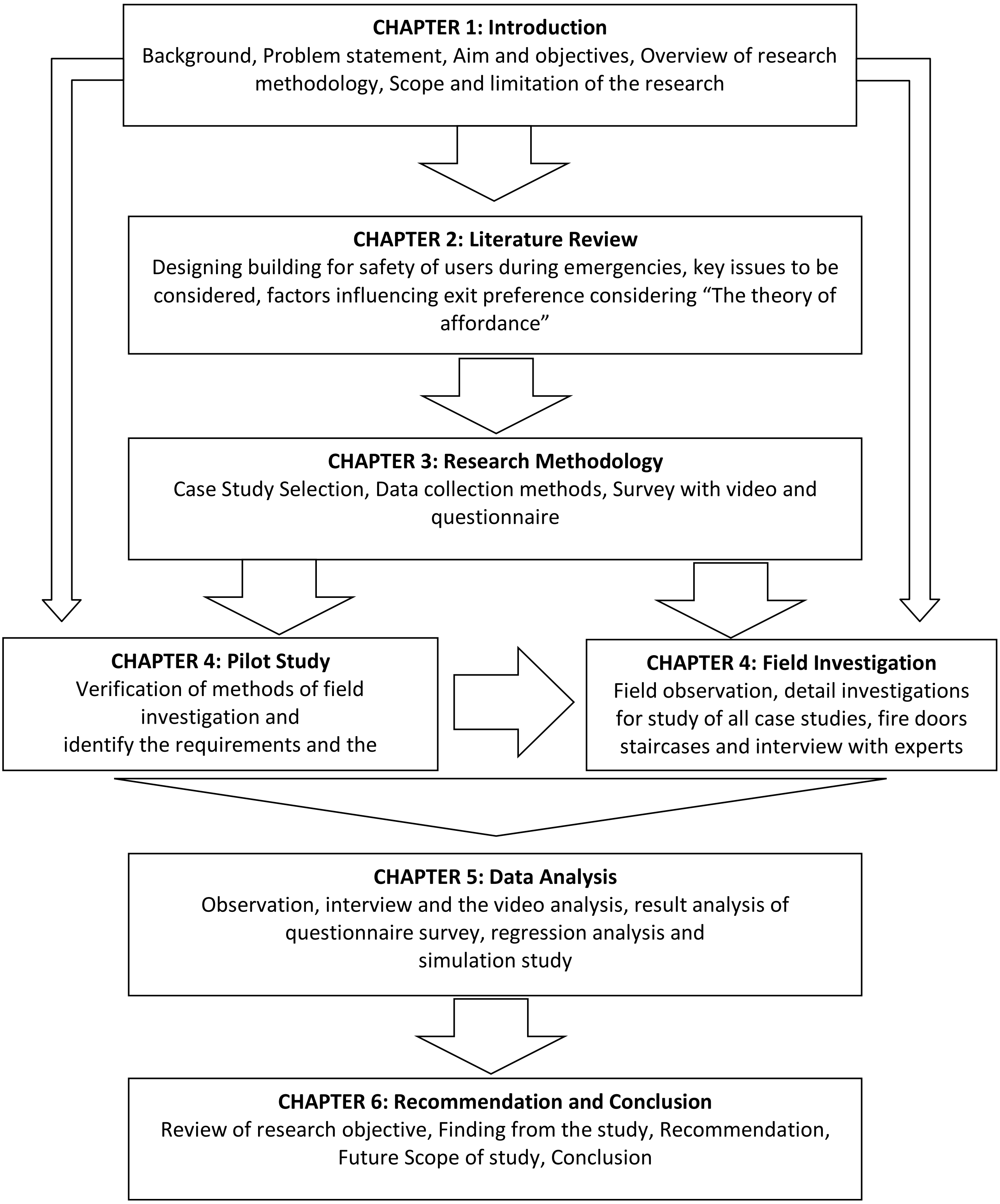


Figure1.2: Organization of the chapters and structure of the thesis.

1.7. Scope and limitation of the research

The primary purpose of this study is to develop a methodology to include dynamic building information associated with the interaction of people with each other and with their immediate environment in the building design process. Factors that affect the evacuation time and behaviour of RMG workers during emergency events are identified in this research. This research explores the building design issues associated with safety and security and focuses on building occupants' exit preferences during emergency evacuations. Some recommendations and guidelines are derived to improve the architectural layout by considering human behaviour to achieve adequate fire safety in RMG buildings of Bangladesh.

The research work concentrates on strategies focused on architectural design. Only fire drill evacuation is considered; actual fire and smoke conditions are not evaluated. The research focuses solely on production workers' evacuation and does not consider evacuating non-production areas such as a store, generator, office area, and canteen. This research's recommendations and design guidelines are made considering fire disaster threats only, not the personal crime or operational fault.

Considering time and resource constraints for the research, the evacuees' panic behaviour due to fire and structural or MEP design, construction, and maintenance cost was beyond the scope of this thesis.

1.8. Summary

The research started to overcome some constraints mentioned in Section 1.2. The gradual development of the study from the literature review and incorporation of research findings at each stage made objectives, methodology, and limitations of the research more defined, refined and detailed. Table 6.1 summarises the research's key findings regarding the goals, the methods, and the concerned chapters.

CHAPTER 2: LITERATURE REVIEW

2.1. Preamble

After some recent fire accidents, the safety issue in RMG factory buildings has become resilient because it deals with human life, national resources, and overall business interest due to compliance requirements from western buyers. In Bangladesh, there are few types of research undertaken on building design concerning fire safety. Multidisciplinary issues need to be addressed to assess research on fire safety. Discussions in this chapter provide the contextual issues and theoretical framework of the present study.

The literature survey was done in two phases to perform to achieve the objectives of this study. The first phase focused on understanding building design for fire safety during an emergency with background study on current building codes, standards, and requirements. The second phase focused on understanding human behaviour in fire and the crowd dynamics in evacuation. Finally, a theoretical framework is developed to identify the factors influencing users' exit preferences during evacuation. Figure 2.1 denotes the detailed framework of the literature review, which was discoursed throughout this chapter.

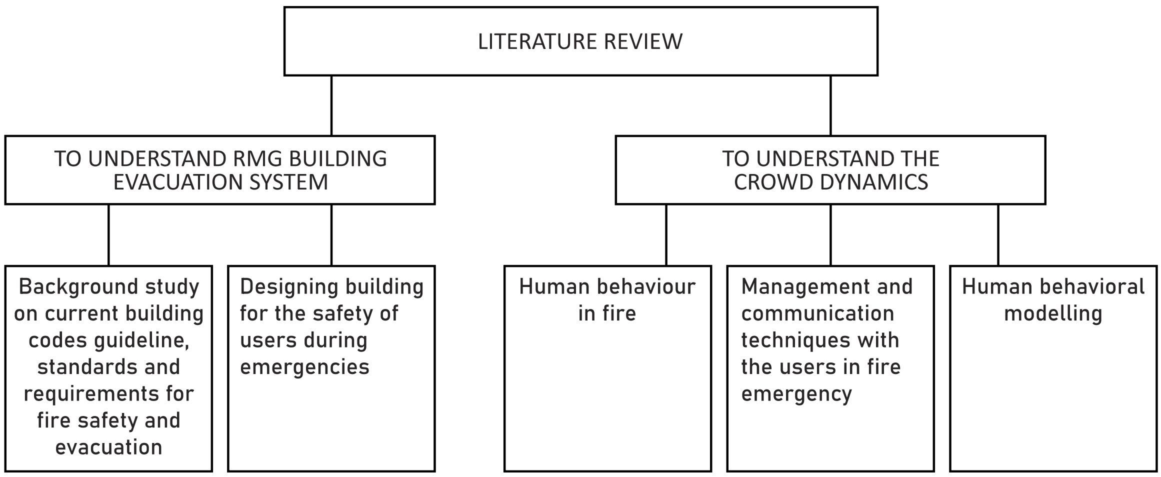


Figure 2.1 The Framework of literature review

2.2. Background

The research on evacuation began during the early 20th century (O'Connor, 2005) when the focus was on the movement of people in corridors, on stairs, and through doors. Several researchers, including Pauls (1984), Fruin (1993), and

Melinek (1975), worked on detailed information about occupant density and travel speed (Kobes, 2010). Their learning had a significant influence on the current approach to fire safety building regulations worldwide. Primarily the findings have led to a minimum width of evacuation staircases, a maximum flow rate capacity for fire exits, the required number of fire exits, and other specific architectural features (Kobes, 2010).

At the end of the 20th century, the interpretation of the fire safety of buildings changed from a technological to a more behavioural perspective (Kobes, 2011). Studies in the field of human behaviour in a fire started rigorously during the 1960-the 70s with the work of Bryan (2002) in the United States and Canter (Canter, 1980), Sime (1980), and Wood (1972) in the United Kingdom. Publication in 1980, the book 'Fires and Human Behaviour', edited by David Canter, was one of the pioneer contents and still applicable (Proulx, 2001). Proulx (2001) claimed that fascinating studies regarding response to fire cues, the timing of escape, the impact of training, original wayfinding systems were among the few projects being started a few decades ago.

Several studies show that occupants are often unable to escape the fire hazards or smoke in time, and a long time passes before their movement to escape (Kobes, 2011). Although the buildings are designed by following the regulation where occupants can escape in a fire, delay time happens because of the perceiving and validating of danger clues and decision-making processes before and during the actual movement (Purser, 2001). Precaution for safety and security is not just a few integrated applications after the construction of buildings; some key issues have to be considered to enhance building design (Sagun, 2013). It is better to let buildings' fire safety be based on actual human behaviour in fire instead of assuming that human behaviour will comply with technology-based safety measures.

Kobes (2010) stated that pre-movement Time and pre-movement behaviour are critical aspects of the evacuation process. He mentioned that these findings have come from the research of Sime (1980), Proulx (2007), and Fahy (2005). Incident analysis from World Trade Centre in 2000, Mont Blanc tunnel in 1999, and some other accidents in residential towers and hotels have shown a connection between a delayed evacuation and a high number of fire death and injuries (Kobes, 2010).

To date, several evacuation models and tools have been developed to predict the safety of a building by comparing the Time necessary to evacuate it and by analyzing the decision-making behaviour of evacuees and the factors affecting their behaviour during emergencies (Lovreglio, 2016). "Exit choice in fire emergencies" by Daniel Nilsson (2009), "Designing Buildings to Cope with Emergencies: Findings from Case Studies on Exit Preferences" by Aysu Sagun (2013), and "Modelling Decision-Making in Fire Evacuation based on Random Utility Theory" by Ruggiero Lovreglio (2016) are renowned research on exit preference of evacuee in fire emergency evacuation. Several research papers also have been published on the evacuation decision-making simulation model based on human behaviour in evacuation scenarios, such as the preference for specific routes or exits or the Time needed to gather and interpret information (Kobes, 2010). In this research, the qualitative investigation methodological approach of Daniel Nilsson and Aysu Sagun was followed to achieve the research objectives.

Research undertaken on building design concerning fire safety in Bangladesh is limited. Comprehensive research on factory buildings of Bangladesh was conducted by Prof. Dr Nizamuddin Ahmed in Sheffield University in 1987 as part of his Ph.D. and later published in 'Industrial Architecture for Developing Countries' in 1992. In more recent times, a study was undertaken by Ahsan Firoz in 2011 at BRAC University, Dhaka, which aimed to understand the vulnerability level of RMG workers in Dhaka in the case of the disaster from the perspective of an emergency evacuation. In 2018 Shuhana Sharmin Choiti, Department of Architecture, Bangladesh University of Engineering and Technology (BUET), conducted detailed research titled 'Spatial Analysis of Buildings on Relation to fire drills in RMG factories with particular reference to emergency escape routes. It focuses on how a suitable spatial layout may help a fire drill be more effective in case of fire to reduce vulnerability (Choiti, 2018). In the perspective of relevant literature review, in this chapter, the significance of architectural layout of factories on exit preference of the evacuee during the fire has been investigated in the context of large-scale medium hazard factories, i.e., RMG factories in Bangladesh.

2.3. Designing buildings for the safety of users during emergencies

The consequence of recent extreme events worldwide such as natural disasters, accidents or humanmade disasters has raised awareness of the most crucial aspect of a building design associated with safety and security. A safe built environment follows the fundamental principle for protection to ensure the occupants are safe during an emergency event and in normal condition (Sagun, 2013). It provides the possibility of a safe escape (Kobes, 2010). The evacuation strategy is usually utilized for the buildings with assembly occupancy, such as shopping malls, night club, worker-intense factory buildings, and campuses. Even though technological progress in the last decades has reduced the number of deaths or injuries, it cannot always be possible to predict and prevent human behaviour during fire emergencies entirely. An increase in the safety level and flexibility of new and existing buildings in emergencies requires a deep understanding of how evacuees behave and the factors affecting their behaviour during such emergencies.

2.3.1. Accidents in RMG

The production spaces of the RMG manufacturing units comprise a vast number of workers involved in activities, e.g., sewing, cutting, ironing, and finishing. Nearly 4.2 million workers are now directly involved with this industry; about 70% of them is women (Choiti, 2018). It is crucial to provide a safe and secure workplace for garment workers. In recent years, the statistics of fire hazards incidences in RMG factories reveal an alarming rate of causing the death of hundreds of people in fire incidents. The Fire Department of Bangladesh has recorded that 1304 workers were killed in 169 factories due to fire hazards, with other incidents from 2012 to 2019 (Solidarity Centre, 2019). Study shows that a crucial reason for casualties in fire breaks out in a factory is the fire itself and the triggering components, such as electrical short circuit and panic behaviour. The subsequent impacts of fire on the human mind (e.g., panic causing a stampede, locked exit route, smoke, and suffocation) are the significant reasons for casualties (Firoz, 2011). An interview of a key person of Fire Service and Civil Defence depicts that if the management conducts regular drills and if the workers are well trained and oriented, panic and stampede can be avoided, then the loss of human lives could be reduced drastically (Firoz, 2011).

a) Eight-storied factory building of Matrix Sweater Ltd, Gazipur, 2/2/2016,

b) Tazreen Fashions Limited, Ashulia, Dhaka, 24/11/2012)

c) Seven-storied Dignity Textile Limited building in Betjuri area of Sreepur upazila 30/5/2015

d) Sinha Opex Group factory, Kanchpur ,Narayanganj, Sonargaon. 27/2/2017

Figure 2.2: Few major fire incidents in Bangladesh RMG sector

In Tazreen Fashions Limited, Ashulia, Dhaka, a fire broke out on 24 November 2012. At least 117 people were confirmed dead in the fire, and over 200 were injured, making it the deadliest factory fire in the nation's history. After the Tazreen incident, the Tripartite Partners (Government, Employers, and Workers) adopted a joint statement of commitment during a meeting organized by the

Ministry of Labour and Employment and International Labour Organization(ILO). Furthermore, they tried to ensure an integrated approach to promote fire safety in Bangladesh, particularly in the RMG sector (Choity, 2018).

2.3.2. Safety in RMG

Safety regulations in Bangladesh

In Bangladesh, the "Bangladesh National Building Code" (BNBC, 2006) is the main guideline for certifying the overall safety standard of buildings. The government of Bangladesh drafted a law in 2008 and passed it in the parliament in 2009, titled "Mahanagar Imarat Nirman Bidhimala – 2008". This law set is obligatory to be followed in Dhaka and Chittagong city corporations. For the construction of factories within the 'Export Promotion zones,' a separate set of laws is in practice, "Bangladesh Export Promotion Zone - EPZ building rules (2006)"- required for self-constructed buildings. There are rules and regulations in BNBC, Rajuk Imarat Nirman Bidhimala (Building Construction Rules of RAJUK 2008), Bangladesh Labour Act (2006), and Accord Manual (2013) to support RMG factories in the implementation of fire protection measures for existing or new RMG Buildings. In formulating these rules, the International Codes and Standards, notably the National Fire Protection Association (NFPA 1) codes, are considered mainly. The NFPA is an international non-profit organization (headquarters location: Quincy, Massachusetts, United States) devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazards.

According to the Bangladesh Fire Service and Civil Defence, the factories must have regular fire drills with the workers and keep all entrance/exit gates open when working in the factories (Choity, 2018). BNBC (2006) provided the guidelines for each building with an emergency evacuation protocol, first aid firefighting plan, training, and responsibilities of the occupants complemented with the provisions. It can be noticeable that codes and rules indicate a prescribed route towards evacuation destination shall be marked in buildings. Codes on a fire safety plan means of egress, exit, and travel length have suggested different aspects of this route. According to BNBC (2006), the exits shall be located and arranged to provide continuous and unobstructed means of egress to the exterior of the building leading to a street or other designated area of refuge. Exits shall be easily visible and accessible from the area served by them. The required width of exit for RMG factory buildings is 4mm per occupant (with or without a sprinkler system installed in the building). The necessary number of exits shall depend on the occupant load. Minimum 2 exits are required for an occupancy load of 500 or less; a minimum of three exits is necessary for an occupancy load of 501 or 1000; a minimum of four exits are needed if the occupancy load is more than 1000.

Fire safety plan

A fire safety plan is also known as a fire safety and evacuation plan. According to BNBC (2006), in preparation of fire safety and evacuation plan, all individual floor layouts, total occupancy load on each floor, number and kinds of exits available, zoning of the floor by area, and occupancy should be taken into consideration. The plan proposes safe and orderly evacuation guidance for a part of the whole building to the occupants. In a fire emergency, the plan guides them in the shortest possible time to a safe exit through the means of egress (Choity, 2018). The use of in-built facilities of fire warning and firefighting, e.g., escape routes, fire exits, fire alarm, first aid, and hose, for safeguarding the building users' lives are also detailed here. The plan shall be rehearsed through a fire drill, and the written plans containing instruction shall be updated if needed. [Draft BNBC, 2015, 4- 58, 4-59] The fire safety plan needs to be approved by the Department of Fire Service and Civil Defence.

2.4. Principle of evacuation planning

The evacuation planning principle is to provide a safe evacuation route from any point of a building to a safe area outside the building.

Characteristics of a safe evacuation route are the following (JICA, 2003) (Figure 2.3, 2.4).

- Same with a path of flow in the daily route
- Always ready for evacuation

- Continuous with one or more exits and public ways
- Resistant to fire and smoke
- Enough in capacity
- Redundant by plural paths of travel
- Not delayed by any obstructions
- Suitable for all type of occupant

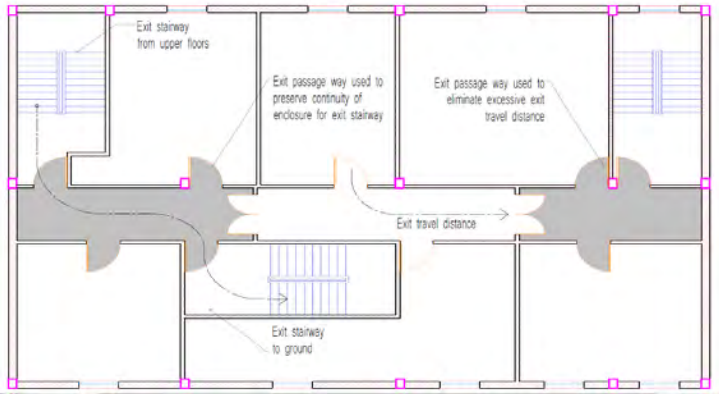


Figure 2.3: Continuity of Horizontal Evacuation Route (Hesson, 2020)

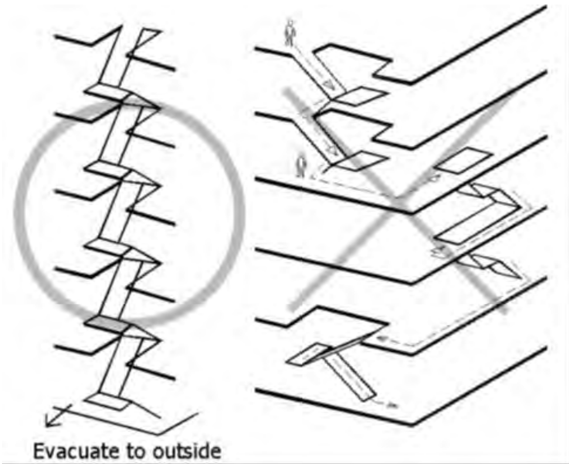


Figure 2.4: Continuity of Vertical Evacuation Route (JICA, 2003)

2.5. The basic idea of evacuation planning

The basic idea of evacuation planning is to complete evacuation before smoke builds a hazardous level that the smoke descends to the height at which it obstructs evacuation. The evacuation time must be shorter than the Time for smoke descent (JICA, 2003). i.e.

$$T_{evacuation} \leq T_s \qquad (2.1)$$

($T_{evacuation}$: Time to complete evacuation; T_s: Time for the smoke descent to the hazardous level)

1) Time to complete evacuation ($T_{evacuation}$)

$T_{evacuation} = t_{start} + t_{evacuation}$ …………………….. *(2.2)*

2) Time for the smoke to descend to the hazardous level (T_s)

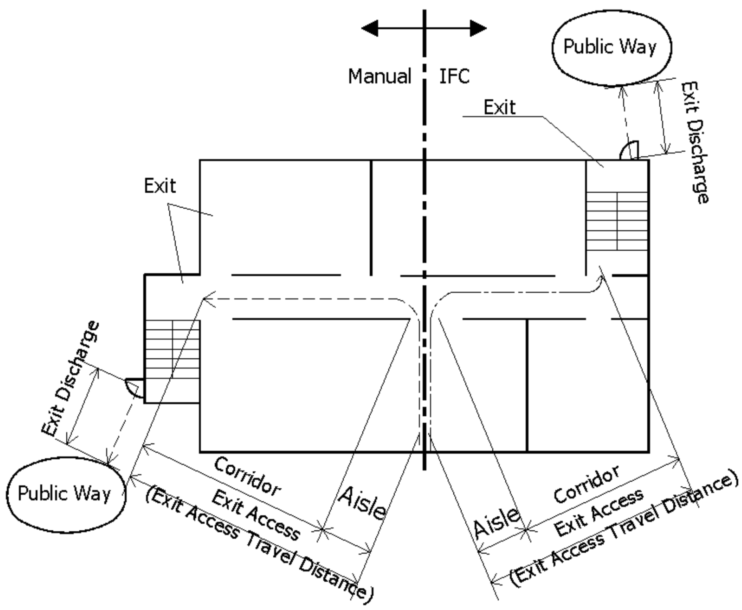
$T_s = \sum t_i$………………………………………….... *(2.3)*

- (T_s = Time for the smoke to descend to the hazardous level (Ts). Ts is the accumulated time in which smoke spreads to space in front of escape stairways.
- (t_i = Time for smoke spillage in each room, located along the path from the fire origin to an escape stairway)

2.6. Components of evacuation route

The evacuation route comprises three portions: exit access, exit, and exit discharge (Figure 2.5). Those three components are considered as means of egress.

Means of egress in an evacuation system is a continuous and unobstructed way of exit travel from any point within a building to a designated area of refuge. The means of exit travel within a building from any point is the means of egress. It



consists of three parts as follows (Draft BNBC, 2015, 4-58).

Figure 2.5: Components of the evacuation route (JICA, 2003).

- Exit Access: This portion leads to the entrance of an exit and is included in the measure of travel distance to reach a door.
- Exit: The exit itself shall be considered protected from the incidence area and provides a safe path to the exit discharge.
- Exit Discharge: The exit discharge shall comprise any travel portion between the termination of an exit and the exterior and the area of refuge.

Generally, lifts, escalators, and moving walks shall not be regarded as components of means of egress, except when they are designed and installed for safe operation during fire shall be included as components of means of egress

2.7. The capacity of the evacuation route

The evacuation route must have sufficient capacity to allow smooth evacuation. The ability is directly related to the width of the evacuation route. Fire codes in different countries usually regulate a minimum width for evacuation routes based on occupants' number. For example, the fire code in the United States specifies: 'width of the stairway (B)' should be not less than 'the unit width (w= 0.3 inch/occupant)', multiplied by 'the number of occupants (P)' to ensure complete evacuation within two minutes (T), (whereby, Neff = 45 occupants/unit/minute, 1unit = 22inch) (JICA 2003).

Time to discharge

$\boldsymbol{T = P/(B * N_{eff}) = P/(P * w * N_{eff})}$…………… *(2.4)*

=1/ (0.3 X 45/22) = 1.63 minutes

In BNBC, the number of occupants for which the exit facilities are to be provided shall be computed as follows (Draft BNBC, 2015):

- no. of occupants = Total gross floor area in sq. meters / 10

- the occupant load calculated as above need not exceed one person per 0.3 sqm of usable floor space.

2.8. Fire corridor and passageway

All users need to reach an exit after crossing any fire corridor or passage. In addition to safety, the corridors and aisles require sufficient capacity for the occupants who evacuate through these parts. Where there is no exit, the length of this type of passage will not be more than 10 m. The minimum width of fire corridors and passageways depends on the occupant's load per floor, as shown in Table 2.1. Fire codes in Thailand, Japan, and the United States regulate the minimum width of corridors: (JICA 2003).

- 1.55 m uniformly in Thailand,
- 1.2 m for corridors serving only one side and 1.6 m for corridors serving both sides in Japan,
- 0.914 m for 50 occupants or less, and 1.8 m for more than 50 occupants in the United States.

Table 2.1: Width of fire corridors and passageways (BNBC Draft 2015)

Occupant's load/floor	Minimum width of Fire corridor
50 or less than 50	0.9 m
More than 50	1.1 m
Occupancy Type: B (Educational Institutes)	1.8 m
Occupancy Type: D (Hospitals)	2.4 m
Occupancy Type: G (Factories)	1.8 m

Form of Corridors and Aisles

The corridors and aisles form the horizontal part of the evacuation routes. These horizontal parts are connected to an escape stairway and exit discharge. Firstly, the corridors and passageways must be safe and secure through the provision of the following.

- Flat and slip-resistant surface

- Fire and smokeproof construction
- Noncombustible interior finish
- Fire protection at openings

2.9. Multiple evacuation routes

Fire can start in any part of a building, including evacuation routes. Therefore, any point in a building must have two or more evacuation routes (Figure 2.6). Fire codes in different countries require the number of evacuation routes by floor area or occupants' number (JICA 2003).

1) Fire codes in the United States require the following.

- Two or more exits for a room or floor with 50 occupants
- Three or more exits for a room or floor with 500 occupants
- Four or more exits for a room or floor with 1,000 occupants

2) Fire codes in Japan require two through stairways or more for a floor with the following.

- 50 m^2 for hospitals
- 100 m^2 for hotels and multi-story housing
- 200 m^2 or 400 m^2 for offices, schools, factories, and department stores

The evacuation route should be simple, well-balanced in its location and connected with escape stairways at the end of its path.

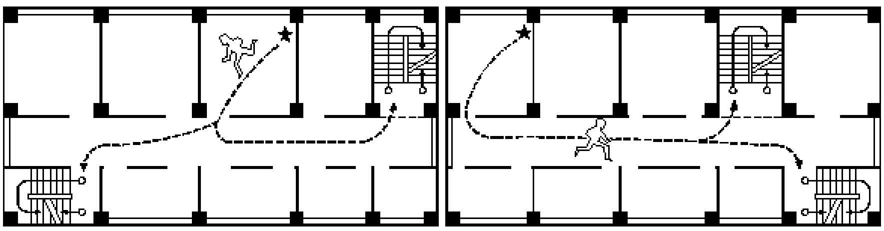


Figure 2.6: Well-balanced Layout of Escape Stairways (left) and Unbalanced Layout of Escape Stairways (right)(JICA, 2003).

2.10. Form of evacuation route

2.10.1. Exits

According to BNBC (Draft, 2015), the exits shall be located and arranged in a manner so that they provide continuous and unobstructed means of egress to the exterior of the building leading to a street or other designated area of refuge. Exits shall be easily visible and accessible from the area served by them. The required width of exit for RMG factory buildings is 4mm per occupant (with or without a sprinkler system installed in the building). The necessary number of exits shall depend on the occupant load. Minimum 2 exits are required for an occupancy load of 500 or less; a minimum of three exits is necessary for an occupancy load of 501 or 1000. A minimum of four doors is required if the occupancy load is more than 1000.

2.10.2. Exit access

Aisles and passageways

The aisle is the pathway between rows of seats or a workstation. In addition to safety, the corridors and passageways require sufficient capacity for the occupants who evacuate through these parts. According to BNBC (Draft, 2015) code, the minimum aisle width must be 1.2 m and uniform in shape. The production area aisles in the RMG act as a means of egress, giving access to the exit from any workplace location. The aisles should be free of obstruction leading to the exits (Draft BNBC, 2015, 4-17).

Staircases

The stairways are another means of escape. It needs to be headed towards exit discharge and help achieve change in elevation by steps. Stairway steps are a combination of identical risers and trades as per provisions of the Code (Draft BNBC, 2015, 4-20 to 23).

Width of escape stairway

The sufficient width of the escape stairway is essential to secure smooth evacuation. The width of escape stairways must be adequate for the occupants on each floor and floors above and below an intermediate floor if the escape stairway connects to the middle floor. Different fire codes that specify the width of escape stairways are attached in Appendix E.

Form of miscellaneous facilities of stairway and corridor

In a crowded evacuation route, occupants cannot move with complete control. They may not be able to see their feet. Sudden changes in stair configuration can cause people to lose control and fall. Tread and riser have to be consistent from the top to the bottom of an escape stairway. This consistency aims to provide a steady movement for the occupants. Handrails in an escape stairway help prevent occupants from falling and support occupants who have impaired mobility. Hand-rails should be installed as follows.

- At both sides of the escape stairways, preferably to either dominant hands
- In the middle of the stairway, if the width of the escape stairway is more than 2.2 m

Landings control the distance that occupants can fall and provide a resting space for occupants with difficulties walking.

Fire door

Door or opening protection is an obstruction for the occupant to pass through exit access to exit until and unless installed as per the Code (Draft BNBC, 2015). Doorways along an evacuation route are essential for controlling occupants' passage and the intrusion of smoke and fire. The doors should have fire resistance, an automatic closing system, and the opening direction the same as the evacuation direction. When the opening movement is opposite the evacuation direction, occupants will not open the door for the crowd in front of the door. Preferred doorway types are single, double, and automatic types with a manual operating mechanism in the power supply cut.

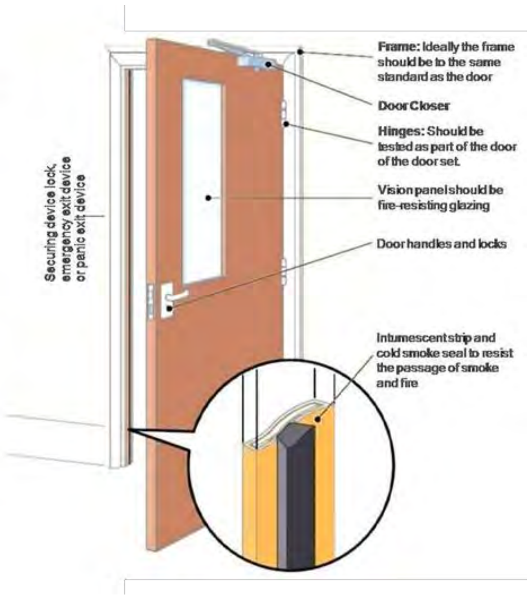
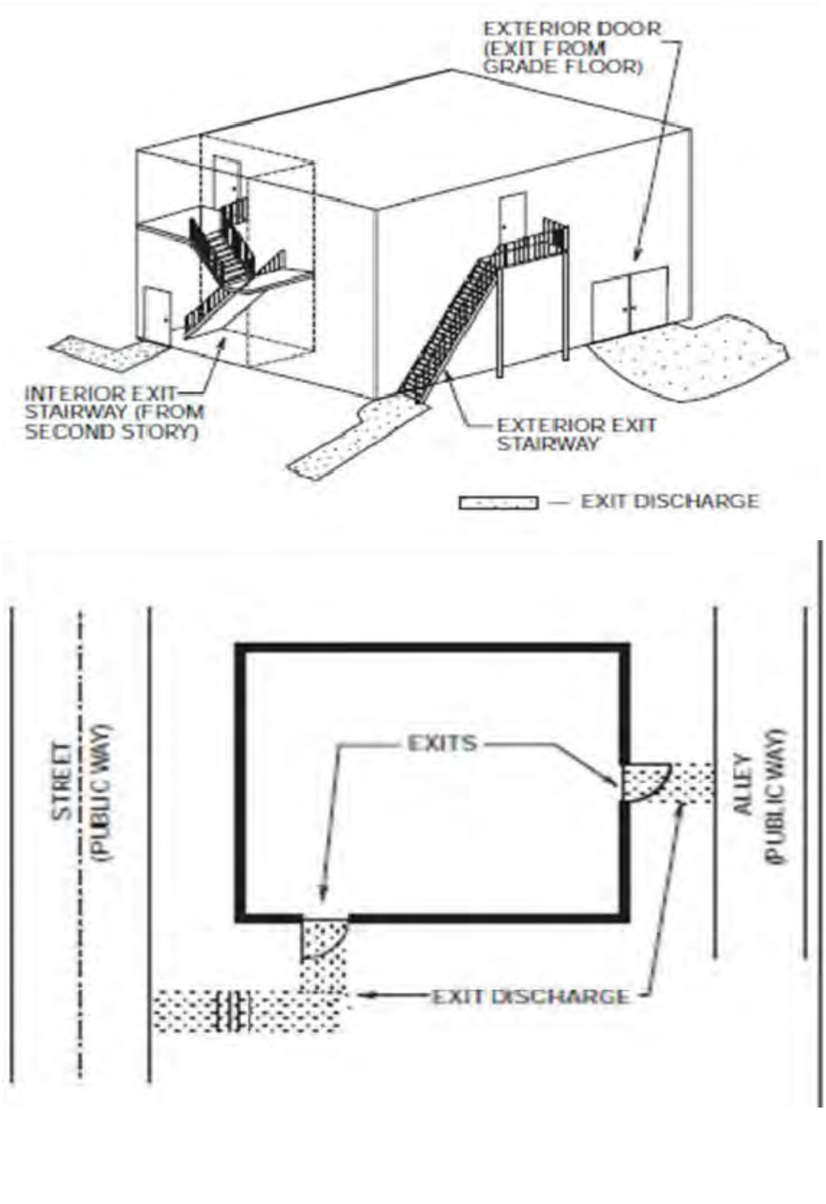


Figure 2.7: Fire door with standard features (BCMG, 2018)

2.10.3. Exit discharge

The exit discharge is the portion of an evacuation route from an exit to a public way (Figure 2.8). The exit discharge must have sufficient width and fire protection to at least the same fire safety standard as the exit connecting to the exit discharge. The exit discharge will typically begin when the building occupants reach the exterior at or near grade level. It provides occupants with a path of travel away from the building. All the components between a building and public way are considered exit discharge, regardless of the distance. In areas of the sloping terrain, it is possible to have steps or stairs in the exit discharge leading



to the public way (CCFS 2018).

Figure 2.8: Exit discharge (CCFS 2018)

2.10.4. Floor plan

The floor plan of the entire building with floors with different configurations showing firefighting facilities' locations shall be kept under the Fire Safety Director's command with a copy to Fire Department (BNBC, 2006, Act: 4.8.9).

2.10.5. Occupant load

Total occupant load means the summation of all occupants of only one level at the pick hour of occupancy, where maximum occupants are present. According to BNBC (2006), 10m^2 spaces shall be provided for every worker employed in an RMG Building. Bangladesh Labour Act 2006 recommends a minimum of 2.3 m^2 areas per labourer.

2.10.6. Length of travel

When a fire breaks out, occupants must reach an exit as soon as possible. The maximum exit access travel distance regulates the full length from any part of a building to an exit (Figure 2.9). It aims for the well-balanced layout of evacuation routes. Occupant load and components of doors shall be arranged so that the travel path from any point in the area to the vestibule or balcony of a smokeproof staircase or exit discharge shall not exceed the maximum travel length. For existing RMG factory buildings equipped with an automated alarm and appropriate fire-fighting system, the length of travel shall not exceed 60m (Draft BNBC, 2015). Wherever more than one exit is required in a room or on any floor, they shall be placed as remote as possible.

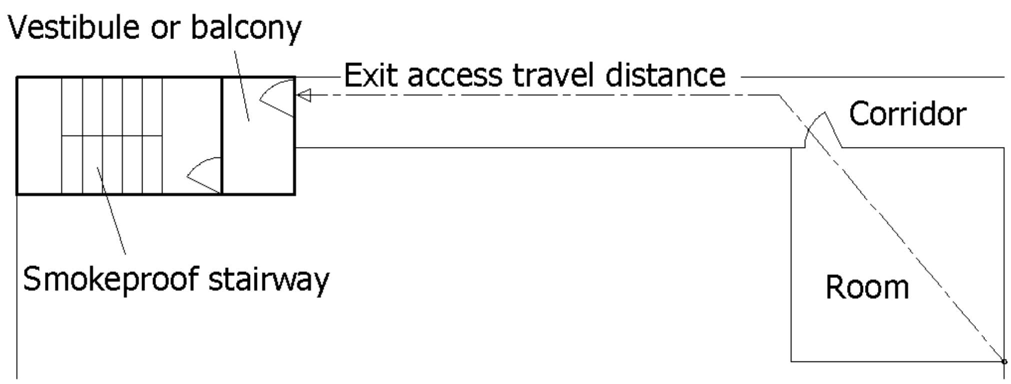


Figure 2.9 Maximum exit access travel distance (JICA, 2003).

2.11. Fire drill

BNBC states that Fire Drill shall be conducted as detailed under the fire safety plan. Fire Drill is a rehearsal of the fire safety and evacuation plan. It is arranged to train the occupants of a building in first aid firefighting, relocation, and orderly evacuation (Draft BNBC, 2015). The fire drill frequency shall be monthly – if the industry has an occupancy of more than 150 and shall be quarterly if it has less than 150 (Draft BNBC, 2015, 4-59). All occupants of the buildings, building service employees, including fire safety and evacuation plan staff, shall participate in the fire drill. According to NFPA, responsibility for the planning and conducting of drills shall be assigned only to competent persons qualified to exercise leadership (Draft BNBC, 2015, 4- 59) (Figure 2.10, 2.11).

Figure 2.10: Fire warden preparing for a fire drill.

Figure 2.11: Trainer conducting monthly fire training in the assembly area.

2.11.1. Signs and floor plan

BNBC (2006) code depicts that all floors must contain exit signs, with a floor plan posted on a wall containing the exact location of the stair and the relative position between the symbol and the stair, to navigate the occupant in times of emergency. As per NFPA 1 instruction, symbols of exit signs, lettering, and arrows shall be written with vernacular alphabets in a high contrast background. The signs may be posted directly on a noticeable location securely attached to the wall surface (Draft BNBC, 2015, 4-58) (Figure 2.12). It is also stated in Code that corridors and passages leading to the exit discharge shall be marked and signposted to guide the evacuees as per the provision of the Code (Draft BNBC 2015, 4-26). From exit access, all exits shall be visible (Draft BNBC 2015, 3-14). The Bangladesh Fire Service and Civil Defense (BFSCD) department must approve the fire safety plan. The program includes a fire fighting team categorized based on a fire extinguisher, search, rescue, and first aid. Department of Inspection for Factories and Establishments (DIFE) of the Government of Bangladesh is responsible for approving the Machine Layout of RMG Factories to issue License for Production. On the other hand, Fire Service and Civil Defense are responsible for supporting each factory's 'Fire Safety and Emergency Evacuation Plan' as per the Bangladesh National Building Code (BNBC).

Figure 2.12 Sample Evacuation plan of RMG

2.12. Limitations of existing codes and comparison to international standards

Sagun (2008) claimed that technical documents focus on a specific standard, guideline, or Code of practice for designing buildings to improve people's safety during disasters and emergencies. However, these are not intensive with crowded behaviour or management. The above literature review found that nowadays, the building codes and infrastructure codes can be classified into prescriptive-based and performance-based (Lovreglio, 2016). The performance-based approach requires comparing the ASET (Available Safe Egress Time) and the RSET (Required Safe Egress Time). ASET is a time-threshold representing the tenable limits after which the conditions of the given environment become unacceptable, while RSET is the time needed by evacuees to escape safely (Proulx, 2002). Studies on human behaviour have a more significant and more direct impact on the final design of buildings and infrastructures in the performance-based context.

In the local Code, i.e., BNBC, the guidance is mainly founded on the prescriptive-based approach; for example, load on the evacuation route is determined mathematically. 'Architectural Layout' and 'Exit Preference' is can also be recommended on a quantity-based approach.

2.12.1. Comparison between Bidhimala - 2008 and EPZ (2006) building code

The government of Bangladesh drafted a law in 2008. It passed in the parliament in 2009, titled “Mahanagar Imarat Nirman Bidhimala – 2008”, this set of rules is mandatory to be followed in Dhaka and Chittagong city corporations. For the construction of factories within the “Export Promotion zones‟, a separate set of laws is in practice titled “Bangladesh Export Promotion Zone 2006”- required for self-constructed buildings, especially factory buildings. Apart from many commonalities, the two codes have differences as well. In general, the “Manhanagar Imarat Nirman Bidhimala - 2008” is both more detailed and more specific, contrary to the building code for EPZs. Although less elaborate than Bidhimala(2008) in many dimensions, the segregation between direct distance and travel length is a positive aspect of EPZ building rules (Firoz, 2011). Table 2.2 shows the comparison between Bidhimala (2008) and EPZ (2006) building code requirements for self-constructed buildings (Firoz, 2011).

Table 2.2: Comparison between Bidhimala (2008) and EPZ(2006) building code (Firoz, 2011)

Mahanagar Imarat Nirman Bidhimala – 2008	**EPZ (2006)**
The maximum distance from the fire exit is 23 m (for factory buildings)	The distance from any point to the nearest stair shall not exit 100 feet. (30.50m).
Provides a formula to calculate the size and dimension of an emergency exit and provides a proper specification for the same	Provides a "slab-based" chart for calculating stair width, especially for buildings that will have more than 150 people
Direct distance and length of the line of travel are not defined separately.	Fire exits from the building shall not be more than 45 m (150 ft) from any point along the travel line.

2.13. Key issues to be considered

During the early stage of a fire, the people in a building typically have to depend on themselves or be rescued by others from their immediate locality (M. Kobes, I. H., 2010). The assistance of the professional emergency services, such as rescue operations by firefighters, can only be provided after that first and most crucial fire stage. Therefore human behaviour is an essential factor in survival (Pires, 2005). Kobe (2010) stated its definition as that people's actions are based upon their perception of the situation, their intention to act, and their considerations before any activity is carried out. Accordingly, how people behave during an escape is referred to as evacuation behaviour. Fire safety refers to fire prevention, limiting the spread of fire and smoke, extinguishing a fire, and the chance of a quick and safe exit. The fire safety policy depends on building location and occupancy type, such as hospitals, where patients are confined to their beds, occupants are relocated to a safe place on the same floor instead of being evacuated. However, an evacuation strategy is usually utilized for assembly occupancy buildings (Kobes et al., 2010).

2.14. Human behaviour in fire

The field of scientific research into human behaviour in a fire is relatively new. The study of building evacuation began at the start of the 20th century, mainly focused on the people's movement in circulation spaces (O'Connor, 2005), occupant density, and travel speed (Fruin, 1993). As a result, the necessary measures for fire safety were predominantly technology-based and rarely considered how a building is used and the users' actual evacuation behaviour (Kobes et al., 2010). Interpretation of buildings' fire safety changed from a technological to a more behavioural perspective at the end of the 20th century.

Kobes et al. (2011) stated that human behaviour in fires is mainly studied by incident evaluations and real-life experiments, such as unannounced evacuation

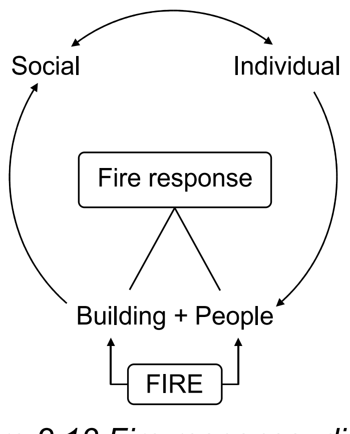


Figure 2.13 Fire response diagram

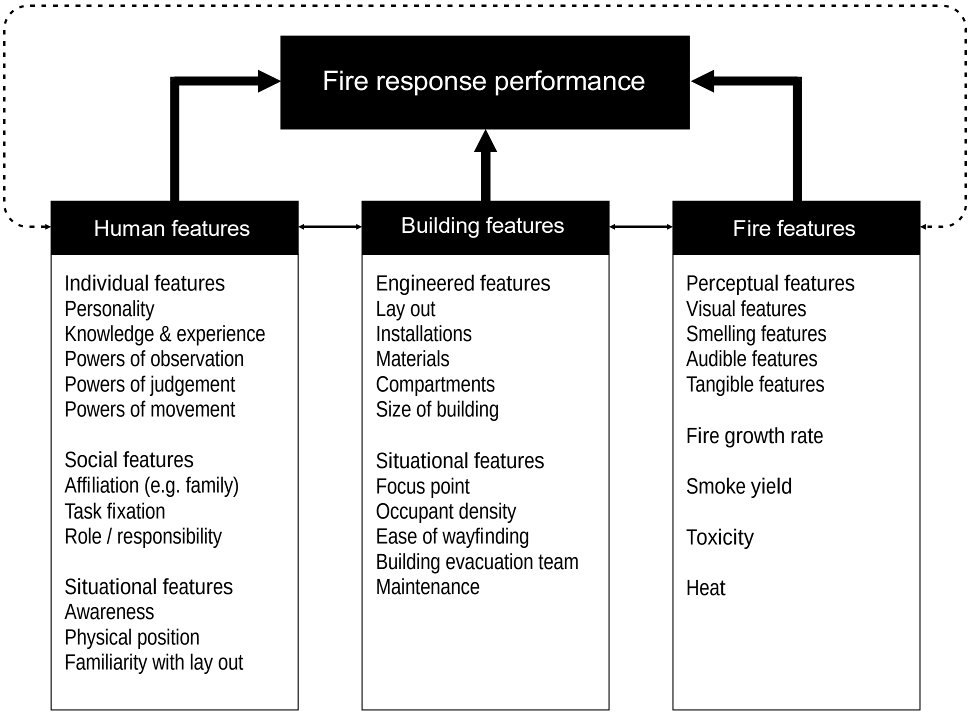
drills and investigation of the incident survivors. Peoples' reaction and performance in a fire depend on the occupant's ability to perceive and interpret a sign of danger and then make and carry out their decisions to survive a fire. Sagun's (2008) study shows people's behaviour may be affected by the conditions of their immediate environment due to interactions with space and other people's behaviour. Lovreglio (2016) proclaimed that studies on human behaviour could improve the safety and resilience of new and existing transportation systems and building design in different and interrelated ways. Canter (1980) said that these studies could assess the risk, the training and preparation for future fire events, and fire safety design. It is essential to bring buildings and infrastructures into line with evacuees' needs during an incident. It is needed to understand how people behave in fire evacuation (Kobes, 2010). These studies are fundamental to develop new codes and regulations aimed at addressing this design issue.

2.14.1. Fire response behaviour

A fire is a process of the ignition and combustion of materials, which generates heat and smoke. The nature of fire itself has a direct influence on the degree of fire response performance. Building characteristics also have a direct impact, as the building is a physical encloser for people. Finally, human nature directly influences the degree of fire response performance (Figure 2.14) (Kobes, 2010). The study showed that the fire response performance of humans is influenced by (the behaviour of surrounding) people, the building design and (the effects of) the fire—these three elements interplay in the whole development and the outcome of the event. The behaviour of people in fires contains the following dimensions.

- Individual features

- Social features (group behaviour)



2.1 *Figure 2.14: Fire response performance model (Kobes et al., 2010)*

The literature review shows that the number of factors that simultaneously impact the occupants' behaviour during a fire is described in Table 2.4 (Proulx, 2001).

Occupant Characteristics

Profile	Knowledge and experience	Condition at the time of the event	Personality

Gender Age Ability Limitation	Familiarity with the building Past fire experience Fire safety training Other emergency training	Alone vs with others Active vs passive Alert	Influenced by others Leadership Negative toward authority Anxious Role –Visitor, Employee, Owner
Building Characteristics			
Occupancy	**Architecture**	**Types of the building**	**Activities in the building**
Residential (low rise midrise, high rise) Office Factory Hospital Hotel Cinema College and University Shopping Centre	Number of floors Floor area Location of exits Location of stairwells The complexity of space/ Wayfinding Building shape Visual access	Residential Commercial Educational Industrial	Fire alarm signal (type, audibility, location, number of nuisance alarms) Voice communication system Fire safety plan Trained staff Refuge area
Fire Characteristics			
Visual cues	**Olfactory cues**	**Audible cues**	**Other cues**
Flame Smoke Deflection of wall/ ceiling, floor	Smell of burning Acrid smell	Cracking Broken glass Object falling	Heat

Table 2.3: Factors having an impact on human behaviour in fire (Proulx, 2001)

Building characteristics are the passive (static) measures, and the occupant and fire characteristics are the active (dynamic) steps altogether work as fire factors. Li (2017) stated that the decision-making process is mainly based on individual judgment and the probability of keeping rational, personal, and personal spatial cognition. Galea (2005), Kobes (2010), Li (2017), Lovreglio et al. (2016) have done research on individual diversity, social and cultural impact on the occupant decision-making process during evacuation. People's behaviour may be affected by the conditions of their immediate environment resulting from interactions with space and other people's behaviour.

2.15. Evacuation behaviour

Kobes et al. (2011) stated that evacuation is when the people present in a building notice a fire. So they experience several mental processes and carry out several actions before and during the movement to a safe place in or outside the building. The evacuation process can be summarised by following three specific steps of the occupants (Kobes, 2011).

Response Phase:

- Awareness of danger by external stimuli (cue validation)
- Validation of and response to danger indicators (decision-making)
- Movement Phase, movement to / refuge in a safe place (movement/refuge).

The Required Safe Egress Time (RSET) is the amount of Time (also measured from fire ignition) required for occupants to evacuate a building or space and reach the building exterior or a protected exit enclosure.

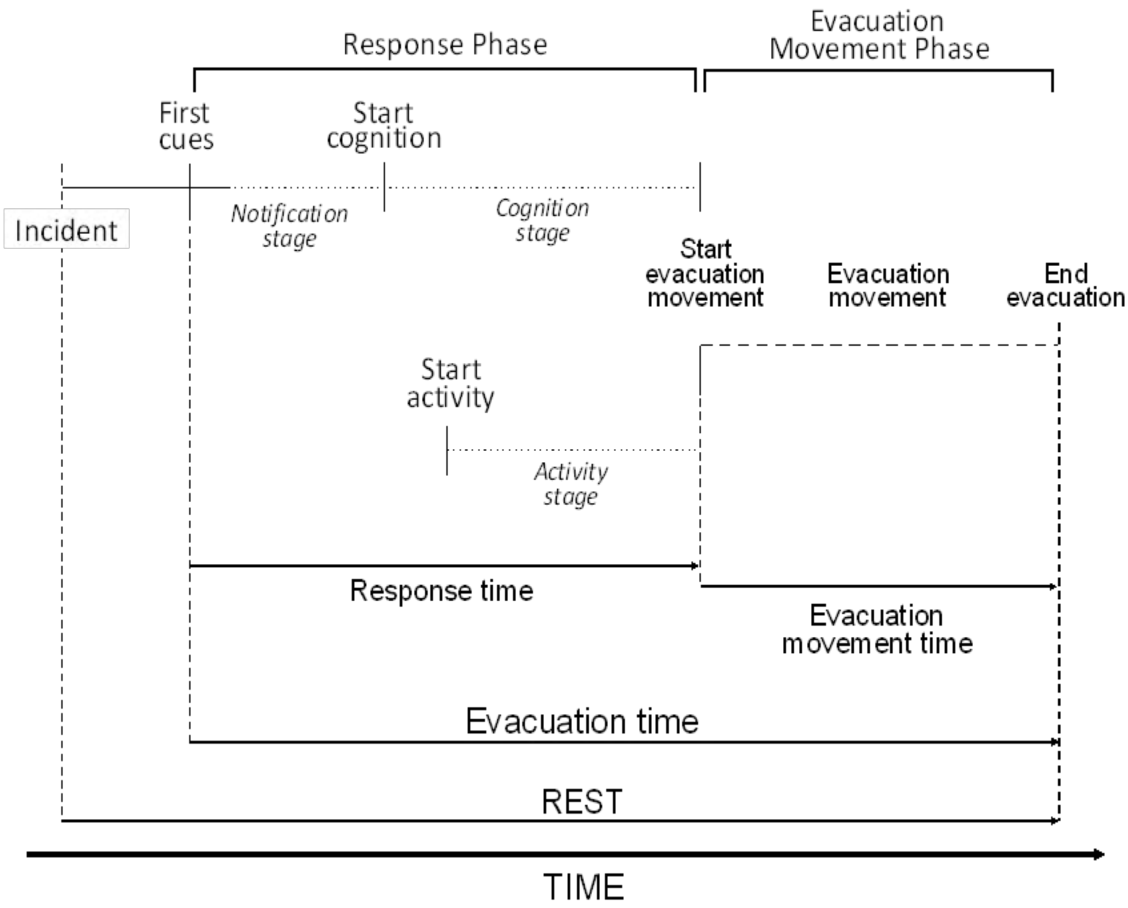


Figure 2.15: Framework for describing evacuation behaviour (*Galea, 2013)*

2.15.1. Pre-movement time

The clue validation period and the decision-making period are referred to as the pre-movement phase (Kobes, 2010). After an emergency alarm, occupants may perform various actions such as searching for something/someone around; and warning other people before moving to escape routes. During a phenomenon, it is likely to occur that occupants can choose their familiar or closest way to escape if the surrounding is acquainted with them. The survey also found that not everyone chooses his path by his own decision; some follow the crowd or the conductor. It may increase the average evacuation time of all occupants (Kobes, 2010). Thus, pre-movement Time and behaviour are currently regarded as vital aspects of the evacuation process. So, the behavioural approaches can be stated as follows:

- Phase 1: Perception of the cue(s)
- Phase 2: Interpretation of the cue, situation, and risk
- Phase 3: Decision-making
- Phase4: Actions *(*Galea, 2013)

2.15.2. Time to start evacuation

The Time- delay to start evacuation increases the risk to life in a building and needs paramount consideration in building design. The occupants spent time investigating and finding information to interpret the perceived cue or indication of danger or fire. Once occupants are sure that this is indeed a fire or an emergency, they become active. They are then likely to engage in finding children or valuables before deciding to evacuate the building. Proulx (2002), in his research paper, compiled many studies on the response time behaviour of the occupants. This delay time to start in the response phase was studied in two ways: during evacuation drills and fire victim interviews. Several researchers studied Multi-units residential buildings, large retail stores, office buildings, highrise buildings, healthcare facility buildings, and underground transport systems to understand people's action, cue response, alarm response, and response to the voice communication system or their orientation to local fire warden. From an evaluation study of a large retail store, Shields et al. (1998) found that staff response had the most determinant effect on the occupant time to start their evacuation. They conducted an unannounced evacuation drill of a Marks & Spencer's store using video cameras to record behaviour and movement and a questionnaire administered to evacuees after the drill. The fire alarm was activated in the entire store. Although floor staff was not aware of the training, their fast response was vital in prompting customers' movement and significantly impacted the rapid evacuation of the store. For large spaces or large crowds, it is not practical to rely entirely on staff to direct occupants to safety, but also it is more efficient to use the voice communication system and CCTVs.

2.16. Wayfinding

The wayfinding process is when the occupant attempts to find a path that leads him to relative safety. Kobes et al. (2010) show that in the past 15–20 years, comprehensive research has been conducted into way findings. Car parks, shopping malls, underground facilities, hospitals, and airport terminals are the subjects of wayfinding. It is found that complex circulation or lack of spatial connections and layouts can create unnecessary stress for the people who are using the buildings. Architects need to give attention to evacuation guidance design solutions for occupants' safety for complex or massive infrastructure.

2.16.1. Evacuation guidance

One of the most critical awareness measures of a building evacuation during emergency events is its evacuation guidance. Architects provide emergency exits other than the main exit for the people to exit safely quickly. Real-life experience and many surveys show that people often use familiar doors instead of unfamiliar emergency exits (Nilsson, 2009). Nilsson (2009) stated that one possible way to influence exit choice is to install way-guidance systems. A prerequisite for a successful escape from a fire in a structure is that occupants need to be provided with suitable evacuation opportunities. Both the architecture and evacuation systems, e.g., signage and fire alarms, have to be designed to promote efficient evacuation in the event of a fire. It may be suitable to introduce passive and active measures to improve occupants' conditions (Nilsson 2009).

From the existing literature review, it is found that a passive measure is a static one, i.e., that does not change in the event of a fire. One example is an emergency exit, which is always present and does not require activation or signage or standard emergency exit signs but can also be told as a passive measure. Active action is a dynamic one, i.e., those changes or is activated in the event of a fire. Many active steps of evacuation systems directly facilitate escape from fire by aiding, for example, wayfinding or decision making. One of the most common examples of a dynamic evacuation system is a fire alarm triggered manually or automatically when detected. Nilsson et al. (2009) mentioned in their Ph.D. research that a way to influence people’s choice of exits during emergencies is by using green flashing lights. This type of active evacuation system may significantly improve the occupants' evacuation opportunities; however, related studies in the category have been rare (Yeh, 2012).

2.16.2. Egress

The basic concept of occupant egress implemented in building regulation involves providing an adequately designed means of egress that is continuous and unobstructed from any point in the outside. The means of egress described in the building regulation consist of three parts as follows (Kuligowski, 2004).

- Exit access – is the corridor, aisle, balcony, gallery, porch or portion of a roof over which an occupant must travel to reach the exit.
- Exit – is a door leading to the outside or through a protected passageway to the outside, a smoke-proof tower, protected stairway or ramp, exit passageway, escalator or moving walkway within the building.
- Exit discharge – is the door leading outside with an unobstructed path and is protected by sprinkler and a 2-hour separation from floors below

As a static measure of evacuation design, proper egress design includes the width of the spaces and doors; the direction of the door swings; lighting and marking; protection from the fire and its effects; and geometry of the stairs or ramps, among others (Kuligowski, 2004). It is also necessary for egress design to limit travel distances to reach a means of egress and on a shared path of travel, dead ends and the provision of alternate means of egress if the fire blocks the primary path. The time required to evacuate these occupants is the pre-movement time plus the time necessary to move the (maximum) travel distance and pass through the door. An architect needs to consider the following factors in egress design (Sagun, 2008).

- Number of evacuation routes and doors

- Travel distances
- Dimension of the routes and doors

The entrance/ exit and the circulation around the building need design consideration for better accessibility to the building. These are the static data of the physical design requirement, which can be found in design standards and guidelines. Architects and engineers also have to keep in mind that egress design is highly influenced by the consequences of individual and group behaviours. This fact highlights the need to investigate the influence of behavioural factors on building design to enhance safety and security.

2.17. Fundamental building design collaboration for safety and security

From the literature review, it can be summarised that the building design issues, measures for safety and security, can differ in many ways rather than existing practice. Building design aspects are done by architects, engineers, and safety security aspects are done by technical persons, which can have conflicting elements. It could be that it studied different contexts for different types of disasters and emergencies, identified common risks, and found alternative solutions for conflicting issues. In his study, Sagun (2013) mentioned that main building design issues need to be measured as follows.

- Location of the building
- Size and capacity of the building
- Entrance to the building
- Building layout
- Characteristics of construction and finishing materials (e.g. flammability)

Architects need to work on some specific issues for better fire safety design. The exterior façade (e.g. external grill, façade material), interior design with proper material choice (e.g. security glass that can resist high pressure), the circulation design (e.g. handrail, stair riser-trade design), and the hazard detection system with various communication devices (e.g. fire detector, warning system, escape lighting and signage), are the major field of attention. Over-reliance on standards may limit the designer’s ability to express their design ideas or develop better design solutions fully. It also may create a problem by limiting their responsibility and causing inefficiency to avoid design issues that are not stated in standards or codes of practice. Comprehensive planning for safety and security in a built environment respecting codes and standards and understanding crowded dynamics are the basis of building design collaboration.

2.18. Human behavioural modelling and “The theory of affordance.”

Researchers in various disciplines have studied human decision behaviours, such as artificial intelligence, psychology, cognitive science, and decision science (Lee, 2008). The human crowd is a fascinating social phenomenon in nature. This study focuses on the premise of perception to overcome the challenge of addressing humans in systems, guiding humans' actions towards their goal (Joo, 2013). For individuals and social groups, the crowd-related behaviours are modelled according to the findings and theories observed from social psychology (e.g., affordance theory, social attachment theory) (Luo, 2008).

In his affordance theory, American cognitive psychologist James Jerome Gibson (1904–1979) states that one perceives the world not only in terms of object shapes and spatial relations but also as object action possibilities (affordances). It means that one’s perception of an object implies the action associated with it (Gibson, 1979). Gibson defined affordance as the interdependence between the agent and the context or environment (Nye, 2012). Gibson used the theory as a way of explaining how individuals perceive things they see. Over the years, affordance theory has a significant impact and various implications for design, human-computer interaction, visualization, human factors engineering and ergonomics. It is, in part, concerned with the perceived affordances of an object design (Hartson, 2003). The four types of affordances introduced by Hartson (2003) for interaction design: sensory, cognitive, physical, and functional based on how they support the user.

- Sensory affordances support the user in sensing, e.g., seeing something. An example of this feature can be large letters or symbols that make a sign easy to read and understand sensory affordances.
- Cognitive affordance supports understanding the observed object, e.g., how it is used or what it is used. If the door handle of an emergency door is difficult to know for the user group, they do not know how to use it; then it will not provide the user with the cognitive (reasoning) affordance.
- Physical affordance supports physically performing something, e.g., opening or closing a door. An example of a feature that provides physical affordance is that an exit door handle is placed appropriately.
- Finally, functional affordance helps the user achieve their goal, i.e., completing the task they have set out to perform. If a person wants to escape as quickly as possible, a fire extinguisher will not offer functional affordance, although it is easy to see, understand, and operate. Fire extinguishers do an essential function for extinguishing the fire but not for users to escape.

Nilsson (2009) studied that this affordance theory helps analyze exit design. The meaning of affordance is the use or purpose that a thing can have that people notice as part of how they see or experience it. For example, one of the goals in the event of a fire emergency is to escape. Therefore, emergency exits should provide affordances to support the escape with adequately marked and distinguishable from surroundings. Moreover, it should be easy to open and unlock. Figure 2.16 can be used to describe the conflict in affordance. The only difference between the two exit doors is the 'right exit door' with the "No Admission" sign mark. The sign shows that the right door is not supposed to be used in a normal situation but only for emergency purposes. However, this simple modification may potentially change people's perception of the exit. The two signs provide *conflicting cognitive affordances* in an emergency, i.e., information that 'right exit door' should not be used and that the 'left' should be used. This conflict may cause uncertainty and possibly prevent people from using the exit to escape.

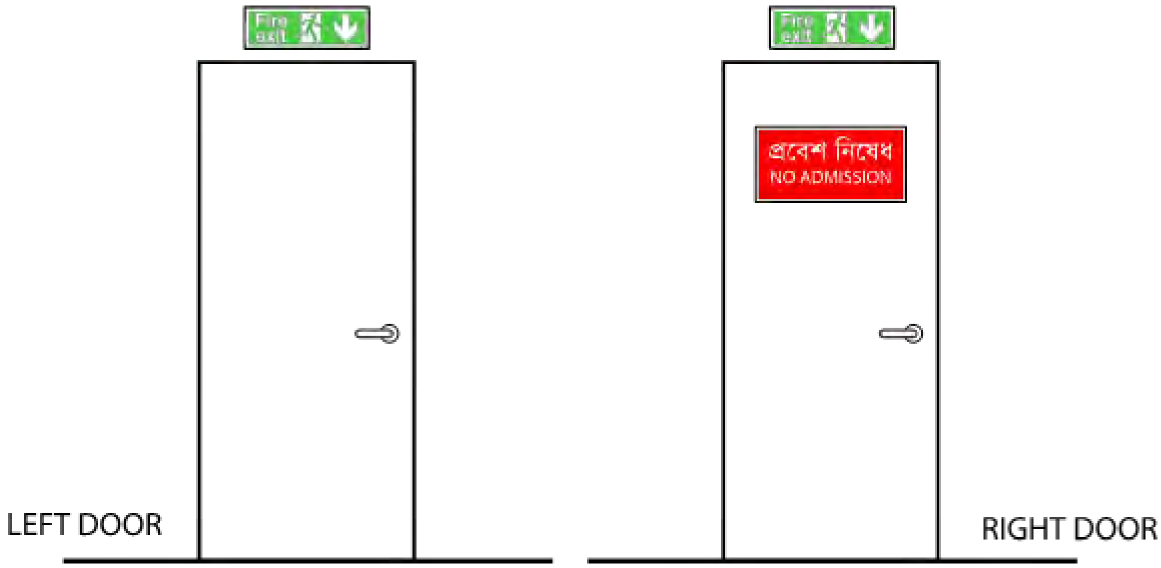


Figure 2.16: Sample exit door showing conflicting cognitive affordances

There are many features of the exit that can provide different types of affordances in a fire emergency. Since the door is a different colour than the background, it is distinguishable and easy to identify. The contrast between the door and the wall can, therefore, be a sensory affordance. Another sensory affordance is the distinguish emergency exit sign or flashing light, which stands out on the white wall. People are familiar with the sign's meaning; it also provides cognitive affordance since it informs potential users that the door can be used in an emergency. Therefore, the simple door handle may provide physical affordance by making the door easy to open to the user. The exit may also offer functional affordance for a person who wants to escape. Therefore, the Affordances theory can analyze an emergency exit design to influence the user's exit preference. The concept of affordance is to understand the safe exit as a collectively planned design process of developing and cultivating a space’s optimum affordances. Moreover, its effectivity in surroundings enables it to represent the immediate human actions considering emergency psychology.

2.19. Summary

It is understood that one of the significant components in fire safety design is evacuation guidance. With the theory of affordance, occupants' exit preference can be defined to establish an effective guidance system. This chapter also reviews the existing fire prevention rules and regulations and identifies some aspects to recognize emergency evacuation. It is observed that there is a scarcity of guidelines for designing or assessing effective evacuation procedures and layouts concerning human behaviour in fire and wayfinding. This chapter reviews some building design parameters identified and measured regarding occupant's choice and needs attention for effective escape route planning, particularly in factory buildings. Finally, it offers an agent-based Crowd Simulation and Analysis framework to conduct tests on the factors identified in the literature review and field investigation, which affects the evacuation and design process of the selected RMG's.

CHAPTER 3: METHODOLOGY

3.1. Preamble

This research is designed to investigate building design issues to improve the safety of occupants during emergency events focusing on the exit preference of occupants. The methods used in this research include an extensive literature review; relevant data collection of selected RMG buildings for identification of people's behaviour, movements via observations through videos, CCTV records, and questionnaire surveys after a fire drill; interviews with the safety and security experts; processing and analyzing the data with statistical analysis (regression model); simulation study by agent-based modeling and compiling the findings for a recommendation. This chapter discourses the research methods and methodology of the research approach.

3.2. Research methods

Research design is the comprehensive planning of the research study, giving a general statement of its methods. The framework is a blueprint for the research study that guides the collection and analysis of data. This research design is a descriptive/ diagnostic study; the first step is to specify the objectives precisely to ensure that the data collected are relevant. It is essential to carefully consider both the choice of research methods and the data collection techniques before a study is initiated. The present chapter focuses on methodological aspects and concludes with a description of the research strategy. This chapter describes the selection of case studies, selection of samples, data collection procedure, data processing and analyzing method.

3.3. Field investigation and selection of case study

The choice of an appropriate method is an essential step towards solving a research problem. There are many different methods, and some of the most common are experiments, case studies, surveys, and archival analysis (Yin, 2003). Investigations of fire accidents are needed for information about human behaviour in the event of a fire, but accidents need to be studied systematically to gather valuable data. In an unannounced fire evacuation drill, the participant was not informed about the evacuation beforehand. Therefore, it is reasonable to suspect that people acted as they would have done in a real emergency. It is expected to better result from the pre-movement time and movement patterns and occupants' premovement behaviour in unannounced evacuation drill study (Nilsson, 2009). Nilsson (2009) stated that field experiment of case studies had been used frequently in the past to study human behaviour in the event of a fire, for example, Frantzich (2001a), Kimura and Sime (1994), Proulx and Sime (1991), and Shields and Boyce (2000). Field investigation of several case studies of an unannounced fire drill with systematic observation, questionnaire, interviews, which provide valuable information about people’s response to active evacuation systems, have been used as a research method for this research.

3.3.1. RMG selection

An investigation and questionnaire survey was conducted on three purpose-built RMG factories. The case studies were selected following the ‘purposive non-probability sampling method’ from the Dhaka region. The criteria fixed for case selection were that the RMG factory's production floor has to be open planed with more than one exit. It is needed to offer choices for the occupants during an emergency evacuation. One is the main exit/entry, as it is used as the most familiar entry/exit for daily use. Others are used occasionally and dedicated to an emergency exit. Three types of occupancy load were ensured: range up to 500 workers - Type A; from 500 up to 1000 workers – Type B; and from 1000 up to 1500 workers – Type C.

The selected cases were of three types, and they are – 1) case study one Knittex Industries Ltd, 2) case study two AJ Super Garments (Feroja), and 3) case study three Power Tex Fashions Ltd. Knittex Industries Ltd is a medium occupancy loaded RMG (total 1308 workers) with two exit- discharges. AJ Super Garments (Feroja) is a medium occupancy loaded (total 980 workers) with three exit-discharges, and Power Tex Fashions Ltd is small occupancy loaded (total 488 workers) RMG building with two exit- discharges.

3.3.2. Pilot study

A quick pilot study with one of the case studies was done to identify the standard requirements and considerations in management in a survey of the evacuation drill. The researcher needs to update the criteria for drill assessment; fix the cameras' location or identify the CC TV coverage; define several people to volunteer during the drill, and position the volunteers for suitable design of the observational case study. This pilot study also helped to identify the fitted method of data collection for selected case studies. Then detailed observational case studies were done to collect data on users' exit preferences in three RMG buildings.

3.3.3. Observational case study

Detail observational case study was done for understanding the user’s behaviour and exit preference in the fire emergency conducted by an unannounced fire drill. The production sewing floor was selected for the survey as the stationed workers' data were needed. The researcher collected CCTV footage or video during fire drills and fire personnel’s interviews to analyze people’s reactions concerning fire alarms and count their pre-movement time and evacuation time. A later questionnaire survey on the fire drill participants was conducted to determine users’ preference for the exit door, reasons for choice, orientation with the fire marshal and signage, and to find bottleneck areas.

3.3.4. Sample selection

Samples for study were selected from production floors. Like a typical RMG factory in Bangladesh, most of these studied RMGs are female (more than 65%), and their age range is 18 to 39 years. For this study, samples are chosen from the sewing section floors from each selected RMG. The reason for choosing sewing floors was to ensure more generous use of different occupants' exit doors. On other floors of RMG factories, the ratio of male and female workers is approximately equal. They use separate exit points for discharge as per the instruction of authority. On the sewing floors, the female workers are higher in ratio, about 85% to 90%. On these floors, the doors are not specified for males/females, and they use all the exits for discharge. Stratified random sampling is followed for the questionnaire survey. As distance data is required for this study; therefore, only stationed workers are selected for sample. Machines were labeled with numbers. From every four machine operators, one was chosen randomly who was also willing to participate. The questionnaire was distributed to them. Volunteers helped the participants to understand and to fill the questionnaire.

3.3.5. Data collection methods

Three techniques often mentioned and considered vital for the present research are observations, questionnaires, and interviews. These instruments can be used individually, but they are preferably combined to improve research quality.

3.4. Preparation for observation checklist

General information, predrill, drill time, and post drill assessments were collected by observation, interview with assigned persons, and fire drill checklist. The checklists are attached in Appendix B. Following steps were followed.

- Collection of necessary information of the RMG factory: number of floors, type of occupancy in each floor, number of occupants in each floor, and size of the production floor. The production floor with a maximum number of occupants was selected for a detailed study.
- After selecting the particular production floor, drawings such as architectural plan, furniture, and machine layout were collected from the RMG authority.
- The width of exit doors and positions, the exit lobby and staircase, machinery and furniture dimensions were measured to cross-check the drawings.
- Sewing machines were numbered to locate their position on the floor.
- Existing fire-safety measures posted an evacuation plan, and photographs were collected for the selected production floor.

After the collection of the information, cases were prepared for the questionnaire survey and fire drill assessment.

3.4.1. Apparatus

Evacuations were filmed with a handy video camera that was located in front of the main exit door. Research volunteers held it with a comprehensive overview of the room rather than just the exit. It was used to cover the pre-movement activities of the users after the alarm was ringed. Where there was CCTV inside the production floor, the video recording was not needed. The CCTV camera was just necessary to adjust its position according to the requirement. Two timer clocks were used with the video camera to calculate the premovement time and total evacuation time.

3.4.2. Main survey

The focal survey was carried out from the starting of the unannounced fire drill. The video camera started recording five minutes before the alarm rang. After the alarm activated, the occupants began to move to the exits and left the room immediately. The camera filmed their activity in between alarm stared and their movements towards the exit. The survey had two parts. The first part consists of recording the CCTV/video to analyze (based on the literature review Section 2.12). In light of the research of Galea and Proulx (2013), the checklist is prepared.

Few persons were assigned from the existing floor with fire drill training to comply with the code (BNBC, 2006). They worked as fire wardens. The RMG authority had to provide 18% of their workers as fire personals per the local code for each case. The fire wardens' activity is to facilitate fire extinguishing and rescuing in the event of a fire. They also help and guide the occupants in an evacuation. The intervention of the fire wardens during evacuation provides the occupant instructions to leave the area promptly. They worked similarly in fire drill as a real emergency. It was their part of the training.

From the pilot survey, a suitable survey method was identified. The number of people for each gate is counted, and the questionnaire survey respondents are selected by stratified random sampling method.

3.4.3. Video analysis and equipment setup

Video footage of the fire drill was analyzed frame by frame to determine response times and response phase behaviours. It is possible to decide on someone's behavioural changes from which they were involved earlier to the notification stage, and it is collected from the video footage. Those behaviours can be defined as the activity stage, such as seeking information, packing away belongings, and shutting down equipment (Galea, 2013). Therefore, in the video analysis, the cognition and activity stages were collectively referred to as the activity stage (Section 2.10). As a result, video analysis provides the following information.

- The number of people observed and the type of tasks performed.
- Pre-movement time of the workers –started from the unannounced emergency bell rang to the starting of the first person's exit.
- Evacuation time – it started from the alarm to the last person's evacuation from the room.
- Pre-movement behaviour (Response phase behaviour) - The start of the response phase (i.e., the start of the notification stage) is indicated by the first notification cues, e.g., the alarm's sound. It is the end/start of the notification/activity stage where people start to perform purposive movement towards an exit (action before beginning the evacuation movement phase) (Section 2.11.5).

3.4.4. Questionnaire design

The development of an effective evacuation egress system with passive and active measures can benefit from a clear theoretical framework. Nilsson (2009) studied that a theory that is useful for analyzing exit design is the 'Theory of Affordances' introduced by Gibson (1979) (Section 2.13). Gibson (1979) used the theory as a way of explaining how individuals perceive things they see. In this study, a theoretical framework is developed to identify how the occupants perceived the exit during an emergency evacuation, and the result was interpreted using the theory of affordances. Nilsson (2009), in his Ph.D. research, used this framework for understanding and analyzing the exit preference of the users for both an office building and a cinema theatre in an unannounced fire evacuation experiment.

In this study, an unannounced evacuation was performed in RMG buildings to study which exit door the workers have chosen and the factors influencing people's perception of exit. The results were interpreted using the theory of affordances. The evacuation process is dependent on the performance of the exits. It refers to how well the exits enable speedy evacuations by facilitating the efficient flow of people. People profoundly rely on their personal experience in decision-making. Sagun (2013) compiled that people take their decision considering the following factors.

- Signage
- Visibility of the exits
- Building geometry
- Circulation routes
- People flow rate
- Obstacles on the way to exits (e.g. furniture and columns)
- Door condition (open or closed)
- Door dimensions

From the above discussion, it can be summarized that factors mentioned in Table 3.1 can be related to the characteristics of both the building and the building occupants for the exit preference. These are the checklists for developing the questionnaire for this research. These checklists are developed by following the research work of Nilsson (2009) and Sagun (2013) and with the help of expert opinion to cross-check its suitability for the local context. The design of buildings can be improved to mitigate the impact of emergencies on people if these factors are investigated (Sagun 2013) to develop guidelines for a design solution for different types of buildings, circumstances, and emergency events.

3.4.5. Questionnaire

A questionnaire is defined as a set of written questions that the respondent answers in writing, is often a practical measuring instrument. The questionnaire was distributed to the selected sample after the fire drill, and occupants came from the assembly area to their workplace. The questionnaire pattern was developed from the research work of Sagun (2013) and Nilsson (2009). A framework (Theory of Affordances) is used to interpret the findings, and a research strategy for developing and testing evacuation systems is proposed. The questionnaire was divided into four parts.

Table 3.1: The categories that are used to classify an answer to the questionnaire (Nilsson 2009, Sagun 2013)

Factors	**Description**	**Affordance**
Signage	The exit was marked with an emergency exit sign	Sensory
Familiarity with the exit door	The exit was: known; the main exit/entrance; and was regularly used	Cognitive
A movement to other people	Others used the exit (social influence)	Cognitive
Orientation with fire warden	Fire warden’s guidance	Cognitive
Distance	Closest exit or a short distance to an exit	Physical
Queuing	Crowded or many people at the exit or in the staircase	Physical
Obstacles on the way to exit	The exit or stairs were small; narrow; had a limited capacity, and had obstacles on their way	physical
Door dimension	The exit or stair was wide and had a large capacity	Functional

In the first part (Figure 3.1), participants were asked about their background, e.g., name, gender, age, and seat number. The seat number was recorded to identify the respondents’ location before the drill. In the drawing of each case study's floor plan, the seat numbers were marked so that the researcher could easily find out the respondent's location drawn in the questionnaires.

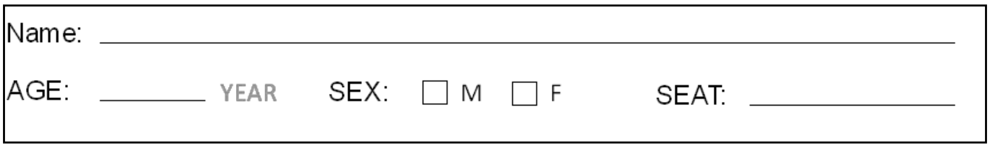

Name:
AGE: YEAR SEX: M F SEAT:

Figure 3.1: Questionnaire part 1

The second part (Figure 3.2) contained questions about the evacuation, e.g. their location; which exit they chose; understanding signage and orientation with the warden and familiarity with the emergency door. The second part was used to get an evacuation scenario and their concern about this evacuation process from the occupants.

1. What was your location before the drill?

☐ In my seat ☐ Not in my seat

2. Which exits have you chosen for evacuation?

☐ 1. Main door – which you use for entry /exit every day

☐ 2. Alternative exit/emergency exit A

☐ 3. Alternative exit/emergency exit B

3. Are you familiar with the emergency exits? ☐ Yes ☐ No

4. Were you aware of the emergency signs during the evacuation? ☐ Yes ☐ No

5 Did you follow the fire warden's instruction during the evacuation? ☐ Yes ☐ No

Figure 3.2: Questionnaire part 2

The third part (Figure 3.3) is all about the exit preference. There were nine alternate options to select. The question was a multiple-choice question, and respondents could choose among one from nine. These factors and categories were compiled from the literature review (Sagun, 2013) and were designed to elicit affordance associated with exit (Table 3.1).

6. What is the reason behind your chosen "Exit" for evacuation?

☐ 1. Because I use it to enter everyday

☐ 2. Because of visibility

☐ 3. Because It was the closest to me

☐ 4. Other door was crowded

☐ 5. Because there were obstacles on the way

☐ 6. Warden told me to use that door

☐ 7. I followed the other people/friend(s)

☐ 8. I followed the emergency sign

☐ 9. Other reason

Figure 3.3: Questionnaire part 3

The last part was the question to identify the location of the bottleneck if they experienced it. The questionnaire is attached in Appendix C (translated from Bangla). The questionnaire was carefully designed to ensure that the topic was clearly defined and the questions were relevant. It was also followed that the questions were not biased and that the risk of misinterpretation was minimal.

7. Where did you face the most congestion and crowding during evacuation?

☐ 1. The main exit door of your room
☐ 2. Exit corridor to main staircase
☐ 3. Discharge point of main staircase
☐ 4. The emergency door
☐ 5. Exit corridor to emergency staircase
☐ 6. The discharge point of emergency staircase

Figure 3.4: Questionnaire part 4

3.4.6. Ethical clarification

Since the fire drill is unannounced, it is not possible to get informed consent before evacuation. According to the autonomy principle of research, the lack of informed consent is known as ethical loss for participants (Nilsson, 2009). This loss can be partly compensated by providing adequate information after evacuation to the users and following proper procedures of the study. A fire drill is a regular RMG factories procedure to meet the code and compliance (Draft BNBC, 2015, 4-59). Fire drill can be both announced and unannounced, but it has to be suitably in practice as instructed in BFSCD compliance. It is also likely that the participants benefit from the evacuation drill because the experience may make them better prepared for a real fire accident. After the fire drill, the studied floor participant became well informed by the researcher and authority about the questionnaire survey (Appendix E: consent letters). The RMG employees who were willing to participate could only attend the study. Moreover, the research result is hopefully applicable to designing buildings for workers' safety, which motivates them to respond.

3.5. Data analysis

Data analysis was done by compiling the questionnaire results, literature review findings, interviews, and video analysis. Points of research were the following.

- Factors that affect the evacuation time and behaviour of RMG workers during a fire drill
- Familiarity with the emergency exits
- Awareness of the emergency signs

- Orientation with fire warden
- Exits that were used to evacuate the building
- Use of unfamiliar / emergency exits
- Identify situations and scenarios on the exit point

Selection of statistical model

The role of statistics in research is to function as a tool in designing research, analyzing data, and drawing conclusions. Statistical model suitably reduces the large volume of raw data to read quickly and can be used for further analysis. The regression technique can be applied when there is any cause and effect relationship between the two variables in the bivariate population or between one variable on one side and two or more variables on the other side in a multivariate population.

Therefore, in addition to the percentage calculations of the data collected from the questionnaires, Logistic Regression Analysis was used to build a statistical model of the exit preferences of building occupants using the distance data and the factors identified in the questionnaire (Sagun, 2013). Logistic regression is a statistical analysis approach used to study the data to predict a non-quantitative (categorical) variable from a set of independent variables. The logistic regression model's principle is to link the occurrence or non-occurrence of an event to independent variables (Menard, 2001).

Logistic regression, also known as Logit Regression or Logit Model, is a mathematical model used in statistics to estimate (guess) the probability of an event occurring, having been given some previous data (Gujarati, 2003). Logistic Regression works with binary data, where either the event happens- (1); or the event does not occur -(0). The logistic regression model's principle links an event's occurrence or non-occurrence to independent variables (Gupta, 1997). The non-quantitative data (such as yes/no, male/female, accepting/not accepting) is defined by assigning 1/0 as positive/negative values.

The odds ratio is the probability of success/probability of failure. The odds are a numerical expression, usually expressed as a pair of numbers, used in statistics. In statistics, the odds for or odds of some event reflect the likelihood that the event will occur, while odds against it reflect the likelihood that it will not. Probability, odds ratios and log odds are all the same thing, just expressed in different ways. **Log odds** play a central role in logistic regression. Every probability can be easily converted to **log odds** by finding the odds ratio and taking the logarithm (Gujarati, 2003). Probability never goes below 0 and above 1. Logistic regression is based on the following fundamental assumption. L is called the logit, which is the log of the odds ratio (Gupta, 1997).

$$Logit\ L = log\left({}^{p}/_{1-p}\right) = log(probability\ of\ event\ happening/\ probability\ of\ event\ not\ happening) = log(odds)$$
.......(3.1)

$$log\left({}^{p}/_{(1-p)}\right) = Y \qquad \text{............... ....(3.2)}$$

$$Y = C + \beta 1y1 + \beta 2y2 + \cdots + \beta nyn \qquad \text{.......................(3.3)}$$

$$L = log\left({}^{p}/_{1-p}\right) = C + \beta 1y1 + \beta 2y2 + \cdots + \beta nyn \qquad \text{.............(3.4)}$$

Where β are parameters of the regression model, Y represents regression and y are the independent variables, and C is a constant value for each variable.

$$log(odds) = log\ e^{Y} = eta \qquad \text{...........(3.5)}$$

Finally, the following equation is used to convert the odds to probabilities (Gupta, 1997):

since $p = {}^{e^{Y}}/_{1+e^{Y}}$

$$p = {}^{exp(eta)}/_{1+exp(eta)} \qquad \text{............... (3.6).}$$

On the other hand, a logistic regression produces a logistic curve (Figure 3.5), which is limited to values between 0 and 1. Logistic regression is similar to linear regression, but the curve is constructed using the natural logarithm of the “odds” of the target/ independent variable rather than the probability. Moreover, the predictors do not have to be normally distributed or have equal variance in each group (Gupta, 1997).

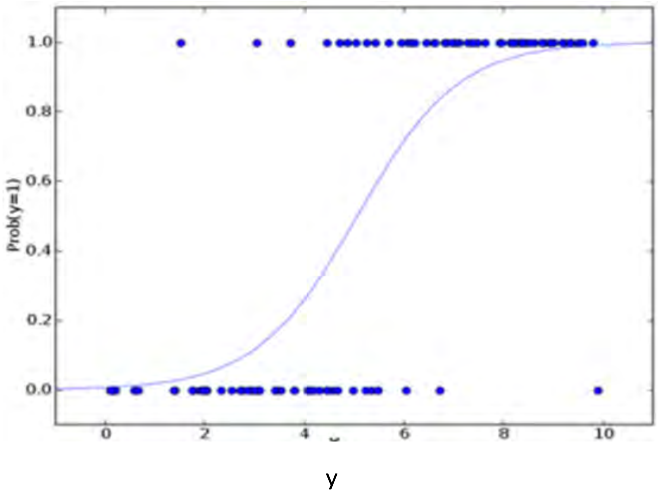


Figure 3.5: Typical logistic model plot

In this research, the purpose is to find out the "Likelihood of choosing the emergency door" during evacuation or the "probability of choosing the main door" during an emergency evacuation, where one of the independent variables is not quantitative, "being familiar to emergency doors". Therefore, this independent variable can be coded as 1 and "not being familiar with the emergency exits" be coded as 0. Similarly, 1 can be assigned for "preferring the main exit", and 0 can be assigned for "not preferring the main door" for the dependent variable. The probabilities can be defined in terms of:

***p* =** *the probability of choosing the main door;*

***1-p* =** *the probability of not choosing the main door (probability of choosing an alternative door)*

Consequently, the above-discussed logit model can measure the probability of preferring exit doors by the users. Then, the equation for this study would be (Sagun, 2013),

$$\boldsymbol{eta} = \boldsymbol{C1} + \boldsymbol{\beta C2} + \boldsymbol{FC3} + \boldsymbol{R1C3} + \boldsymbol{R2C3} + \boldsymbol{R3C3} + \boldsymbol{R4C3} + \cdots + \boldsymbol{R9C3} \ldots (3.7)$$

Where $\boldsymbol{\beta}= {dE}/{dM}$ (ratio of distance to the emergency exit door to the distance to the main door) works as a continuous variable; **F** = familiarity with the emergency exit; **R1** to **R9** are the factors or reasons to choose the exit doors by the evacuee surveyed in the field investigation, and **C** is the constant value for each variable (Sugan,2013). The model would be used to predict the odds that a subject will choose the main/emergency exit with a given familiarity factor (0 or 1) by the following formula (Sagun, 2013),

$$Odds = exp(eta) = \ e^{C1+\beta C2+FC3+R1C3+R2C3+R3C3+R4C3+\cdots+R9C3} \quad \ldots (3.8)$$

Finally, converting the **odds** to **probabilities** by the formula, as mentioned in Equation 3.6.

The logistic regression analysis results are conducted in '**BigML** -a machine learning tool' for the three cases to justify the findings from the questionnaires (see Appendix D). Regression problems can be solved using supervised Machine Learning techniques. The Machine Learning algorithm is used to build a model that predicts a continuous value to predict an output variable. The logistic regression uses maximum likelihood estimation techniques to learn the n coefficients (C1, C2, C3,….Cn) of the regression function. BigML logistic regression is an optimized implementation of the lib-linear library, which uses the Trust-Region Newton Optimization method to estimate the Coefficients (BigML, Inc., 2020). Different charts and graphs of probability and likelihood from regression analysis and the partial Deepnet plot graph (PDP) and correlation graphs of the reasons for exit preferences are presented and analyzed during data analysis with the machine learning interface – 'BigML.' (Section 5.3.1).

3.6. Simulation study

There has been an increasing trend in Modelling and Simulation in public safety and security planning and decision support. Simulation models are now becoming helpful in replicating scenarios of the safety/mission of critical systems. It provides a risk-free, low-cost, time-independent, and harmless experimental environment where modelers can exhaust trials of different nature to gain insights into the system. Mahmood (2017) states that modeling and simulation play a vital role in solving crowd evacuation problems, comparing other alternatives, finding the best design parameters, and gaining tremendous momentum in investigating crowd dynamics. A simulation study was conducted to test various evaluation scenarios for the crowed movement, found from the observational case studies of RMG buildings. The purpose of the simulation studies was to investigate how factors identified in observational case studies affect the evacuation and design process using evacuation modeling techniques.

3.6.1. Crowd dynamics and human behavioural modeling

Thalmann (2007) distinguished simulation into two broader areas. The first one focuses on the realism of behavioural aspects, e.g., evacuation simulators, sociological crowd models, or crowd dynamics models. The second area aims at a high-quality visualization of the crowd with a convincing visual result and an emphasis on rendering and animation methods (Musse, 2007). Most of the evacuation (simulation) models that exist are based upon calculations in which the distance to exits, walking velocity, and the flow rate capacity of corridors, doors, and stairs are significant (Kobes, 2010). Kobe (2010) also mentioned that few simulation models are based on human behaviour in evacuation scenarios, such as the preference for specific routes or exits or the time needed to gather and interpret information. For this research, a simulation and analysis framework is required with the following capacity.

- To model a significant number of factory workers as agents and in real scale environments, e.g., factory area as spatial networks.
- To simulate movements of density crowd of fire evacuation drill in the modeled environments using real or virtual time simulation approaches using different experimental settings
- To provide an assessment of different crowd management and control strategies of an emergency evacuation.

After reviewing several works of previous researchers (Scherer, 2018; Mahmood, 2017; Joo, 2013; Luo, 2008; Lovreglio, 2016), this research proposes an agent-based crowd simulation and analysis framework that made a comprehensive approach and fulfill the following criteria. Agent-based modeling is a powerful simulation modeling technique that has been used for several applications in the last few years, including applications to real-world business problems, ecology, sociology, economics, traffic simulation, and many others. The proposed framework incorporates the use of ‘Anylogic Platform’ (AnyLogic, 2002) for agent-based modeling of pedestrians at a microscale, where each agent possesses structure (attributes) and behaviour (states). A population of agents is modeled as a crowd using the pedestrian library (Table 3.2). The crowd simulation is built in Anylogic and is integrated with optimization and analysis modules and can interoperate with the studied framework under different experimental settings. This interphase can use DXF files containing buildings' geometry and have 2D and 3D visualization properties to present different scenarios. Moreover, it is done by changing the people's properties (e.g. age and gender) using different experimental settings and analysis modules with simulation runtime to evaluate evacuation strategies.

3.7. Anylogic simulation

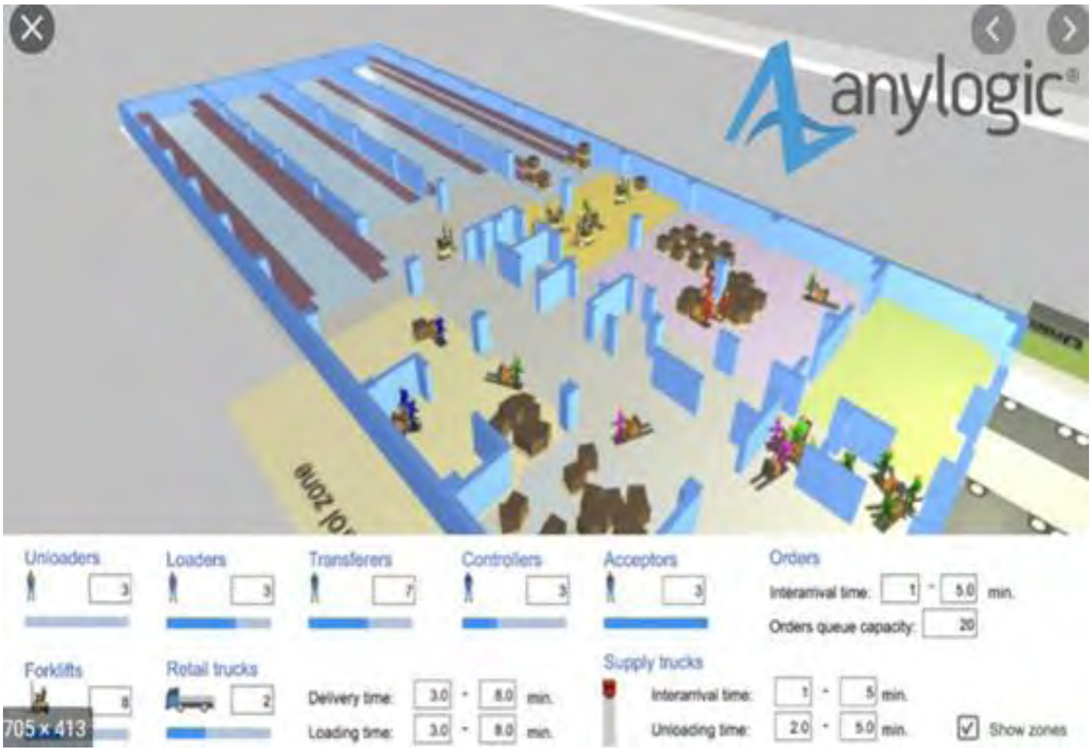
Mahmood (2017) stated that Anylogic Simulation could provide a user-friendly Integrated Development Environment (IDE) and an efficient simulation engine that allows the modelers to quickly create and simulate high-reliability models of complex systems. Different modeling techniques, such as discrete-event, agent-based, and system dynamics modeling, are supported by the ‘Anylogic platform.’ This platform provides a user-friendly interface with a Java-based development environment and multipurpose component libraries, which help speed up the modeling process.

3.7.1. Anylogic Pedestrian Library (APL)

Anylogic includes a pedestrian library (Table 3.2) that primarily deals with different modeling aspects of crowd simulation (AnyLogic, 2002). It is used to model pedestrians' microscale behaviour using the agent-based approach and simulate the pedestrians' flow in physical environments such as shopping malls, airports, and subway stations. Pedestrian models consist of two main parts –

environment and behaviour. The environment incorporates walls, different areas, services, queues etc. In addition to the processes defining behaviour, mark-up elements are used to describe the structure of the environment where people are moving in or setting walls, services, attractors, and escalators. These mark-ups are also stored as part of the database and used to model entrances, exits, obstacles, and service parts. Generally, an environment object consists of its graphical definition, composed of specific space markup shapes. Resources (for instance, services) are also elements of the environment. Pedestrian "lives" in the defined environment and move according to simulated physical rules.

On the other hand, pedestrian moves in a flowchart just like other agents. Target Line is used in all pedestrian models since it defines where pedestrians appear in the simulated space. Pedestrians' behaviour is characterized by a flowchart (Figure 3.10), which is easy to create and understand. Anylogic with the Pedestrian Library (APL) contains logical elements defining the behaviour of people. Several behavioural patterns such as normal pedestrian movement or emergency movement, or fire scenarios can also extend here, and they can be found by using a process database (Scherer, 2018). The output statistics of the model allow users to assess facility capacity and throughput, count pedestrians in different zones, measure waiting and service times, and represent pedestrian flow density display on a density map. An agent model with a more significant

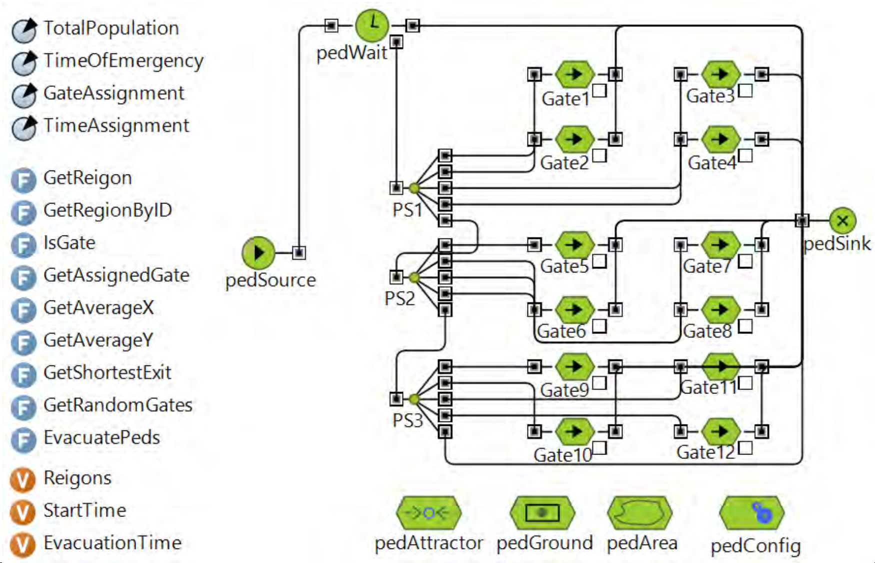


number of details and many populations can be executed here with cloud computing (Mahmood, 2017).

Figure 3.6 'Anylogic' - multimethod simulation modeling tool interphase (AnyLogic, 2002)

Table 3.2: Pedestrian library control blocks of APL

Pedestrian flow blocks		
	PedSource	Generates an initial population of pedestrians with given arrival rates
	PedSink	Disposes pedestrians. Pedestrian are removed on entering PedSink
	PedEnter	Places pedestrians into an area defined by a Space markup element.
	PedExit	Removes pedestrians from an area
	PedGoTo	Directs selected pedestrians to go to a specified target, defined by a point, line or area (e.g., Exit gate).
	PedWait	It causes pedestrians to wait for a specified time in a specified location.
	PedelectOutput	Routes the incoming pedestrians to 1/N output ports, depending on a specified condition or assigned probability.
Settings blocks		
	PedConfiguration	Configures general parameters related to all objects of the Pedestrian Library
	PedGround	Defines a 2D surface in the simulated environment, representing a floor on which pedestrians can walk
	PedArea	Represents an area defining physical rules and restrictions for pedestrian behaviour



	PedAttractor	Allows controlling pedestrian's location when waiting.

Figure 3.7: A sample of pedestrian process flow control chart (AnyLogic, 2002.).

3.8. Simulation and analysis framework

In this study, an agent-based model of an emergency evacuation scenario of the three case studies are a built-in Anylogic framework. The methodology consisted of three main elements developed by (i) Modeling, (ii) Interfacing and (iii) Analysing framework displayed in Figure 3.8 (Mahmood, 2017).

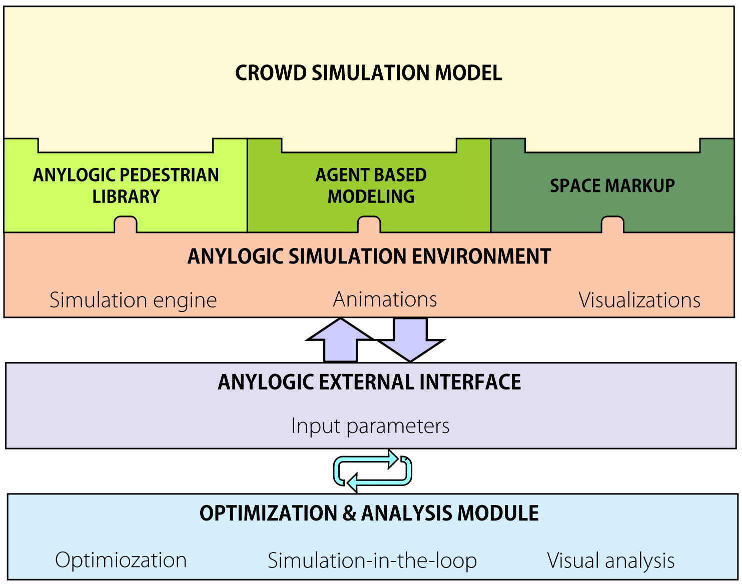
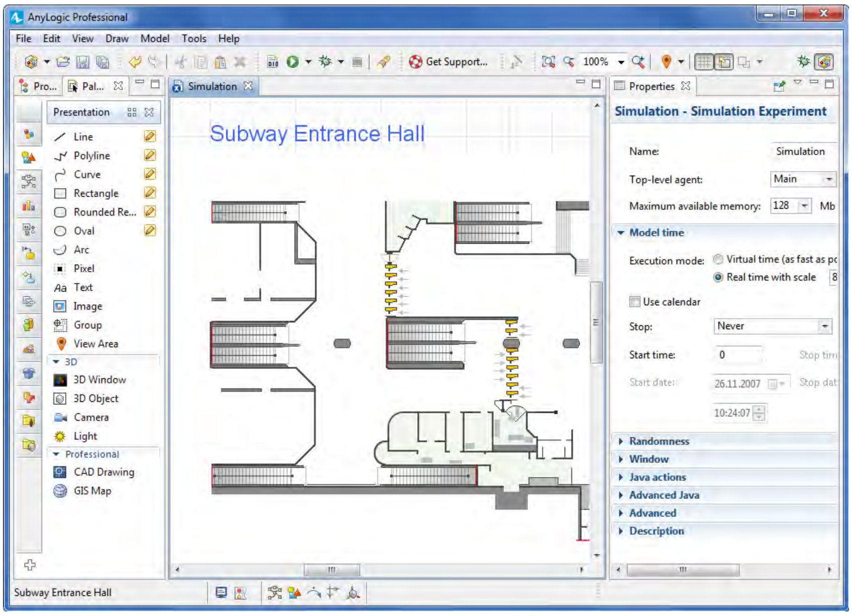


Figure 3.8: Three steps of crowd simulation and analysis framework for Anylogic (Mahmood, 2017).

3.8.1. Simulation environment

Spatial model

In the first step of developing the crowd model, the AutoCAD DXF formatted drawing of the studied floors of all the case studies is imported into the Anylogic Graphic editor. The spatial elements from pallets are used to draw the floor plan using Polylines. The polylines are converted into walls, and the primary and emergency entrance/exit points are marked, as shown in Figure 3.9. These walls are drawn above the image and define the processing logic: how they move inside the building. The entire floor plans are recreated in the Anylogic model platforms in single line drawings compared with the meter unit scale. Pedestrian pathway for agent path, a rectangular wall for obstacles and workspace, target lines for agent sources are used to complete to build physical environment for modeling. In this study, three case study floor plans are modeled with the appropriate spatial setting to make the basis of the simulation layer shown in next



Chapter 5.

Figure 3.9 Sample Spatial layout in Anylogic using APL pallet (AnyLogic, 2002)

Agent design

In the crowd simulation model development, a modeller can use default agents or create new agents with a custom physical and behavioural design. The physical structure includes attributes such as age, gender, height, and weight, whereas behaviour includes states such as: healthy, injured, critical, unconscious, or deceased. Agents can also be related to each other in many ways, e.g., family relations, group members, and nationality.

In this study, the default physical structure with the in-built behaviour of the agent is used. Instead of distributing the agents group-wise, this research used a probability model for distribution. The probability model was generated from logistic regression from this study, and the simulator initialized agent generation through a randomizer. For further research, the modeler can consider the detailing of the agent as his requirement.

3.8.2. External interface

Model simulation has a specific settings external interface with input parameter (Second step shown in Figure 3.8). A group of model settings is called an experiment that helps create the interface experiments and is displayed at the bottom of the model branch in the workspace tree (Figure 3.7).

Pedestrian behaviour

The crowd simulation's behavioural logic is implemented using pedestrian flow controls for the agents, as shown in Figure 3.10. At first, the Pedestrian Configuration block is used to assign types of individual entities. In this research, the default class of Pedestrian *(Ped)* is selected, and the pedestrian had to reach a given point by *PedGoto*. A *target line* defines the location, and pedestrians find a path to the specified destination within the current level. The path choice route was in *follow route* mode to determine ways manually. The pedestrians exited via *PedExit* block with a *comfortable speed* in the absence of external factors; the pedestrian moved with this speed. The pedestrian flow charts of three case studies are presented in the next chapter in Figure 5.7.

With the help of the Ped Flow chart, the model is running after configuring the flowchart blocks and examining how the established variables change their values over time. There is no need to add any charts. AnyLogic automatically collects data history for dynamic variables and provides a simple tool for examining their model runtime values - inspect windows that work as Anylogic external interface.

This simulation experiment is shown in the following data analysis chapter (Section 5.4) as the case studies Models.

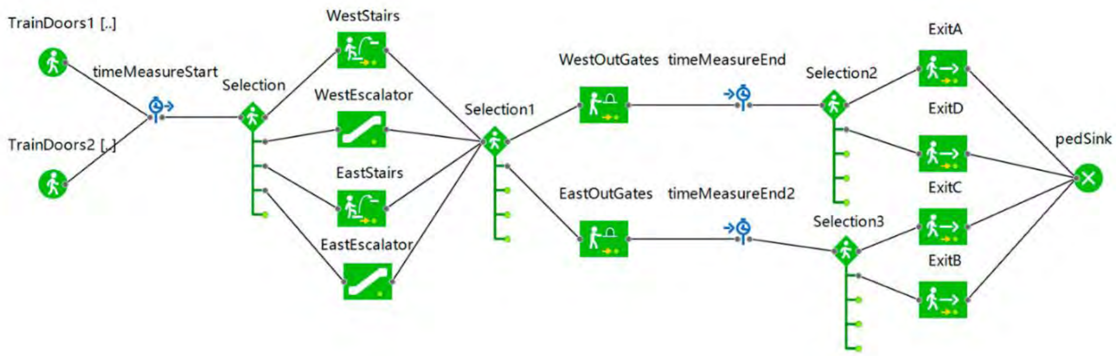


Figure 3.10: Sample of the flowchart to define the pedestrian flow (AnyLogic, 2002)

3.8.3. Optimization and analysis layer

The third step of the simulation is the Analysis layer (Figure 3.8). The primary purpose of this layer is to allow users to implement and integrate optimization algorithms or use external java frameworks for such purposes. This layer enables flexibility and independence for using any optimization approach and utilizes the interface layer for interacting with the simulation model in various ways.

In this study, the simulation module uses default Simulation Experiments via the interface layer to initialize and execute the simulations with appropriate parameters determined by the previous regression data gathered. When the general algorithm initializes with an initial population for each candidate solution, the simulation run is performed by communicating with the interface layer, which sends the agents' parameters to the simulation model. Once the simulation is finished, the 'callback function' is invoked that returns the simulation results. The following data analysis chapter presents three case studies simulation models

(Section 5.4), where emergency evacuation strategies are applied from the questionnaire survey and regression analysis. Although the flowchart is animated for each model, it can visually represent those three-case studies model in 2D. For further data analysis, other graphics of the *density map* were created. AnyLogic enables collecting statistics on the density of moving units in the simulated space and displaying this information on animation by density map (Section 5.6).

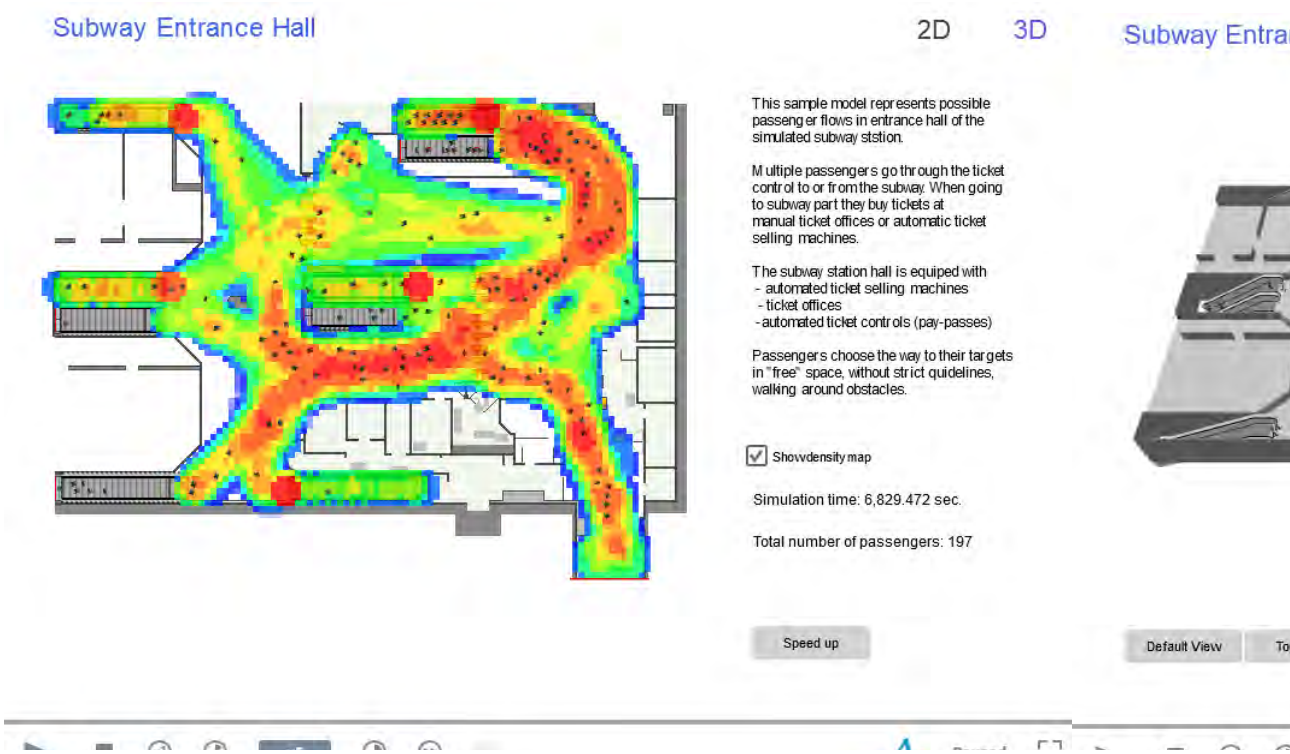


Figure 3.11: A sample 2D view of a simulation model with a density map of Anylogic (AnyLogic, 2002)

3.9. Summary

This chapter has discussed the methodology and structure of the research towards achieving the objectives. The detailed field survey results and simulation analysis of case studies have been presented in Chapters 4 and 5.

CHAPTER 4: FIELD INVESTIGATION

4.1. Preamble

This chapter broadly discusses the three cases to understand the functional layout, particularly their production area's exit points, workers' exit choices in fire evacuation drills, and their pre-movement time and activity. In this study, an unannounced evacuation was performed to identify workers' exit preferences in an emergency, including the workers' behaviour in pre-movement time and the time of their evacuation. and to determine the reasons behind their preference Field observation

4.2. Field observation

The data were collected from the observational case study, video recording, questionnaire survey, and the result were interpreted using the theory of affordance and logistic analysis.

The purposes of these case studies are the following.

- Observe the evacuation time and evacuee's action that affects the evacuation time.
- Identify the factors affecting the exit choice.
- Identify exit preferences during evacuations.

4.2.1. Criteria for observation

The case studies were selected following the 'purposive non-probability sampling method' from the Dhaka region. Table 4.1 shows the necessary information about selected RMG factories. In every case, the sewing production floors were chosen.

Table 4.1: Basic information of case studied RMG factories

Case Study	**Knittex Industries Ltd.**	**AJ Super Garments Ltd.**	**Power Tex Fashions, Ltd.**
RMG Factory Location	Konabari, Gazipur	Goshbari, Shavar,	N. University Gazipur
No. of floors	6	6	6
No. of total workers	1308	980	488
Floor Area under study (sqm)	1755 sqm	1556 sqm	504 sqm.
No. of exits	2	3	2
Purpose-Built/ Non-Purpose Built	Purpose-built	Purpose-built	Purpose-built
Building Reg. to BGMEA & DIFEA	Yes	Yes	Yes

4.3. Pilot study: Knittex Industries Ltd.

The pilot case study was conducted in Knittex Industries Ltd before the primary survey. This pilot survey identified the fields of assessment and eliminated any difficulties faced in the evacuation drills to properly design the methodology of field investigation and data collection.

Table 4.2: Checklists of pre-drill assessment for Knittex Industries Ltd.

PRE-DRILL ASSESSMENT	***YES***	***NO***	***N/A***
Were instructions given to move to the designated assembly points?	✓		
Exits are marked clearly.	✓		
Are emergency evacuation plans procedure posted?	✓		
Are evacuation emergency signs in good condition?	✓		
Egress routes appropriately lighted.	✓		
Exit signs are appropriately illuminated.	✓		
Exit doors operating correctly.	✓		
Has the fire warden been assigned and trained?	✓		
Do fire wardens have vests or caps for identification?	✓		
Have assembly areas been designated and employees trained?	✓		

Table 4.3: Checklists during drill assessment

Method of Drill Activation:	***Alarm ✓Activation***	***PA system***	***In-House Word of Mouth***	***Other***

Communication	***YES***	***NO***	***N/A***
Drill preannounced		✓	
Fire department present for drill		✓	

Evacuation	***YES***	***NO***	***N/A***
Elevators/lifts were used during the evacuation		✓	
All occupants participated and evacuated	✓		
Occupants evacuated immediately after the evacuation was initiated	✓		
All rest-rooms, conference rooms were checked for occupants	✓		
The person with particular need was assisted	✓		
Did fire door operate correctly	✓		
Were all exits used	✓		
Was evacuation orderly and quick	✓		

Bottleneck problem in evacuation route	***Yes***	***No***	***N/A***
Is there any bottleneck problem in the Main staircase		✓	
Is there any bottleneck problem in the emergency staircase		✓	
Is there any bottleneck problem in the main exit door	✓		
Is there any bottleneck problem in the emergency exit door		✓	

Table 4.4: Checklist for post drill assessments

POST DRILL ASSESSMENT	***YES***	***NO***	***N/A***
Electrical appliances were turned off	✓		
Evacuation performed according to plan	✓		
Was there any significant disruption in the action plan		✓	
Occupants meet at designated meeting places according to plan		✓	
located at safe distances from the building	✓		
Fire drill response team(s) carried out assigned duties	✓		
Did all alarms work properly?	✓		
Fire alarm heard in all areas clearly	✓		

The checklists for the rest of the case studies are attached in appendix B. In later stages of research, the pilot study helped to form the basis to identify the fitted method for data collection for users' exit preference. It also helped identify the factors that affect the evacuation time, defining the number of people to assist the drill, finding a suitable location of the camera, and an interview with the fire personals. The following assessment checklist was prepared after the pilot survey used for primary field investigation for the case studies.

4.4. Case study 01: Knittex Industries Ltd.

4.4.1. General information

Knitex Industries Ltd. is a medium-capacity garments factory with six floors. Its rectilinear plan with the floor about 1755 sqm (18,885 ft) size (86m * 20m).

Table 4.5: General information about Knittex Industries Ltd.

Name of the RMG factory	**: Knittex Industries Ltd.**
BGMEA serial No	:1908
Address	: Plot 247-252, Bipyl, Konabari, :Gazipur.
Approval Authority of the Building Plan	: Gazipur City Corporation
Year of Approval of the Building Plan	:2019
Year of Establishment of the factory	:2006
Category of the RMG Factory: according to Ownership	: Owned
Category of the RMG Factory: according to Building type	: Purpose Built

Figure 4.1: Knittex Industries Ltd.

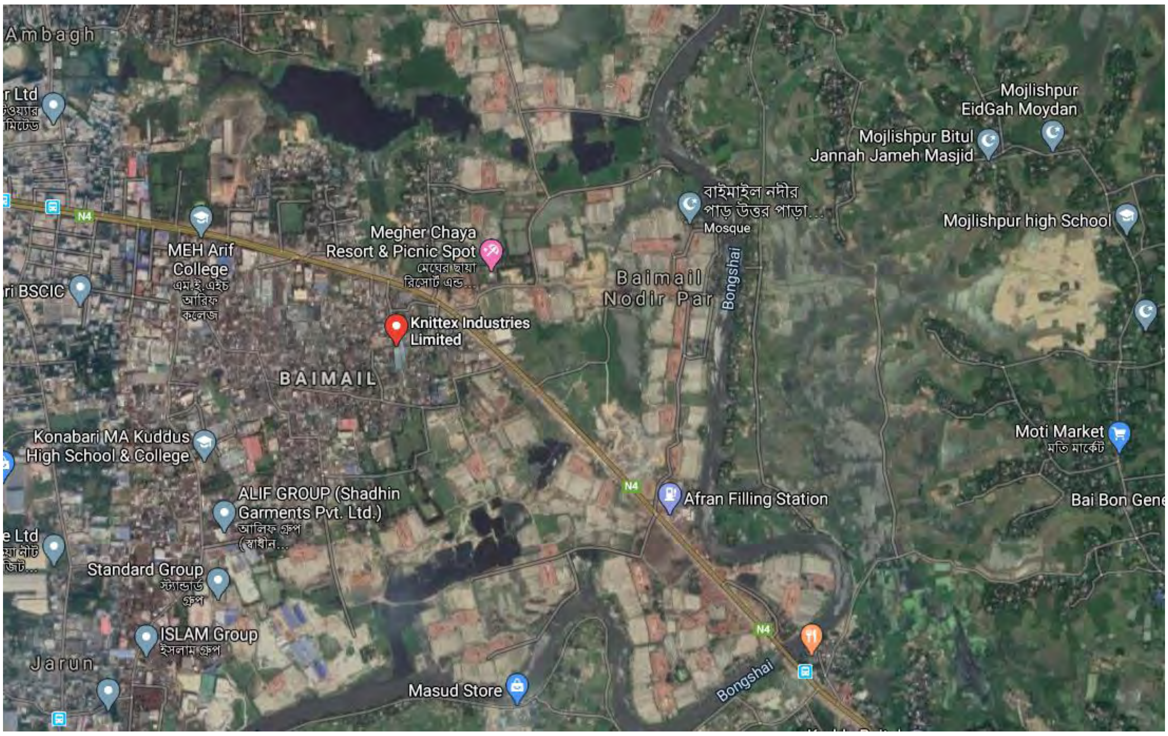


Figure 4.2: Location of Knittex.

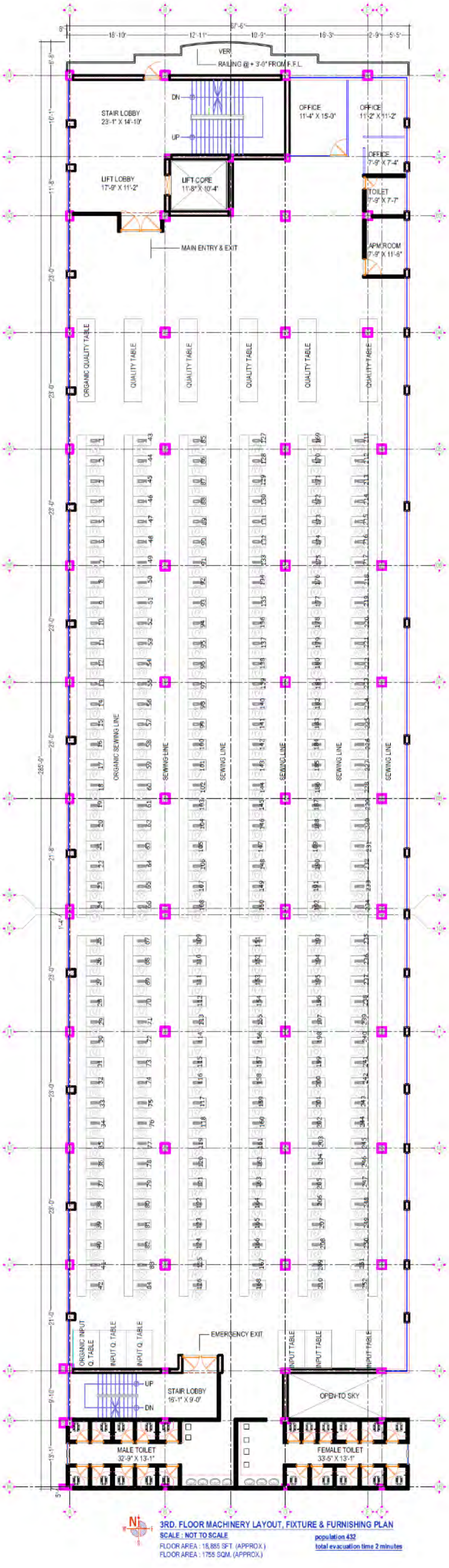


Figure 4.3: Floor plan of Knittex Industries Ltd.

4.4.2. Functional layout:

The Production area under study was at level 3, having sewing sections and quality control (Figure 4.3). An enclosed area is located beside the main entrance for office use. It has two exit corridors towards the ground floor; one is the main entrance with lift lobby and staircase (95 sqm.) at the north side, and another one is the emergency exit corridor and staircase (26.5 sqm.) at the south side of the building. This building was a part of an industrial complex, surrounded by another garment building on the west side and a dying shade on the east side and a central open space (used for assembly place and parking lot) on the north side. This building is connected with both construction through the ground floor, and both staircases were used frequently for goods transfer and people movement

Table 4.6: Studied floor information of Knittex Industries Ltd.

Floor understudy	Production (sewing) floor on 3rd floor, with six machine lines 42 machines each, 1755 sqm
Total occupants of the studied floor	Total: 432 Female:368, Male: 64
Exit door	One main door, 2.4 m wide
	One emergency door, 2.1 m wide
Maximum Travel distance	33.5 m

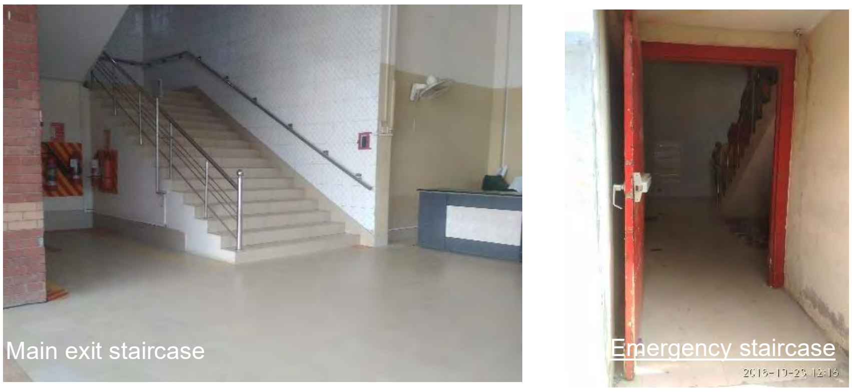
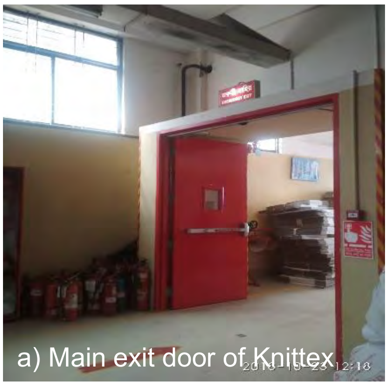


Figure 4.4 Staircases of Knittex Industries Ltd.

The workstations and sewing tables were arranged following the layout approved by the regulatory authority (DIFE). The actual layout had some differences with the factory management approved layout due to the functional need for running production. They also had a separate marking machine line for organic line production. The production floor mainly was an open plan layout in which the aisles separated different functional areas. Some enclosed area exists at the north and south side of the floor. There were two staircases at two sides (north and south) of the production floor, and each stair was directly accessible from the production area through the exit doors. The main entrance landing lobby (58.6 sqm.) shares both lift and staircase. The main entrance/exit door was 2.4 m wide, double swing type with a fire-rated door. The emergency exit door was 2.1 m wide, double swing type with fire rated door containing a 15.8 sqm landing area. Both landings were perpendicular to the longitudinal aisles of the floor. This production floor has six longitudinal aisles [vertical in the plan] and three


a) Main exit door of Knittex


b) Emergency exit door of Knittex

Figure 4.5 The Exit doors of 3rd floor, Knittex Industries Ltd.

transverse aisles [horizontal in the plan] for circulation. The machines were placed in line along the aisles, and most workers faced the upper transverse aisle. Despite many accessories and machines, most of the longitudinal aisles maintained the required minimum width (1m) following the floor's marking.

4.4.3. Workers

About 432 workers were present in the open floor area during the fire drill. The majority of workers were female on this floor (368 females and 64 males). Among

252 workers were engaged in the sewing section, 134 helpers, 20 were engaged in other works, 20 were quality and official staff, and 6 were maintenance staff moving in the floor. There were six production lines on this floor, with 42 machines in each straight line on average. Among the occupants, 18% of people were trained for fire drill and rescue activity in an emergency as per compliance.

4.4.4. Fire drill

This time an unannounced fire drill was performed. Fire wardens played their role to reflect the situation that would occur during an actual emergency case.

Table 4.7: Drill information for Knittex Industries Ltd.

1.	Date of the Fire drill	23/10/2018, 11: 50 am
2.	Location of drill	Factory premises
3.	Duration of drilling period	25 minutes
4.	Number of total persons present in the time of drill in the building	1308 no
5.	Weather condition:	Cold/ ✓warm / Hot
6.	Wind:	Calm ✓/ Breezy/ Windy
7.	Precipitation:	Sunny ✓/ Cloudy/ Rain

The survey had two parts. The first part consists of recording the CCTV video to analyse the followings.

1. Pre-movement behaviour (response phase behaviour) and the pre-movement time of the workers– it started from the unannounced emergency bell rang to the starting of the movement.
2. The evacuation time started from the first person’s exit to the last person’s evacuation from the room.

There were 432 people in the room before the drill started based on the researcher's manual count. Table 4.8 shows the evacuation time of the case study of Knittex Industries Limited.

Table 4.8: Evacuation time of Knittex Industries Ltd.

Time to start evacuation	0 min 38 sec
Time to complete evacuation from the floor	2 min 00 sec

Total evacuation time from Building to the assembly area	3 min 10 sec

Field observation found that workers had received fire drill training and were fully aware of the evacuation procedure. They nevertheless spent time finishing their current work, put aside their work and began to move. Many had to be prompted to move by their local fire warden.

The number of people analysed by CCTV was 104 in number (83 female, 21 male). Video analysis showed that, just before the alarm, 89 people worked with their assigned task, 8 people were moving and walking, and 3 people were doing other activities such as social engagement. In between the alarm's time, the movement started (response time) three types of actions, as shown in Table 4.9.

a) Fire warden's activity during fire drill

b) Video footage showing workers evacuation

c) Fire drill assembly area

d) Congestion at discharge corridor

Figure 4.6: Fire drill field survey images of Knittex Industries Ltd.

Table 4.9: Population calculation Pre-movement behaviour of Knittex

Action	Number of people
Those who responded just to the sound of the alarm	63
Those who started activity after staff intervention	28
Those who are socializing and waiting for movement	13

The second part of the survey was conducted after the fire drill and consisted of a questionnaire survey. The questionnaire was distributed after the occupants were seated properly at their workplace after returning from the assembly. Among every four operators, one questionnaire was given who is willing to participate. Several volunteers helped to make the questionnaire understandable to them and to fill it appropriately.

4.5. Case study 02: Nassa AJ Super Ltd.

4.5.1. General information

AJ Super was an extension building of Nassa A. J. Super Ltd. Garments. It has been a rectilinear plan with stager on the south and west side measuring 52 m X 36 m, about 1556 sqm (16,750 square ft.) approx on each floor.

Table 4.10: General description of AJ Super

Name of the RMG factory	: Nassa AJ Super Ltd.
BGMEA serial No	: 4103
Address:	: Holding No-07/538/1. Road No-01, Block-C Goshbag, Zirabo, Savar, Dhaka-1341.
Approval authority of the building plan	: Savar City Corporation
Year of approval of the building plan	: 2017
Year of the establishment of the factory	: 2015
Category of the RMG factory (according to ownership)	: Owned
Category of the RMG Factory (according to building type)	: Purpose-built

4.5.2. Functional layout

Understudy, the production area was at level 5, having a sewing section, finishing area, and maximum finishing area. The male and female toilet section was at the north and the northwest corner of the floor. There is a small office enclose for this floor in the finishing area. It has three exit corridors towards the ground floor. The south-west corner entry was considered the main entrance, which consists of the lift and staircase lobby size is 80 sqm in total and lobby 43.6 sqm. Another two exits were at the southeast corner (front) and north (back), considered emergency exits. The front exit (south-east corner, named emergency exit A) is used for the executive entrance. It leads towards the main office block of the total factory complex on the fourth floor, and the back exit (north side, named emergency exit B) was used for only emergency exit purposes. The fire assembly area was situated at the entrance of the factory complex. The exit A discharge point was in the assembly area. The exit B discharge point was on the north

Figure 4.7: AJ. Super Ltd.

Figure 4.8: Location of AJ Super limited

setback of the building, directly connected to the assembly area. The main entry used for the workers' daily entrance was far from the assembly area than the other entrances (Figure 4.11g). Both emergency stairs had an exit corridor and staircase. The emergency Exit A lobby size is 38.5 sqm, and the emergency Exit B lobby size is 1907 sqm. All the exit doors were fire doors.

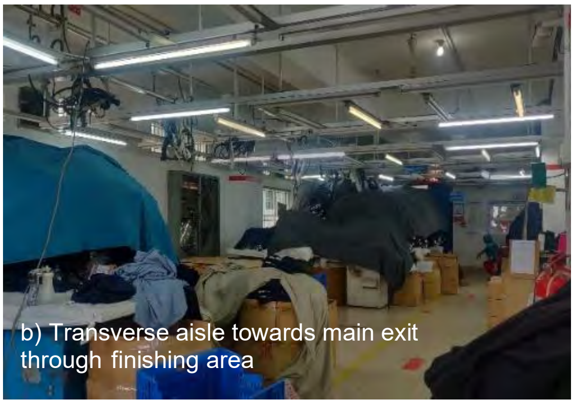


Figure 4.9: Longitudinal and transverse aisle of AJ Super Ltd. production floor,

The main exit door and exit A were double-swing fire-rated doors, size 2 m and exit B are also double-swing fire-rated doors with 1.5 m wide. The workstations and finishing tables were arranged following the layout approved by the regulatory authority (DIFE). Production Floor was an open plan layout in which the aisles only separate different functional areas. It consisted of a sewing section, finishing section and maximum finishing section. The three staircases of the production floor were directly accessible from the floor. The main exit of the lobby was parallel with the longitudinal aisles of the floor, and the emergency exit lobby is perpendicular to the long aisles. The production floor has six longitudinal aisles (horizontal in the plan) and three transverse aisles (vertical in the plan) for circulation (Figure 4.10).

The machines were placed in line along the aisles, and most workers faced the upper transverse aisle. Despite many accessories and machines, most of the longitudinal aisles maintained the required minimum width (1m) following the floor's marking.

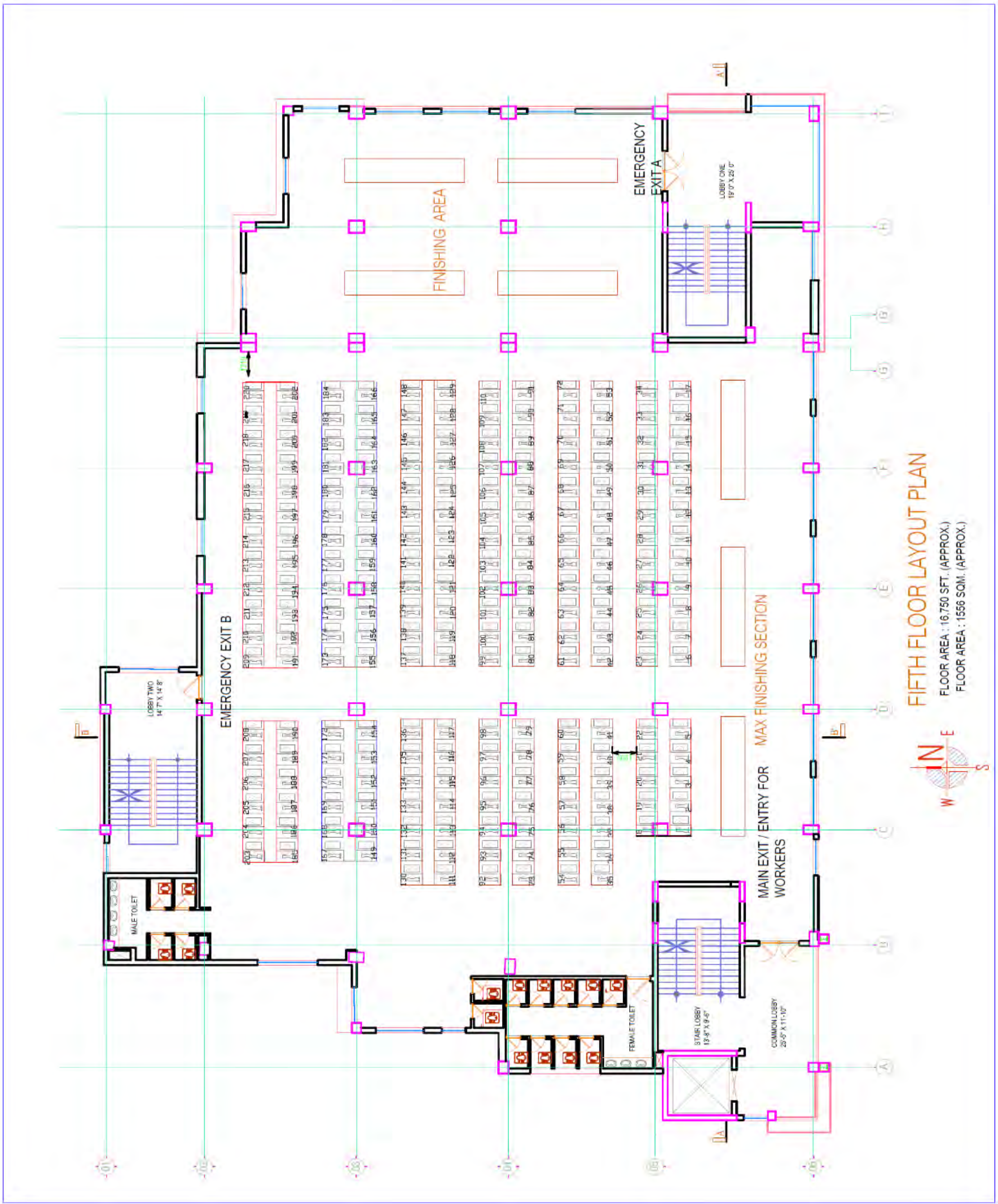


Figure 4.10: Floor plan of AJ Super Ltd.

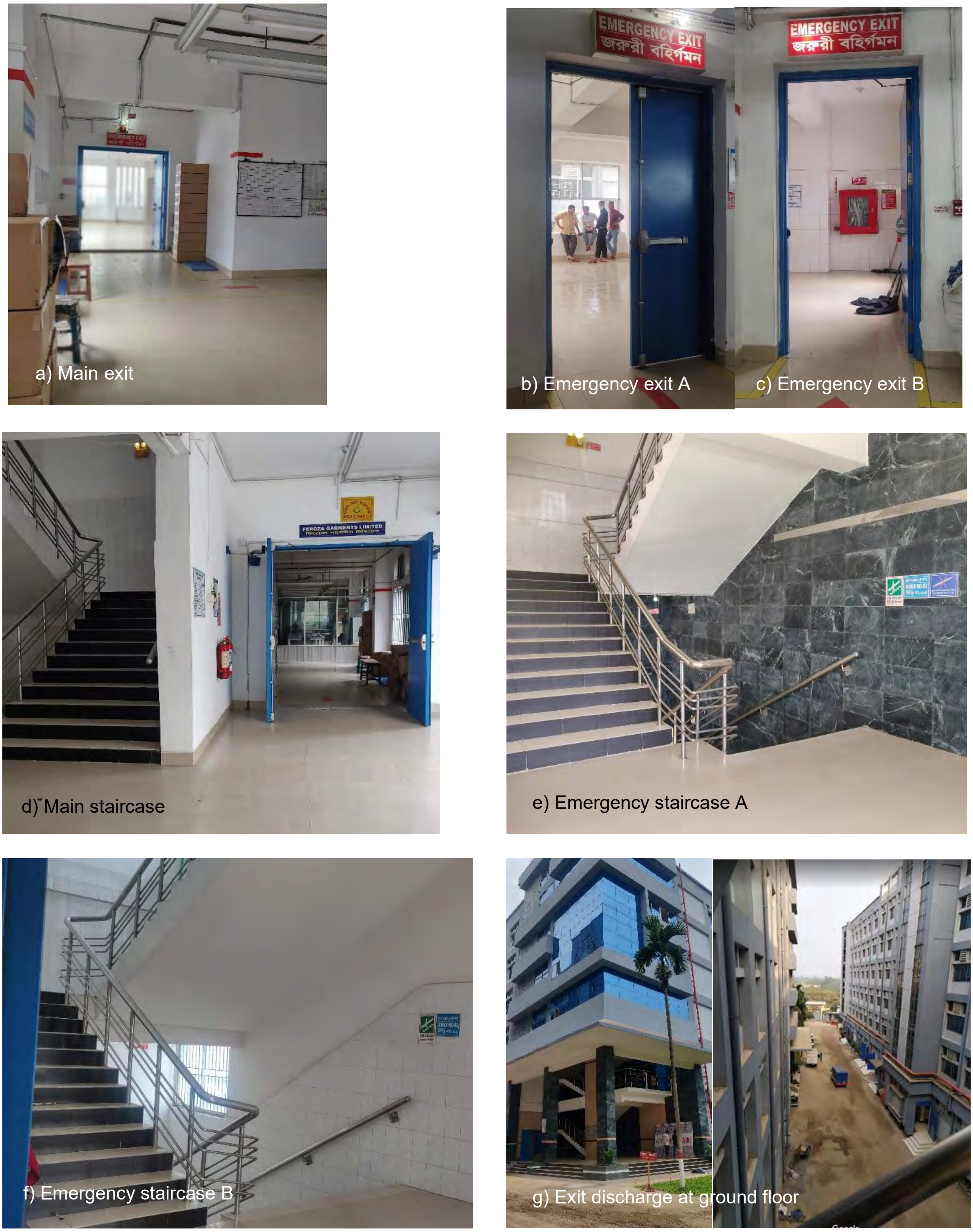


Figure 4.11: Images of all means of egress of AJ Super Ltd

4.5.3. *Workers*

There were 420 workers presented in the studied factory floor area during the Fire Drill. The majority of workers were female on this floor (274 female, 146 male), 220 machine operators, 148 helpers, and 52 other staff. There were six production lines on this floor with 38 machines in each line on average in two straight lines. About 75 persons got fire training, and ten persons worked as fire warden.

Table 4.11: Studied floor information of AJ Super

Floor understudy	Production (sewing) floor on 5th floor, with five machine lines 46 machines each, 1556 sqm
Total occupants of the studied floor	420, Female:274, Male: 146
Exit door	Exit Main: One main door, 2 m wide
	Exit A: One emergency door, 2 m wide
	Exit B: One emergency door, 1.5 m wide
Maximum Travel distance	30 m

Evacuation plan

The complete instructions of the approved egress system marking the escape routes from the exit access towards the exit door are shown on the evacuation plan. There was a fire safety and emergency evacuation plan posted on the walls of the main staircase lobby. Besides, the list of personnel responsible for firefighting was also displayed on separate notice boards. The escape route or emergency evacuation pathway is founded of eight longitudinal aisles inside the production area, and five transverse aisles along the perimeter were connecting three stairs. The transverse aisle located in the middle of the room was considered the primary aisle, based on functional arrangement and exits. The floor marks, i.e. the arrows, indicated up to the transverse aisle, the evacuees would have to run in one direction towards the longitudinal primary aisle in front and others towards the north and east side emergency exit. The room was marked with emergency signage. The final finishing section and another finishing area have also contained some circulation inside. However, along with aisles, the main path was worked as one of the significant circulations of those areas.

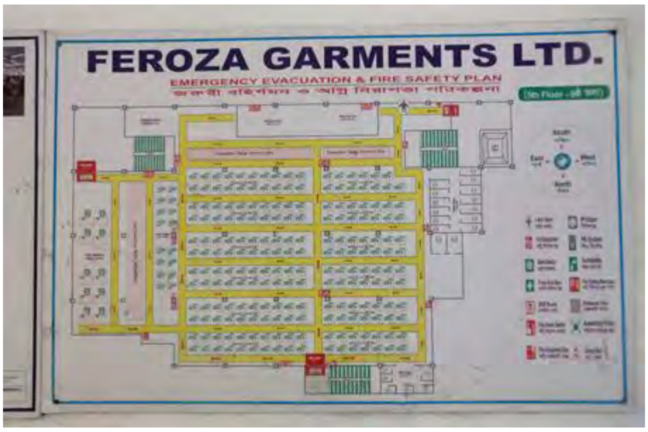


Figure 4.12: Evacuation map posted on the main staircase of AJ Super Ltd.

4.5.4. Fire drill

As the research methodology requirement, the unannounced fire drill was performed in AJ Super on 22 January 2020 at 10:30 AM. Assigned fire wardens also played their roles. The video filming started before the fire alarm and continued until the last person left the room. There was 22 manual call point for the bell, 35 sound enhancer speaker, and one good audible quality fire alarm for a fire drill operation. Drill assessment requirements are attached in Appendix B. AJ Super Ltd's case study was conducted on the production floor (5th floor, sewing unit). This building is more significant in size compared to the third case study. There was no CCTV camera inside the production, and the video was captured by a movable video camera. The volunteer stood near the main exit and was capturing the video covering the production areas partially. A timer

Fire drill

Video footage of fire drill

Figure 4.13 Images of fire drill survey of AJ Super Ltd.

calculated the evacuation time and occupant's response time phase.

Table 4.12: Drill information for AJ Super Ltd.

1.	Date of drill	22/01/2020, 10: 30 am
2.	Location of drill	Factory premises
3.	Duration of drilling period	25 minutes
4.	Number of total persons present in the time of drill in the building	980 no
5.	Weather condition:	Cold✓
6.	Wind:	Calm ✓
7.	Precipitation:	Sunny ✓

Table 4.13: Evacuation time of AJ Super Ltd.

Time to start evacuation after the alarm started	0 min 22 sec
Time to complete evacuation from the floor	1 min 40 sec
Total evacuation time from Building to the assembly area	3 min 00 sec

From the video analysis, it was found that:

Table 4.14: Pre movement behaviour

action	*Number of people*
Those who responded just to the sound of the alarm	51
Those who started activity after staff intervention	19
Those who are socializing and waiting for movement	15
Number of people observed by video analysis	75

Among 420 people present on the studied floor, 54 men and women responded to the questionnaire survey. All of them were machine operators. After the fire drill, the workers returned from the assembly; the questionnaires were distributed to the aforementioned samples. The volunteers helped the workers to understand the questionnaire and assisted them in filling it out. The drill assessment and thbvcbcbcvcbve interview with fire expert personnel were done within the field investigation time.

4.6. Case study 03: Power-Tex Fashions Ltd.

4.6.1. General information Power Tex Fashions Ltd

Power Tex Fashion Ltd. was housed in a small factory with a rectilinear plan measuring 64 m X 16 m, about 503 sqm on each floor. It is a purpose-built factory.

Table 4.15: General Information on Power Tex Fashions Ltd

Name of the RMG factory	: Power Tex Fashions Ltd
BGMEA serial No	: 3999
Address	: Dr. Latif Ayesha Tower, National University, Gazipur
Approval Authority of the Building Plan	: Union Polished
Year of Approval of the Building Plan	: 2007
Year of Establishment of the factory	: 2006
Category of the RMG: according to Ownership	: Owned
Category of the RMG Factory: according to Building type	: Purpose Built

Figure 4.14: Picture showing the building (right) and location map of Power Tex Fashion Ltd. (Left)

4.6.2. Functional layout

The Production area under study was at level 4, having sewing sections and quality control (Fig 4.15). There was a toilet section for males and females at the northwest corner of the floor. There is no office enclosed for this floor. It has two exit corridors towards the ground floor; one is the main entrance with the lobby of lift and staircase (57.2 sqm) at the south side, and another one is the emergency exit corridor and staircase (27 sqm) at the north side of the building. The workstations and QC tables were arranged following the layout approved by the regulatory authority (DIFE). Production Floor was an open plan layout in which the aisles only separate different functional areas. There were two staircases at two sides (north and south) of the production floor, and each stair was directly accessible from the production area through the exit doors. The main entrance lobby (14.7 sqm) shares the lift and the staircase both.

The main entrance /exit door was single swinging and fire-rated door with a 1.5 m width and it worked as the central passage for goods transfer and people’s movement. The emergency exit door was 1.2 m wide, single swinging and fire-rated door containing 10.6 sqm lobby. It was a single flight staircase with a 9 m long passageway. This passage was used as a store of temporary goods that created a narrower passage for the occupants. This emergency staircase was not used frequently by the users; it was used only for fire drill practice. The main exit of the lobby was perpendicular to the longitudinal aisles of the floor, and the emergency exit lobby was parallel to the long aisles. This production floor has five longitudinal aisles (horizontal in the plan) and two transverse aisles (vertical in the plan) for circulation. The machines were placed in line along the aisles, and most workers faced the upper transverse aisle. Most longitudinal passageways maintained the required minimum width (1m) following the floor's marking despite many accessories and appliances.

a) Main exit door (4th floor)
b) Emergency staircase
c) Main aisle showing emergency exit of Power Tex
d) Ground floor discharge area
e) Main Exit staircase

Figure 4.15: Images of all means of egress of Power Tex Fashion Ltd

Figure 4.16: *Floor plan of Power Tex Fashion Ltd.*

4.6.3. Workers:

About 260 workers were in the open factory area during the fire drill. The majority of workers were female on this floor (180 females, 64 males), 120 machine operators, 120 helpers and 20 other staff. There were two production lines on this floor with 30 machines in each line on average in two straight lines. About 36 persons got fire training, and five persons worked as fire warden.

Evacuation plan

There was a fire safety and emergency evacuation plan posted on the entrance lobby walls near the entry doors outside the production area. The complete instructions of the approved egress system marking the escape routes from the exit access towards the exit door are shown on the evacuation plan. There was also denoted the location of emergency firefighting equipment on the wall. The list of personnel responsible for firefighting was also displayed on separate notice boards. The escape route or emergency evacuation pathway is founded on five longitudinal aisles inside the production area and two transverse aisles at the perimeter connected to two stairs. The Middle longitudinal aisle was broader than the peripheral aisles (Figure 4.16). Based on functional arrangement and relation to exits, the longitudinal aisle located in the middle of the room was considered the primary aisle. The floor marks, i.e. the arrows, indicated up to the transverse aisle, evacuees would have to run in one direction towards the longitudinal primary aisle in front and others towards the back-side emergency exit. The room was marked adequately with emergency signage.

4.6.4. Fire drill

Table 4.16 Drill information for Power Tex Fashion Ltd

1.	Date of drill	22-09-2019 12:50 pm
2.	Location of drill	Factory premises
3.	Duration of drilling period	30 minutes
4.	Number of total persons present in the time of drill in the building	488 no
5.	Weather condition:	Hot✓
6.	Wind:	Breezy✓
7.	Precipitation:	Sunny ✓

As the research methodology requirement, the unannounced fire drill was performed in Power Tex Fashion Ltd. on 22 September 2019 at 12: 50 p.m. Assigned fire wardens also played their roles. The video filming started before the fire alarm and continued until the last person left the room. Fire drill-related assessment was done by the researcher and the volunteers (predrill, during drill and post drill assessment) attached to Appendix B. There were 260 people in the room before the drill started based on the manual count by the researcher.

a) Video footage of fire drill evacuation

b) Fire drill evacuation

Figure 4.17: Evacuation images of Power Tex Fashion

Table 4.17: Fire drill information of Power tex. fashion Ltd

Date of the Fire drill	22/09/2019, 12: 50 pm
Floor understudy	Production (sewing) floor on 4th floor, with two machine lines 60 machines each, 503 sqm
Total occupants of the studied floor	260, Female:180, Male: 64
Exit door	Exit Main: One main door, 1.5 m wide
	Exit emergency: one door, 0.6 m wide
Maximum Travel distance	18.9 m

The survey of Power Tex Fashion Ltd. was conducted on its production floor (4th floor, sewing unit). This building is the smallest in size comparing to the other two case studies. The timings were calculated using a manual timer and a video camera during the unannounced drill. A mobile phone-based video camera was used to capture workers pre-drill movement as there was no CC TV there. From the video analysis, the following evacuation time and the pre-movement behaviour were found.

Table 4.18: Evacuation time

Time to start evacuation	13 sec
Time to complete evacuation from the floor	1 min 30 sec
Total evacuation time from building to the assembly area	2 min 28 sec

Table 4.19: Population calculation of pre-movement behaviour of Power Tex Fashion Ltd.

Action	**Number of people**
Those who responded just to the sound of the alarm	**20**
Those who started activity after staff intervention	**18**
Those who are socializing and waiting for movement	**4**
Number of people observed by CCTV analysis	**42**

Since the research requires distance data, only the machine operator workers (80% of total worker are female) were chosen as questionnaire sample. Each machine was marked with the number showing in Figure 4.15. The questionnaires were distributed to the operators after coming from drill assembly and settled down to their seats. A sample of the questionnaire is attached in Appendix C. Volunteers helped them to figure out the questionnaire. As per rule, 46 people among 260 workers of this floor were trained up fire personnel. There were four persons appointed previously as a fire warden during the drill time. Monthly one fire drill had done by the authority. Sometimes it was announced, or sometimes it was unannounced. This time an unannounced fire drill was performed. Fire wardens played their role to reflect the situation that would occur during an actual emergency case. Pre-movement behaviour, time (the time between the alarm and first movement to the exit doors) and the evacuation time were notified by analysing video and the manual timer. The fire drill requirement was fulfilled with the HR manager's help and the observation (Appendix B).

4.7. Observation, interview, and the video analysis

Attributes observed and the analysis of CCTV records and video records during the fire drill are presented in Table 4.20 and 4.21.

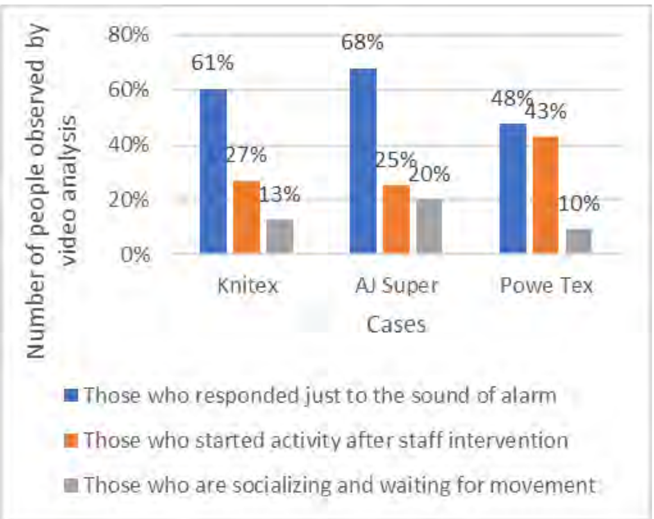
Table 4.20: Attributes observed during the fire drill

Case Study on	KNITTEX	AJ SUPER	POWER TEX
Pre-movement time[1]	0 min 38 sec	0 min 22 sec	0 min 13 sec
Evacuation time of the studied floor[2]	2 min 0 sec	1 min 40 sec	1 min 30 sec
Total evacuation time of the building	3 min 10 sec	3 min 0 sec	2 min 28 sec
Audible quality of fire alarm	Audible	Audible	Audible
List of Pre movement activity of the occupants	▪ Engaging in machine shut down ▪ Socializing ▪ Preparation for the fire drill	▪ Engaging in machine shut down ▪ Socializing ▪ Preparation for the fire drill	▪ Engaging in machine shut down ▪ Socializing ▪ Preparation for the fire drill
Observation of movement	Disciplined	Disciplined	Disciplined
Fire Wardens activity	Satisfactory	Satisfactory	Satisfactory

1. Pre-movement time of the workers – it started from the unannounced emergency bell rang to the starting of the first person's exit.
2. Evacuation time – it started from the alarm to the last person's evacuation from the room.

Table 4.21: Evacuation response phase behaviour of three cases

Case studies on	KNITTEX INDUSTRIES Ltd.	AJ SUPER Ltd.	POWER TEX FASHION Ltd.	Total
Those who responded just to the sound of the alarm	63	51	22	136
Those who started activity after staff intervention	28	19	18	65
Those who are socializing and waiting for movement	13	15	4	32
Number of people observed by video analysis	104	75	42	221



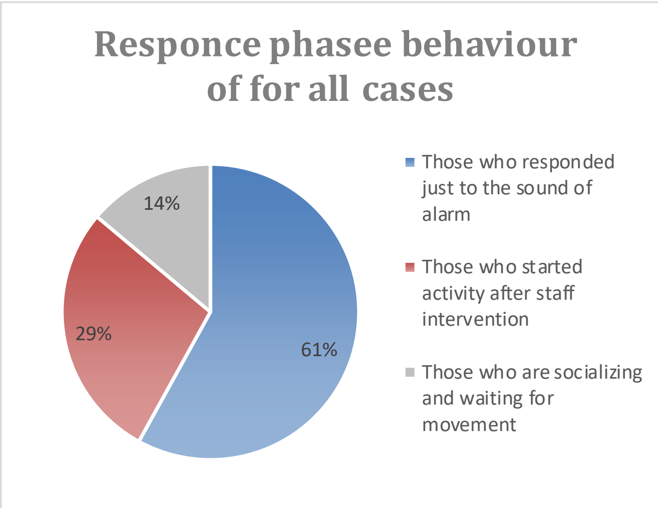


Figure 4.18: Evacuation response phase behaviour of three cases in percentage

From the above analysis, the average pre-movement time of the three case studies is 24.33 seconds and average total evacuation time from the floor is 1 minute 43 seconds and the average total evacuation time from the building is 2 minutes 53 seconds. From the analysis, it can be stated that the maximum number of workers (61%) responded to the fire alarm. Some people (29%) needed the staff intervention for the following action/ movement, and few people (14%) were not thoughtful for their responsive activity or showing alert for their following action of movement. From observation and interview with the expertise, it can be stated that performing a fire drill every month made the workers comfortable with 'dos and don'ts' of the fire drill. It also helped to reduce the pre-movement time and organize their behavioural response. It has an impact on this video analysis. It was noticed that all three case studies had a good quality of alarm audibility, which also impacted shorter premovement time. A good quality audible alarm needs to alert the occupants of a fire or other emergency conditions requiring action. The presence of wardens and the fire drill staffs reduced the need for information exchange between the occupants. In all three case studies, the fire wardens played their role to reflect the situation during an actual emergency case. It was anticipated and supported by the results of the questionnaires that the wardens did not have an influence on exit preference but have an influence on the pre-movement time, the time between the alarm and first movement to the exit doors.

4.8. Result analysis of the questionnaire survey

4.8.1. Analysis of the case studies questionnaire

The questioners, which was distributed to the samples, was tried to identify the followings:

- Location of people in the building
- Familiarity with the emergency exit
- Awareness and clarity of signs
- The orientation of people by the fire wardens
- Exit choices
- Reasons for preferences
- Bottleneck problem

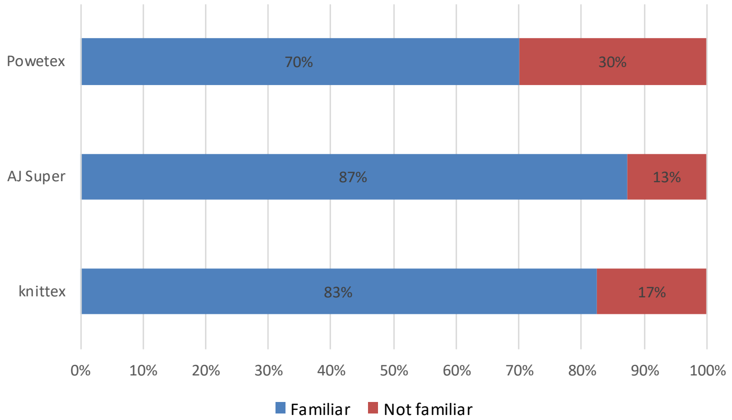
The numbers of respondents are the following:

- Knittex - 63 among 260 people
- AJ Super- 55 among 220 people
- Power Tex- 30 among 120 people.

4.8.2. Familiarity with the emergency exit

The results of the questionnaires revealed that most of the building occupants were familiar with the emergency exits. Only a few respondents indicated that they were not aware of the existence of emergency exits in Knittex Industries Ltd. (52), AJ Super Ltd. (48) and Power Tex Fashion Ltd. (21) (Figure 4.19)

Figure 4.19: Percentages of familiarity with the emergency exit for three case studies



4.8.3. Awareness of the emergency signs

Most of the respondents were not aware of the emergency signs during the evacuation time. Though signages and instructions were posted in the studied buildings, most occupants do not follow those at the evacuation time. Figure 4.20 shows the percentages and response levels.

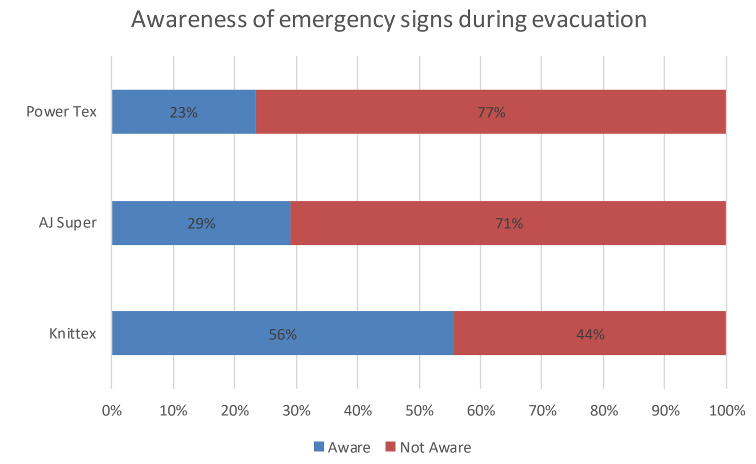
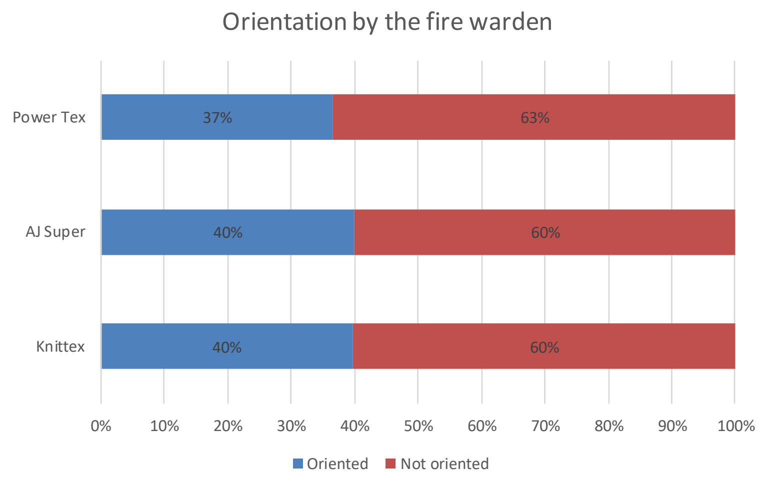


Figure 4.20: Percentages of awareness of the emergency signs for three case studies

4.8.4. Orientation by the fire wardens

It was observed that the fire wardens played their role during the fire evacuation drills in order arned people



about the emergency and asked them to leave the building. In Knittex Industries Ltd., 25 people were oriented with the warden during the drill, but only 2% followed the door that the warden instructed them to use (section 4.8). In Power Tex Fashion Ltd., 11 was oriented with the warden, but only 1% of occupants influenced. For AJ Super Ltd., there was 22 of people's orientation with fire warden, and only 6% of people's exit choice is influenced by the warden's instruction (Figure 4.21)

Figure 4.21: Percentages of orientation by the fire wardens of all the cases

4.8.5. *Exit preference*

Each building had a different number of exits. Both Knittex Industries Ltd. and Power Tex Fashion Ltd. had two exits on each floor. The percentages of main exits and alternative emergency exits are illustrated for each building in Figure 4.22. The use of main exits was found to be respected for the two cases Knittex Industries Ltd. and

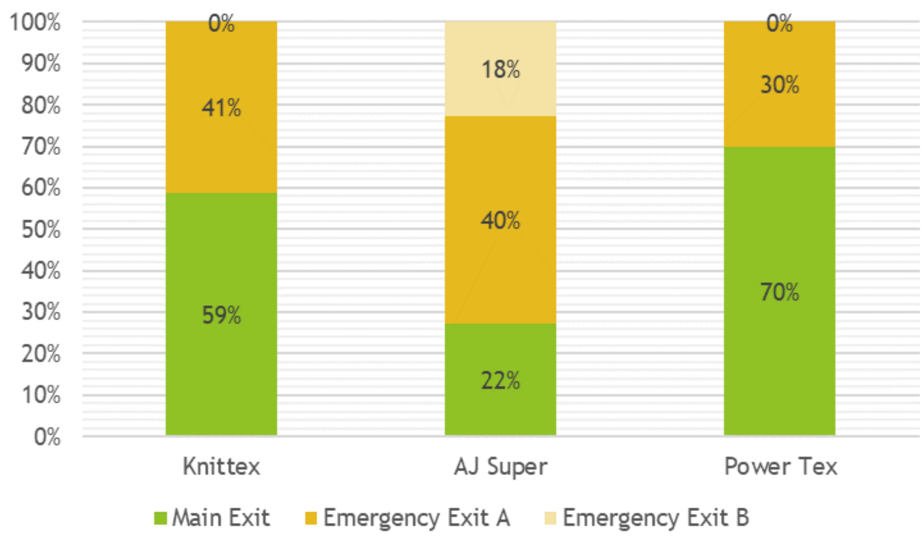


Figure 4.22: Main and Emergency exit chosen by the occupants

Power Tex Fashion Ltd. is 37, 21, and an emergency exit is 26 and 9. AJ Super Ltd. had three exits where 22 occupants used emergency Exit A, and 12 used the main exit, which the workers used as their daily entrance staircase. Only ten evacuees used the rear emergency Exit B for evacuation.

4.8.6. *Reasons for exit preferences*

The list of reasons for exit preferences listed in the questionnaire illustrates the percentages for each case study in Figures 4.23, 4.24, 4.25. The questionnaires' results revealed that proximity or closeness to the exit was the main factor affecting exit preference in all two cases. There are 25 for Knittex, 22 for AJ Super Ltd. And 12 users for Power Tex Fashion Ltd. have chosen closeness to the door for exit preference.

The other two most important factors for Knittex Industries Ltd., AJ Super Ltd. and Power Tex Fashion Ltd. respectively are: "familiarity" (Knittex Industries

Ltd.14, AJ Super Ltd. 14, Power Tex Fashion Ltd. 11 respondent), “following other people” (Knittex Industries Ltd. for 10, AJ Super Ltd. 9, Power Tex fashion Ltd. 1 respondent) and visibility” (Knittex Industries Ltd. for 8, AJ Super Ltd. 6, Power Tex Fashion Ltd. 4 respondents). “Orientation by the wardens” (Knittex Industries Ltd. 2, AJ Super Ltd. 3, Power Tex Fashion Ltd. 2 respondents) factors were the following most important factors. The percentages for the other factors on the list are very low. “Crowding in front of the doors”, “Obstacles”, and “Following emergency signs” were not even chosen as a reason for exit preference by any respondent in case studies.

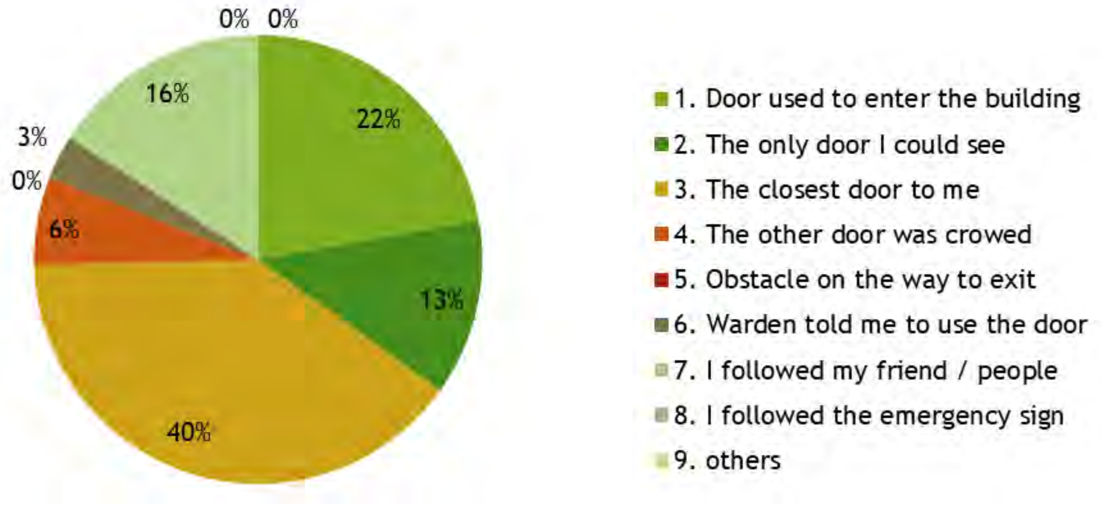


Figure 4.23: Reasons for exit preferences of Knittex

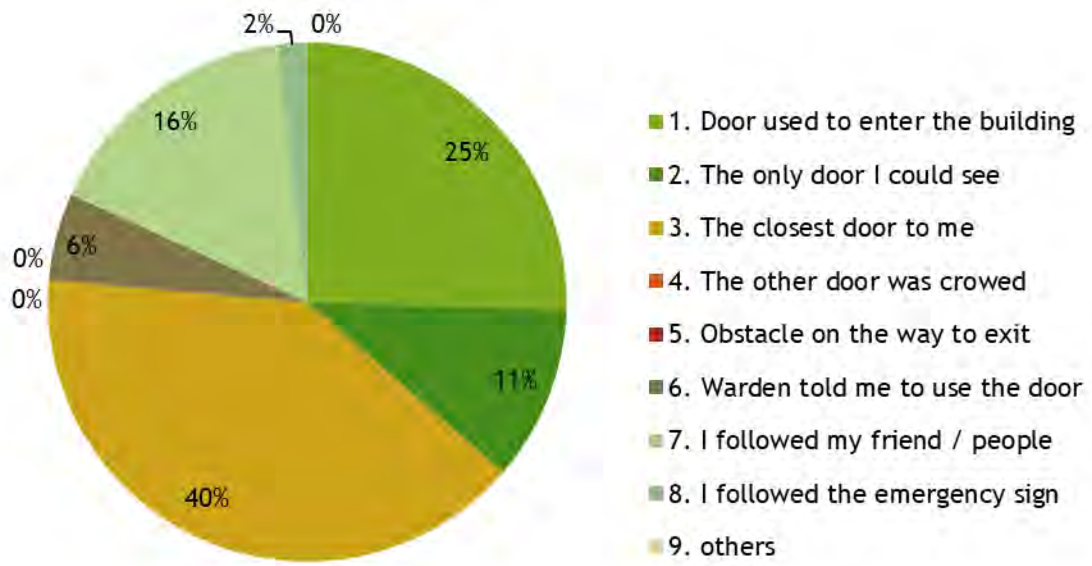


Figure 4.24 Reasons for exit preferences of AJ Super

Most people indicated that they use the nearest emergency exit, but many people use the main entrance or follow others. These findings are in line with the results found in the literature (Sagun, 2013).

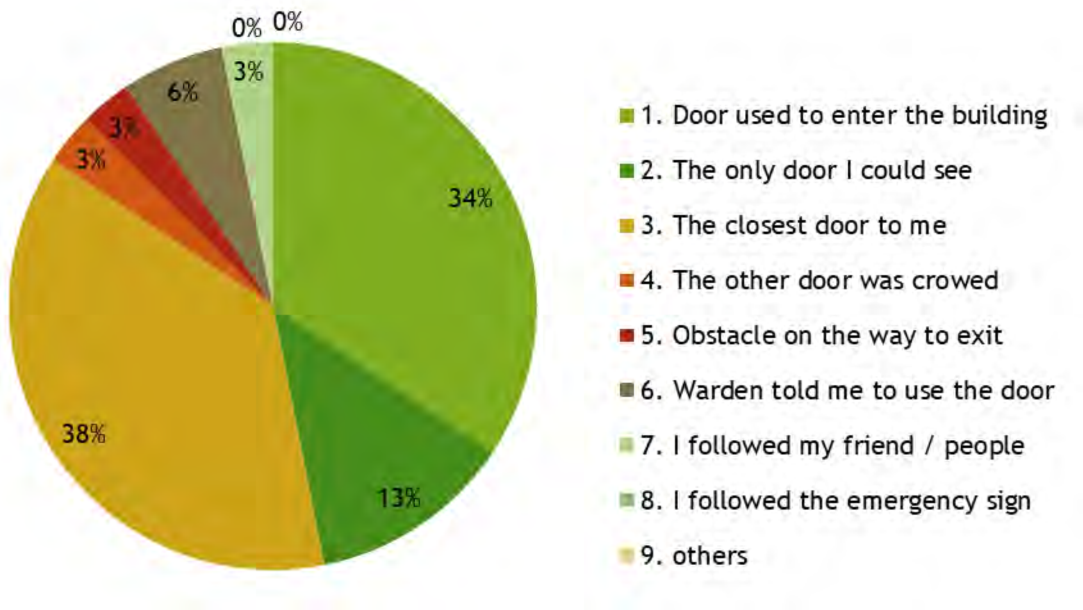


Figure 4.25 Reasons for exit preferences of Power Tex

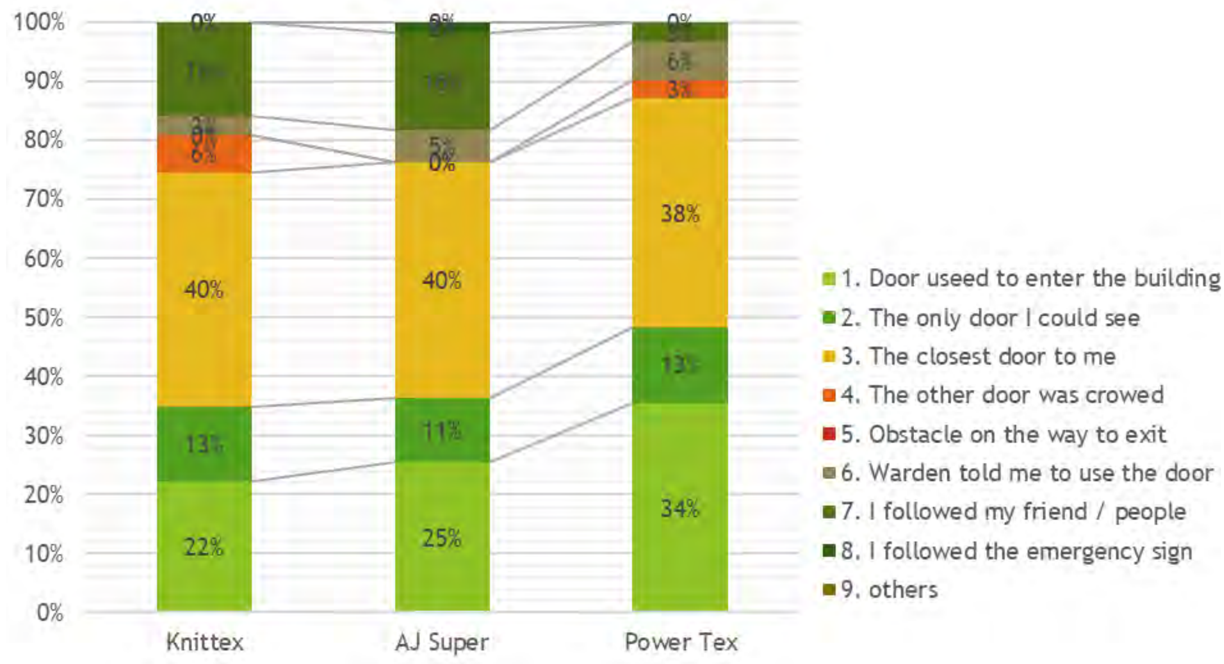


Figure 4.26 Chart showing combined results of exit preference of the occupants

Table 4.22: Reasons for exit preference (All cases)

	Cases	**Knittex Industries Ltd.**	**AJ Super Ltd.**	**Power Tex Fashion Ltd.**	**Average**
	Total respondents	63	55	30	148
1	Door used to enter the building	22%	25%	37%	28%
2	The only door I could see	13%	11%	13%	12%
3	The closest door to me	40%	40%	40%	40%
4	The other door has crowed	6%	0%	3%	3%
5	Obstacle on the way to exit	0%	0%	3%	1%
6	Warden told me to use the door	3%	5%	7%	5%
7	I followed my friend / people	16%	16%	3%	12%
8	I followed the emergency sign	0%	2%	0%	1%
9	Others	0%	0%	0%	0%

4.8.7. Bottleneck problems

To identify the bottlenecks during evacuation process, both direct observation and quantification methods could be applied (Ma, 2014). This analysis shows where the respondent was facing a bottleneck problem in their entire evacuation route. Their opinion was based on their chosen evacuation route. In Knittex Industries Ltd., 59%, Power Tex Fashion Ltd. 70%, and AJ Super Ltd., 22% (Figure 4.27) among the respondents were given their opinion about the bottleneck. The rest of the respondents did not. These data show that they were not very concerned about this problem, and it has no significant influence on decision-making. Figure 4.28 shows the result of their opinion. From observation, it was found that the entire evacuation process was reasonably organized, and the staircases satisfied the codes and compliance of BNBC (2020). Its reflection could find in the data. Only the main exit door of Knittex Industries Ltd. and Power Tex Fashion Ltd. had the congestion problem. Other exit discharges of the emergency route points of Knittex Industries Ltd. and Power Tex Fashion Ltd. had a minor issue.

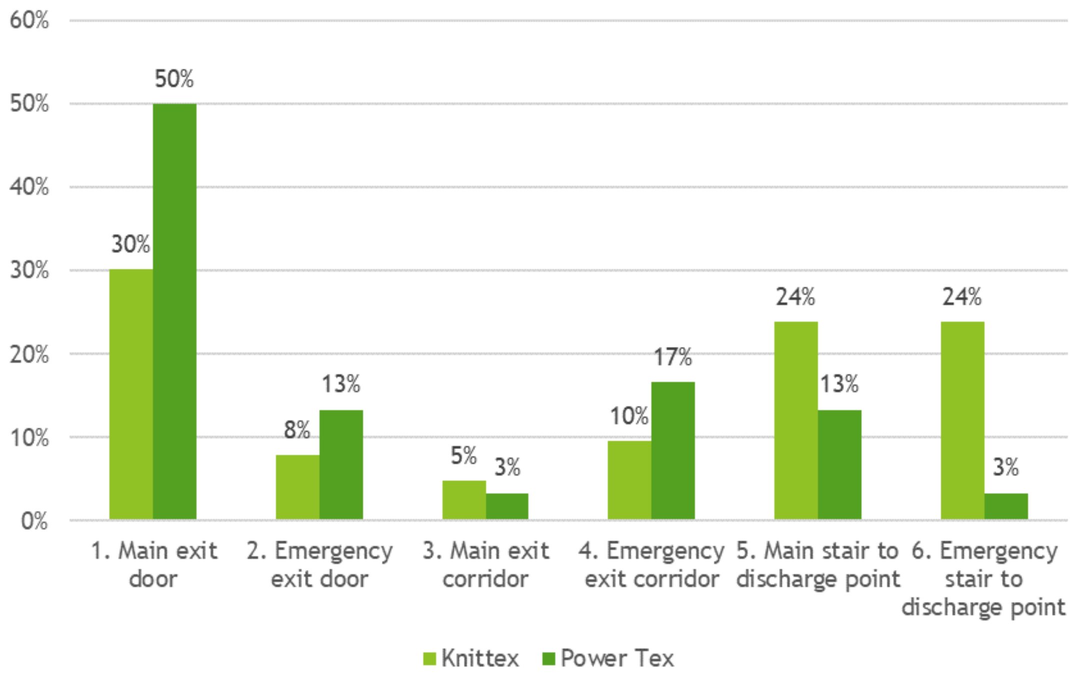


Figure 4.27 The bottleneck problem in Knittex and Power Tex Fashion Ltd.

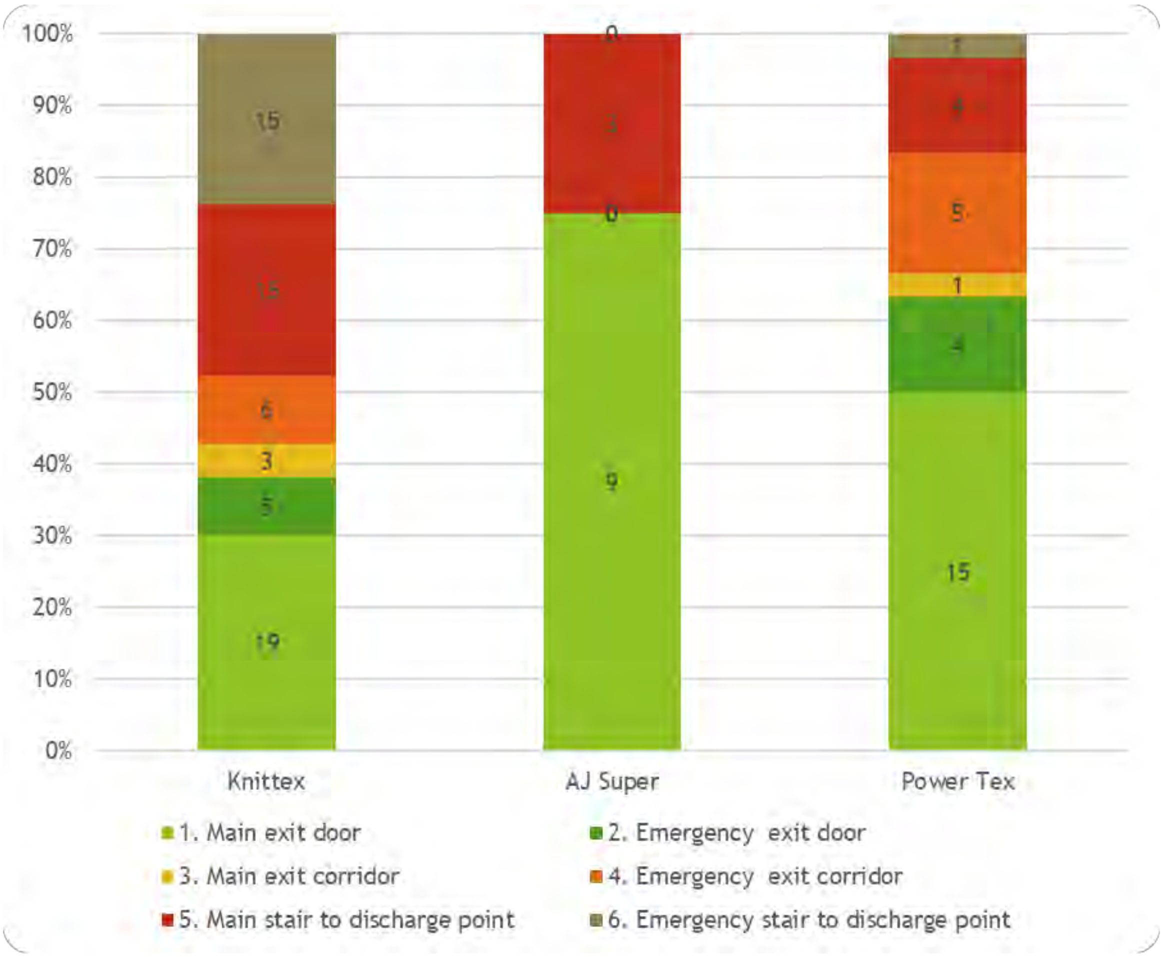


Figure 4.28 Bottle-neck problems for three case studies

There was no significant bottleneck problem in AJ Super Ltd, supported by the observation of the researcher and questionnaire data by the respondent.

4.9. Observation of fire doors and staircases

During the field survey, it was observed that the RMG factory authority had installed a single swing or double swing fire door compliant with a fire-resistant rating as a part of a passive fire protection system in all three cases. The doors comply with code regarding their width and height. The entire entries include a push bar as a handle, and some have a vision panel, automatic closing devices, ball bearing hinges, a positive latching mechanism, smoke seals, and gas seals. Exit doors are marked with a sign or symbol. Their compliances are detailed out in Table 4.23.

Table 4.23: Checklist for fire door compliances

	Rules and regulations according to draft 2015 BNBC	Case study		
		KNITTEX	**POWER TEX**	**AJ SUPER**
Fire exit doors	The width of the door is not less than 1 m	✓	✓	✓
	Exit doors are sewing or pivoted of side hinged type	✓	✓	✓
	Fire-resistant door	✓	✓	✓
	Swing outwards from the room	✓	✓	✓
	Exit doors do not open directly on a flight of a staircase. A clear width of the door leaf min 0.9m is maintained	✓	X	✓

Table 4.24: Staircase measurement for three case studies

	Main staircase			Emergency stair		
Case Study	**Exit Door width (m)**	**Staircase lobby area (sqm)**	**Width of stairways (m)**	**Exit Door width (m)**	**Staircase lobby area (sqm)**	**Width of stairways (m)**
Knittex	2.4 m	52.3 sqm	2.1 m	2.1 m	13.5 sqm	1.3 m
AJ Super	2 m	30.6 sqm	2 m	A 2 m	43.6 sqm	1.8 m
				B 1.2 m	19.7 sqm	2.05 m
Power Tex.	1.5 m	14.7 sqm	2.2 m	1.2 m	10 sqm	1.88m

During the field survey, case studies maintained their compliance on least dimension in landing, proper use of handrail, and minimum size in the stairways. Emergency staircases were built with a smoke-proof and fireproof enclosure. For Power Tex, some goods were stored on the emergency exit corridor, not allowed in codes and conduct. All case studies staircases were built adjacent to the lift lobby without any fire or smoke proofing enclosure, making them non-compliant to the code. AJ Super Limited and Power Tex Fashion Ltd. had separate lift lobby spaces but no separator door. The evacuation plans were posted on the lobby wall near the exit door in all three case studies. The local fire service authority approved the escape route layout. A list of legends was posted in the evacuation plan that explains the signs and symbols used in the design.

4.10. Discussion

The data obtained from observations of fire drills and the questionnaire survey are used to analyze the user's preference about exit choice. This section discusses the summary of the observations and the findings, with some suggestions.

- **To reduce evacuation time-** frequent fire drill practice and warden intervention need to be inaugurated.

Building management authority needs to give attention to regular fire drill practice to increase familiarity with the emergency exit doors, which will increase the probability of choosing an emergency exit in the time of emergency. The significance of users' exit preferences is identified in this research (Section 4.9.6 and Section 5.3.3), leading the designers to understand the human behavioural approach in a fire drill. Increased visibility to the exit door, free and easily accessible exit door, and easy circulation can make the user confident. Social influence in choosing the exit has a significant impact.

- **To reduce the evacuation response time –** installation of the different active devices for attention.

Different measures can be taken to effectively reduce the evacuation response time and make evacuation fast and organized. An active fire alarm system via notification appliances or voice evacuation messaging, visual means to identify exits - usually signage and flashing lights, which are not obscured by smoke and placing horns or voice evacuation speakers over exit doors. Any innovative device can be recognized by making it possible for occupants, even those who have never heard an instrument react quickly and confidently.

- **To increase familiarity with an emergency exit or alternate exit-** provide way guidance design for better accessibility to the egress route.

Evacuation times must be decreased during a fire emergency to reduce or eliminate loss of life or injuries; however, various situations can delay or hinder evacuation or relocation. So, architects need to provide multiple way guidance solutions in egress design, orienting people in circulation with building design or providing a different perspective to familiarize building occupants with the building and exit door. Building authority should provide warden's intervention during evacuation and fire drill practice.

- **To reduce bottleneck problem-** increase familiarity with emergency exit.

The bottleneck problem can also be reduced if the users choose the emergency exit; however, they frequently use the main door. Bottleneck or obstacles in exit-route is also due to irregular fire-drill. Proximity and Familiarity of exit problem arises when the industries do not follow mandatory fire-drills, emergency exit route or when Fire-Warden do not have adequate command over the workers.

Familiarity with the emergency door can bring significant change in decision-making. The architects also need to provide the way guidance design towards the emergency doors to make them more accessible and attractive to the user to increase its familiarity.

4.11. Summary

This chapter described three case studies concerning functional layout, configurational layout, fire drill observation and users' response. The summary of the study identifies specific attributes that are discussed in detail. These observations are further compared with the result of the analysis to understand the findings discussed in Chapter 6. The data obtained from this chapter is carried out to the next Chapter 5 for regression analysis.

CHAPTER 5: DATA ANALYSIS

5.1. Preamble

Findings derived from the field investigation is highlighted in previous chapters and will be analysed in this chapter. Evacuation behaviour data were collected from questionnaire and fire drill. A total number of 148 set questionnaires from the field survey were used for the analysis. Information of fire drill evacuation was obtained from the observation of researcher, video/CCTV footage and opinion of drill experts of corresponding case studies. The result of the case studies was aligned with the findings under observation, interview and video analysis; analysis of the case studies questionnaire; and logistic regression analysis of the data from case studies.

5.2. Data analysis

Necessary data is collected from the survey and observation from the selected three case studies. This dataset included three unannounced evacuation drills and was carried out in sewing production floors of RMG buildings involving 1152 participants.

Table 5.1: Summary of the necessary information for three cases

Name	Knittex Industries Ltd.	AJ Super Ltd.	Power Tex Fashion Ltd.
Floor understudy	3rd floor	5th floor	4th floor
The sample size for the questionnaire survey	63 no, 84% female,16% male, all were stationed before the drill	55 no, 65% female 35% male, all were stationed before the drill	30 no, 80% female 20% male, all were stationed before the drill
Description of the main door	2.4 m wide double swing fire door, parallel with the longitudinal aisles	2 m wide double swing door, parallel with the longitudinal aisles	1.5 m wide, single swing, fire door, perpendicular to the longitudinal aisles
Main Stair	4.5 m wide, half turn stair, with 58.6 sqm lobby sharing lift; leading directly towards the main assembly area on the ground floor	4.2 m wide, half turn stair, with 43.75 sqm lobby sharing list; leading directly towards the internal road of the complex on the ground floor	4.7 m wide, half turn stair, with 14.7 sqm lobby sharing lift; leading directly towards the main assembly area on the ground floor
Description of emergency door	One emergency exit, 1.5 m wide, double swing fire door,	Two emergency exits. Exit A is 2 m wide double swing,	One emergency exit,1.2 m wide, single swing fire door,

Table 5.1 continued

	Ltd.	per Ltd.	Power Tex Fashion Ltd.
	perpendicular with the longitudinal aisles	perpendicular with the longitudinal aisles; Exit B: 1.5 m wide double swing, perpendicular with the longitudinal aisles	perpendicular with the longitudinal aisles
Emergency stair	2.7 m wide, with 13.4 sqm lobby, half turn stair; leading towards the side setback beside the boundary on the ground floor	Exit A 3.96 m wide, half turn stair, 38.5 sqm lobby; leading directly towards the main assembly area on the ground floor Exit B: 4.48 m wide, half turn stair, 19.7 sqm lobby; leading towards the side setback beside the boundary on the ground floor	1.88 m wide, with 15.8 sqm lobby, straight stair; leading towards the side setback beside the boundary on the ground floor
Maximum travel distance	33.5 m	30 m	18.9 m

5.3. Regression analysis

5.3.1. Logistic regression analysis of the data from case studies

In addition to the percentage calculations of the data collected from the questionnaires, logistic regression analysis was used to build a statistical model of the exit preferences of building occupants using the distance data and the factors identified in the questionnaire. Logistic regression, also known as Logit Regression or Logit Model, is a mathematical model used in statistics to estimate (guess) the probability of an event occurring has been given some previous data (Gujarati, 2003). Logistic Regression works with binary data, where either the event happens (1) or the event does not happen (0). The principle of the logistic regression model is to link the occurrence or non-occurrence of an event to independent variables (Gujrarati, 2003). The non-quantitative data (such as yes/no, male/female, accepting/not accepting) is defined by assigning 0–1 as positive and negative values. For example, in this case, one of the independent variables is not quantitative, “being familiar with emergency exit doors”. It is coded as 1, and “not being familiar with the emergency exits” is coded as 0. The objective was to find out the "likelihood of choosing (familiar) main doors" during evacuations. Similarly, 1 is assigned for "preferring the main door", and 0 is given for "not preferring the main exit" for the dependent variable.

Table 5.2: Summary statistics of the variables that were primarily considered to develop regression models

Types of Variables	***Description***	***Representation***	***Purposes***
Independent variable	Being **familiar** with emergency exit doors	Coded as *F=1*	likelihood of choosing emergency doors Or the probability of choosing the main door
	Not being familiar with the emergency exits	Coded as *F=0*	
	Distance ratio (ratio of distance to the emergency door to the distance to the main door)	Continuous variable $\beta = {}^{dE}/_{dM}$	
	Reasons for exit preference	*R1, R2, to R9*	
Dependent variable	**Main door**	Coded as *M=1 or 0*	
	Emergency door	Coded as *E =0 or* 1	

From section 3.5.1, it is found that the equation for this study would be,

$$\boldsymbol{eta = C1 + \beta C2 + FC3 + R1C3 + R2C3 + R3C3 + R4C3 + \cdots + R9C3} \ldots (5.1)$$

Where $\boldsymbol{\beta} = {}^{\boldsymbol{dE}}/_{\boldsymbol{dM}}$ (ratio of distance to the emergency exit door to the distance to the main door) works as a continuous variable; **F** = familiarity with the emergency exit; ***R1*** to ***R9*** are the factors or reasons to choose the exit doors by the evacuee surveyed in the field investigation, and **C** is the constant value for each variable (Sugan,2013). The model would predict the odds that a subject will choose the main/emergency exit with a given familiarity factor (0 or 1) by the formula mentioned above (Sagun, 2013).

The collected data set from the questionnaire survey is used in the analysis graph (Figure 5.1 to 5.5) using the following abbreviations.

$M = Main\ Exit$

$E = Emergency\ exit$

$Dist.Main\ (dM) = distance\ (in\ meter) from\ seat\ to\ main\ door$

$Dist.Emergency\ (dE) = distance\ (in\ meter) from\ seat\ to\ emergency\ door$

$$\boldsymbol{distance\ ratio\ \beta = {}^{dE}/_{dM}} \qquad \text{………………..(5.2)}$$

Reason for exit preference

R1 = Door used to enter the building
R2 = The only door I could see
R3 = The closest door to me
R4 = The other door crowed
R5 = Obstacle on the way to exit
R6 = Warden told me to use the door
R7 = I followed my friend/people
R8 = I followed the emergency sign
R9 = others

$F = Familiarity\ with\ the\ emergency\ exit$

$A = \ Awareness\ of\ the\ users\ to\ the\ emergency\ signages\ during\ evacuation$

$O = Orientation\ with\ the\ warden\ during\ fire\ drill$

5.3.2. BigML: the machine learning algorithm

The logistic regression analysis results in **BigML** for the three cases supported the findings from the questionnaires. BigML is an influential machine learning algorithm with an easy-to-use interface for the users to import their data to create a model for solving regression problems. It gives predictions out of it with the help of classification and regression (e.g. trees, ensembles, logistic regressions and deep nets), and time series forecasting, cluster analysis, anomaly detection, topic modelling, association discovery, and Principal Component Analysis (PCA) (Appendix D). Both classification and regression problems can be solved using supervised Machine Learning techniques. They are called supervised as the output variable values have either been provided by a human expert (e.g., an event does or does not happen) or by a deterministic, automated process (e.g., an event occurs for a specific period, are labelled as “delinquent”). The objective field values and the input fields need to be collected for each instance in a structured dataset used to train the model (BigML, Inc., 2020). The algorithms learn a predictive model that maps the input data to a predicted objective field value. It is needed to use some test data different from those used to train the model to evaluate the regression model's performance. Then BigML creates a prediction for every instance and compares the actual objective field values of the instances/ cases in the test data against the prediction results. This way, it can be checked the model strength using that performance measures based on the correct outcomes and the model's errors.

The analysis was conducted using the factors that were listed in surveyed questionnaires. The model was formulated by independent variables - *"the ratio of the distance to emergency exit to distance to the main exit"* (*β) as a* continuous variable, *"familiarity with the emergency exits", "the factors of preference",* and the target variable (dependent variable) showing the occurrence or non-occurrence - "exit to choose". All the data were compiled in an Excel sheet to put in the BigML dashboard to analyse and find the regression and probability graph.

5.3.3. Discussion

This final logistic regression analysis shows the results of fitting a logistic regression model to describe the relationship between exit preference (target variable) and the two independent variables: *distance ratio and familiarity*. Table 5.3 shows the total regression analysis concerning respondents' location on the studied floor and their probability of choosing the exit considering 'reasons for preferring the targeted door'. In this research, it is found that different factors/variables are not equally performed for the users' exit preference among the nine variables evaluated in the survey (Section 4.9.6). For instance, if anyone is standing at the same distance to both exits, where the distance ratio is one, and he/ she is not familiar with the emergency exit (coded as 0 for the emergency door). Then the probability of choosing the main exit is higher than he/she is familiar with the emergency exit (coded as 1 for the emergency door) (Table 5.3).

Furthermore, probability differs for various reasons or factors. The analysis found that exit preference's primary determinant factor is the *'proximity to the exit'(R3).*

The respondents who are the nearest to the exit door, either it is the main or emergency, always chose that nearest exit. Other than that, there are three variables- *“door used to enter the building (R1)”, “The visibility to the exit (R2)”* and *“other people’s influence (R7)”* significantly essential that are used to build the statistical model. The probability for the factors *“obstacle on the way to exit (R5)”, “following the emergency sign (R8)”,* and *“other (R9)”* are not showing in Table 5.3 as the results are insignificant.

When the distance increases, another factor works in; it is a natural phenomenon. In table 5.3, if the respondents are closer to the emergency exit, the ratio shows the value of less than one. For the equal distance, the ratio is 1; closer to the main door concerning the emergency door, the ratio is more than one. In this study, the highest distance ratio was 4.5 found in Knittex Industries Ltd. and the lowest ratio of 0.06 in Power Tex Fashion Ltd. In regression curves for all case studies, it is found that when the distance ratio more than 1.5, the curves become levelled (Figure 5.1).

BigML machine learning algorithm recognizes the evaluation of *‘ Regression model Fit Test’,* which determines whether the logistic function adequately fits the observed data. The evaluation results are based on the following metrics or measures: Accuracy, Precision, Recall, F- measures and Phi-coefficient (BigML, Inc., 2020). The phi correlation coefficient (phi) is one of several correlation statistics developed to measure the strength of association between two variables (Glen, 2016). The phi coefficient is a symmetrical statistic, which means the independent variable and dependent variables are interchangeable. The range is from -1 to 1, where 0 is for no relationship, 1 is for a perfect positive relationship (most of the data fall along with the diagonal cells), and -1 is for a perfect negative relationship (most of the data is not on the diagonal). For this research, the regression model is found that the average **phi correlation coefficient (phi)** is 0.7221, which shows a ‘very strong positive relationship’ (Glen, 2016). There is no reason to reject the adequacy of this fitted model at the 86.2% or higher accuracy level because the average phi correlation coefficient (phi) is greater than .05.

Analysis of Fit test evaluation of the regression model

- Precision 85.9%
- Accuracy 86.2%
- F- measures 0.8606
- Phi-coefficient 0.7221
- Recall 86.3%

The few additional calculations for 'fit test evaluation' are attached in Appendix F. Here, the evaluation process has done through the BigML Dashboard using the 80% / 20% automatic split of the dataset to training and test dataset.

Table 5.3 Regression analysis of all case studies showing different distance ratio

Reasons (R)	Familiarity 0 (not familiar to emergency exit)		Familiarity 1 (familiar to emergency exit)	
	Probability for Exit chosen (%)		Probability for Exit chosen (%)	
	The main door (M)	Emergency door (E)	The main door (M)	Emergency door (E)
When distance Ration β= 0.1 (i.e. users' position is equal distance from the main exit and emergency exit)				
R1	97.36	2.64	93.10	6.90
R2	71.00	29.00	47.26	52.74
R3	70.96	29.04	47.21	52.79
R4	65.72	34.28	41.24	58.76
R6	78.92	21.07	57.82	42.18
R7	85.70	14.30	68.68	31.32
When distance Ration β= 0.5 (i.e. users' position is nearer to emergency exit)				
R1	84.54	15.46	66.69	33.31
R2	26.64	73.36	11.73	88.27
R3	26.6	73.4	11.71	88.29
R4	22.14	77.86	9.43	90.57
R6	35.71	64.29	16.89	83.1
R7	47.05	52.95	21.54	75.46
When distance Ration β= 1.4 (i.e. users' position is nearer to the main exit)				
R1	99.41	0.59	98.42	1.58

R2	91.85	8.15	80.48	19.52
R3	91.83	8.1	80.45	19.55
R4	89.82	10.18	76.36	23.64
R6	94.52	5.48	86.32	13.68
R7	96.50	3.50	90.99	9.01

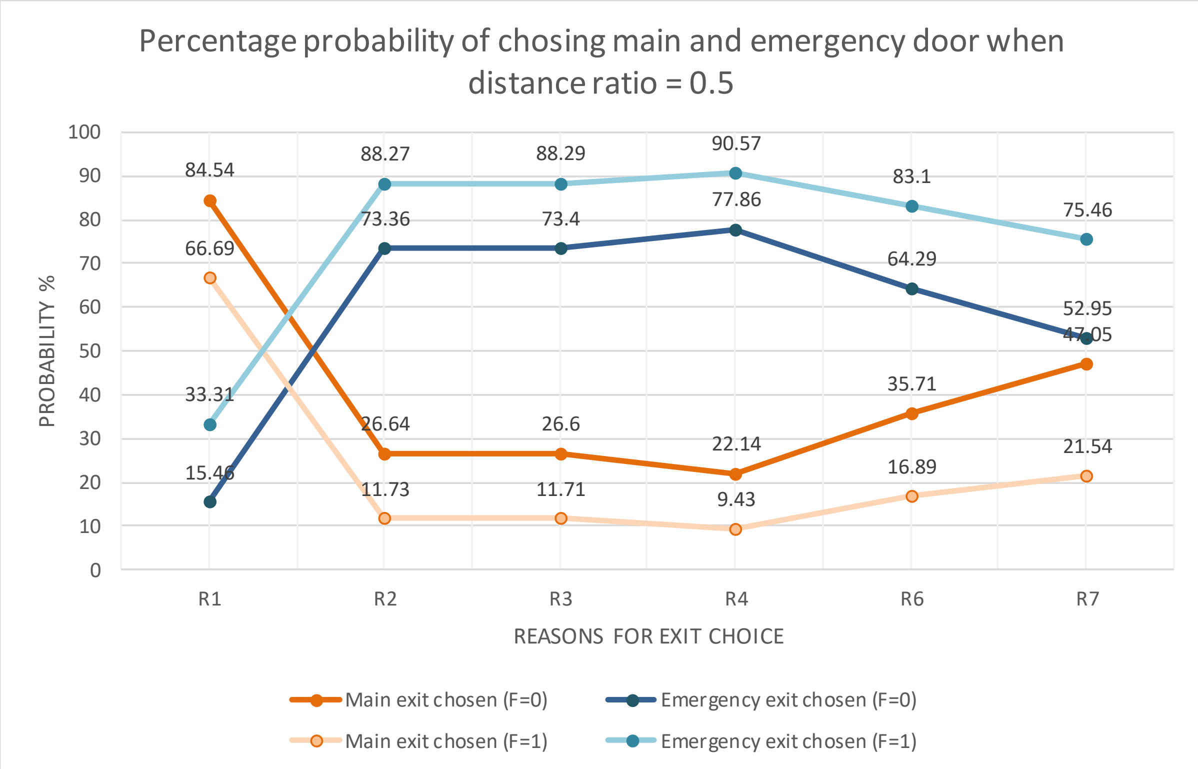
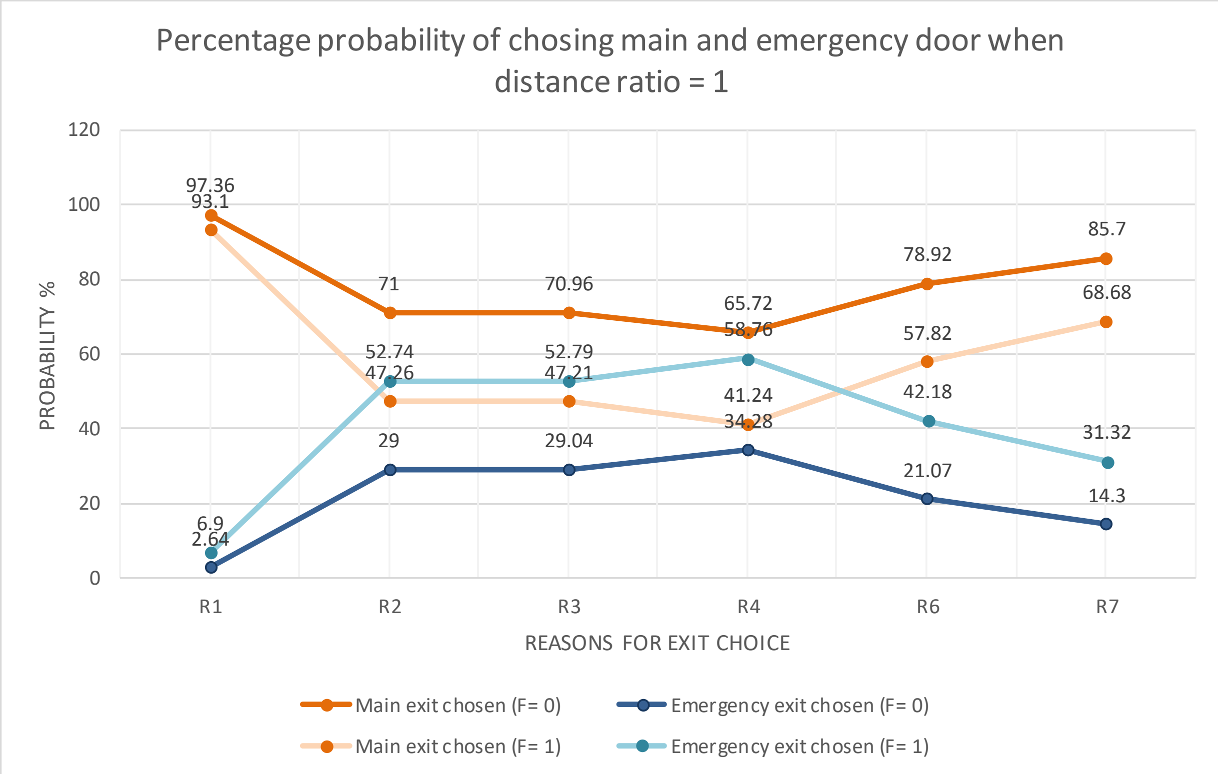


Figure 5.1(a) Percentage probability of using exits in distance ratio 0.5



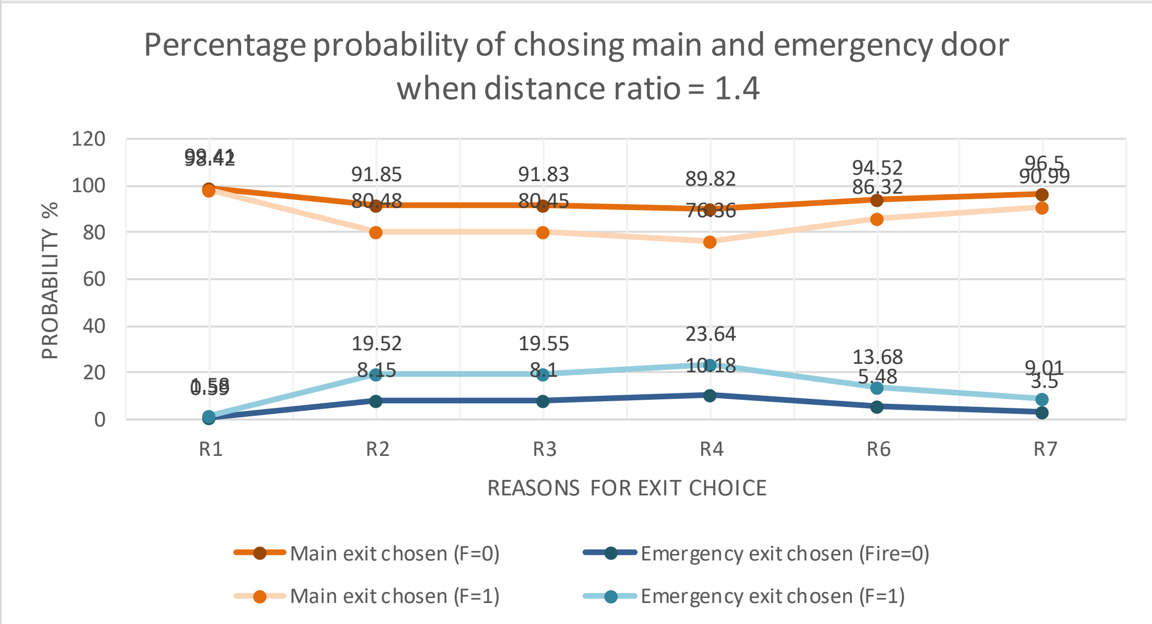


Figure 5.1(c) Percentage probability of using exits in distance ratio 1.4

Case: Respondents familiar with the emergency exit

The following graphs present the prediction curves of two exits (the main and emergency) by distance ratio in the X-axis ranging from 0 to 1.5 and the Y-axis probability. The blue curve of regression is for the emergency exit, and the orange curve is for the main exit chosen by the users. The familiarity with the emergency exit is (coded as one) an independent variable for all graphs (Figure

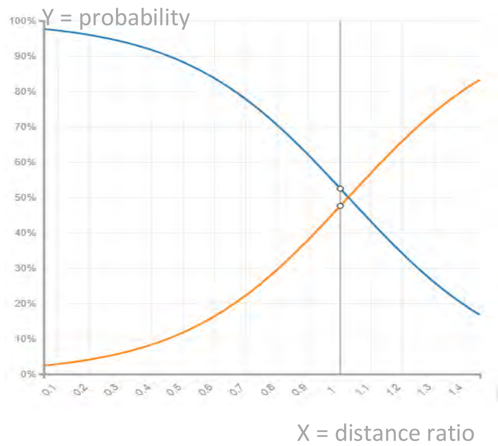
5.2) with different reason variables (R1 to R8). The grey colour line on distance ratio 1 denotes the equal distance from both doors, comparing both probability curves' position. Detailed calculations of *'F measures'* and *'phi coefficient* ' for the following models are attached in appendix F. The objective is to find out the "probability of choosing the main door" during "evacuation" (target variable) when the respondents consider their reasons for exit preference.

Graph 5.2(a) shows that the door users use to enter the room every day is the preferable door (93% probability) in case of familiarity to emergency exit =1 in coding for emergency evacuation when both doors are in the same distance. For the three points in figure 5.2(a), the curves intersect at a distance ratio of 0.32, which means the probability of choosing both exits is 50%. If the respondents prefer the door, they enter every day. However, the curve changes if the reason changes. Figure 5.2 (b) shows that the user likes more the emergency door if it is visible. In figure 5.2 (c), If the respondents chose the door due to reason 3 (nearest exit), the curve intersection point shifts to a distance ratio of 1.03, which denotes that users perceive distance drives him/her to prefer the door. However, he is at the same distance from both entrances. Figure 5.2 (d) shows that the other door crowed if the respondent chooses the door (R4). He has a 50% probability of taking any door at a distance ratio of 1.1 and avoids the main door for congestion. Following friends or other person or obeying wardens' instruction also directs the users to select the emergency doors, which can be found in figure 5.2 (e) and (f). Similarly, the intersection points change due to reason change and individuals' location change, shown in Figure 5.2 (a – f).

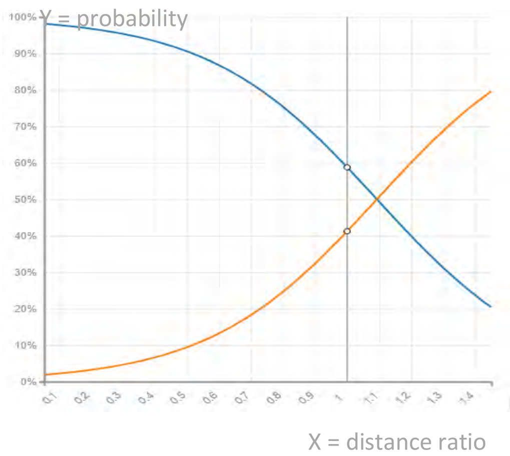
The above graphs display that there is a relationship between distance and familiarity in choosing an exit. If the distances to two different exits are the same, the decision-maker will choose the most familiar one. By increasing the distance to the familiar one, the tendency to choose the other exit (i.e., emergency exit) is increased until they reach an intersection point on the graph. Both exits are equally often chosen. After that point, the emergency exit is increasingly more frequently chosen. It is also found in figure 5.2 (b to f, i.e. R2 to R7) that the probability of 'choosing an emergency exit' started to increase by the following factor. These are 'social influence/ following other people' (probability 31% for

R7, *β= 1;*) 'fire warden's instruction' (probability 42% for R6, *β = 1)* or 'crowd in the other exit door' (probability 48% for R4, *β = 1)* other than R1 (6.9% probability, *β = 1*) (Table 5.3). Most people indicated that they use the nearest emergency exit, but many people will also return to the main entrance due to familiarity with the main exit. When the respondents are near the main exit (distance ratio of more than 1), the probability increases to choose the main exit (Table 5.3). In regression curves for three case studies, it is found that when the distance ratio is more than 1.5, the curves become flatter. It means that where more people are far from the emergency exit, the tendency to choose the main exit increases (Figure 5.1c).

As mentioned above, distance to the exit is vital for the subject's exit choice. The prediction is that the closer the exit is, the more attractive it is. It is assumed that the subjects/ respondents tend to choose a normal exit before an emergency one when the distance to the alternatives is about the same. When the distance to the typical/ main door is doubled, its attractiveness declines, and the closer located emergency exit becomes more attractive and will be more often chosen.

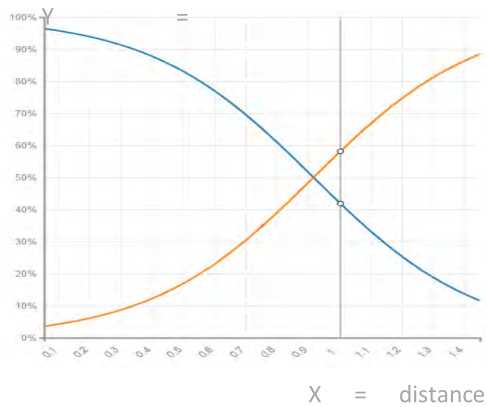


c) *R3* - The closest door, Familiarity 1

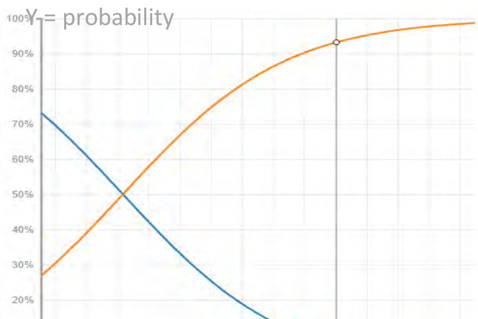


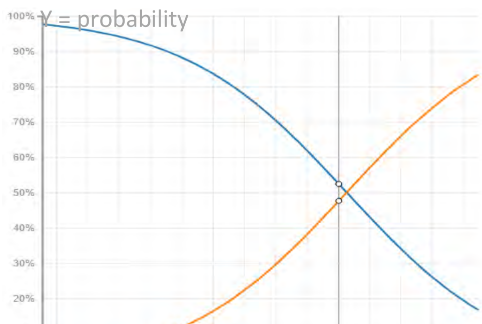
d) *R4* - The other door was crowed, Familiarity

e) R 7- Follow friend and other persons, Familiarity 1



f) *R6* Follow Warden's instruction, Familiarity 1





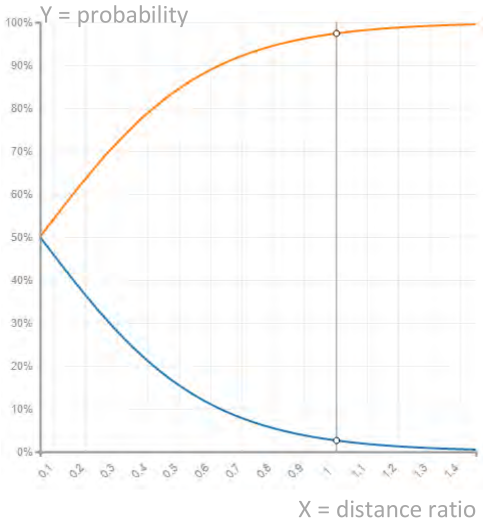
Case: respondents not familiar with the emergency exit

Figure 5.3 presents two exits' prediction curves (primary and emergency) by distance ratio in the X-axis ranging from 0 to 1.5 and percentages of probability in the Y-axis. The blue curve is for the emergency exit, and the orange curve is for the main exit chosen by the users. The familiarity with the emergency exit is coded as 0 as an independent variable for the graphs (Figure 5.3) with different reason variables (R1 to R8). The objective is to find out the "probability of choosing the main door" during "evacuation" (target variable) when the respondents consider their reasons for exit preference when the respondent was not familiar with the emergency exit. The fit text measurement of the following depicted models of detail calculations on *'F measures,'* accuracy, and *'phi coefficient* ' are attached in Appendix F.

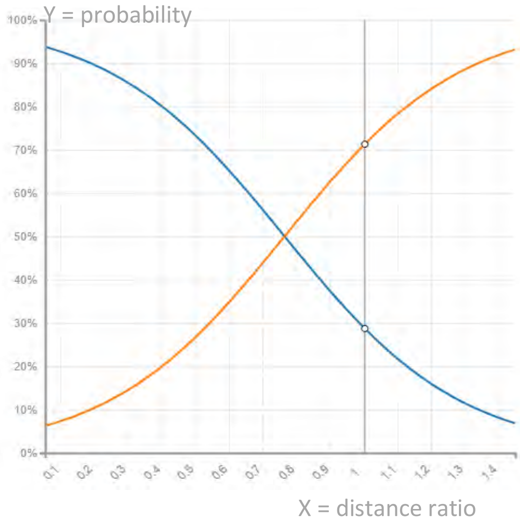
If the emergency exit is not familiar to the respondents, they choose the main exit dominantly for evacuation, though the emergency exit is nearer. It is visible in Table 5.3 and the following graphs in figure 5.3. Figure 5.3(a) showed the 100% probability when the respondent chose the main door due to R1 (R1=Door used to enter the building). For other exit preferences (R2 to R8), when the distance ratio decreases (β less than 1), the likelihood of choosing an emergency door increases but familiarity with the main door dominates the users' preference all the time. It increases the bottleneck problem at the main entrance that finding is also supported by observation and survey (Section 4.9.7). The changes in orange curves show that (Figure 5.3a) the probability of choosing the main door is very high though the subjects are located nearer to the emergency door. Only for the R4 (the other door crowed) when the main exit is not easily accessible, the topics choose the emergency exit for evacuation (probability 34.28% at β =1, probability 77.8% at β = 0.5). (Figure 5.3.d). The graph (Figure 5.3.f) also shows that when a person is not familiar with the exit, they depend on more friends and other people's choices and choose the main door or ordinary door for evacuation.

However, the emergency exit is nearer to him. This finding denotes how familiarity with the emergency door plays a vital role in decision-making.

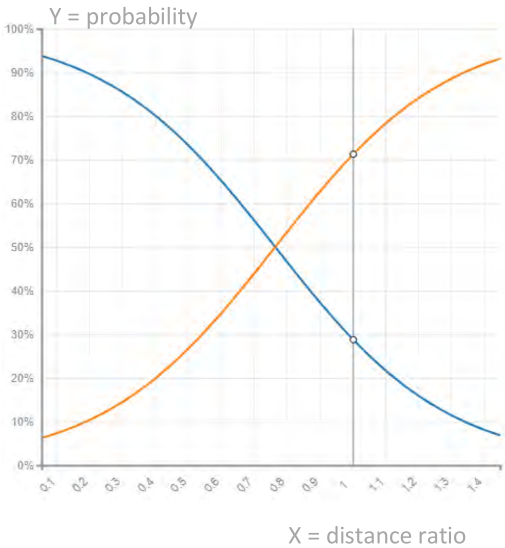
The authority of fire drill and building operation needs to increase familiarity of the emergency exit door to the user in the reasonable condition, which will increase the probability of choosing emergency exit preference in the time of emergency. The architects also need to consider an emergency door's design to make it more accessible and attractive to the user to increase its familiarity.



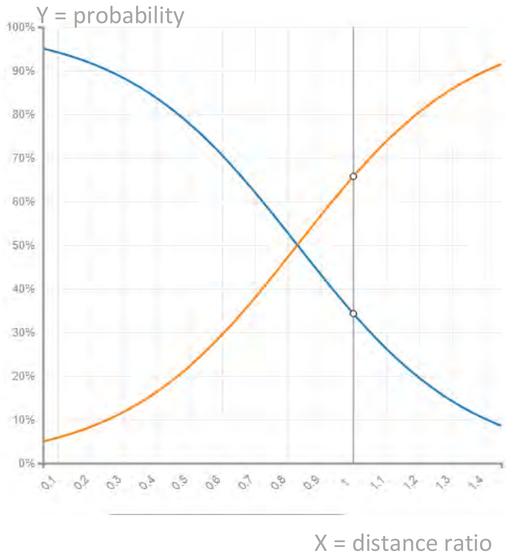
a) *R1*- Door used to enter, Familiarity 0



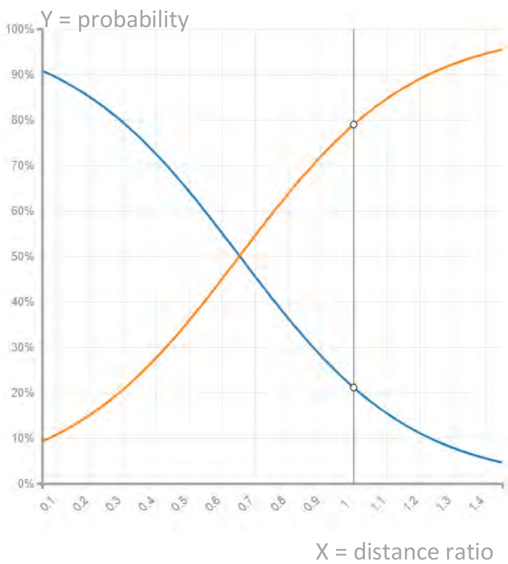
b) *R2*- Visibility of door, Familiarity 0



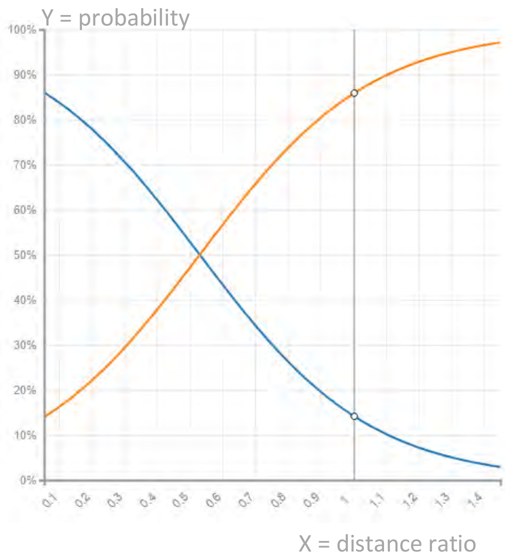
c) *R3*- The closest door, Familiarity 0



d) *R4*- The other door was crowed, Familiarity 0



e)R6 - following Warden's instruction, Familiarity 0

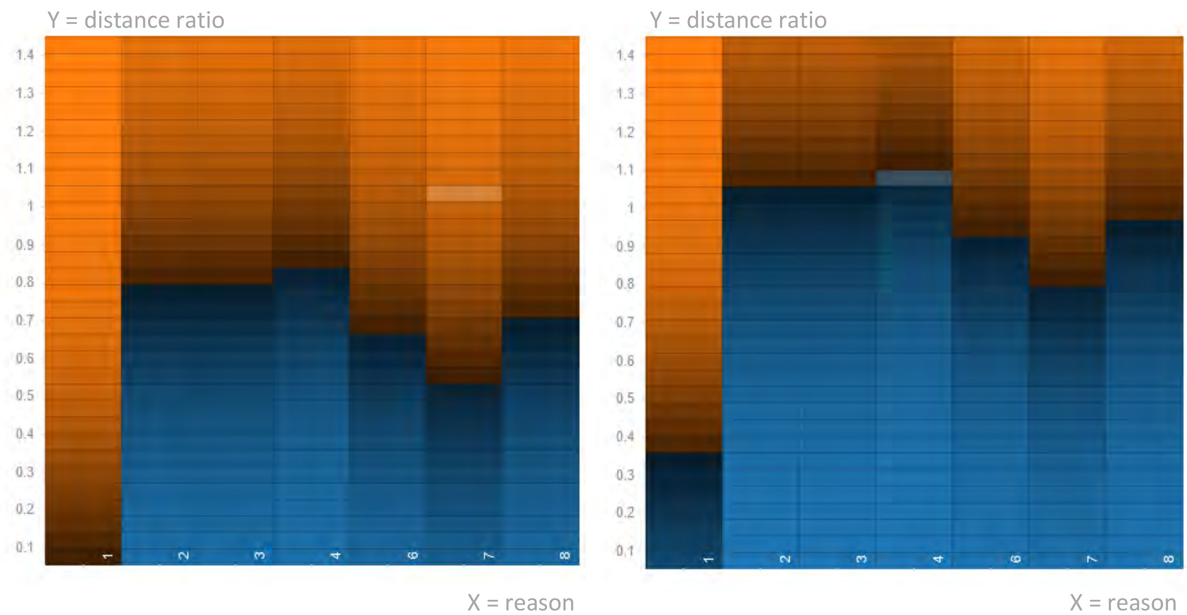


f)*R7*- Follow friend and family, Familiarity 0

Figure 5.3 The above six graphs show the regression analysis for three case studies when the user is not familiar with an emergency exit (coded as 0). The X-axis shows the distance ratio, and the Y-axis shows the probability percentages. The blue curve is for the emergency exit, and the orange curve is for the main exit chosen by the users.

PDP graph

The partial Deepnet plot graph (PDP) (BigML, Inc., 2020) in Figure 5.4 shows the colour mapping of the total result of the regression analysis for the exit chosen. Deepnet is an optimized implementation of deep neural networks, supervised learning algorithms that can solve regression and classification problems. The blue colour represents the emergency exit, and the orange colour represents the primary exit preference in the Deepnet graph. The graph shows the relationship of distance ratio (Y-axis), and various reasons (X-Axis) with the familiarity of users with the emergency door (coded added as 1) can bring significant change in decision making. Each column is for different reasons in X-axis, which are R1(door to enter every day), R2 (visibility), R3 (proximity), R4 (crowdest door to avoid), R6 (follow warden's instruction), R7 (follow friend or other people), and R8 (follow emergency signs). Y-axis ranges from 0 to 1.5.



a) Familiarity coded as 0

b) Familiarity coded as 1

Figure 5.4: PDP showing the results of regression analysis for exit chosen (graph a showing -X-axis reason R1, R2, R3, R4, R6, R7 and R8, Y-axis distance ratio with familiarity code 0) and (for graph b showing -X-axis reason R1, R2, R3, R4, R6, R7 and R8, Y-axis distance ratio with familiarity code 1). The blue colour is for the emergency exit, and the orange colour is for the main exit chosen by the users.

The colour plotting shows the changes in users' decisions due to different variables. PDP shows (Figure 5.4) that the user prefers the main exit for R1 (familiarity to the main door) (column 1) and for R7 (the social influence -following other people) (column 6). However, they are standing closer to the emergency exit. Bottleneck problem (R4- crowd in the other door) (column 4) also drives the users to choose the emergency exit though they frequently use the main gate.

Co-relation graph

The correlation between different variables is shown in the correlation graph (Figure 5.5). Graph (a) shows that users' exit preference shifts for familiarity/unfamiliarity with any door in different distance ratios (between 0.6 to 1.1 for code 1 and 0.4 for code 0). Here Y-axis is the distance ratio, and X-axis shows various reasons variables (R1 to R 8). The second (middle) graph (b) shows users' exit preferences in different users' proximity positions. The third one is showing users preferences and their familiarity with an emergency exit. The blue colour represents the emergency door, and the orange colour represents the primary exit preference.

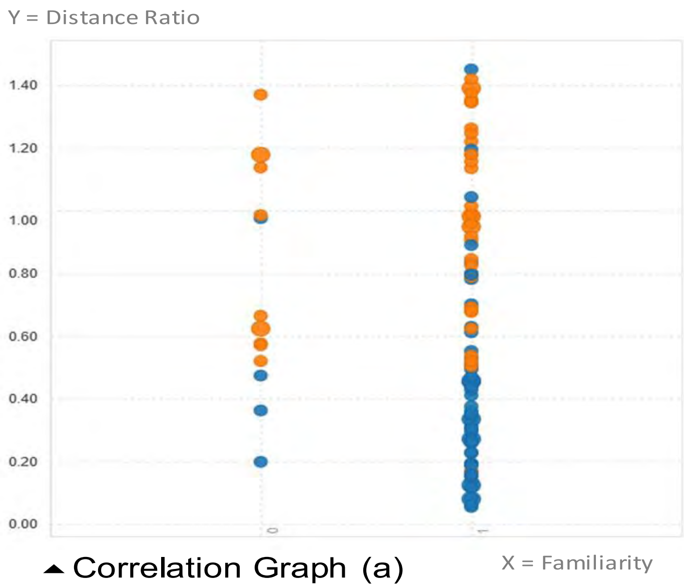
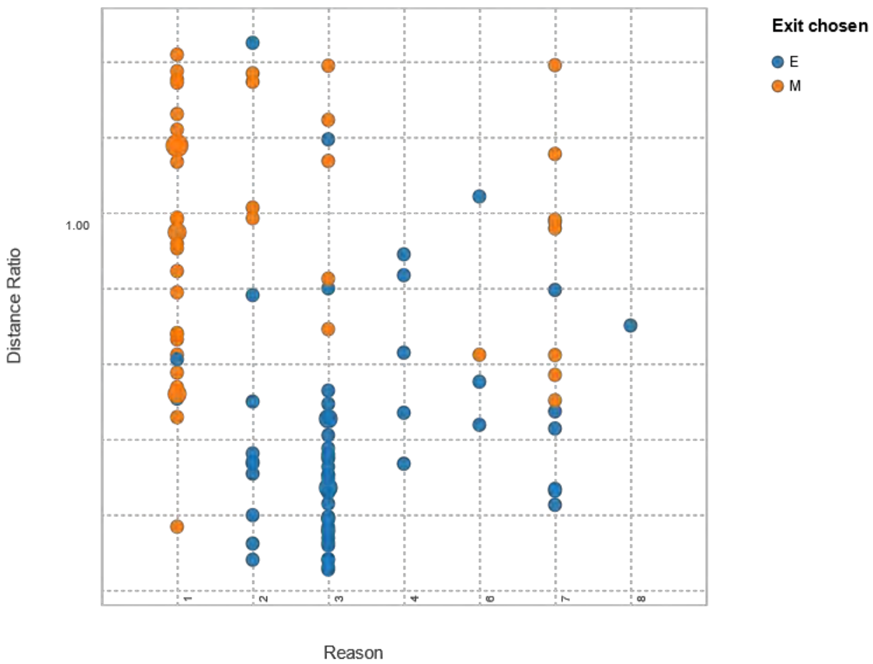


Figure 5.5 (a) Correlation graph (a) Here, Y-axis is the distance ratio, and X-axis shows 0 for not familiar and 1 for familiar to an emergency exit. The blue colour

represents the emergency door, and the orange colour represents the primary exit preference.

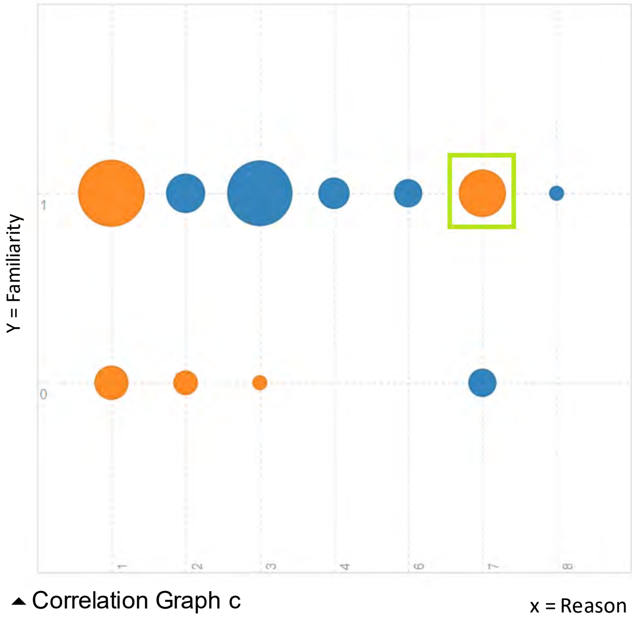
Figure 5.5(a) shows that familiarity with the emergency door increases the opportunity to use this alternate door in emergency time. Figure 5.5(b) shows that the users do not always choose their nearest door for departure. They change their decision regarding social influence, congestion in the nearest door, and warden's instruction. Figure 5.5(c) shows the comparisons among the impact of exit preferences of the evacuees regarding familiarity.

From the statistical and regression analysis, it can be stated that the 'proximity to the door' and 'familiarity with the door' work as the most critical factors affecting the exit preferences of the case studies. Therefore, familiarity with the emergency door can bring significant change in decision making, and bottleneck problems can also be reduced if the users choose the emergency exit by frequently using the main gate.



▲ **Correlation Graph b**

Figure 5.5(b) Correlation graph (b) Here, Y-axis is the distance ratio, and X-axis shows various reasons variables (R1 to R 8). The blue colour represents the emergency door, and the orange colour represents the primary exit preference. It shows the users' choices in a different proximity.



▲ Correlation Graph c

Figure 5.5(c): Correlation graph (c) Here, Y-axis is Familiarity with the emergency exit, and X-axis is the reasons for preference. Here shows that social influence (R7) has a significant role in choosing a different door.

5.4. Simulation analysis

Kinda. et al. (2012) claimed that the agent model is instrumental in acquiring a better understanding of the cognitive basis of natural movement and probably explains navigation and wayfinding. While agents are released from the source (target line drawn by the researcher on the model) after analyzing their surroundings, the system shows a map indicating the movement path by the agents and their preferred choice of the route during evacuation. Figures 5.8 to 5.13 show the agent movement maps and density maps. It represents the agents' movement during fire drill modeling in real-time with the selected exit choice algorithm. Figure 5.6 shows the line colours- *blue, deep green, and dark red* for the target lines (PedSource) of agent release; for the case study of Knittex Industries Ltd. *Light brown* clours are the obstructions of agent movement, and *light green* lines are the exits (*PedExit and Pedsink*). Every *Pedsource* and

Pedsink has different algorithms, according to the research findings. Similarly, in AJ Super Ltd. and Power Tex Fashion Ltd's spatial layout, *the light green, blue,* and *magenta* denote as *PedSource* and the colour *dark green* line as *Pedsink*.

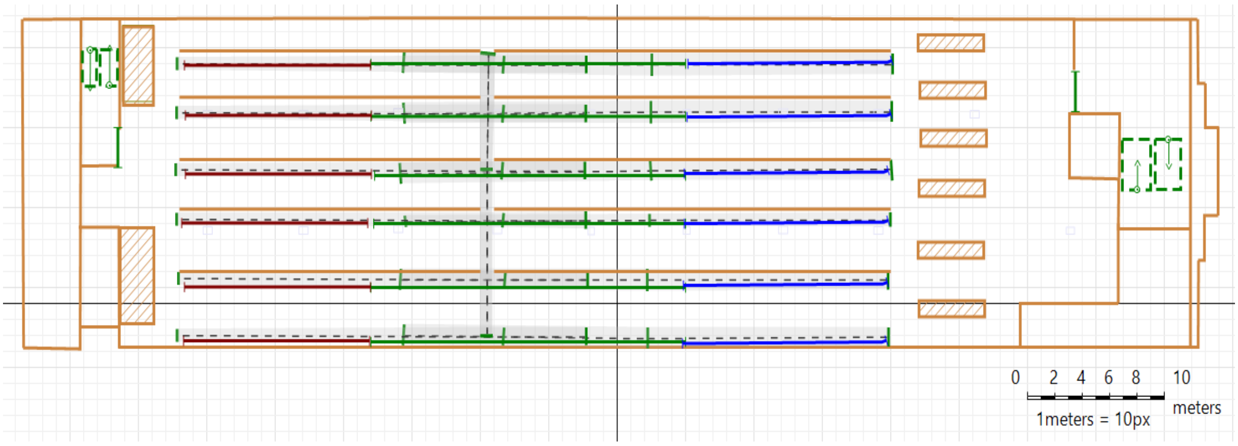


Figure 5.6 (a) Spatial layout of Knittex Industries Ltd (3rd floor plan). Deep green and dark red colour lines are showing as the target line (PedSource) of agent release. Light brown colours are the obstructions of agent movement, and light green lines are the exits (PedExit and Pedsink).

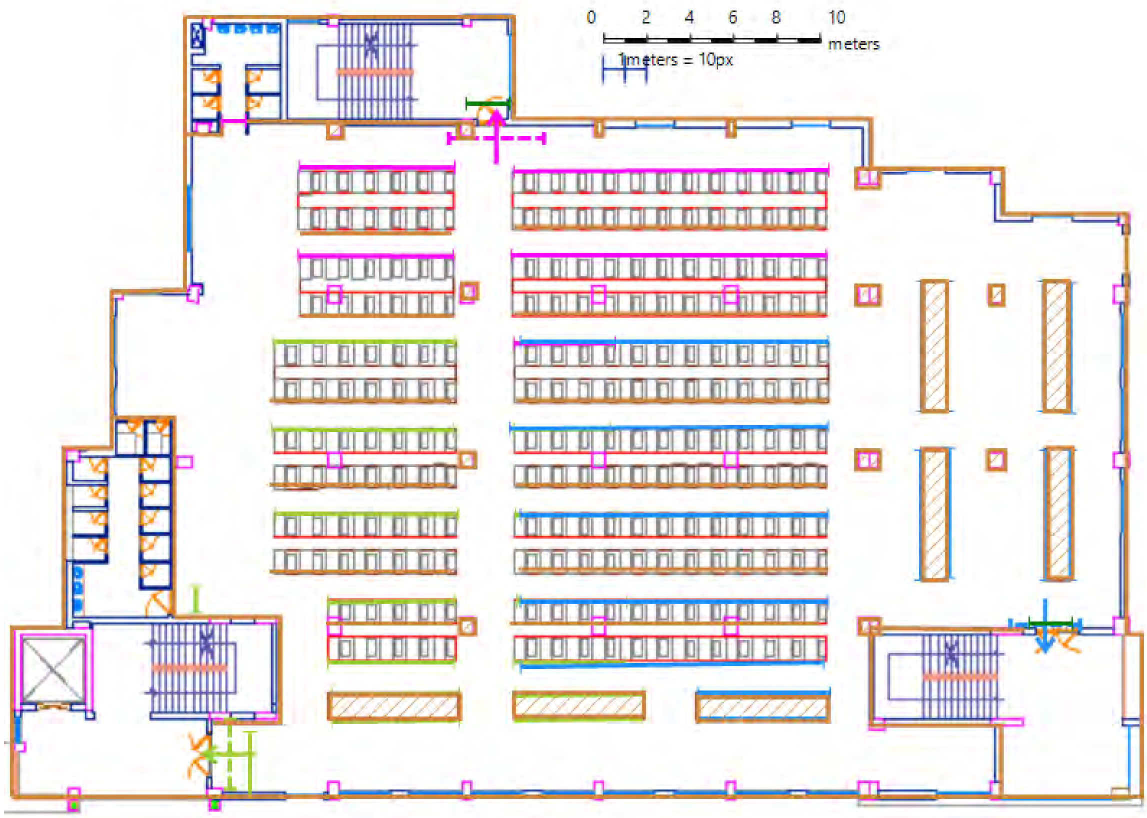


Figure 5.6(b) Spatial layout of AJ Super Ltd. (5th-floor plan). Light green, blue and magenta denotes as PedSource and dotted line as PedSink

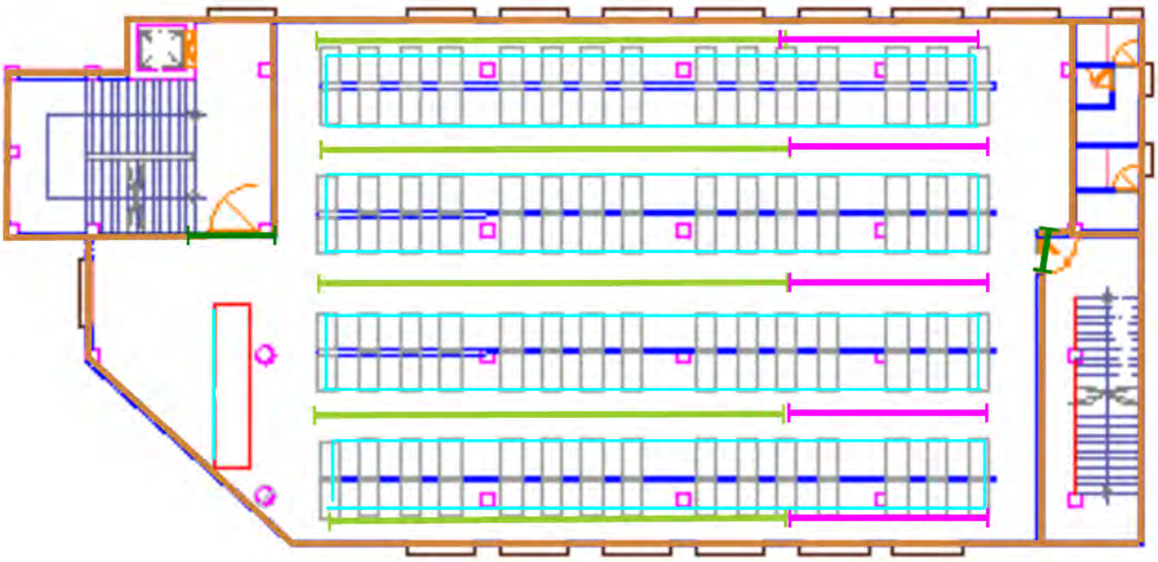


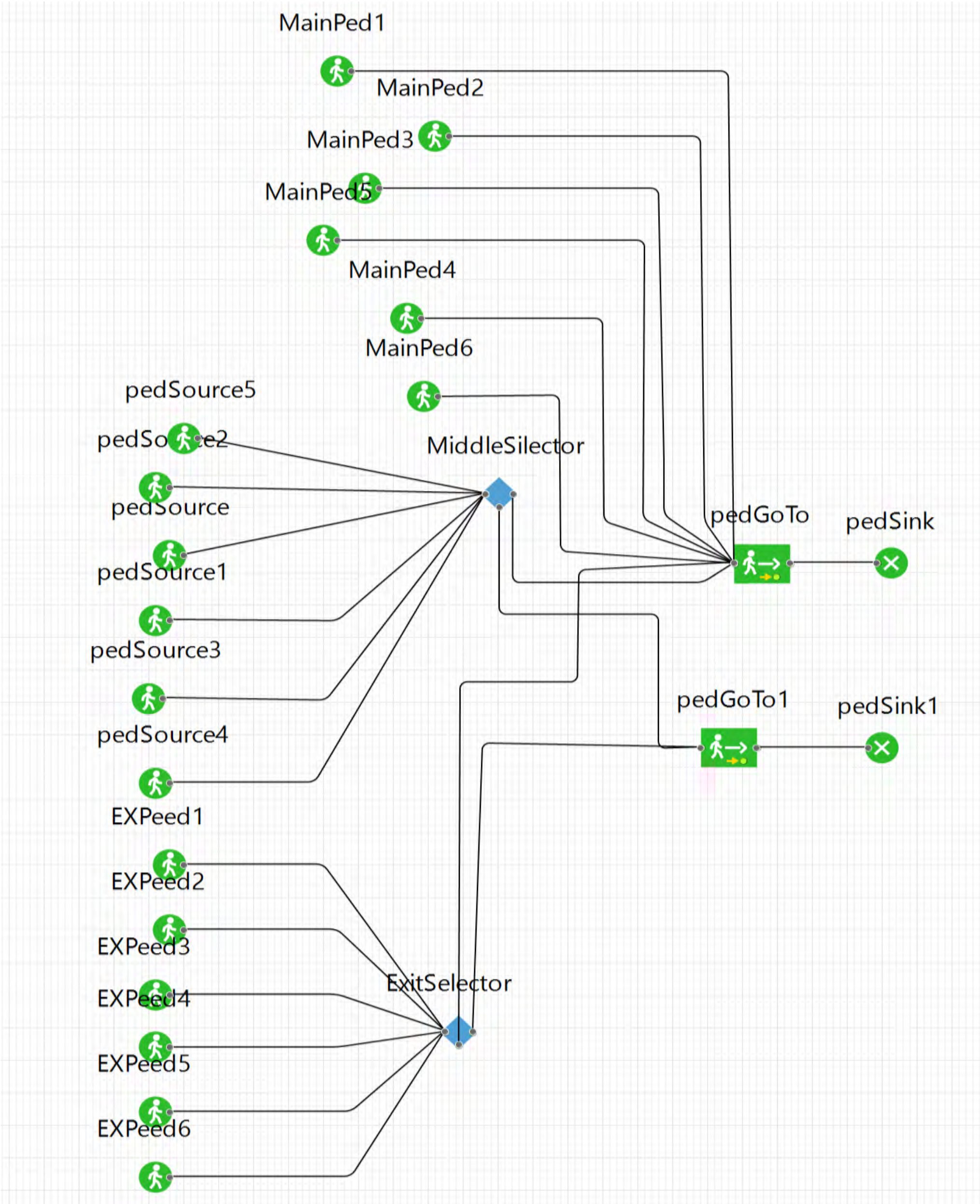
Figure 5.6(c) Spatial layout of Power Tex (4th floor plan). . light green, blue and magenta denotes as PedSource and dark green line as PedSink.

5.5. Movement maps

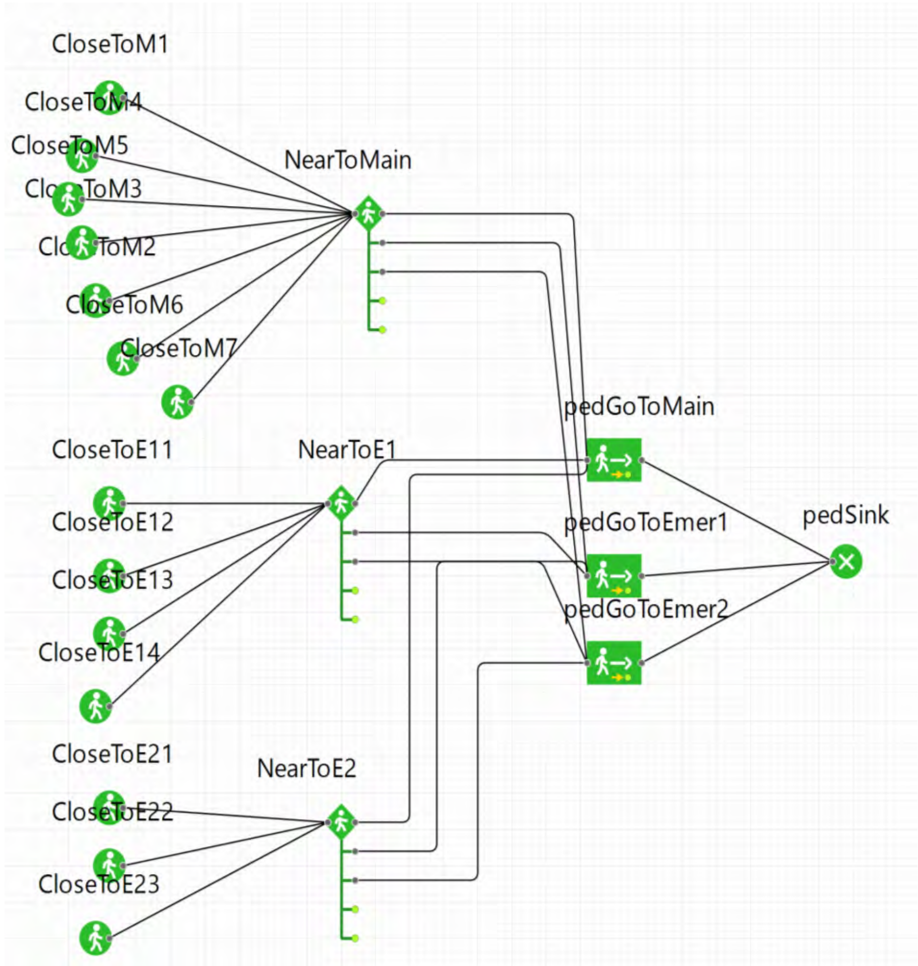
Three cases under study were housed in purpose-built buildings with a functional layout of machines laid by management. The evacuation plans were marked and finally approved by the authority for use. In three case studies, the agent's simulated movement, which follows the probability algorithm in emergency targeting the 'Exit' only, was different from the natural movement, i.e., that movement from every point to every other issue. The agents follow the shortest and the most accessible route—the route to a familiar exit, which data is applied from the regression analysis (Table 5.3). Figures 5.6 (a), (b), and (c) show three spatial layout maps for three case studies. Different colour lines denote the *'PedSource'* and *'PedSink'*; those are mentioned in figure 5.6. The process flowcharts (Figure 5.7) start with the source block *PedSource* that generates new agents. All agents that pass through these flowcharts are of the type 'evacuee'. Having finished the process, agents are not removed from the system, but they leave the flowchart only(via the exit block – *'PedSink'*). In the simulation, the response phase time is not considered. Different time movements (8th, 20th, and 100th second) are displayed here (Figure 5.8 - 5.10). The animation created by the simulation has shown the total evacuation time.

Some time frame of agent movement mapping is explained here to portray the situation. Figure 5.8 (top image with 8th second of the simulation) shows that the agent initially chose an exit and has begun to move. Within 20 sec. (middle image 5.8b) the transverse aisles are crowded. It shows that the agents are not only choosing the nearest exit but also alternate exit because of other factors for exit preference, such as social influence (R7), visibility (R2), the crowd in the other door (R4). The 100th-second image (bottom image) shows more congestion than the emergency exit, which means more people choose the main door for exit.

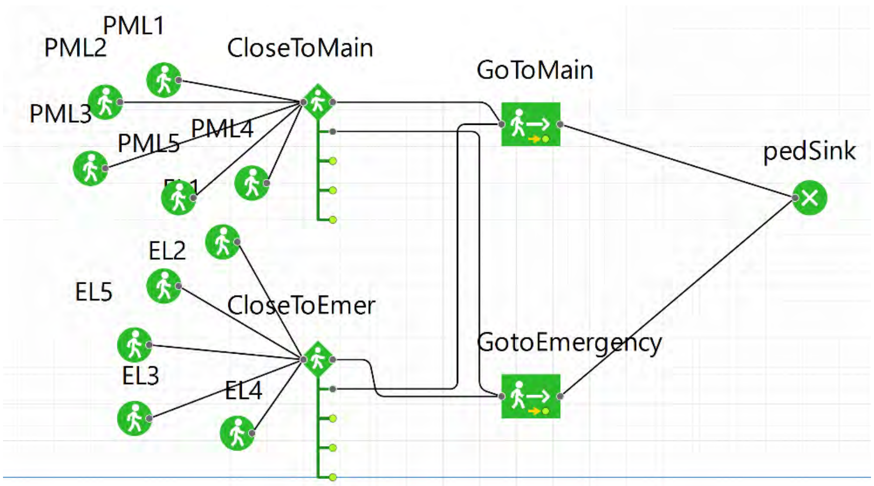
Figure 5.9, case study AJ Super Ltd., shows that the main movement occurs in the middle transverse aisles. The three doors are at the three corners of the layout plan. The people prefer the main exit and emergency 'Exit A' for discharge (main exit 42% and emergency Exit A 40%). That is why the middle transverse aisle carries the maximum movement of people with slower velocity. From the field observation and questionnaire survey, it was found that there was not significant congestion in the exit doors but the transverse aisle. This simulation model also is aligned with this finding. The movement maps show the problematic points of agent movement in the case studies' spatial layout.



a) Flow chart of Knittex Industries Ltd.

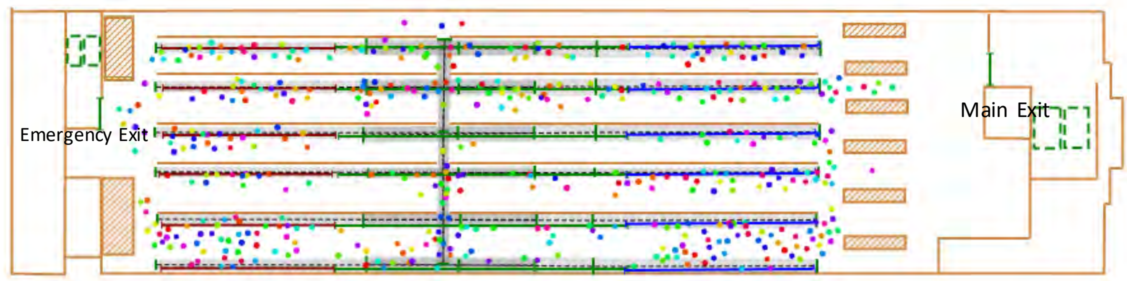


b) Flow chart of AJ Super Ltd.

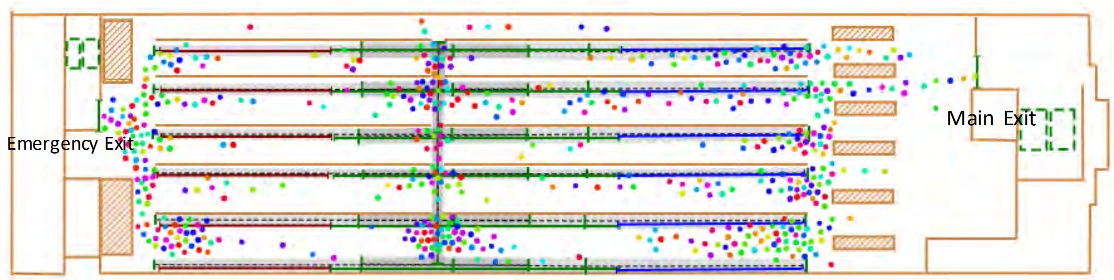


c) Flow chart of Power Tex Fashion Ltd.

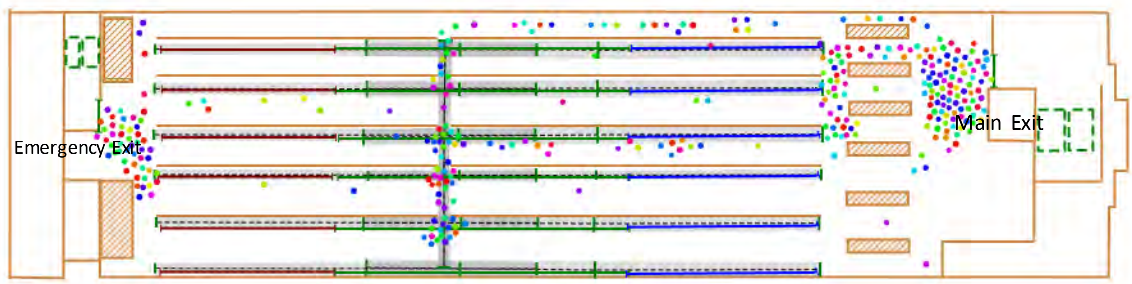
Figure 5.7 Creating flowcharts to define the pedestrian flow for three case studies



At 8th second



At 20th second



At 100th second

Figure 5.8 Agent movement map of Knittex Industries Ltd.

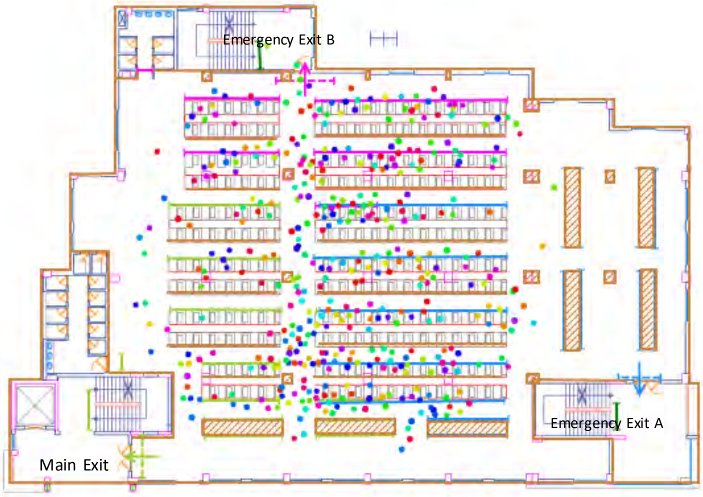
Within the three case studies, Power Tex Fashion Ltd. is the smallest in size. Power Tex Fashion Ltd. has no transverse aisle, and the aisles are narrower (only 1.2 m). Figure 5.10 shows that, when emergency evacuation occurs, both-way movements create, as most agents (70%) prefer the main exit for evacuation to the other case studies. The evacuation time in Power Tex Fashion Ltd. is the shortest. However, it is observed that due to the aisle characteristics stated above, the agent movement is slower. Even there is a lower pedestrian volume at the emergency exit; it has created some congestion in the pathways, which is visible in the 100th-second image of the simulation.

5.6. Density maps

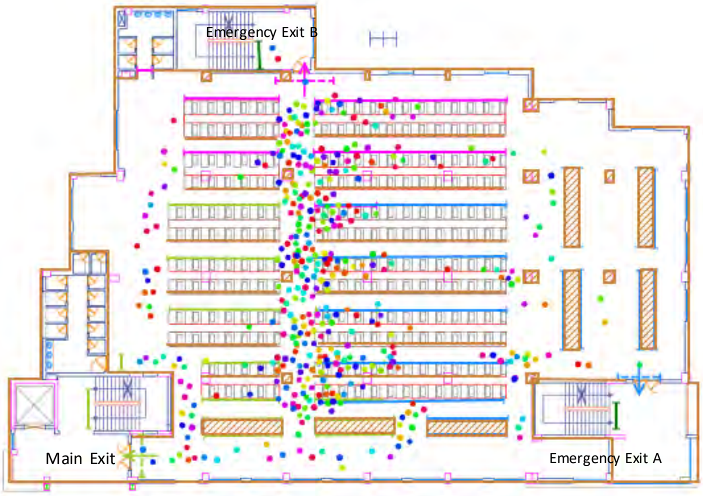
AnyLogic enables collecting statistics on the density of moving units in the simulated space and displaying this information on animation as a density map. Within the same context, the density map is generated in the simulation model of three case studies that show pedestrians' movement in the simulated space by showing the layout, which is gradually painted in different colours from blue to green to red. The colour of every point of the space corresponds to the current density in this particular area. The red colour indicates the critical density (by default, it is equal to 1.5 units/m^2). The blue colour is used for low densities. When the density in some areas is zero, the density map for that specific area is not drawn. In Figures 5.11 - 5.13, the density map of three case studies is displayed. These maps show that the people were oriented to the nearest exits in evacuation modeling simulations to achieve equally balanced exits and other doors due to other preference factors. For further experimental research, it can be shown that blocking any entry in a simulation representing the unused door may result from a hazard and increase the evacuation time. It will also show the changed movement scenario for blocking doors. It can also help shift the exit position, and the sizes of the exits may vary the movement pattern and evacuation time. The average increase in evacuation time for imbalanced exit use compared to the equally balanced use of entries can be found this way. The awareness and control of the evacuation time are vital, which is not considered in the current building codes, standards, and guidelines.

5.7. Discussion

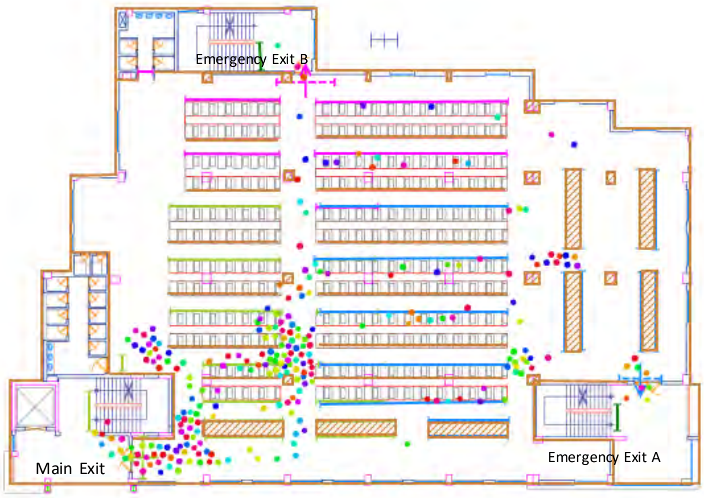
The observations from the simulation analysis of agent movement are discussed at the end of every section, and finally, a comprehensive finding with some suggestions is given here. From the simulation analysis, it can be summarized that the emergency door can not be served as equally balanced to the main door as the users' exit preference creates an impact on the route to the main exit. The assumption of equally balanced use of all the exits by not valuing users' choice in current building guidance can lead to insufficient and unsafe designs that consider incorrectly predicted evacuation times.



At 8th second



At 20th second



At 100th second

Figure 5.9 Agent movement map of AJ Super Ltd.

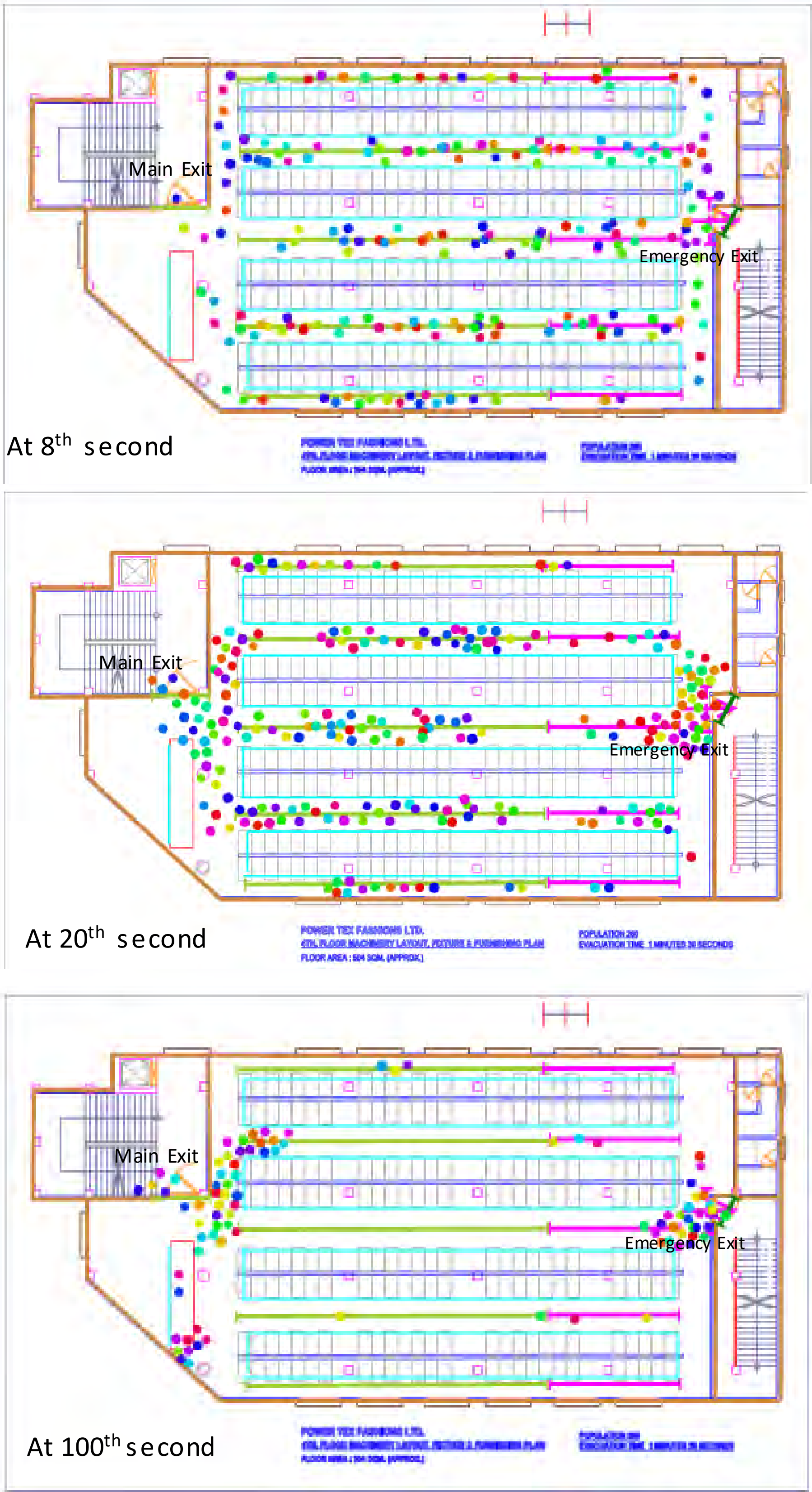
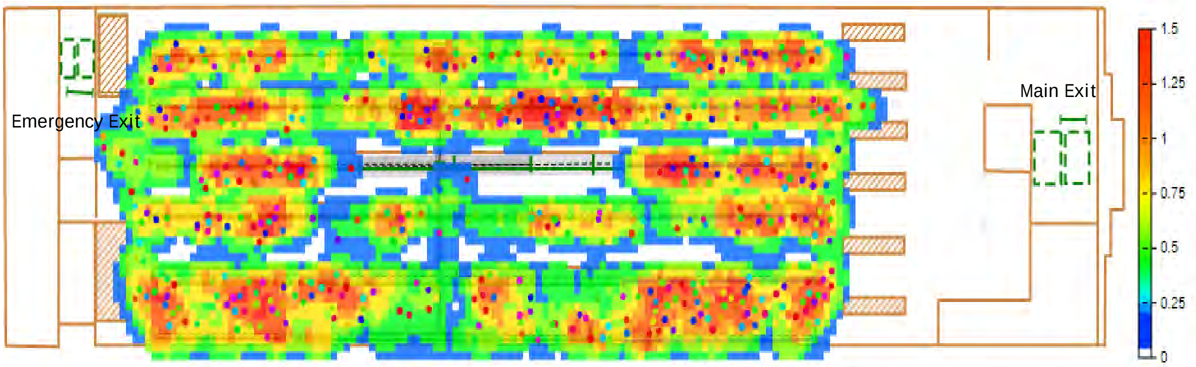
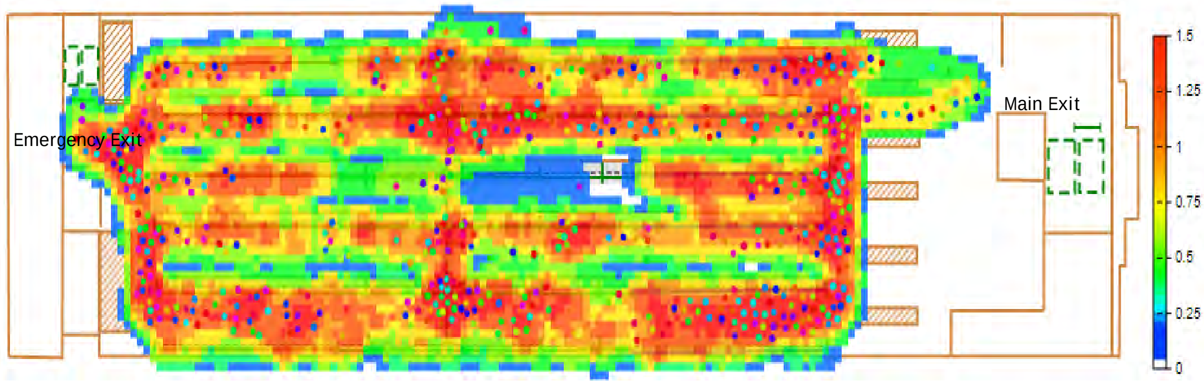


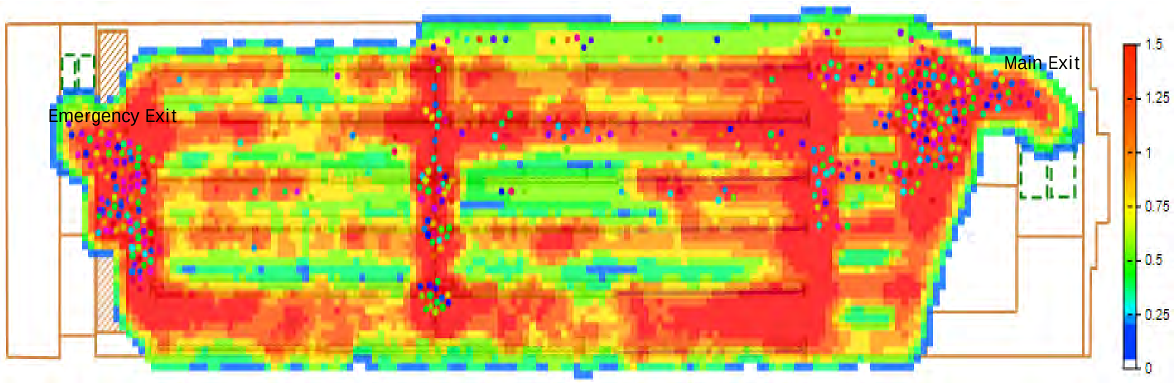
Figure 5.10 Agent movement map of Power Tex Fashion Ltd.



At 8th second



At 20th second



At 100th second

Figure 5.11 Density map of Knittex Industries Ltd. The red colour indicates the critical density (by default, it is equal to 1.5 units/m^2). The blue colour is used for low densities. When the density in some area is zero, the density map for this particular area is not drawn.

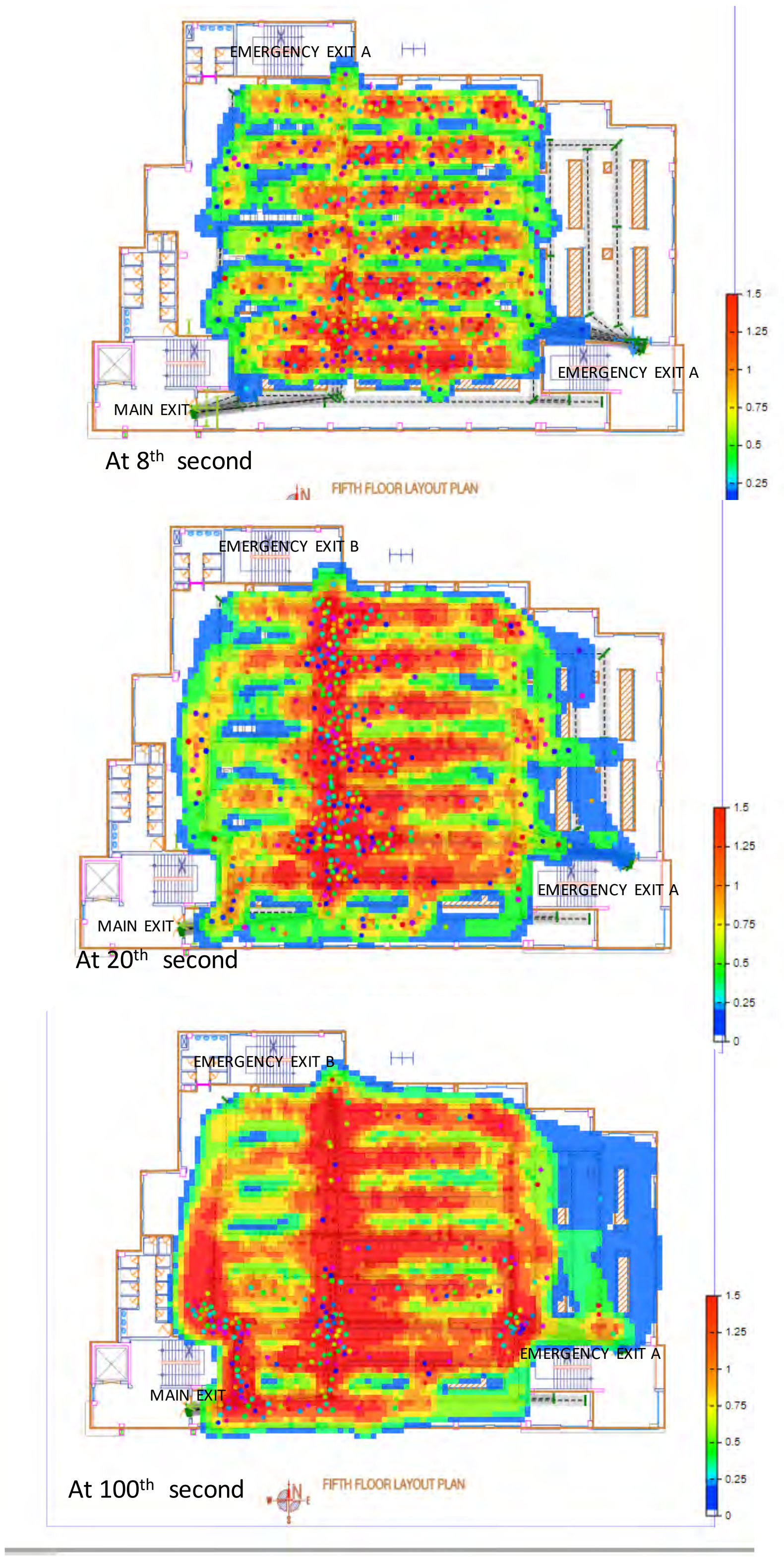


Figure 5.12 Density map of AJ Super Ltd. The red colour indicates the critical density (by default, it is equal to 1.5 units/m^2). The blue colour is used for low densities. When the density in some area is zero, the density map for this particular area is not drawn.

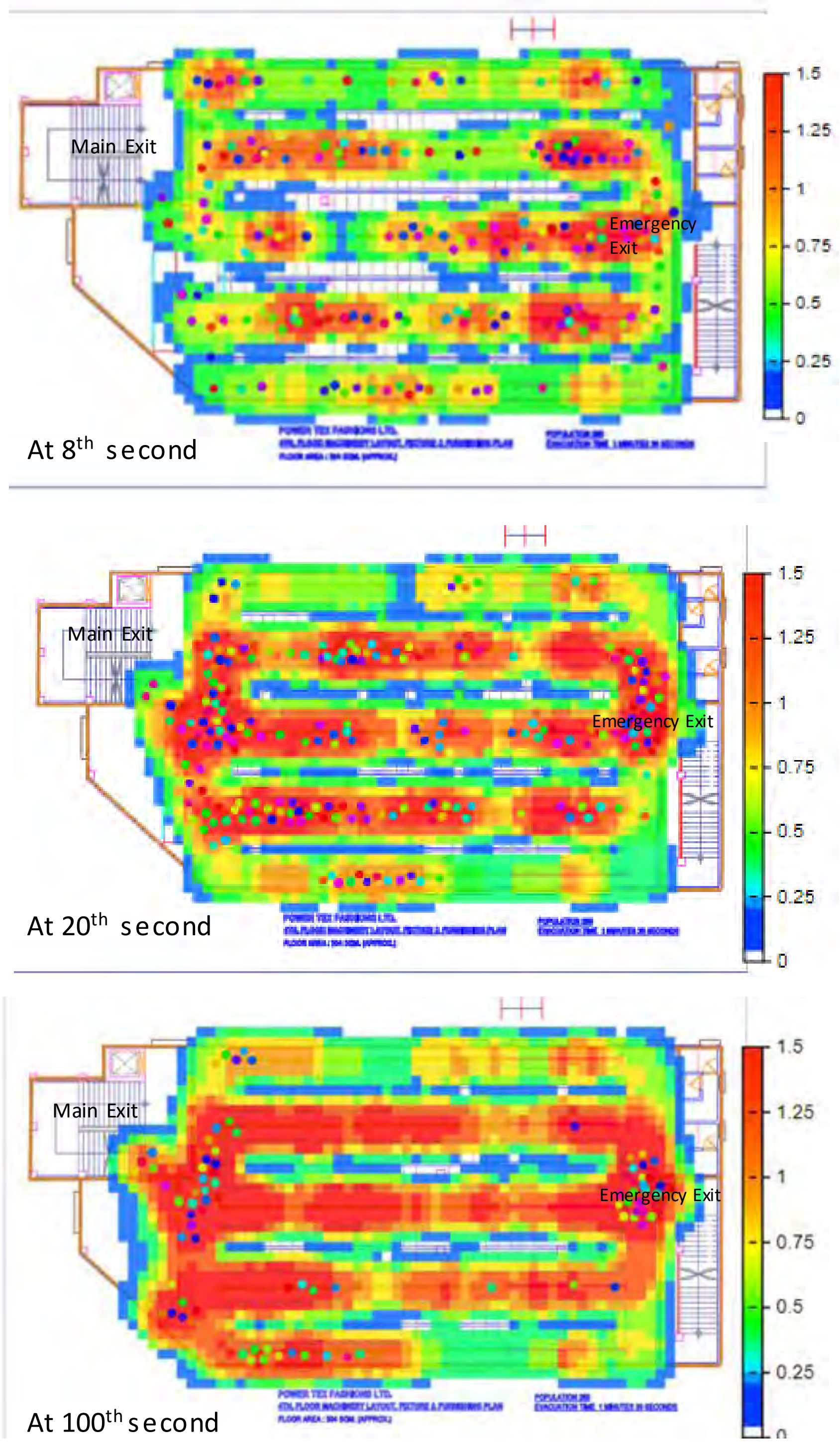


Figure 5.13 Density map of Power Tex. The red colour indicates the critical density (by default, it equals 1.5 units/m^2). The blue colour is used for low densities. When the density in some areas is zero, the density map for this area is not drawn.

- **To make it more effective, the current building code and standards** need to incorporate dynamic measures such as the valuation of users' egress preference.

The current BNBC guideline is inadequate in users' performance-based measure. It's only based on prescriptive-based measure mainly (Section 2.3). Inadequately predicted evacuation times could provide insufficient and unsafe designs. Therefore, there is a need to revise the current building design guidance to encourage designers to use dynamic information regarding 'exit preference based on user behaviour' in an emergency evacuation.

- **To increase evacuation efficiency-** incorporating simulation in the design process to assess a design solution for the current shortfall or future building design as imbalance use of exits increases the evacuation time.

The consultant can incorporate simulation in design procedures to assess design solutions for current shortfalls and specify generic design solution for current and future building design and construction. The graphical representation of the 2D and 3D view of the simulated model can be a very well communicative tool for design analysis for architects, designers, researchers, and clients.

5.8. Summary

This chapter compiles all the data and analytics to identify and validate the critical building design parameters that are important during emergency evacuations. Two analytical models are used here- the regression analysis and the crowd modelling simulation study. The results and findings from the entire research are further discussed in the next chapter.

CHAPTER 6: RECOMMENDATION AND CONCLUSION

6.1. Preamble

The purposes of this study are to develop a methodology to include dynamic building information associated with the interaction of people with each other and with their immediate environment in the building design process. It is imperative to understand the RMG workers' behaviour during an emergency as they are the most vulnerable to the accident. The assumption is not the solution; scientific research on their evacuation behaviour associated with building architecture can help professionals achieve a practical guideline. This chapter concludes this research with the achievement of objectives mentioned in the first chapter, recommendations, scope of further studies, and limitations.

6.2. Findings and Conclusion

The research summarized the literature review on building design issues related to human behaviour in fire, evacuation behaviour, wayfinding, and exit preference during building evacuation. It helped to develop the research methodology of this study. The data is collected by observation of the selected case studies, a questionnaire survey of the workers after an unannounced fire drill, and the interview of the fire expertise of RMG sectors. The achievement of this research's objectives, developed in Chapter 1 (Section 1.3), is discussed in this section. This research aims to create architectural planning strategies to meet the requirements and procedures of adequate crowd safety in evacuation with a focus on the exit preference of the occupants during fire emergencies in the context of RMG buildings of Bangladesh.

6.2.1. Evacuation time and behaviour of RMG workers

The first objective was to observe the evacuation time; factors that affect the evacuation time; and behaviour of RMG workers during a fire alarm. It is achieved through a field survey at three RMG buildings at the Dhaka division with occupancy load ranging from up to 1500 occupants. The study shows that the average pre-movement time of three case studies is 24.33 seconds. The average total evacuation time from the studied floor is 1 minute 43 seconds, and the average total evacuation time from the building is 2 minutes 53 seconds. Another finding from this study is that frequent fire drills can train users for disciple evacuation to reduce the evacuation time. Though it was an unannounced drill, the participants were well trained for quick and disciplined evacuation from their previous experience. The fire wardens - a group of people prepared for evacuation and hazard management, have done their duty to reflect the situation during an actual emergency case. Most workers (61%) shut down their works and got prepared for an evacuation right after the fire alarm as it is their fire drill training (section 4.8).

Factors that affect the evacuation time

The study reveals that the frequently (once in a month approximately) performing fire drills helped reduce the pre-movement time and organize their behavioural response. A frequent fire drill practice can train up the users for disciple evacuation to minimize the evacuation time. Though it was an unannounced drill, the participants were well trained for quick and disciplined evacuation.

Good quality of alarm audibility has an impact on shorter premovement time. Audible alarm (fire alarm), with several sound enhancer devices, helped facilitate the user's attention to start their evacuation activity.

The presence of wardens and the fire drill staff reduced the need for information exchange between the occupants. Staff intervention and monitoring reduce the response time to start evacuation and evacuation time by promptly providing occupants instructions to leave the area.

As a part of fire training, the users are instructed to do specific works right after hearing the alarm, which positively impacts evacuation time and behaviour. The management of building occupants with practice and training of fire drill integrates with visual and audio notification. This practice can be implemented in different occupancy type buildings and hefty user-loaded buildings.

6.2.2. Exit choice of RMG workers during evacuations

The second objective was to identify exit preferences and factors affecting the exit choice of RMG workers during evacuations. It is achieved through a questionnaire survey (Section 4.9) of selected respondents from the selected RMG's production floor and analyzing the data by a logistic regression model (Section 5.3). The most important two factors for exit preference of the users found from this study are 'proximity to exit" *(avg. 40%) (probability to choose main door p= 70.96%, when F=0, β=1; p=47.21% when F=1, β=1)* and "familiarity with the exit" (*avg. 28%) (p= 97% when F=0, β=1; p=97% when F=1, β=1)*. Other than these 'following friends or other people" *(p= 85% when F=0, β=1; p=68.7% when F=1, β=1)* and "visibility to the door" (avg. 12%) *(p= 71% when F=0, β=1; p=47% when F=1, β=1)* and "following warden's instruction" (avg. 5%)*(p= 78% when F=0, β=1; p=57% when F=1, β=1)*. The average F-measure is 0.8462%, Phi-coefficient is 0.72, and Precision is 82.5% for the regression evaluation data. These are the most influencing factors for an individual's exit choice. (section 4.9.6)

The regression analysis is done to gain the probability of using the familiar exit and unfamiliar exit. The logistic regression model represents the odds and the probabilities for studied cases. Substitution of different familiarity levels and other factors of choosing exits with the emergency and primary door distance ratio gives the possibility percentages of evacuees who would use the familiar exit (Section 5.3.3). The ratio of distance to emergency door to the distance to the main door was used to define the distance factor, which substituted various familiarity levels in the percentage of the evacuees who use the main exit. There is a 66% to 97% probability of choosing the main door if the user is unfamiliar with an emergency exit and stands equal from both entrances. However, if he is familiar with the emergency exit with the same condition, the probability of choosing the primary door is 41% to 93%. If the distance ratio is more than 1.5, the probability of choosing the primary exit is more than 99% (average F-measure is 0.8462%, Phi-coefficient is 0.72, and Precision is 82.5%). Within this context, the research continued with an agent-based simulation study to identify how to exit preference can change the evacuation time and evacuee's movement pattern based on the familiarity factor (Section 5.4).

The users also prefer the departure concerning familiarity with the exit and the distance to the exit and for other factors, such as ‘following other people’ *(p= 85% when F=0, β=1; p=68.7% when F=1, β=1)* or ‘following wardens’ instruction’ *(p= 78% when F=0, β=1; p=57% when F=1, β=1)* or ‘crowd in the other door’ *(p= 65.7% when F=0, β=1; p=41.24% when F=1, β=1*) (Section 5.3.3). The user prefers the door for emergency evacuation that they usually use to enter the workplace every day. However, they change their decision to take an emergency exit only if they are nearest to the doors or follow friends or other people or congestion or obstacles on the route. Other than those factors, *‘obstacles in the other door*’ (1%) and *‘following emergency sign’* (1%) were not found to be significant in the statistical analysis of this study.

Factors that affect exit choice

The performance of evacuation is highly dependent on the behaviour and preferences of occupants during the emergency event. The study identified the factors affecting people's exit preferences during emergency events via literature review and case studies within this context. It was found that people's exit preferences are influenced by various factors related to people's interactions with other people and their immediate environment.

The most dominant factors are found - ‘proximity’ and ‘familiarity’ to the exit for users' exit preference.

The users prefer the departure concerning familiarity with the exit and the distance to the exit and other factors, such as ‘visibility to the door’, ‘following other people’ or ‘following wardens’ instruction’ or ‘crowd in the other door.’

Other than those obstacles in the other door,’ and ‘following emergency sign’ were not significant in this study. In this case, the buildings were plentiful, and participants in the evacuation drills used the space every day, so they already knew the location of exit doors. They had an idea and experience in terms of perceived distance to exit doors from their place. It is the reason why visibility and signage were not particularly important in users' exit choices. It is in line with the literature review that population characteristics and routine building use should be considered in the design of means of egress.

The efficient design of evacuation routes and exits can decrease the evacuation time by providing precise and short routes and minimizing the bottlenecks. In this way, safety can be ensured effectively.

When the distance ratio of the unfamiliar exit to the familiar or main exit is more than two, the user prefers the main exit for evacuation though the travel distance is high. Therefore, unfamiliar exits or emergency exits need to place considering proximity.

The literature review found that perceived distance for a person inbuilt environment can change with many factors such as geometry and obstacles on the way when compared with the actual measured distance. It often happens when considering the users' cognitive affordance in preference of exit in large public buildings where they are not familiar with the infrastructure.

Individuals are more likely to use the unfamiliar exit if they are standing nearer to it. If one is standing equidistance to both the main entrance and the emergency exit, it is more likely for her/him to choose the familiar door. Therefore, there is not an equally balanced use of exits during the evacuation process.

The significance of the factors of users' exit preferences are identified in this research can lead the designers to better understand the human behavioural approach in a fire drill. There is a need to revise the current building design guidance to encourage designers to use dynamic information based on occupant's behaviour in an emergency.

6.2.3. Crowd movement for different architectural layout

The third objective was to compare different scenarios and crowd movement for different architectural layouts of RMG buildings. Agent-based simulation modeling has been done using the 'Anylogic' platform to compare different scenarios and crowd movement for different architectural layouts of RMG buildings.

The simulation study validates the statistical and regression analysis findings. Moreover, it graphically represents the emergency movement scenarios of three case studies and identifies the effect of exit choice on different times and the agent's movement patterns. The graphical presentation (snapshot) of 2D animation of agent movement (Figure 5.8 to 5.10) and their density mapping (Figure 5.11 to 5.13) represent a comparative analysis for movement patterns in different

Architectural layout regarding exit preference

From the simulation analysis, it can be briefed that the emergency door can not be served as equally balanced to the main gate as the users' exit preference impacts the route to the main exit. The assumption of equally balanced use of all the doors by not valuing users' choice in current building guidance can lead to insufficient and unsafe designs that consider incorrectly predicted evacuation times.

The large capacity of the main staircase was encouraging, and the limited capacity of the other staircases was discouraging. From this research, it can be stated that these factors work as background knowledge of familiarity to the user; though, the door appearance cannot provide it.

The evacuation modeling software can help test design options to achieve working solutions to increase safety in the building and building design process. The research continued with simulation to identify how to exit preference can change the familiarity factor's evacuation time within this context.

The summary of this research's key findings concerning the objectives, methodologies, and concerned chapters is presented in Table 6.1.

6.3. Recommendations

From this research, the following specific and general recommendations are drawn to develop architectural design strategies to meet the requirements and procedures for adequate crowd safety during evacuation, focusing on the exit preference of the occupants during fire emergencies in the context of RMG buildings of Bangladesh.

To reduce the evacuation response time - different active devices can be installed. These may be a dynamic fire alarm system (e.g., notification appliances or voice evacuation messaging), visual means for identity exits (e.g., usually signage and flashing lights for smoke), and horns or voice evacuation speakers over exit doors. It can be installed to seek occupants' attention.

Table 6.1 Key terms and concepts: Summary of the key findings of the research concerning the objectives, methodologies, and concerned chapters:

Objective	**Methods**	**Chapter**	**Key findings**
Objective 1: To observe the evacuation time, factors that affect the evacuation time and behaviour of RMG workers during a fire alarm.	Field investigation	*Chapter 4*	The study shows that the frequent fire drill practice (once a month approximately), sound audible fire alarm, and staff intervention and monitoring reduce the response time to start evacuation and the evacuation time. The evacuees do the specific tasks as part of fire drill training, which also positively impacts evacuation time and behaviour.
Objective 2: To identify exit preferences and factors affecting the exit choice of RMG workers during evacuations	Questioner Survey and statistical analysis	*Chapter 4* and *Chapter 5*	The two most important factors are found in this study are 'proximity to exit" and "familiarity with the exit." Other than these 'following friends or other people" and "crowd in the other exit" are the most influencing factors for peoples exit choice.
Objective 3: To compare different crowd movements for different architectural layouts of RMG buildings	Simulation analysis	*Chapter 5*	The simulation study validates the statistical and regression analysis findings. Moreover, it graphically represents the emergency movement scenarios of three case studies and identifies the effect of exit choice on evacuation time and the agent's movement patterns.

- **To reduce evacuation time -** frequent fire drills and active warden intervention need to be ensured.
- **To increase familiarity with an emergency exit or alternate exit -** provide way guidance design for better accessibility to the egress route.
- **To make it more effective -** the current building code and standards need to be incorporated dynamic measures such as the valuation of users' preferences in the means of egress.
- **To increase evacuation efficiency-** incorporating simulation is necessary for the design process to assess shortfalls and direction for a proposed design.

6.4. Contribution to knowledge

Fire safety needs the utmost importance in the present context of RMG Factories in Bangladesh. This research attempted to suggest a human-centric design approach to address the 'Architectural Layout' and 'Exit Preference' to the national guideline for fire safety. Evaluation could have given good input to BNBC for improvement and directly contributed to ensuring factory building compliance to earn an excepted national target.

6.5. Suggestions for future research

The following are the critical areas that need to be explored in the future concerning developing a possible design strategy for substantial occupant load evacuation.

- This study concentrates only on the medium hazard industry with building open plan and single level. For further research, multi-level, segmented, and sophisticated layouts with different hazard level buildings can be studied.
- Less than 60% of the participants responded to the field observation and questionnaire survey in this research. If a larger sample could be analyzed in an investigation and different case studies could be included, the result

would be more specific and integrated. It could not be possible in the limited scope of this research work. Therefore, the findings of this research can be supported via more evacuation case studies with quantified approaches to produce proposals for developing new and revising current building design guidelines.

- It is possible to gain more specific results for different occupancy type buildings (e.g., schools, shopping centres, schools, mosques, and multifamily residential), different geometries (e.g., circular and rectangular), different sizes of buildings (e.g., buildings with one or two levels or high rise buildings), additional occupants (demographic or socio-cultural deference) or for any other classifications. These classified results were obtained from various case studies that can guide architects and designers, enabling them to compare their possible outcomes.
- The buildings where the users are not very familiar with all the exits, such as a large shopping mall, university campus, retail marketplaces, museum, or prominent religious place, need extra attention to enhance attractive egress design. It will increase the scope of work to the designer in egress design incorporating user's preference.
- This research can also assist in defining deficiencies and addressing failures in current standards and practices. This research can help researchers and developers model and simulate evacuation efficiencies by incorporating the exit preferences and designing new behaviour.
- Analyzing the factors of exit preference and incorporating it with evacuation design can lead an architect to efficient egress design for better building safety and security.

In future studies, the approach proposed in this paper can be used to design a guide for improving evacuation efficiency.

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Appendix A: General requirements for means of egress

FIRE PROTECTION PLAN AND FIRE CLASSIFICATION:

Buildings need to be designed to offer an acceptable level of fire safety and minimize the risks from heat and smoke. The primary objective is to reduce within acceptable limits of death or injury to the occupant and others who are involved in the fire and rescue service to protect the contents and to ensure safety as much as possible for a building.

Occupancy Classification

Every building or portion thereof and land-use shall be classified according to its use or the character of its occupancy as a building of Occupancy A, B, C, D, E, F, G, H, I, J, K, L or M (Miscellaneous) as defined below:

Occupancy A	Residential	Occupancy G	Industrial
Occupancy B	Educational	Occupancy H	Storage
Occupancy C	Institution	Occupancy I	Assembly
Occupancy D	Health Care	Occupancy J	Hazardous
Occupancy E	Business	Occupancy K	Garages
Occupancy F	Mercantile	Occupancy L	Utilities

Fire Protection Plan has to be applied in _

(1) High rise building sections exceeding 20 M in heights.
(2) The building or Building sections classified in the occupancy group J, G, H, K and M which are two or more stories in height with over 1858 sqm per gross floor area or are two or more in height with a total area exceeding 4717 sqm gross floor area.
(3) Building classified as A3 (Flats / Apartments) containing 30 or more dwelling units.
(4) A portion of Building used as mercantile, assembly or institutional for care having gross floor area over 930 sqm.

NOTE: A Fire protection plan shall be signed by the same architect who is signing on the proposed drawings for building approval and any person responsible for the Fire protection design.

The classification of fire is described in the below chart:

Fire classification	**Fire involving materials/equipment**
Fire class: A	Ordinary combustibles such as wood, paper, plastics, clothes etc.
Fire class: B	Flammable liquids and gases such as gasoline, propane and solvents
Fire class: C	Live electrical equipment such as a computer, fax machine etc.
Fire class : D	Combustible metals such as magnesium, lithium, aluminum etc.
Fire class: K	Cooking media such as cooking oils and fats.

GENERAL REQUIREMENTS FOR MEANS OF EGRESS:

1. **In case of level change of Exit access :**

(a) Changes in levels - 533 mm or more walking surface of the means of egress shall be achieved either by a ramp or by a stairway.
(b) For more than 300 mm, then the ramp is a must.
(c) Height of riser: 200 mm is considerable (where a definable person and senior citizen are not allowed to use that riser)

2. **The ratio of a ramp of Exit access:** it can be a ratio of 1:8 (for existing) and 1:12 (for new)

3. **Consideration of tread and riser for Exit access :**
<u>It consists of one step :</u>
(a) Depth of tread: 275 mm (minimum)
(b) Height of riser: 100 - 200 mm
[Source: Dhaka Imarat Nirman Bidhimala – 2008]

Consist of a minimum of two steps :
(a) Depth of tread: 330 mm (minimum)
(b) Height of riser: 229 mm (maximum)
[Source: Bangladesh National Building Code (BNBC)]

4. **Height of all means of egress:** Minimum height of all means of egress: 2.3 M (7'-6") with projections from the ceiling not less than 2.03 M (6'-8").

[**NOTE:** Minimum ceiling height shall be maintained for at least 2/3 of the space or room]

5. Fire watch personnel shall not be assigned other duties.

6. Stairways, passageways, and gangways shall not become obstructed by storage of building materials, tools or accumulated rubbish.

7. Exits shall not be used for any other purpose at any time that would obstruct the intended use of those components during an emergency.

8. Where corridors or passages are components of exits shall not be designed or used as components to supply or return air.

9. The means of exit and exit access in buildings requiring more than one exit shall be artificial lighting.

FIRE-RESISTANCE RATING :

- **The fire-resistance rating of structural elements:** The fire-resistance rating of structural elements, which are widely used in Bangladesh, is provided in the table below as a guideline.

Structural Element	Fire Resistance Rating
1. **SOLID WALLS** (a) 75 mm thick walls of clay bricks (b) 125 mm thick walls of clay bricks (c) 250 mm thick walls	 (a) 0.75 hour (b) 1.5 hours (c) 5.0 hours
2. **RC WALLS** (a) 150 mm thick RC wall (b) 200 mm thick RC wall (c) 250 mm thick RC walls (d) 300 mm thick RC walls	 (a) 3.0 hours (b) 4.0 hours (c) 5.0 hours (d) 6.0 hours
3. **RC SLABS** (a) 100 mm RC slabs with 13 mm cover over reinforcement (b) 150 mm RC slabs with 19 mm cover over reinforcement (c) 200 mm RC slabs with 19 mm cover over reinforcement (d) 250 mm RC slabs with 25 mm cover over reinforcement	 (a) 1.0 hour (b) 2.5 hours (c) 3.75 hours (d) 5.0 hours
4. **RC COLUMNS (1:2:4)** (a) 250 mm x 250 mm with 25 mm cover over reinforcement (b) 300 mm x 300 mm with 25 mm cover over reinforcement (c) 400 mm x 400 mm with 25 mm cover over reinforcement (d) 400 mm x 400 mm with 50 mm cover over reinforcement	 (a) 3.0 hours (b) 4.0 hours (c) 6.0 hours (d) 8.0 hours

- **The fire-resistance rating of exit:** The fire-resistance rating of exit depends on how many stories are connected. These are described in the table below :

Connecting no. of stories	Fire-resistance rating
Three or fewer stories	1.0 hour (minimum)
Four or more stories	2.0 hours (minimum)

NOTES :
(a) Floor penetrated also will be the same fire-resistance rating but will not need to exceed 2 hours.

(b) The rating of the exterior wall of the exit shall extend 3.05 M (10'-0") beyond the ends of the stair structure.

OCCUPANT LOAD :

The number of occupants for which the exit facilities are to be provided shall be computed as follows:

- **No. of occupants = Total gross floor area in sq. meters / 10**
- **The occupant load calculated as above need not exceed one person per 0.3 sqm of usable floor space.**
- **For fixed seats without dividing arms, the capacity shall be taken as one person for every 500 mm of the seat.**

The occupant load, (in several persons for whom means of egress are required), shall be determined based on the occupant load factors in BNBC as follows :

(a) Assembly with tables and chairs: 1.5 sqm (16 sft) per occupant
(b) Assembly without fixed seats: 0.7 sqm (7 sft) per occupant
(c) Offices : 10 sqm(100 SftSft) per occupant gross
(d) Industrial : 10 sqm(100 sft) per occupant gross
(e) Storage : 30 sqm(300 sft) per occupant gross
(f) Hazardous : 10 sqm(100 sft) per occupant gross

FIRE CORRIDOR OR PASSAGE :

- All users have to be reached at an Exit after crossing any fire corridor or passage. But where there is no Exit, then the length of this type of passage will not be more than 10.0 M

- **Width of Fire corridors and passageways:** The minimum width of fire corridors and passageways depends on the occupant's load per floor. Such as _

Occupant's load / floor	**Minimum width of Fire corridor**
(a) More than 50	(a) 1.1 M
(b) 50 or, less than 50	(b) 0.9 M
(c) Occupancy type: D	(c) 2.4 M
(d)Occupancy type: B	(d) 1.8 M

- **Height of Fire corridors and passageways:** A clear height of 2.4 M (minimum) has to be maintained for fire corridors and passageways.

- **Fire rating:** Fire rating for _
  (a) Fire corridor of Exit access: 1 hour (minimum)
  (b) Fire door towards Exit corridor: 1/2 hour (minimum)

RAMP :

- The minimum width of the Exit ramp will be as per the width of the Fire corridor.
- As per the code of ACCORD / ALLIANCE, the minimum width of a ramp shall be 1.1 M (44 inches)
- The Exit ramp ratio shall be 1: 12 (maximum) and shall not exceed 1: 8.
- If the Exit ramp ratio is more than 1: 15, the handrail is a must for both sides.
- The length of the sloping portion of ramps shall be 915 mm (minimum) and 9145 mm (maximum) long between level platforms or landings.
- Ramp approaching basements or any parking structure shall not be credited as an exit ramp when the slope is steeper than 1 in 8.

ASSEMBLY SEATING AND WAITING :

- Seats not fixed to the floor shall be permitted in restaurants and other places, provided that 1.25 sqm of floor space is allotted for every seat, excluding the dancing floor and stage.
- The minimum width of level or ramped aisles shall be as specified below:
  (a) 1.0 M is for seats on both sides of the aisle
  (b) 0.9 M is for seats on one side of the aisle
- The minimum width of stepped aisles shall be as specified below:
  (a) 1.2 M is for seats on both sides of the aisle
  (b) 1.0 M is for seats on one side of the aisle

- The minimum clear gap between rows, measured as the clear horizontal distance between the back of the row ahead and the nearest projection of the row behind, shall be 300 mm.
- For rows of seating served by an aisle or doorway at only one end of the row, the travel path shall not exceed 10.0 M from any seat to the aisle or door. The minimum clear gap between rows shall be increased beyond 300 mm by 15 mm for each seat above 7, but the clear gap need not exceed 550 mm.
- In any assembly occupancy, spectators can wait in the lobby or similar space within the building until seats are available. Exits shall be provided for the waiting spaces based on 0.28 sqm areas per person waiting for space and one wheelchair space for every 100 occupants. Such waiting occupant load shall be added with the main assembly load for calculating exit size for the assembly.

<u>TRAVEL LENGTH :</u>

Travel length depends on two factors:
(a) No. of storied
(b) Occupant's load
The travel length of different types of the building will be as follows :

Building Type	Maximum no. of storied	Maximum occupant's load	Maximum travel length
A1	4	12	23.0 M
A1,A3,A4 & A5	10	4 units / floor (Max.)	23.0 M
B,C,D,E,F & G	2	50	23.0 M
H	1	30	30.0 M
J	1	5	8.0 M

NOTE :

- Only one no. The exit is required for the criteria mentioned above.
- If the occupant's load and travel length cross the limitations mentioned above, it needs two nos—exit doors.
- In Hazardous occupancy (Occupancy: J), travel length should be performance-based but shall not exceed 15240 mm.

For more than one nos. Exit the travel length of different types of building will be as follows :

Building Type	Maximum travel length
A,B,C,D,I & J	25.0 M
F & H	30.0 M
G	45.0 M

As per the BNBC and ACCORD / ALLIANCE code, the travel length of Building type: G-2 (RMG sector) also depends on the system of fire protection. Like _

Travel length	An applied fire protection system
Increased to 60.0 M (200 ft.)	The automatic fire detection system, portable fire extinguishers, standpipe system.
Increased to 120.0 M (400 ft.)	Automatic sprinkler system, automated fire alarm system, portable fire extinguishers.

<u>NUMBER OF EXITS :</u>

The required number of exits shall depend on the occupant load as specified below :

Occupant's load	Minimum number of Exits
Less than 50	One exit
From 50 to 500	Two exits
From 501 to 1000	Three exits
More than 1000	Four exits

NOTE :

- In case of more than one exit, all Exits' positioning has to be far away from each other.
- Any occupant has to be reached at an Exit by using any pathway.
- Minimum of two nos. Exits are required for _
  (a) All types of building if these buildings are more than _
  Ten storied or 33.0 M in height. [As per Dhaka Imarat Nirman Bidhimala – 2008]& 6 storied or 20.0 M in size. [As per BNBC]
  (b) Other types of building (Like Educational, Health care, Industrial, Institutional, Business, Assembly, Storage & Hazardous) have an area of 500 sq.m per floor.

EXIT DOOR :

- Measurement of Exit door : (a) Width : 1.0 M (minimum)
  (b) Height : 2.0 M (minimum)
- As per the code of ACCORD / ALLIANCE, in the case of existing Means of Egress, the door's width will be 0.8 M (minimum).
- No Sliding, Hanging or revolving, Roll down, and Shutter door shall be used as a Means of Exit. If the occupant load of a room is less than 10, sliding doors can be installed.
- All exit access doors shall be of a side-sewing type.
- Both side – sewing/revolving doors shall not be used as a means of exit in assembly, educational or institutional buildings or in spaces with an occupant's load of 200 or more.
- In the case of side - sewing door, if the user number is more than 50 or in a hazardous occupancy, then the door sewing will be outward. Moreover, it should keep in mind, if the door sewing creates an obstacle to the corridor's width, then the narrower width of the passage will be 0.9 M (minimum) in that case.
- Exit doorways shall not open directly on a flight of stairways. A clear area that is more than the door leaf's width as specified in the above (0.9 M) shall be maintained immediately outside the doorway.
- All exit doors shall be openable from the side they serve without the use of a key.

EXIT STAIR :

1. **Width of Exit stair :**

Exit stair's width shall be as follows :

Building Type	**Minimum width of Exit stair**
A1 , A2	1.0 M
A3, A5	1.5 M
A4	As per code of 2 nos. residential units per floor
B (a) user no. up to 150 (b) user no. more than 150	 (a) 1.5 M (b) 2.0 M
E1 , E3 , E5	2.0 M
E2 , E4 , E6	1.5 M
Others	1.5 M

NOTE :

- As per the code of ACCORD / ALLIANCE, the width of Exit stair for Industrial occupancies shall be 1.25 M (minimum), and for Assembly, occupancies shall be 2.0 M (minimum).
- There is only one stair; then, the width must be taken from the higher value between the Exit stair's width and the general stair's width as per code.
- Stairways are serving more than the three-story building that has a capacity of more than ten occupants shall have visual enclosures to avoid any impediments. The stair is used by a person having a fear of height; any arrangement intended to meet this requirement shall be at least 1070 mm in size.
- A single traffic lane shall be calculated at 559 mm, and two traffic lanes shall be calculated 1118 mm in the stairway.

2. **Tread and Riser of Exit stair :**

- Combination of the tread and the riser dimensions shall be such that the sum of the riser height and the tread depth shall be between 400 mm (15.75 inches) and 425 mm (16.73 inches) with a minimum tread depth: 215 mm (8.46 inches) and a maximum riser height: 215 mm (8.46 inch).

- The allowable length of nosing at the tread's outer edge shall not be included in the tread depth measurement. The maximum rise of a single flight between landings shall not be exceeded 3658 mm, and in the case of a large assembly, a total rise of a single flight between landings shall not be exceeded 2438 mm.
- There shall be no variation above 5 mm in the depth of adjacent treads or the height of adjacent risers. The tolerance between the most significant and smallest tread or between the most essential and smallest riser is 10 mm in any flight.
- Alternate tread devices shall be permitted in Monumental stairs, Circular stairs, Curved stairs, Spiral and winders, stepped and rung ladders.

3. **Landing and platform :**

Measurements of landing and platform shall not be less than the stair's width and shall be leveled. But in the case of the straight run stair, the length of landing between two flights will be 1.2 M (minimum)

4. **Consideration of spiral stair :**

(a) Residential areas or spaces with an occupant's load of 5 or less are only the applicable sector for spiral stairs as Means of Escape.
(b) The spiral stair can be used on the mezzanine floor in a residential zone, where the area is not more than 25.0 sq. meters.
(c) Measurement of spiral stair shall be as specified below :

- Width : 650 mm (minimum) [As per Imarat Nirman Bidhimala – 2008]
  660 mm (minimum) [As per BNBC]
- Depth of tread: 200 mm (minimum) [As per Imarat Nirman Bidhimala – 2008]
  191 mm (minimum) [As per BNBC]
- Height of riser: 225 mm (maximum) [As per Imarat Nirman Bidhimala – 2008]
  241 (maximum) [As per BNBC]
- Headroom: 1980 mm (minimum) [As per BNBC]

NOTE: All treads shall be identical. Moreover, the tread depth shall be measured at a point 305 mm from the narrower edge.

5. **Hand rail's position:** The position of the Handrail depends on the width of the Exit stair as mentioned below:

Stair's width	Position of stair's handrail
1.0 M	One side continuous handrail
More than 1.0 M to 2.2 M	Two continuous side handrail
More than 2.2 M	Continuous handrail on both side, including intermediate position.

6. **Consideration of winders :**

(a)Shall be permitted in stairs where occupant load shall not be more than three.
(b) Shall have a tread depth not less than 152 mm and a tread depth not less than 279 mm at a point 305 mm from the narrowest edge.
(c) The clear width of the stairs shall not be less than 660 mm.
7. **Consideration of Alternate tread device :**

(a) Condition of applicability: Where the occupant load shall not exceed three.
(b) The handrail shall be provided on both sides of alternate tread device having a clear width: 432 mm (minimum) and 610 mm (maximum)
(c) Height of Headroom: 2000 mm (minimum)
(d) The angle of the device shall be between 50 degrees and 68 degrees to horizontal.
(e) Depth of tread: 147 mm (minimum), and each tread provides 241 mm of depth, including overlapping treads.
(f) Height of riser: 241 mm (maximum)

8. **Height of Handrail :**

(a) As per the code of Dhaka Imarat Nirman Bidhimala - 2008, the height of the stair's handrail will be 900 mm (minimum). Moreover, as per BNBC, the handrail height shall be 860 mm (minimum) and 960 mm (maximum).

(b) As per the code of ACCORD / ALLIANCE, the height of the handrail will be as follows :

- For new building: 865 mm (minimum) and 965 mm (maximum)
- For existing building: 760 mm (minimum) and 1100 mm (maximum)

Note: All measurements should be measured from the leading edge of the tread. All exit stairways shall be constructed by materials that conform to the building's type of construction's fire resistance requirements, except that solid wooden handrails shall be permitted for all types of construction.

9. **Guards :**
As per code of ACCORD / ALLIANCE, Guards shall be provided at all open sides of Means of Egress that exceeds 760 mm (30 inches) above the floor or the finished ground below.

The minimum height of guards will be as follows :

- For new building: 1067 mm (42 inches)
- For existing building: 760 mm (30 inches)

SMOKE-PROOF ENCLOSURE :

- An interior stairway (within an envelope) conforming to other egress criteria has to be entered from an exterior balcony or through a ventilated vestibule (a hall/lobby): no direct opening or any aperture allowed on the walls of the stair from the building side.
  [**NOTE:** All exit stairways mentioned above shall be protected by a smokeproof enclosure when serving occupants are located more than 23.0 M above the ground]

- The minimum fire-resistance rating of the walls forming a smokeproof enclosure around the stairway, including the vestibule thereof, shall be 4 hours and separated from the area of incidence having no openings other than a fire door for the entry to the entrance.

- All doors in the smokeproof enclosure and the vestibule shall be a self-closing type, or they shall be fitted with automatic closing devices actuated by the fire detection system.

- The vestibule shall have adequate natural ventilation. Each entrance shall have a minimum area of 2 sqm. It is divided into two in an exterior wall facing a courtyard, street, or public way more packed than 6.0 M. The location of one opening measuring 1.5 sqm shall be as high as possible, and another shall be 0.5 sqm as low as possible.

- If the enclosed staircase and vestibule are windowless, mechanical ventilation shall be installed. Emergency illumination shall also be provided in this case.

FIRE LIFTS :

- Fire lifts, where installed, shall be fully automated from the ground level with all through fire-rated and protected wiring and switches and shall have a minimum capacity of 8 persons.
- Fire lifts shall be operated and maintained by the inmates of the building except during fire. During a fire, Firemen shall takeover to operate such lifts.
- The lift's speed shall be such that it can reach the top floor from ground level (non – stop) within 1 minute.
- Smoke detectors shall be installed at a distance of 3.0 M from every entry door of Fire Lifts and links with a corresponding lift control panel to prevent lift doors from opening in case of fire at any level.
- All lifts in tall structure, stretcher, and hospital lifts. Lifts installed for accessibility shall be operable during a fire.
- The lift lobby shall be connected with at least one fire stair utilizing the exit component.

EXIT OF STORAGE BUILDING :

Minimum of two nos. Means of Exit is required for storage building (Building type: H) if _

- The user number of storage is more than 10.
- The floor area is more than 1400 Sq.meter.

SMOKE AND HEAT VENTS :

Smoke and heat vents shall be installed in restricted ventilation areas such as windowless buildings, underground structures, and factories floor spaces of limited ventilation.
Smoke and heat vent size and spacing depends on Occupancy type as mentioned below :

Occupancy Type	**Hazard Condition**	**The ratio of Vent area to the Floor area**	**Maximum Spacing of Vent Centres**
Occupancy: H1	Low Hazard	1: 150	45.0 M
Occupancy: H2	Moderate Hazard	1: 100	36.0 M
Occupancy: J1	High Hazard	1: 30 to 50	22.5 M to 30.0 M
Occupancy: J2, J3, J4	High Hazard	1: 30 to 50	22.5 M to 30.0 M
Occupancy: K1, K3	Low Hazard	1: 150	45.0 M

NOTE :

- The center to center spacing of vents within a curtained area shall not exceed 2.8 H, where H is the ceiling height.
- Minimum vent opening shall not be less than 1250 mm in any direction.

HORIZONTAL EXITS :

- The connection between an area of the building that the horizontal exit serves and the area of refuge or another facility shall be provided with protected openings in 2-hour fire-resistance-rated walls or by an open-air balcony or bridge with protected outlets.
- The horizontal exit shall be protected from the area of incidence by a self-closing type fire door.
- When the horizontal exit is used from one side, then the exit door shall be outward. Moreover, when used from both sides, the exit door shall be operable, or two separate exit doors must be installed.
- The width of this exit shall be 1.0 M (minimum).
- In the case of a ramp for horizontal discharge pathway, the ramp's ratio shall be 1: 12 (maximum), and single-step shall not be allowed in this case.
- The floor area of the refuge will be as follows :
  (a) 0.28 Sq.meter area is for per healthy occupant and 0.30 Sq.meter per wheelchair
  (b) In the case of Building type : D, where patients exist, the refuge area shall be 2.8 Sq.meter per bed.

EXIT DISCHARGE :

The exit discharge shall be at grade or provide direct access to the stage. Exit discharge shall not re-enter a building. The exit discharge unless meeting the requirements of the following:
Egress court: An egress court serving as a portion of the exit discharge shall be open to the sky or provided with a fire-resistance-rated enclosure the same as the exit enclosure. Egress courts less than 3050 mm (10'-0") in width (as measured from the building and the adjacent property line) shall be provided with walls having a 1-hour fire-resistance-rated construction for a distance of 3050 mm (10'-0") above the floor of the court.

Interior building exit discharge: A maximum of 50 % of the number and capacity of the exit enclosures can discharge through areas on the level of exit discharge where all of the following are met :

- Automatic sprinkler protection is provided throughout the exit discharge level or portion of the discharge level, separated from non-sprinkler parts of the floor by fire barriers with the same fire-resistance rating as the exit enclosure.
- The interior discharge is not through storage or hazardous occupancy.
- The entire exit discharge area is separated from areas below by construction having a fire-resistance rating not less than that required for the exit enclosure.
- The way to the exterior shall be free and unobstructed and shall be readily visible and identifiable from the interior exit point of discharge.

Appendix B: Drill assessment for the case studies

AJ Super Garments Ltd

Pre-drill assessment

1.	Location of drill	Factory premises
2.	Time: drill initiated	Date: 22/1/20 Time: 10:30 am
3.	Duration of drilling period	30 minutes
4.	Number of total persons present in the time of drill in the building	980
5.	Number of total workers in the studied floor present in the time of drill	420 (274 F, 146 M)
5.	Weather condition:	☑ Cold ☐ warm ☐ Hot
6.	Wind:	☑ Calm ☐ Breezy ☐ Windy
7.	Precipitation:	☑ Sunny ☐ Cloudy ☐ Rain

Checklists

	PRE-DRILL ASSESSMENT	Y	N	NA
1.	Were instructions given to move to the designated assembly points	✓		
2.	Exits are clearly marked	✓		
3.	Are Emergency Evacuation Plans Procedure posted	✓		
4.	Are Evacuation' Emergency signs are in good condition	✓		
5.	Egress routes properly lighted	✓		
6.	Exit signs are properly illuminated	✓		
7.	Exit doors operating properly	✓		
8.	Have Fire Warden been assigned and trained	✓		
9.	Do Fire wardens have vests or caps for identification	✓		
10.	Have assembly areas been designated and employees trained	✓		

Post drill assessment

	POST DRILL ASSESSMENT	Y	N	NA
	Electrical appliances were turned off	✓		
	Evacuation performed according to plan	✓		
	Was there any significant disruption in the action plan		✓	
	Occupants meet at designated meeting places according to plan	✓		
	Designated meeting places: located at safe distances from building	✓		
	Fire drill incident response team(s) carried out assigned duties	✓		
	Did all alarms work properly?	✓		
	Fire alarm clearly heard in all areas	✓		

Drill assessment

Method of Drill Activation:	☑ Alarm Activation ✓ ☐ PA system ☐ In-House ☐ Word of Mouth ☐ Other

Communication	Yes	No	N/A
Drill preannounced		✓	
Fire department present for drill		✓	

Evacuation	Yes	No	N/A
Elevators / lifts were used during evacuation		✓	
All occupants participated and evacuated	✓		
Occupants evacuated immediately after the evacuation was initiated	✓		
All rest-rooms, conference rooms were checked for occupants	✓		
Person with special need were assisted	✓		
Did fire door operate correctly	✓		
Were all exits used	✓		
Was evacuation orderly and quick	✓		

Bottleneck problem in evacuation route	Yes	No	N/A
Is there any bottle neck problem in the Main staircase		✓	
Is there any bottle neck problem in the emergency staircase		✓	
Is there any bottle neck problem in the main exit door		✓	
Is there any bottle neck problem in the emergency exit door		✓	

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Power Tex Fashions Ltd.

Pre-drill assessment

1.	Location of drill	Factory premises
2.	Time: drill initiated	Date: 22/9/19 Time: 11:00
3.	Duration of drilling period	30 minutes
4.	Number of total persons present in the time of drill in the building	488
5.	Number of total workers in the studied floor present in the time of drill	260, 180 F 64 M
5.	Weather condition:	☐ Cold ☑ warm ☐ Hot
6.	Wind:	☐ Calm ☑ Breezy ☐ Windy
7.	Precipitation:	☑ Sunny ☐ Cloudy ☐ Rain

Checklists

	PRE-DRILL ASSESSMENT	Y	N	NA
1.	Were instructions given to move to the designated assembly points	✓		
2.	Exits are clearly marked	✓		
3.	Are Emergency Evacuation Plans Procedure posted	✓		
4.	Are Evacuation' Emergency signs are in good condition	✓		
5.	Egress routes properly lighted	✓		
6.	Exit signs are properly illuminated	✓		
7.	Exit doors operating properly	✓		
8.	Have Fire Warden been assigned and trained	✓		
9.	Do Fire wardens have vests or caps for identification	✓		
10.	Have assembly areas been designated and employees trained	✓		

Post drill assessment

	POST DRILL ASSESSMENT	Y	N	NA
1	Electrical appliances were turned off	✓		
2	Evacuation performed according to plan	✓		
3	Was there any significant disruption in the action plan		✓	
4	Occupants meet at designated meeting places according to plan	✓		
5	Designated meeting places: located at safe distances from building		✓	
6	Fire drill incident response team(s) carried out assigned duties	✓		
7	Did all alarms work properly?	✓		
8	Fire alarm clearly heard in all areas	✓		

Drill assessment

Method of Drill Activation:	☑ Alarm Activation ☐ PA system ☐ In-House ☐ Word of Mouth ☐ Other

Communication	Yes	No	N/A
Drill preannounced		✓	
Fire department present for drill		✓	

Evacuation	Yes	No	N/A
Elevators / lifts were used during evacuation		✓	
All occupants participated and evacuated	✓		
Occupants evacuated immediately after the evacuation was initiated	✓		
All rest-rooms, conference rooms were checked for occupants	✓		
Person with special need were assisted	✓		
Did fire door operate correctly	✓		
Were all exits used	✓		
Was evacuation orderly and quick	✓		

Bottleneck problem in evacuation route	Yes	No	N/A
Is there any bottle neck problem in the Main staircase		✓	
Is there any bottle neck problem in the emergency staircase	✓		
Is there any bottle neck problem in the main exit door		✓	
Is there any bottle neck problem in the emergency exit door		✓	

BGMEA No - 3999

[illegible] 22/9/19

Appendix C: Questionnaire for workers

Exit Preference Survey

Case Study

QUESTIONNAIRE
FOR WORKERS

________________________ ________________
DATE

Name: ____________________________________

AGE: ________ YEAR SEX: ☐ M ☐ F SEAT: ______________

1. What was your location before the drill?

☐ In my seat ☐ Not in my seat

2. Which exits have you chosen for evacuation?

☐ 1. Main door – which you use for entry /exit every day

☐ 2. Alternative exit/emergency exit A

☐ 3. Alternative exit/emergency exit B

3. Are you familiar with the emergency exits? ☐ Yes ☐ No

4. Were you aware of the emergency signs during the evacuation? ☐ Yes ☐ No

5 Did you follow the fire warden's instruction during the evacuation? ☐ Yes ☐ No

6. What is the reason behind your chosen "Exit" for evacuation?

☐ 1. Because I use it to enter everyday

☐ 2. Because of visibility

☐ 3. Because It was the closest to me

☐ 4. Other door was crowded

☐ 5. Because there were obstacles on the way

☐ 6. Warden told me to use that door

☐ 7. I followed the other people/friend(s)

☐ 8. I followed the emergency sign

☐ 9. Other reason

7. Where did you face the most congestion and crowding during evacuation?

☐ 1. The main exit door of your room

☐ 2. Exit corridor to main staircase

☐ 3. Discharge point of main staircase

☐ 4. The emergency door

☐ 5. Exit corridor to emergency staircase

☐ 6. The discharge point of emergency staircase

নম্বর : ________ - "কর্মীদের জন্য জরিপ প্রশ্নপত্র"

"অগ্নিঘন্টার সময় জরুরি নির্গমণ সময়কালে বহিঃগমন পথের জরিপ"

আর এম জি এর নাম: ______________________________

(দয়া করে নিচের প্রশ্নপত্রের সঠিক উত্তর দিন)

নাম: ______________________________ **বয়স :** ________

লিঙ্গ : ☐ পুরুষ ☐ নারী **সিট নম্বর :** ________

১. আজকে অগ্নিঘন্টা বাজার আগে কোথায় ছিলেন ?

☑ 1) আমি মেশিনে বসে কাজ করছিলাম

☐ 2) আমি মেশিনের বাইরে কাজ করছিলাম

☐ 3) অন্যান্য

২. আপনি জরুরী অগ্নিঘন্টা শুনতে পেয়েছিলেন? ☑ হ্যাঁ ☐ না

৩. ঘন্টা বাজার পর আপনি জরুরী নির্গমণের জন্য কোন দরজা দিয়ে বের হয়ে গিয়েছিলেন ?

☑ 1) প্রধান দরজা দিয়ে অর্থাৎ যে দরজা দিয়ে আপনি রুমে ঢুকেন

☐ 2) অন্যান্য দরজা যা জরুরী নির্গমণের জন্য ব্যবহৃত হয়।

৪. আপনি কি এই রুমের জরুরী নির্গমণ দরজার সাথে আগে থেকে পরিচিত ?

☑ হ্যাঁ ☐ না

৫. জরুরী নির্গমণের জন্য যে সাইন ব্যবহার করা হয় তা কি আপনি দেখে অর্থ বুঝতে পারেন ?

☐ হ্যাঁ ☑ না

৬. আপনি কি অগ্নিঘন্টা বাজার পর ফায়ার কর্মীরা যে পরামর্শ/ নির্দেশ দিয়েছিলো তা মান্য করেছিলেন?

☑ হ্যাঁ ☐ না

৭. নির্গমণ পথের কোন জায়গায় আপনি ভিড়ে আটকে গিয়েছিলেন ?

☑ 1) প্রধান দরজার কাছে?

☐ 2) পেছনের জরুরী বের হবার দরজার কাছে ?

☐ 3) প্রধান সিঁড়ির করিডোরে ?

☐ 4) জরুরী পথের সিঁড়ির করিডোরে ?

☐ 5) প্রধান সিঁড়ির মুখে বের হবার পথে ?

☐ 6) জরুরী সিঁড়ির নিচে বের হবার মুখে ?

☐ 7) কোথাও না

৮. যে দরজা আপনি বের হবার জন্য বেছে নিয়েছেন তার পেছনে কোন কারণটি কাজ করেছে ?

☑ 1) এই দরজাটি আমি প্রতিদিন কাজে ঢোকার জন্য ব্যবহার করি

☐ 2) আমার জায়গা থেকে এই দরজাটাই স্পষ্ট দেখা যাচ্ছিলো।

☐ 3) এই দরজাটায় আমার সবচেয়ে কাছে ছিল।

☐ 4) অন্য দরজায় অনেক ভীড় ছিল তাই আমি এই দরজাটা বেছে নিয়েছি

☐ 5) বের হবার পথে অনেক জিনিসের স্তুপ ছিল, তাই আমি এই দরজাটা বেছে নিয়েছি।

☐ 6) ওয়ারডেন আমাকে এই দরজা দিয়ে বের হবার নির্দেশ দিয়েছিলো।

☐ 7) আমার বন্ধু অথবা অন্য মানুষেরা যে দরজা ব্যবহার করেছে আমি সেটাই বেছে নিয়েছি।

☐ 8) আমি জরুরী নির্গমণের সাইন দেখে এই দরজাটা বেছে নিয়েছি।

☐ 9) উপরের একটি কারণও মিলছে না, আমার পছন্দের কারণ হলো

আপনাকে ধন্যবাদ এই প্রশ্নগুলোর সঠিক উত্তর দেবার জন্য।

Appendix D: Specification of tools and simulation software

BigML machine learning tool

Appendix E: Sample of a consent letter. (Information paper submitted to the workers for their consent)

তথ্য পাতা

গবেষণার বিষয়বস্তু -

বাংলাদেশ তৈরি পোশাক শিল্প কারখানার কর্মীদের ফায়ার ড্রিল অনুশীলনের সময় বহির্গমন পথ নিরূপণে তাদের পছন্দ অপছন্দের কারণ অনুসন্ধান। এ ব্যাপারে একটি প্রশ্নপত্র জরিপ করা হবে।আগ্রহী কর্মীবৃন্দ এতে অংশগ্রহণ করবে। এ গবেষণাটি বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়ের স্থাপত্য বিভাগ এর স্নাতকোত্তর পর্যায়ের শিক্ষা গবেষণার অন্তর্ভুক্ত। প্রফেসর মোঃ আশিকুর রহমান জোয়ারদারের তত্ত্বাবধানে ছাত্রী মাসরিফা আহমেদ ও তার সহযোগীবৃন্দ এই জরিপ কাজ পরিচালনা করবেন। এ ব্যাপারে নিম্নোক্ত তথ্যগুলো আরএমজি (RMG) কর্তৃপক্ষ ও কর্মীদের অবগতির জন্য জানানো হচ্ছে।

প্রিয় কর্মীবৃন্দ,

আপনাদের কর্ম ক্ষেত্রে প্রতি মাসে একটি ফায়ার ড্রিল অনুশীলন হয়ে থাকে। যা যেকোন অগ্নি দুর্ঘটনায় আপনাদের জীবন ও সম্পদ নষ্টের ঝুঁকি কমাতে সাহায্য করবে। দুর্ঘটনাস্থল থেকে দ্রুত ও নিরাপদে বেরিয়ে আসতে পারলে বিপদের ক্ষয়ক্ষতি অনেক কমে যায়। এ গবেষণাটি নিরাপদ বহির্গমনের সময় উক্ত পথের নিরাপত্তা ও উপযোগিতা বৃদ্ধির জন্য করা হচ্ছে। এজন্য কিছু কর্মী প্রয়োজন যারা একটি সংক্ষিপ্ত প্রশ্নপত্র জরিপে অংশগ্রহণ করে এ ব্যাপারে সাহায্য করবেন।

ফায়ার ড্রিল অনুশীলনের সময় আপনি কোন বহির্গমন দরজা দিয়ে বের হয়ে যান এবং কেন ঐ দরজাটি আপনি বের হওয়ার জন্য নির্বাচন /পছন্দ করেন, সে ব্যাপারে আপনার মতামত জানার জন্য প্রশ্ন করা হবে।

আপনি যদি সুইং সেকশনের অপারেটর হন এবং এইমাত্র অনুষ্ঠিত ফায়ার ড্রিল এর আগে আপনি মেশিনের সাথে অবস্থান করে থাকেন, তবে আপনি এই জরিপে অংশগ্রহণ করতে পারবেন।

আপনাদের কর্তৃপক্ষ এই জরিপের সম্মতি দিয়েছেন এবং এটি কেবলমাত্র একবারই করা হবে। এতে অংশগ্রহণ করলে আপনার চাকুরী ক্ষেত্রে কোন অসুবিধা হবে না এবং আপনাকে কোনরূপ ঝুঁকির মধ্যে পড়তে হবে না। আপনার ব্যক্তিগত তথ্য হিসেবে কেবলমাত্র আপনার নাম ও বয়স জানতে চাওয়া হবে। আপনার কোন ব্যক্তিগত তথ্য প্রকাশিত হবে না। গবেষণার সকল তথ্য কেবলমাত্র গবেষকরা জানতে পারবেন এবং আপনার মতামত এমন ভাবে প্রকাশিত হবে যা দ্বারা আপনাকে সনাক্ত করা সম্ভব হবে না। যেকোনো প্রকাশিত তথ্যই হবে সম্পূর্ণ নাম পরিচয়হীন।

প্রশ্নপত্রটি আমাদের দলের লোকেরা আপনাদেরকে বুঝিয়ে দিবেন এবং পূরণ করতে সহযোগিতা করবেন। আপনার কোনো কিছু জানতে হলে দলের লোকেরা আপনাকে সাহায্য করবেন। আরো তথ্যের প্রয়োজন থাকলে যোগাযোগ করবেন – **প্রফেসর মোঃ আশিকুর রহমান জোয়ারদার**, মোবাইল নাম্বার – 01713312397, স্থাপত্য বিভাগ, বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়।

আপনি যদি এই প্রশ্নপত্র জরিপে অংশগ্রহণ করতে আগ্রহী হন তাহলে আমাদের দলের সদস্যকে হাত তুলে জানান। তারা আপনাকে একটি সম্মতিপত্র এবং প্রশ্নপত্র সরবরাহ করবে।

সম্মতিপত্র

আমি নিম্নে স্বাক্ষর এর মাধ্যমে জানাচ্ছি যে, আমি তথ্য পাতাটি পড়েছি অথবা আমাকে পড়ে শোনানো হয়েছে এবং আমি বুঝতে পেরেছি।

আমি বুঝতে পেরেছি যে-

১. প্রশ্নকারী আমাকে একটি সংক্ষিপ্ত প্রশ্নমালা জিজ্ঞেস করবেন। আমার মতামত নেয়া হবে।
২. এই প্রশ্নের উত্তর দেয়াতে আমাকে কোন ঝুঁকির মধ্যে পড়তে হবে না।

৩. আমি বুঝতে পেরেছি, এই গবেষণায় অংশগ্রহণ সম্পূর্ণ আমার ইচ্ছাধীন এবং আমার চাকরী ক্ষেত্রে কোন অসুবিধা হবে না।

৪. এই গবেষণার ব্যাপারে কোন প্রশ্ন থাকলে প্রফেসর মোঃ আশিকুর রহমান জোয়ারদার, মোবাইল নাম্বার – 01713312397, স্থাপত্য বিভাগ, বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়, এর সাথে যোগাযোগ করতে পারব।

নাম

স্বাক্ষর

তারিখ

Appendix F: Additional Calculations

For regression and classification models, the evaluation results are based on the following metrics or measures ((BigML, Inc., 2020):

Accuracy is the number of correct predictions over the number of total instances that have been evaluated.

Precision: the higher this number is, the more one can able to pinpoint all positives correctly. If this is a low score, it can be predicted of many positives where there were none.

Recall: if this score is high, it did not miss many positives. However, as it gets lower, it is not predicting the positives that are there.

F-Measure or F1-score: this is the balanced harmonic mean of Recall and Precision, giving both metrics equal weight. The higher the F-Measure is, the better.

Phi Coefficient: The Phi Coefficient takes the True Negatives (explicitly) into account. Which one is appropriate depends on how much attention it wants to pay to all of those negative examples it is getting right. Phi may be better if those are very important (as they might be in medical diagnosis). If they're not very important (like in trying to return relevant search results), F-Measure is often more appropriate.

Knowing whether these measures are good enough to start making predictions with unseen data is entirely subjective. The researcher will need to decide which level of accuracy he accepts to trust his training model. For instance, imagine one owns a supermarket, and he is purchasing two kinds of products. The fresh ones that need to be sold quickly and other products he does not mind having in stock (he would still like to maintain optimal stock levels, however). In the second case, getting a model with 85% accuracy may be acceptable it. For the fresh products, however, a better value for accuracy might be required.

Table F.1: Average F-measure and Phi-coefficient data for regression evaluation

Positive class: E

TP FN FP TN

ACTUAL VS. PREDICTED	E	M	ACTUAL	RECALL	F	Phi
E	42	7	49	85.71%	0.88	0.72
M	5	33	38	86.84%	0.85	0.72
PREDICTED	47	40	87	86.28% AVG. RECALL	0.86 AVG. F	0.72 AVG. Phi
PRECISION	89.36%	82.50%	85.93% AVG. PRECISION	86.21% ACCURACY		

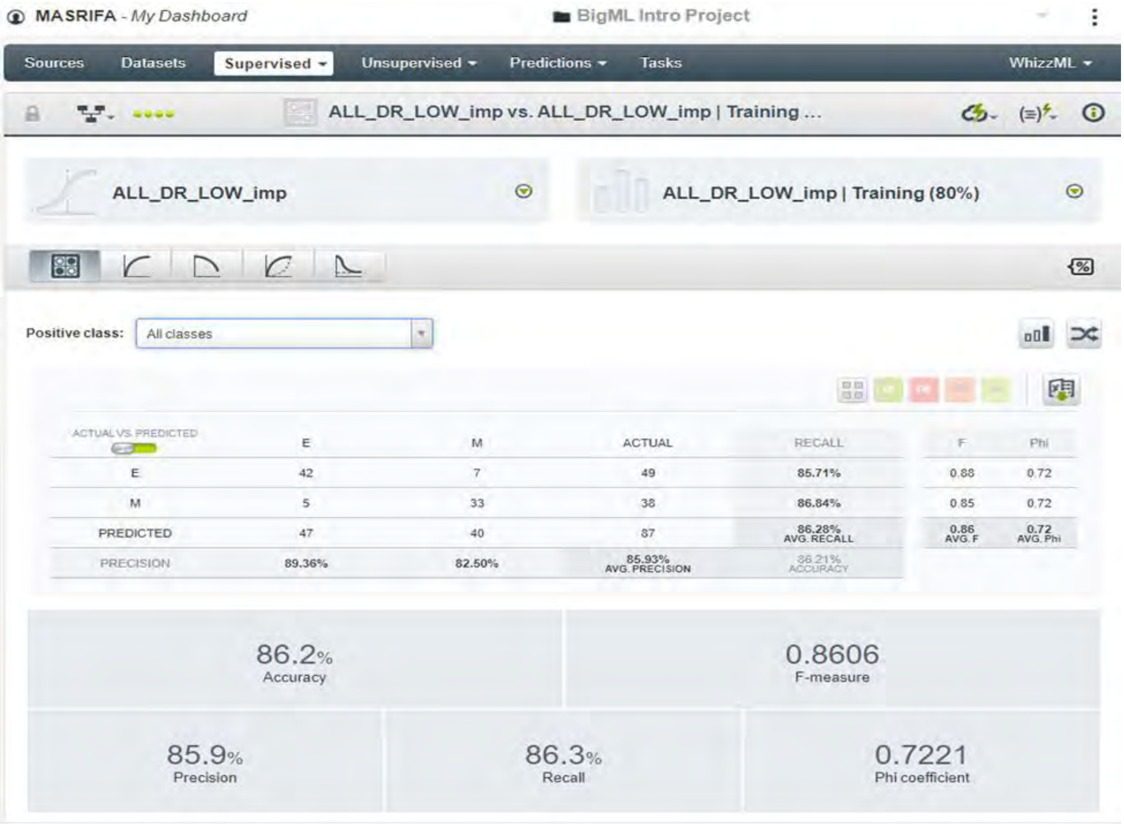
86.2% Accuracy

0.875 F-measure

89.4% Precision

85.7% Recall

0.7221 Phi coefficient



Collected data vs predicted data on BigML dashboard

ALL_DR_LOW_imp vs. ALL_DR_LOW_imp | Training (80%)				True positive		False positive	
ACTUAL VS. PREDICTED				True negative		False negative	
	E	M	ACTUAL	RECALL		F	Phi
E	42	7	49	85.71%		0.8750	0.7221
M	5	33	38	86.84%		0.8462	0.7221
PREDICTEI	47	40	87	86.28%		0.860577	0.722082
PRECISION	89.36%	82.50%	85.93%	86.21%		0.8606	0.7221
						Powered By BigML	

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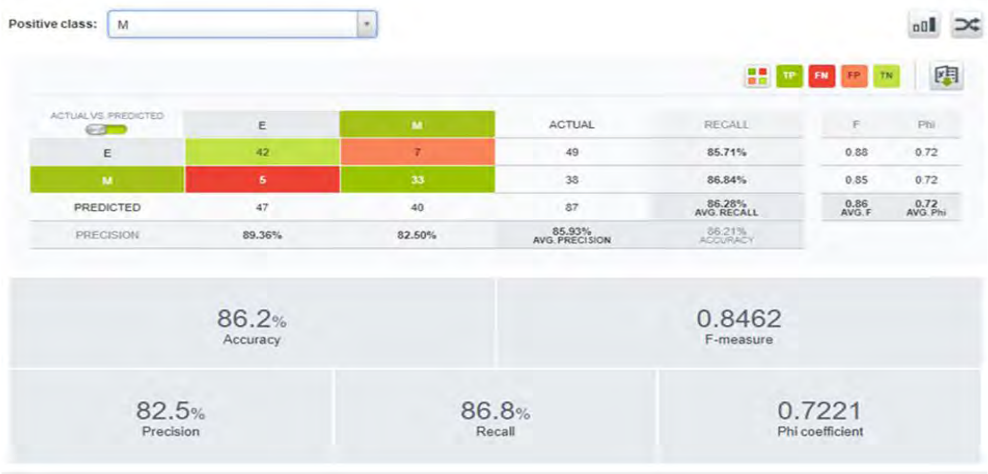

Figure F.1 Regression evaluation result for collected data vs predicted data on BigML dashboard

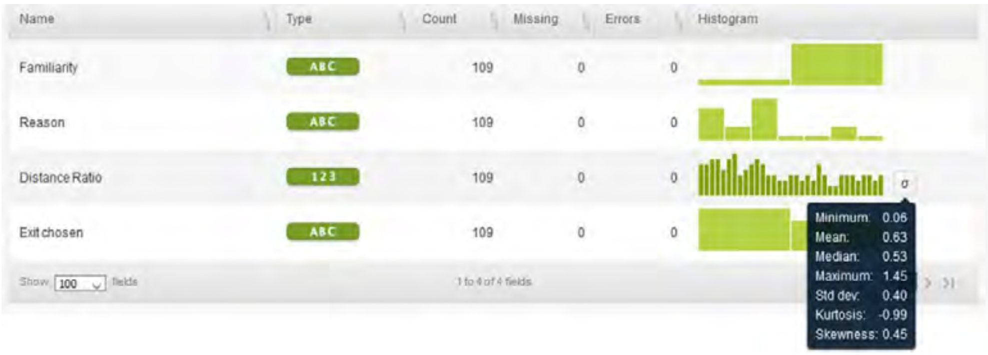

Figure F.2 Histogram of the input data on BigML dashboard