WAY-FINDING AND CROWD MANAGEMENT IN SHOPPING MALL EVACUATION:

A modelling case study of Emporia Mall in Malmö

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Abstract

Becoming more and more important with the passing of time, performance-based design approach is implemented in many complex buildings, e.g. shopping malls, high-rise buildings, industrial facilities, etc. Evacuation modelling, which is the key subject in this study, is one of the main tools used for performance-based design of shopping malls. Including egress simulations of the building occupants, evacuation modelling has different modelling assumptions and modelling input for different types of buildings. Key points employed in the models for shopping malls include the implementation of the data obtained by experiments or drills into the model. The case study for which a great number of simulation studies have been carried out refers to one of the biggest shopping malls in Scandinavia, located in the city of Malmö (Sweden), namely 'Emporia'. A group of hypothetical evacuation scenarios based on the scenarios including locally quickest and shortest algorithm in the current locations of occupants, worst-case scenario and optimal scenario have been simulated. Considering the worst-case scenario and optimal scenario as a benchmark scenario, respectively, the results of egress simulations carried out for different scenarios were compared with the other scenarios. Remarkable differences in the evacuation times were observed for the different scenarios comprising the different evacuation strategies. Additionally, the impact of way-finding and crowd management, particularly staff behaviour on evacuation time were investigated. A considerable difference in the total evacuation time results between the worst-case and optimal scenarios was observed, i.e. the total evacuation time for the worst-case scenario is 40.5% greater than the one for the optimal scenario. A set of recommendations for the design of shopping mall evacuation strategies and improvements of the evacuation conditions were provided.

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SUMMARY

Becoming more and more important with the passing of time, performance-based design approach is implemented in many complex buildings, e.g. shopping malls, high-rise buildings, industrial facilities, etc. Evacuation modelling, which is the key subject in this study, is one of the main tools used for performance-based design of shopping malls. Including egress simulations of the building occupants, evacuation modelling has different modelling assumptions and modelling input for different types of buildings. Key points employed in the models for shopping malls include the implementation of the data obtained by experiments or drills into the model. The case study for which a great number of simulation studies have been carried out refers to one of the biggest shopping malls in Scandinavia, located in the city of Malmö (Sweden), namely 'Emporia'. A group of hypothetical evacuation scenarios including locally quickest and shortest algorithm in the current locations of occupants, worst-case scenario and optimal scenario were simulated. Considering the worst-case scenario and optimal scenario as a benchmark scenario, respectively, the results of egress simulations carried out for different scenarios were compared with the other scenarios. Remarkable differences in the evacuation times were observed for the different scenarios comprising the different evacuation strategies. Additionally, the impact of way-finding and crowd management, particularly staff behaviour on evacuation time were investigated. A considerable difference in the total evacuation time results between the worst-case and optimal scenarios was observed, i.e. the total evacuation time for the worst-case scenario is 40.5 % greater than the one for the optimal scenario. A set of recommendations for the design of shopping mall evacuation strategies and improvements of the evacuation conditions were provided.

ÖZET

Gün geçtikçe önem kazanan performansa dayalı tasarım günümüzde alışveriş merkezleri, yüksek katlı binalar, endüstri tesisleri, vb. karmaşık yapılı birçok uygulamada yer bulmaktadır. Bu çalışmanın ana konusu olan tahliye modellemesi, performansa dayalı tasarımın en önemli unsurlarından biridir. Tahliye modellemesi, bina içinde bulunan kullanıcıların kaçış simülasyonunu içermekle birlikte, her yapı tipi için farklı modelleme varsayımları ve modelleme girdi verileri gereksinimi göstermektedir. Bu çalışma kapsamında, günümüzde sıklıkla sayıları artan alışveriş merkezlerindeki tahliye modellemesinde uygulanan önemli noktalara dikkat çekilmiş, deneyler veya tatbikatlarla elde edilen verilerin modellere uygulanış biçimi hakkında detaylı bilgi verilmiştir. Bu tez kapsamındaki örnek çalışma İsveç'in Malmö şehrinde bulunan, İskandinavya'nın en büyük alışveriş merkezlerinden biri olan ve simülasyon çalışmaları için mimari çizimlerinin kullanıldığı 'Emporia Mall' dur. Bölgesel olarak en kısa mesafe ve en kısa süre algoritmalarını içeren senaryoları, en kötü durum senaryosunu ve en ideal senaryoyu baz alarak oluşturulmuş bir takım varsayıma dayalı senaryoların simülasyon çalışmaları yapılmıştır. Farklı senaryolar için yapılan kaçış simülasyonları ile elde edilen sonuçlar, sırası ile en kötü durum senaryosu ve en ideal senaryo referans senaryosu olarak kabul edilip diğer senaryo sonuçları ile karşılaştırılmıştır. Farklı tahliye stratejilerini içeren senaryolar ile tahliye zamanında anlamlı değişiklikler gözlenmiş olup, yol bulma ve kalabalık yönetimi, özellikle de çalışanların acil durumdaki tutumlarının tahliye zamanı üzerindeki etkisine dikkat çekilmiştir. En ideal senaryo ile en kötü durum senaryosu arasında, toplam tahliye süresi açısından % 40.5 değerinde anlamlı bir fark gözlemlenmiştir. Tahliye şartlarının iyileştirilmesi ve alışveriş merkezlerinde tahliye modelleme tasarımına ilişkin bir takım tavsiyelerde bulunulmuştur.

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List of abbreviations

IMFSE	International Master of Science in Fire Safety Engineering
PBD	Performance-Based Design
NFPA	National Fire Protection Association
IBC	International Building Code
RSET	Required Safe Escape Time
ASET	Available Safe Escape Time
PD	Published Document
SFPE	Society of Fire Protection Engineers
TET	Total Evacuation Time
SD	Standard Deviation
ERD	Euclidean Relative Distance
EPC	Euclidean Projection Coefficient
SC	Secant Cosine

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1. INTRODUCTION

Performance-based design of buildings is getting more and more important for fire engineering applications. Performance-based design is typically used in the cases where prescriptive codes do not sufficiently fulfil the design requirements of the buildings [1]. Evacuation analysis is one of the key issues in the performance-based design. Evacuation modelling tools are used today in a variety of building settings, e.g. shopping malls, high-rise buildings, etc. Evacuation modelling has different modelling assumptions and modelling input depending on the building type. The main issue is the way of implementation of the data obtained by different methods, e.g. experiments, drills, etc. into the model. Apart from the different evacuation strategies, way-finding and crowd management may also have a great impact on evacuation time [2].

There may be many escalators in shopping malls. Since escalators have a variable rise as well as tread geometry, they did not use to be considered as appropriate egress components due to not complying with the regulations/codes [3]. The reason for this, their steps have a great riser height. First, Fixed Guideway Transit committee and Passenger Railway Systems (NFPA 130) [4] gave permission for using escalators at a certain egress capacity (50 %) followed by both Building Construction and Safety Code (NFPA 5000) [5] and International Building Code [6], which permit the use of elevators on condition that the design of elevators fulfil a group of requirements for occupant self-evacuation in an emergency exit [3]. Therefore, elevators are used in buildings as performance-based designs utilizing elevator code requirements. While escalators moving in the direction of evacuation route can continue to work, those moving in the opposite direction should be stopped according to NFPA 130 [5]. In this study, all escalators have been considered to be egress components considering that they also would stop.

In this project, the specific issues associated with the simulation of different evacuation strategies in shopping malls are studied using a computational tool through the analysis of a set of case studies for an existing shopping mall. In the applications of performance-based design, a time based comparison which refers to RSET and ASET calculations is carried out in order to investigate whether the building is safe or not [1]. While RSET, i.e. Required Safe Escape Time is associated with pre-evacuation time and travel time, ASET (Available Safe Escape Time) is related to the tenability limits. If RSET is smaller than ASET, the building can be considered to be safe. ASET calculation is out of scope of this thesis. Apart from the evacuation time, the whole evacuation process, e.g. congestion, exit usage, etc. are analysed. Some hypothetical scenarios are defined, which are the scenarios comprising locally quickest [7] and shortest algorithm methods, worst-case scenario, optimal scenario. While the worst-case scenario represents the most unfavourable conditions due to the occupants following familiar routes and non-use of emergency exits, optimal scenario presents the most ideal situations achieved by successful evacuation strategies. The other scenarios containing locally quickest and shortest algorithm refer to the occupants using the quickest and shortest route in their current locations, respectively. The study of behavioural uncertainty in evacuation simulation results are studied in accordance with the convergence based on simple acceptance criteria. In order to compare the results among different scenarios, a set of operators are used considering a benchmark scenario [8]. Behavioural uncertainty is connected with the stochastic nature of human behaviour and all the occupant behaviour cannot be exemplified by a single simulation or experiment [8]. After discussing and analysing the obtained results, a number of recommendation concerning the use of models as well as improvements of evacuation process are given.

In order to investigate the issues associated with evacuation simulations in shopping mall, a case study has been identified. The case study investigates crowd management and evacuation strategies in one of the biggest shopping malls in Scandinavia, located in the city of Malmö (Sweden), named 'Emporia'. Figure 1 shows an image of the corresponding shopping mall. Having a unique and unusual facade, Emporia has 200 shops, with a total area of 93,000 m^2 and around 25,000 visitors per day. An evacuation drill held in Emporia Mall was observed on the 9th of February, 2016. Some findings observed during the drill have been used as input data in the model. It should be noted that this is a theoretical study aimed at studying shopping malls in general, not only Emporia Mall.

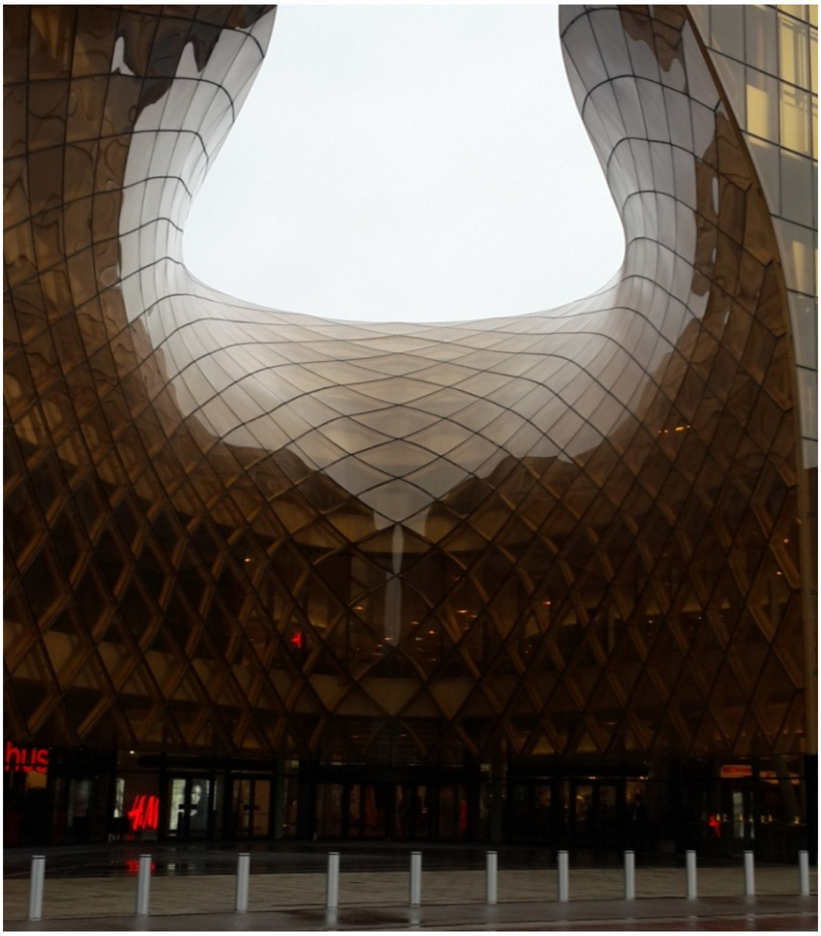

Figure 1. Image of Emporia Malmö

1.1 Objectives

The main object of this thesis is to investigate the use of evacuation modelling for analysing egress strategies in shopping malls. One of the considerably important purposes is to identify and perform simulations of the shopping mall Emporia using evacuation modelling techniques. In order to do that, initially, a set of hypothetical evacuation scenarios in which complex way-finding takes place are provided. The other objectives are to analyse the limitations and advantages of evacuation modelling to perform evacuation analysis in shopping malls as well as compare the impact of wayfinding and exit choices in complex shopping malls in relation to different crowd management and evacuation strategies. The effects of different evacuation strategies, i.e. total evacuation, which refers to the occupants evacuating the building at the same time and phased evacuation, which is associated with the occupants in critical or specified floors or rooms evacuating first followed by those in the noncritical floor/rooms [2], on evacuation time are investigated in order to optimize evacuation time by means of effective crowd management techniques. Additionally, simulated evacuation times, congestion levels and evacuation procedures obtained through the model are analysed and a set of recommendations on the use of evacuation modelling as well as some measures to improve evacuation conditions to for the study of shopping malls are provided.

1.2 Limitations

While the general limitations mainly consist of time and model limitations, the main limitation is the availability of data for calibration of the input. The selection of a model for the simulation might influence the results obtained and produce results with different degrees of accuracy in relation to the embedded modelling sophistication, e.g. different behaviour of occupants, evacuation time, etc. For instance, it is not possible to directly evaluate the coupled effects of fire/smoke on certain evacuation models. Accessibility of the model has also an important role on choosing the model [9].

The model 'Pathfinder' has been used in order to simulate the evacuation. As the effects of smoke cannot be represented directly in Pathfinder version 2015 [7], i.e. reduced travel speed, different exit choices or changing the evacuation route due to the smoke, the scenarios under consideration assume that the occupants were not influenced by negative effects of smoke/fire during their evacuation. Additionally, people in the building have been assumed to evacuate the facilities before the limiting values for critical conditions are exceeded, i.e. evacuating in without being exposed to toxic products, high temperature and radiation, etc. Considering this assumption, ASET calculation has been taken out of context of this thesis.

Since there is no complete information available on the actual evacuation that could take place in the building, the results of the study should be considered only at a general level.

The other main limitation of this work is the time available. Researching the sources concerning this issue might take a long time and the studies carried out so far may not be sufficiently wide-ranging.

2. EVACUATION MODELLING

This section explains the principles and background information of the evacuation simulations conducted within the scope of this thesis.

2.1 Time-line model

Performance-based design is used where the prescriptive codes are not sufficient to implement, e.g. complex and large buildings. Using this approach a time based comparison is made, i.e. RSET and ASET calculations [1]. In order to consider that a building is safe, RSET (Required Safe Escape Time) should be smaller than ASET (Available Safe Escape Time). ASET calculations require defining the tenability limits, i.e. maximum allowable values of visibility, temperature and radiation. RSET calculations are mainly based on pre-evacuation time and movement time. Figure 2 illustrates the simplified schematic of RSET and ASET comparison.

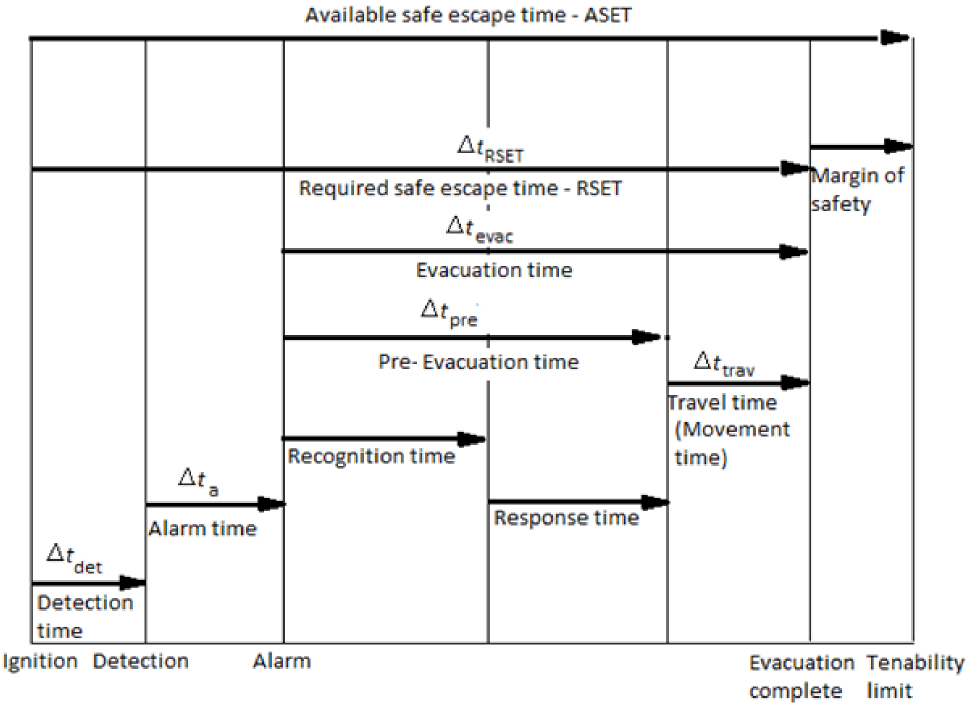

Figure 2. Simplified schematic of RSET and ASET comparison in PD 7974-6:2004 [2] - Redrawn from the original

Simulations provide the total evacuation time (corresponding to the RSET). The Chapter 'Engineering Data' by S.M.V. Gwynne and K.E. Boyce in SFPE Handbook of Fire Protection Engineering [10] and PD 7974 [1] provide a review of available data-sets for pre-evacuation times in accordance to different variables. While PD 7974 recommends the pre-evacuation times in accordance with the building and occupant characteristics, alarm system and fire safety management within a building, Engineering data in SFPE Handbook gives those according to the experiments, drills or fire incidents. Selected pre-evacuation times to be employed to the model are explained in detail in Chapter 4. It should also be borne in mind that the evacuation time is mostly dominated by flow constraints for crowded applications e.g. the shopping mall case study in this thesis, unlike sparsely populated facilities where pre-evacuation as well as movement time are significantly critical [1,11].

2.2 Crowd Management

Crowd management may have a considerably great role in reducing the evacuation time. Occupants in the building, e.g. in super markets, retail stores or shopping malls may not be familiar with the building or fire safety management system. Evacuation time can be decreased by successful management providing well-trained staff to occupants, e.g. residents, visitors, etc. as well as regular drills, well-designed evacuation plan, floor wardens [1].

Crowd management is significantly vital to the Performance-based design applications. Besides, it should be involved in the overall design process so as to meet organizational requirements [12]. Therefore, employers are supposed to choose core crew to take an active role in an emergency situation. They should also provide staff with proper training which should be improved in accordance with the changing demand as well as inspect training and staff performance. [2,12].

2.3 Model Types

There are different types of modelling assumptions used in egress models allowing to estimate the required safe escape time in relation to the space representation. Four main categories can be identified, i.e. course network model, fine network model, continuous model and hybrid model [11]. Each type has its advantages and disadvantages:

- ***Course network models:*** Even though course network models are generally simple and have lower computational cost, they are very user dependent given the use of a grid and user-defined flows [11].
- ***Fine network models:*** Although fine network models are also relatively inexpensive in terms of computational cost as, they are also used for very complex scenarios. However, representing space usage with cells, fine network models results may be grid dependent and occupants movement in this model is overall less realistic [11].

- ***Continuous models:*** Continuous models provide more realistic flows and movement behaviour given the use of a coordinate system to move occupants in space. However, they have a higher computational cost as well as being more program dependent [11].
- ***Hybrid models:*** Hybrid models utilize a mixture of these three fundamental approaches for space discretisation trying to use the benefits of these three methods and increase computational performance as well as give an optimal representation of movements. [13]. In contrast, they may present issues associated with the transition between different modelling approaches [11].

Regarding the overall representation of people, models can be classified into macroscopic and microscopic models:

- ***Macroscopic models,*** e.g. fluid-dynamics models [14], network flow models [15], etc. consider overall conditions taking into account average values to determine evacuation times.
- ***Microscopic models*** take into consideration individual occupant behaviours as well as their interactions [16].

The models can also be classified in relationship to the specific sub-model that they include for the representation of the interaction among occupants:

- Helbing's Social Force Model [17],
- Reynolds' Steering (Flocking or Boids) Behaviours Model [18,19],
- Hydraulic Model [20].

In this context:

- ***Agent based models*** assume that agents can make their decisions individually,
- ***Forced-based model*** assume that movements are influenced by forces.

For example, in the Reynolds' Boids model, the position of each bird is reorganized in accordance with the steering force applied [18,19] while the movement of people is determined by the forces acting on the agents and the activities of the other people or objects around in the Social Force Model [17]. Forced-based models can be integrated with agent based model in which agents can take their decisions individually [21]. While Reynolds employed this approach with the Steering Model, Braun et al. [22] implemented it to the Social Force Model. Hydraulic Model is based on the flow movement described in SFPE Handbook in which walking speeds are adjusted in relation to occupant density [23,20].

2.4 Way-finding

Route choice, in other words, way-finding depends on the attitude of occupants as well as models. Occupants might be individual or arranged in groups as well as being familiar/unfamiliar with the building. Different types of algorithm can be observed in models to solve pathfinding, e.g. flow fields [24] which are used to direct occupants to the exits, potential maps [25] which calculate the movement of occupants to the exits and distance maps [26] which calculates the overall distance to the exit for each point on the spatial mesh. Route choice or exit choice is determined in different ways in models, i.e. distance (e.g. shortest path, distance maps, etc.), optimal time (e.g. quickest path, queuing time, etc.), conditional (e.g. visibility, familiarity, etc.) or user-defined [11]. Shortest way and quickest path may not correspond to the same path. Considering the presence of congestion in the shortest way, another route may be the quickest path.

2.5 Choosing a model

Many factors should be considered when choosing a model. Among these, there is the features/sub-models that the model has. For example, whereas it is possible to observe the fire-human interaction in some models, some do not represent this property. There are also other criteria to be considered for choosing a model. Validation and verification of the models are also considerably important to select a proper model for the intended scenarios [27]. The objectives of the project as well as available information associated with egress analysis should be analysed carefully so that the model can meet the requirements of the specific application [9]. Besides, model availability is also one the key factors on this matter [9,27]. Model availability to users can be in different ways. For example, some models can be free of charge, some can be utilised only by consultancy base for a certain fee, and some can have annual charge or prepaid charge paid only once [28].

The model sources are either open source or closed source. The open source models provide the complete set of equations and assumptions of the model while the closed source does not. Furthermore, model characteristics have a great importance in terms of selecting models, e.g. modelling approach (e.g. conceptual approach associating relationship between processes in terms of theoretical range, movement and behavioural approach based on human movement and behaviour during emergencies, etc.) [9], output data (e.g. textual, visual, qualitative, quantitative, etc.), cost of model, age and generation of model (e.g. teamwork comprise different backgrounds such as psychologists, engineers, etc. or individual), representation (e.g. continuous, network, deterministic, probabilistic, emergency behaviour, evacuation phases, etc.), feedback about the model by other users, etc. [9,27].

2.6 Evacuation strategies

Different evacuation strategies can be implemented into the models. These strategies are as follows [11]:

- ***Total Evacuation:*** All occupants in a building evacuate at the same time causing high densities in stairs and slow movement. For shopping malls, this strategy can be considered to be proper.
- ***Phased or Partial Evacuation***: Occupants in critical or specified floors evacuate first, then occupants in noncritical floor/rooms leave the building. This strategy can be implemented into complex buildings such as high-rise buildings, shopping malls, etc.
- ***Delayed Evacuation***: For a certain time, occupants await assistance, rescue or instructions in refuge areas. This strategy can be appropriate for people with disabilities, particularly in high-rise buildings.
- ***Defend In Place:*** Occupants stay and awaits assistance. This strategy can be proper in some apartment buildings where vulnerable populations may be present.

3. THE EVACUATION OF SHOPPING MALLS

General information about evacuation modelling has been given in Chapter 2. This section gives information about a set of studies carried out in the past regarding evacuation studies or drills in shopping malls, retail stores or big super markets. A set of information obtained by literature review are used as input data which are explained in detail in Chapter 4.

Firstly, relevant factors affecting human behaviour as well as evacuation process should be investigated carefully. These factors can be classified into 3 categories: occupant, building and fire characteristics [29]:

Occupant characteristics:

- gender,
- age,
- movement capability,
- familiarity with the building,
- knowledge about fire safety training,
- alone/with others,
- visitor/staff/employee,
- influenced by others, etc.

Building characteristics:

- architectural features (e.g. location of exits, wayfinding complexity , number of floors, etc.),
- building activities (e.g. working, sleeping, shopping, etc.), fire safety features (e.g. fire safety plan, alarm, voice communication system, trained staff, etc.), etc.

Fire characteristics:

- visual (e.g. flame, smoke, etc.),
- aural (e.g. cracking, broken objects, etc.),
- olfactory (e.g. smell, etc.)
- other (e.g. heat, etc.) cues.

All these factors are crucial for the definition of evacuation modelling inputs. Therefore, in order to acquire the required information relevant to this matter, a literature review should be carried out.

The SFPE Handbook chapter on Engineering data [10] presents a large number of data-sets, e.g. pre-evacuation times, walking speeds, etc. have been collected by reviewing previous studies and it is one of the fundamental sources used in this thesis. A study of evacuation from large retail stores conducted by Shields and Boyce [30] is also one of the key studies in which unannounced evacuations of four different retail stores in UK were analysed. Hidden video cameras and questionnaires prepared for customers were used. Although this study gives considerably crucial information about evacuation studies in retail stores, customer profiles in this study may not representative for this thesis. For instance, the average percentage of females, children and elderly people was given as 80.6 %, 1 % and 37.9 %, respectively. Therefore, different costumer profiles were used in the model for a more realistic and representative approach. The percentage of different occupancy groups are given in Chapter 4. In contrast, pre-evacuation times observed in this study can be representative for the model and these figures also have been given in SFPE Handbook chapter on Engineering data [10].

Another study about staff behaviour in unannounced evacuations of retail stores [2] showed that staff behaviour has a dramatic influence on customer evacuation as well as their exit choice. In order to investigate this issue, a set of scenarios are identified and analysed, e.g. occupants may use the familiar routes, the nearest exits when directed by staff, optimal evacuation strategies implemented by successful management, etc.

Some safety precautions which should be taken by management of such facilities were proposed in a study of evacuation in a case of Large Supermarket in China [31]. As the percentage of each occupancy type in this study can be considered to be more representative of the present case study, some numbers were used as input data.

Data on walking speed and occupant load used in the model case study are presented in Chapter 4.

4. A MODELLING CASE STUDY OF EMPORIA MALL IN MALMÖ

This section explains the input data obtained in the literature review for the model case study. In addition, information on an evacuation drill performed in Emporia Mall has also been employed to perform the model calibration. This section also gives information about the defined scenarios and also simulation of those.

4.1 Building Description

The case study refers to one of the biggest shopping malls in Scandinavia, located in the city of Malmö (Sweden), named 'Emporia'. Having a unique and unusual facade, Emporia has around 200 shops, with a total area of 93,000 m² and around 25,000-32,000 visitors at weekends. Figure 3 shows a front view of Emporia. It is three-storey building and the height of each floor is 6 meters. Level 0, Level +6 and Level +12 in the model refer to lower ground floor, upper ground floor and level 1 (first floor), respectively. The building has an automatic detection and voice message system. Escalators have been using as egress components since some codes, e.g. NFPA 130 [4], NFPA 5000 [5] and IBS [6] permitted the use of those in different types of buildings. There are many escalators which can be used as escape routes within the building assuming that they all stop in an emergency situation. Elevators are used only by people with movement disabilities in an emergency situation, i.e. elderly and disabled people in accordance with Emporia's strategy. The multi-storey building has two entrances: one located on lower ground floor and one on upper ground floor. Swing-doors in the main entrance stop in case of emergency and occupants evacuate the building via exit doors next to the swing-doors, which can be seen in Figure 9 in Section 4.9. Multi-storey car park next to the building is outside the scope of this project. Escape routes, emergency exits and escape stairs in the plans provided by Emporia were used for the simulation of evacuation of occupants within the building in hypothetical scenarios. Detailed building configuration with gross and net areas, occupant loads for each sub-areas, description of area usage, etc. and detailed description of each exit available with their widths has been given in Appendix A and Appendix B, respectively.

4.2 Fire drill in Emporia Mall

An announced drill was held in Emporia Mall around 8.15 am on the 9th of February, 2016 as part of the evacuation training routines in the shopping mall. Researchers at Lund University were invited to be observers of a drill which can be useful to increase the understanding on a possible evacuation in the building. There were also instructors from the Rescue Service South and facility attendants, security guards, shop staff, cleaning staff and a small number of customers during the exercise which was not a full drill with all people in there. Information about evacuation drill to be held on that particular day had been given to all stores before. Two stores were open to the customers during the drill since the activity was performed before the opening time of shops. Although an artificial smoke machine was used to produce smoke, staff had no knowledge of this. The smoke machine was placed on both lower and upper ground floor. The procedure required staff to take on reflective vests guiding customers to the nearest way out. Then the shutters were closed down and the staff went out to each assembly point located on the lower and upper ground level. First, smoke was generated into the building and the alarm was activated manually using the alarm button 4 minutes later. Following the fire alarm as well as a voice message of 'There has been a fire reported in the building. Please proceed to the nearest exit and leave the building', evacuation started. The time between the fire alarm and start of the evacuation was about 1 minute.

An issue of particular importance in building evacuation drills and in general with the evacuation of shopping malls is that staff and customers tend to use familiar routes and exits rather than emergency exits. One of the main purposes of evacuation drills is indeed to train staff and customers in using emergency exits appropriately. During the drill, different behaviours were observed: whereas some people went through the smoke, some turned around and chose another way. It was also possible to do a qualitative estimation of the evacuation time of people on the two floors. The evacuation time on the upper ground floor was approximately 12 minutes, while it corresponded to 5 minutes for those on Level 1.

Despite the number of people involved in the drill and the limited information available to the researchers about the evacuation conditions during the drill, the information collected are deemed to be of interest for the calibration of the input in the model case study. The information about the drill has been obtained by observation during the drill as well as a fire drill report in Swedish [32] provided by an authorized person in Emporia. Figure 3 shows some pictures taken during the drill.

Figure 3. Fire drill in Emporia Mall

4.3 Choosing a proper model

Taking into account that the building type to be analysed in this thesis is a very complex shopping mall, an appropriate model should be selected.

Model types had been explained in Section 2.3. Considering all the possible space representation in existing models, the continuous model representation would be appropriate since it provides realistic flows which are essential for the case under consideration. There are also other criteria to be considered for choosing a proper model. Taking into account also the model availability and output produced, the Pathfinder Model (2015 Version) [7] has been selected in consultation with the supervisor, Enrico Ronchi at Lund University. It should be noted that other models with similar characteristics may have been used for the simulation of the present case study.

4.4 Pathfinder

Pathfinder is an agent-based model [7] allowing users to use steering mode [18,19] or SFPE mode[23,20]. More complex behaviour can be simulated under favour of using steering mode [7]. Pathfinder represents a continuous model structure. It is also possible to define different behaviours in Pathfinder, e.g. go to the certain exits, wait, go to specific rooms, etc. In this way, different evacuation strategies can be implemented. For instance, phased or partial evacuation can be achieved using the behaviour 'waiting' for the occupants in noncritical floor/rooms or 'go to a specified room' directing occupants to a specified rooms as well as managing delayed evacuation by way of using the behaviour 'go to the chosen room'. Apart from the evacuation strategies stated above, total evacuation strategy can be applied allowing all occupants in a building to evacuate at the same time.

4.5 Type of Calculations

Model calculations refer to the amount of information available for the simulation of the evacuation process and different levels are employed in egress modelling, i.e. blind, specified and open calculations [33,34]: Blind calculations are employed considering basic description of scenario and the user should decide the additional details to implement to the model. In contrast, specified calculations are based upon detailed information of model inputs, e.g. occupant characteristics, range of figures concerning model, etc. Open calculations are performed on the basis of complete information about the scenario which are validated for the relative scenario. Blind calculations were employed in this thesis. This is because while basic information was available on the geometry and egress components available for evacuation, several assumptions were done on occupant loads and agent properties. Additionally, user assumptions and choices have a considerably great impact on the results to be obtained, i.e. the user effect [34,35]. It means that assumptions made by inexpert users may lead to unrealistic results.

4.6 Scenarios evaluated for the model

Five different scenarios were analysed for the modelling. These scenarios and the criteria used to choose those are explained below:

- ***Scenario 1:*** All the occupants in the mall use the locally quickest way to the exits. Pathfinder has by default a locally quickest route algorithm [7], which means that the occupants use local information about their current room and global knowledge about the building. Therefore, occupants are assumed to know all the doors in the room where they are present considering also queues at the doors. It is also assumed that they know how far the distance from one of the doors in the room to the current destination [7]. The occupants can change their routes taking into account the queuing time. The aim of choosing this scenario is to investigate the evacuation process and compare the results obtained by the other scenarios (particularly comparing the scenario including the shortest algorithm, i.e. Scenario 3, in order to check whether there is a great difference or not) using Pathfinder's default locally quickest route algorithm.
- ***Scenario 2:*** Scenario 2 assumes a hypothetical worst case scenario in which all people use familiar routes rather than emergency exits. This is in line with Sime’s affiliation theory [36]. For the worst case, all the occupants leave the building through the familiar routes identified and checked during the evacuation drill and main exits on the lower and upper ground floor. This scenario is selected in order to represent an unfavourable case which can be considered to present today's conditions properly.
- ***Scenario 3:*** All the occupants use the nearest exits in the room where they are positioned in order to evacuate the building. The occupants are directed to the nearest exits using the behaviour to be defined in the model or adapting the model representation of the geometry so that occupants can go to the closest exits in the room. This scenario is selected in order to evaluate how different results can be obtained from the worst-case scenario, e.g. how much can the evacuation time be reduced using this algorithm, how much different is congestion level from the one emerging by using worst-case scenario, etc.

- ***Scenario 4:*** Optimal evacuation strategies are carried out for this scenario so as to examine whether there is a way to shorten evacuation time with successful crowd management techniques. To address this issue, phased evacuation strategy is employed, i.e. some occupants in Level +6 wait for all the occupants upstairs to leave the stairs in escape corridors. Detailed information about this scenario is explained in Section 4.9. The aim of this scenario is to evaluate if there is a way to shorten the evacuation time.

- ***Scenario 5:*** This scenario is similar to Scenario 4. The only difference is that occupants do not wait to evacuate using a phased evacuation strategy, unlike Scenario 4 in which some occupants are instructed to wait. The objective of this scenario is to check if there is a great difference in terms of results between Scenario '5' and Scenario '4'.

Modelling of all the scenarios defined above is explained in detail in Section 4.9.

4.7 Uncertainties in Evacuation Modelling

There are four main uncertainties in evacuation modelling in the context of fire safety engineering. These are as follows [8]:

- ***Measurement Uncertainty*** refers to the experimental measurement, e.g. how the data is collected, etc.

- ***Model Input Uncertainty*** relates to the uncertainties associated to the parameters derived from experiments and those used as model input. These types of uncertainties include the modelling assumptions implemented in the input calibration phase.

- ***Intrinsic Uncertainty*** is associated with the assumptions and procedures which are intrinsic to the model formulation (e.g., modelling methods for space representation, movement sub-model, etc.).

- ***Behavioural Uncertainty*** is related to the stochastic nature of human behaviour. One single experiment or simulation may not be representative of the variability of occupant behaviours.

Since models generally consider uncertainty as a stochastic problem, they make use of distributions or stochastic parameters, e.g. distribution values of walking speeds or pre-evacuation times, etc. Various occupant-evacuation time curves are obtained using distributed variables for the same scenario. The main problem encountered by modellers is to decide the number of runs to be employed so as to be representative of the average model results [8]. Different methods to study behavioural uncertainties are as follows [8,11,37]:

- ***Average TET and Standard Deviation***: An arbitrary number of runs is employed. Average evacuation time is given with standard deviation. Even though this method is employed today in many applications, it should be noted that results are very dependent on the randomness in the modelling assumptions.

- ***Convergence based on simple acceptance criteria:*** The error of two consecutive averaged evacuation times as well as standard deviations is essential to identify the number of simulations. The number of runs is terminated when the error is smaller than a pre-defined value specified by acceptance criteria. This method is fast and very simple.

  Two variables are considered to assess the convergence of the simulations [8]:

  1) Total Evacuation Time (TET), i.e. the time for the last occupant's evacuation from the building,

  2) Standard Deviation (SD) of Total Evacuation Times, i.e. the measure of the spread of last arrival times.

  In this study, the following acceptance criteria (threshold values) have been assumed:

- $TET_{convj} < 0.01$ (1%) for 10 consecutive number of runs
- $SD_{convj} < 0.05$ (5%)for 10 consecutive number of runs

  These numbers have also been used in many applications in the past. The term 'convj' is used to present the average value of a specific variable derived after the i^{th} repeated run. In order to decide how many runs are required, these two acceptance criteria defined above should be met, i.e. both TET and SD are supposed to converge.

In order to calculate these variables, the following equations are used:

$$TET_{av\,j} = \frac{1}{j}\sum_{i=1}^{j} TET_i$$

$$TET_{convj} = \left|\frac{TET_{avj} - TET_{avj-1}}{TET_{avj}}\right|$$

$$SD_{convj} = \left|\frac{SD_j - SD_{j-1}}{SD_j}\right|$$

- ***Convergence based on functional analysis:*** This method is associated with different types of operators including some data regarding evacuation times of occupants. These operators are[8,11]:

  - *Euclidean Relative Distance (ERD):* The average difference between the simulated and observed data in an average arrival curve.
  - *Euclidean Projection Coefficient (EPC):* The best possible alliance between the observed and simulated data in an average arrival curve.
  - *Secant Cosine (SC):* Similarity between the curve shape by evaluating the slopes generated by the observed and simulated average arrival curves.

  Despite the fact that this method is relatively time-consuming, it allows to study on the full occupant-evacuation time.

In order to compare the results of different scenarios, a set of functional analysis operators, Euclidean Relative Distance (ERD), Euclidean Projection Coefficient (EPC) and Secant Cosine (SC) should be employed. These operators can be calculated by the following equations:

$$ERD = \frac{||\vec{x} - \vec{y}||}{||\vec{y}||} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_{i)}{}^2}{\sum_{i=1}^{n}(y_{i)}{}^2}}$$

$$EPC = \frac{<\vec{x},\vec{y}>}{||\vec{y}||^2} = \frac{\sum_{i=1}^{n}(x_i y_{i)}}{\sum_{i=1}^{n}(y_{i)}{}^2}$$

$$SC = \frac{<\vec{x},\vec{y}>}{||\vec{x}||||\vec{y}||} = \frac{\sum_{i=s+1}^{n} \frac{(x_i - x_{i-s})(y_i - y_{i-s})}{s^2(t_i - t_{i-1})}}{\sqrt{\sum_{i=s+1}^{n} \frac{(x_i - x_{i-s})^2}{s^2(t_i - t_{i-1})} \sum_{i=s+1}^{n} \frac{(y_i - y_{i-s})^2}{s^2(t_i - t_{i-1})}}}$$

where;

$\vec{x}$: average evacuation time of the benchmark scenario
$\vec{y}$: average evacuation time of the scenario to be compared
t: the measure of the spacing of the data (t = 1 in the case of a data point available for each occupant)
s: the number of data points in the interval (taken as '4' in the present example)
n: is the number of data points in the data-set (corresponds to the total number of people, i.e. 21548)

- ***Functional analysis and inferential statistics:*** This method is very similar to the method called '*Convergence based on functional analysis*'. Statistical testing is also added to the methodology. Although it allows to evaluate behavioural uncertainty deeply compared to the other methods, it should be borne in mind that it is more time consuming.

In this case, convergence based on simple acceptance criteria has been employed in order to define the number of simulations as it is a fast and simple method. The operators used in convergence based on functional analysis have been used instead to compare the model results against each other. Detailed information about the implemented methods is given in Chapter 5.

4.8 Modelling Assumptions

All floor plans in DWG files provided by Emporia Mall Technical Team were imported to Pathfinder to define the geometry. The entire spaces that occupants would use within the building were specified using a continuous 2D triangulated surface named "navigation mesh" within Pathfinder 3D geometric model [7]. Assumed input data have been explained in the following sub-sections:

4.8.1 Occupant Load

The occupants were positioned into the building in accordance with the 'Occupant Load' factor. In order to calculate the number of people per space here called "Occupant Load", the floor area is divided by the Occupant Load Factor specified for each type of occupancy. NFPA 101, Life Safety Code Handbook [38], gives the 'Occupant Load Factor' for each of the occupancy type. Table 1 shows the occupant load factors used in the evacuation modelling of Emporia Shopping Mall based on NFPA 101.

Table 1. Occupant Load Factor in NFPA 101, Life Safety Code Handbook, 2011 Edition [38]

Occupant Load Factor	
Use	**m^2/person**
Assembly Use	
Less concentrated use, without fixed seating	1.4 net
Kitchens	9.3
Storage Use	
In mercantile occupancies	27.9
Business Use	
Offices	9.3
Mercantile Use	
Sales area on street floor	2.8
Sales area on floors above street floor	5.6
Mall buildings	Per factors applicable to use of space

All factors in Table 1 are given in gross area unless specified as "net". Food courts and restaurants in the mall are considered to be in the "Assembly Use-Less concentrated use, without fixed seating". Whereas the net floor area has been calculated for the places without fixed seating such as the food courts and restaurants, the gross area has been taken in consideration for the other areas such as sales areas, kitchens and storages. In order to measure the gross floor area all the spaces within the surface of the walls are considered without subtracting the nonoccupiable spaces, e.g. bathrooms, closets, fixed equipment, stairs, etc, unlike the net floor area for which only actual occupiable spaces are taken into account. So, the toilets, closets, small storage areas, fixed equipment etc. were not subtracted in the sales areas, kitchens and storages. However, to obtain a more realistic representation of the space, the interior walls within the areas were defined for the sales stores which have high occupant load, e.g. super markets, big retail stores, etc. as they might influence the routes the occupants use, though the shelves in these areas were not designated as obstacles since they do not appear in the drawings. The occupant load factor for circulation spaces is considered to be 2.8 with reference to NFPA 101, Life Safety Code Handbook-Figure 7.3.1.2(b) as shown in Figure 4.

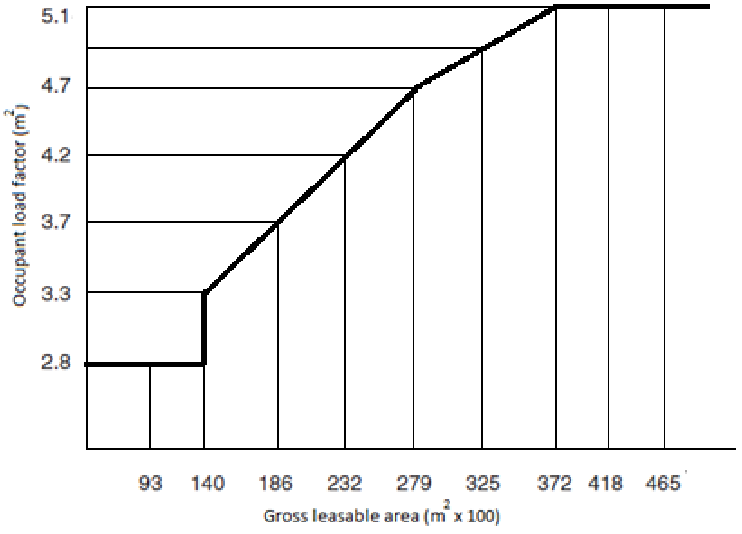

Figure 4. NFPA 101, Life Safety Code Handbook, 2011 Edition-Figure 7.3.1.2(b) - Redrawn from the original

According to the NFPA classification, office and storage facilities incidental to sales areas and positioned in the same building are supposed to be in the 'Mercantile Use' classification. Therefore, the small offices, toilets and storage areas were not subtracted while defining the geometry. However, big storage areas with respect to the shop floor areas, e.g. big super markets or large stores are taken into consideration as 'Storage Use' classification.

4.8.2 Occupant types and Occupant Distribution

Considering all the parameters stated above, occupant groups were placed into the building. Different occupants may visit the shopping mall, thus all types of those having different walking speed and body sizes were specified. However, it is quite difficult to estimate accurately the proportion of the occupant types. 5% of the occupants were assumed to be people with movement impairments, e.g. disabled people and elderly people [39]. Apart from disabled and elderly people, a family group comprising children and parents were defined in the model. In this group parents will have the same speed as children since the children will not be able to evacuate the building without their parents in an emergency situation. In order to represent a realistic attitude, 10% of the occupants were assumed to be children based on the average values presented in Qiang and Hong-yu's paper [31]. The parents were assumed to be 15% of the occupants. The rest of the population constitutes the majority of the occupants, i.e. 70% of the occupants are female adults and male adults. Considering the average percentage of male and female occupants in the relevant study [31], following values were assumed: 25% and 45% for men and women, respectively. Taking into account all the parameters above, the figures for each occupancy type shown in Table 2 were used in the model.

Table 2. Occupant distribution

Occupant types	
Characteristic	**Percentage**
Disabled & Elderly	5
Children	10
Parents	15
Female Adults	45
Male Adults	25

4.8.3 Body Dimensions and Unimpeded Walking Speeds

Each occupant type corresponds to different body size and speed values. Table 3 [24,26] and Table 4 [24] show body dimensions and unimpeded walking speeds, respectively. The body size of the disabled people was assumed to be same as the elderly people. Mean, maximum and minimum values for the unimpeded horizontal walking speeds were obtained and utilized for the input data of the modelling.

Table 3. Body dimensions [24,26]

Body dimensions	
Body Type	**Shoulder Width (m)**
Male	0.270 ± 0.020
Female	0.240 ± 0.020
Child	0.210 ± 0.015
Elderly	0.250 ± 0.020
Disabled	0.250 ± 0.020

Table 4. Unimpeded walking speeds [24]

Occupant type	Unimpeded walking speed (s)		
	Mean	**Standard deviation**	**Range**
Disabled & Elderly	0.8	0.1	0.5-1.1
Children	0.9	0.1	0.6-1.2
Parents	0.9	0.1	0.6-1.2
Female Adults	1.15	0.07	0.95-1.35
Male Adults	1.35	0.07	1.15-1.55

Standard deviation values were assumed based on the three-sigma rule of thumb which is also called 68–95–99.7 rule in statistic [40]. Figure 5 illustrates how the distributed values are deviated from the mean. Taking into account this approach, standard deviation (σ) value was found calculating the distance of '3σ' from the minimum and max values to the mean value. For instance, mean value (μ) for children is 0.9 m/s and minimum value is 0.6 m/s. Subtracting this numbers, 0.3 m/s is obtained. It can be assumed that this value is equal to 3σ. In this way, standard deviation (σ) is calculated as 0.1 m/s. Therefore, the probability of the randomly selected value will be 99.7% in this interval. As σ value is very small, many values randomly selected will be close to the mean value as can be seen in Figure 5.

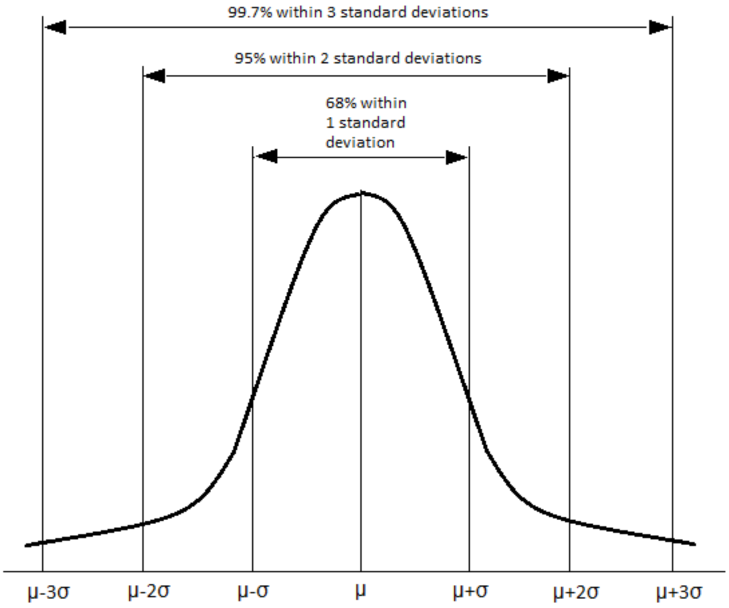

Figure 5. Three-sigma rule of thumb - Redrawn from the original [40]

The implementation of the SFPE sub-model already available in Pathfinder was used for the simulation of people movement on stairs. This speed value is considered to be 0.5 m/s in the case of evacuation via spiral stairs without taking account of stair size [41]. However, it is not possible to assign this value to all the occupants using the spiral stairs in Pathfinder. Therefore, a door with the same length as the stairs width was located at the end of stairs and a set of flow rate values were set for each simulation in order to find a reasonable value by restricting the flow. First, very few people to walk down the stairs were placed and the average speed values were checked using speed contour in Pathfinder. While the average speed was 1 m/s for a few occupants, it was observed that this value expectedly decreases in reverse proportion to the density of occupant. Considering the location of the spiral stairs within the building, a great number of people are likely to use them. In the case of very crowded situation, the values of flow rate and speed were 1.65 pers/s and 0.6 m/s, respectively. In order to reduce the walking speed, flow rate value was set as 1.5 pers/s and speed values were checked via speed contour. Once the number of people started to increase in the staircase average walking speed was around 0.5 m/s or a little less. These numbers can be considered to be reasonable for a more conservative approach. Figure 6 shows the spiral staircase which is 19 meters in length.

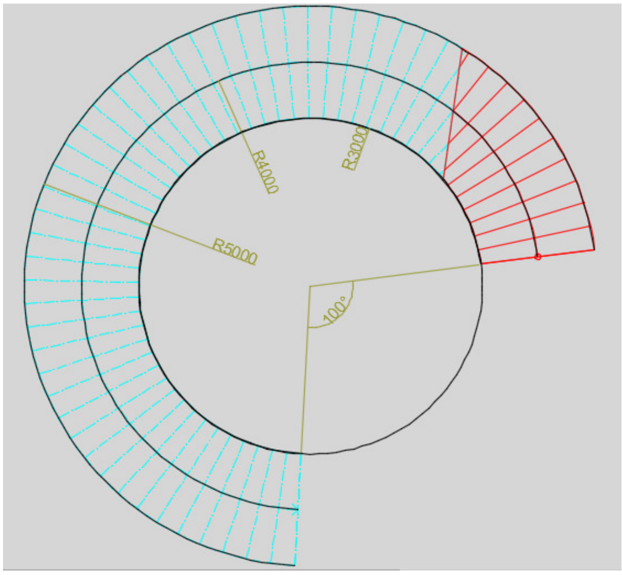

Figure 6. Top view of spiral stairs

4.8.4 Pre-evacuation Times

Published Document (PD) 7974-6 [1] suggests some pre-evacuation time values per design behavioural scenarios and occupant types. There are also some behavioural modifiers in each scenario categories. These modifiers comprise the quality of alarm system classified into levels A1 to A3, the complexity of building varying between B1 to B3 classification as well as the quality of fire safety management classified into levels M1 to M3. Since the concerned building is a shopping mall, corresponding category will be Category B1 in which the occupants are awake and unfamiliar to the building having high density. While the alarm system used in Emporia Mall corresponds to Level A1 by reason of the automatic detection system giving an immediate alarm throughout the building, the building type is classified into B3 due to the complexity of the building considered as very large building complex. Management level can be considered as M1 or M2 level since high or good standard of staff training and fire safety management. Taking into account all the parameters expressed, the corresponding average pre-evacuation time should be 3 minutes in accordance with PD 7974-6.

According to 'Adapted from Fire Safety Engineering in Buildings, Part 1: Guide to the Application of Fire Safety Engineering Principles British Standard Institutue,DD240' [42], this number should be smaller than 2 minutes. Table 5a shows the pre-evacuation times for the respective documents.

Table 5a. Pre-evacuation times (based on the PD 7974-6 and DD240) [1,42]

Document	Pre-evacuation time (s)
Published Document (PD) 7974-6	3 minutes
Guide to the Application of Fire Safety Engineering Principles British Standard Institutue,DD240	less than 2 minutes

However, previous studies [2,30] for large retail stores showed that average pre-evacuation times are considerably less than those provided by D 7974-6 and DD240. Apart from these, evacuation had started after approximately 1 minute of delay after the alarm was manually activated during the drill employed in Emporia Mall. This pre-evacuation time shows similarity to those given in the paper of T.J. Shields and K.E. Boyce [30] and also SFPE Handbook Engineering data [10] where the figures have been provided four different retail stores as shown in Table 5b.

Table 5b. Pre-evacuation times for four different stores (based on the paper of Shields and Boyce) [10,30]

Store	Pre-evacuation time (s)		
	Mean	Standard deviation	Range
Store 1	*37*	*19*	*3 - 95*
Store 2	31	18	4 - 100
Store 3	25	14	1 - 55
Store 4	25	13	2 - 60

Standard normal distribution of pre-evacuation time is employed for the input data to the model instead of a specific value as generally used at the present time. The figures of normal distribution for *Store 1* denoted in the Table 5 were used for modelling input data for a more conservative approach.

4.8.5 Elevators and Escalators

Occupants with movement disabilities in upper floors were directed to the elevators based on to the strategy employed by Emporia. Those in the lower ground floor will be assisted by the staff nominated by Emporia. Default elevators features defined in Pathfinder, e.g. 7,0 s for open + close time, 1,2 m/s^2 for acceleration and 2,5 m/s for maximum speed were used in the model.

There are also 12 sets of escalators within the mall which are used as egress components. It has been assumed that all the escalators would stop in an emergency situation and be used as a component of a required means of egress.

All the elevators and escalators can be seen in Figure 8 and Figure 9.

4.8.6 Wayfinding and exit choices

Since way-finding and exit choices depend on the scenario, all information about these issues are given in Section 4.9 - Simulation of the defined scenarios with Pathfinder.

4.9 Simulation of the defined scenarios with Pathfinder

Once all occupants were placed into the model of the building, input data, e.g. pre-evacuation times, speed values, body size of occupants, etc. were set in accordance with the information/assumptions in use. Figures 7a, 7b, 7c and 7d show schematic plans in the evacuation model of Emporia Mall showing all stores, occupants, stairs, exits, escalators, elevators, etc. While escape corridors were marked in white colour, red areas refer to the circulation spaces within the building. Green and yellow doors point to the exit doors opening to outside and doors opening to escape corridors or circulation spaces, respectively. Other colours identified randomly by Pathfinder indicate the rooms (e.g. shops, toilets, storage areas, etc.). Due to the steering mode of Pathfinder, occupants can evacuate the building avoiding other occupants as well as obstacles.

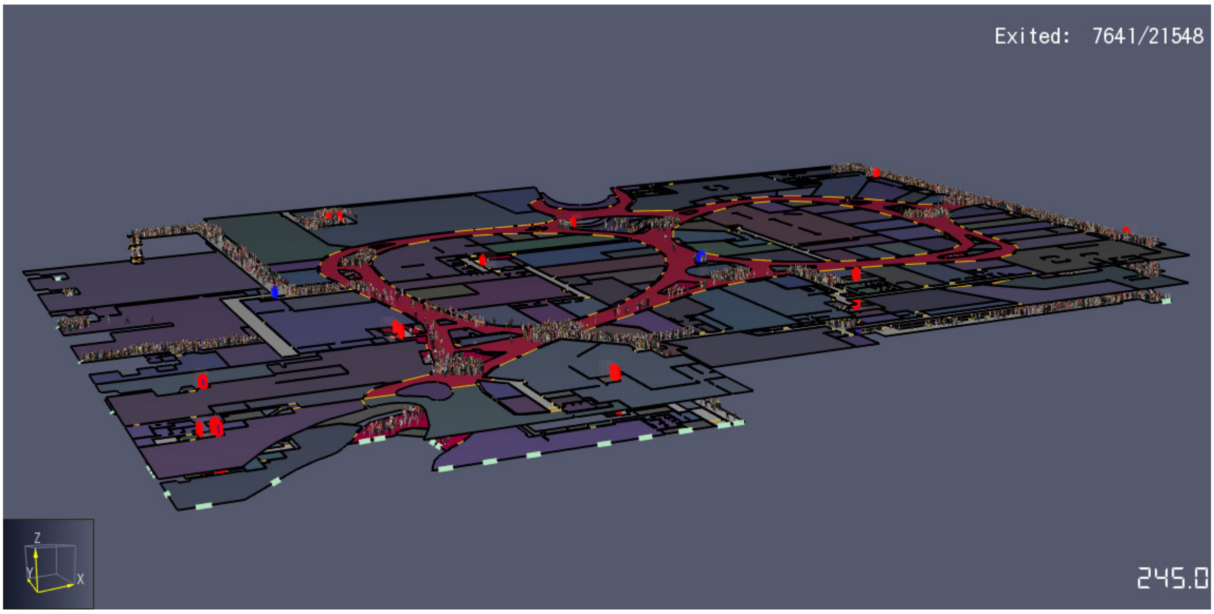

Figure 7a. A schematic plan in the evacuation model of Emporia Mall - Perspective view

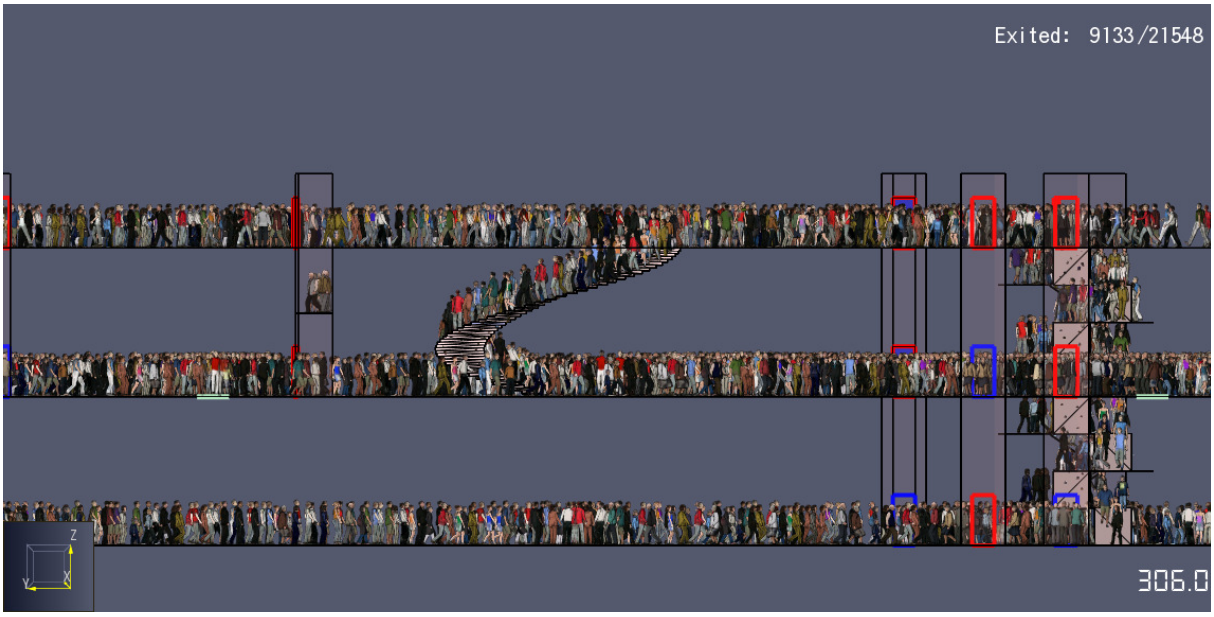

Figure 7b. A schematic plan in the evacuation model of Emporia Mall - Side view

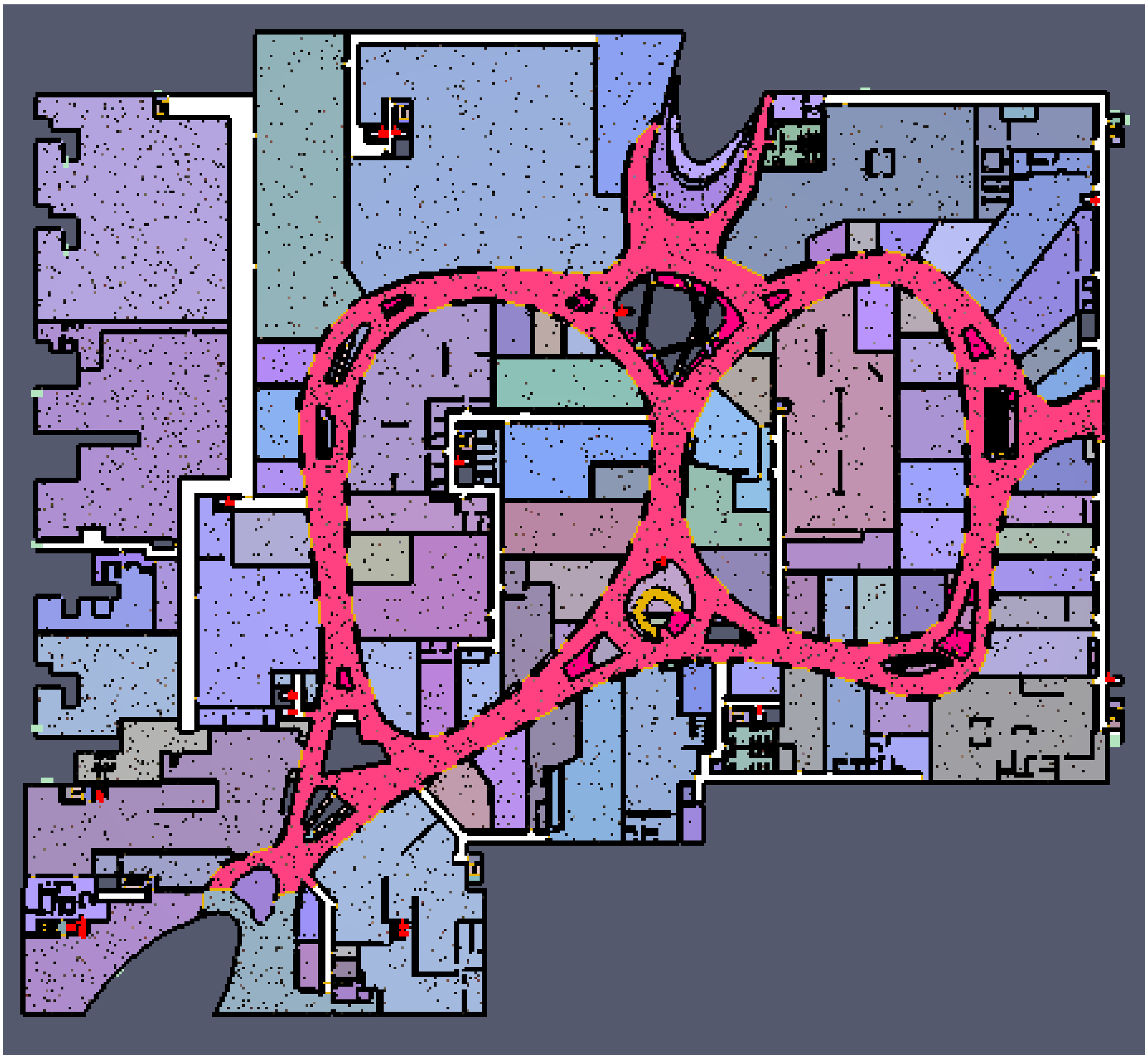

Figure 7c. A schematic plan in the evacuation model of Emporia Mall - Top view

Figure 7d. A schematic plan in the evacuation model of Emporia Mall - Perspective view from a random occupant

Figures 8, 9, and 10 show the top view of lower ground floor, upper ground floor and first floor, respectively, showing all egress components, e.g. exit doors, staircases, elevators, escalators, etc. The exits with an expression 'LOCAL' or 'LOC' mean that these exit doors to the outside located in shops are used only by the occupants who are present at that moment in those shops. The other exits without any expressions are the ones leading directly to the outside located at the circulation areas or escape corridors. It means that these exits can be used by all the people. Denotations were positioned according to the final position of egress components. For example, expression 'elevator x' has been showed on the upper ground floor if the discharge floor is upper ground level. Simulation results will be given in Chapter 5.

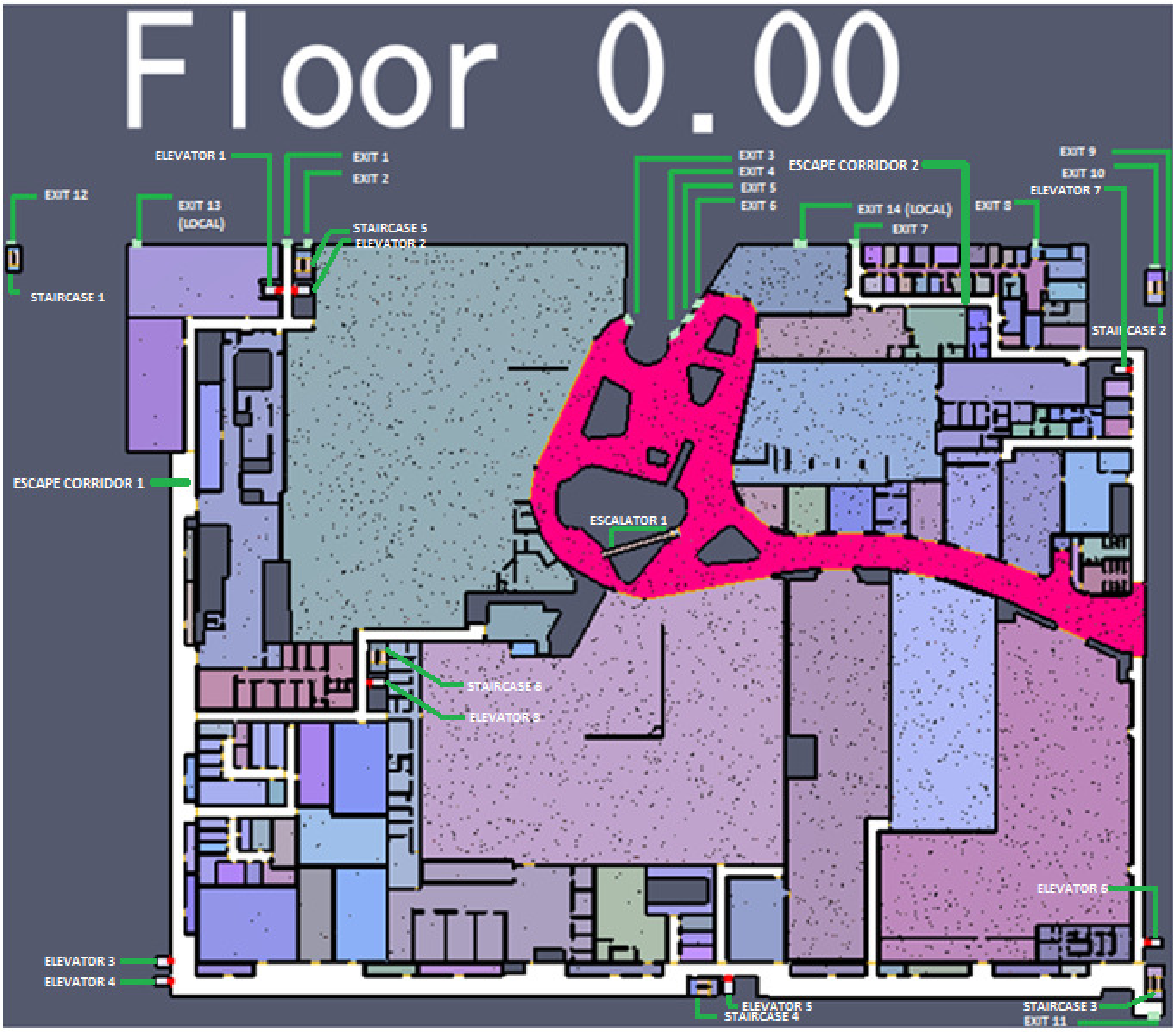

Figure 8. Top view of lower ground floor

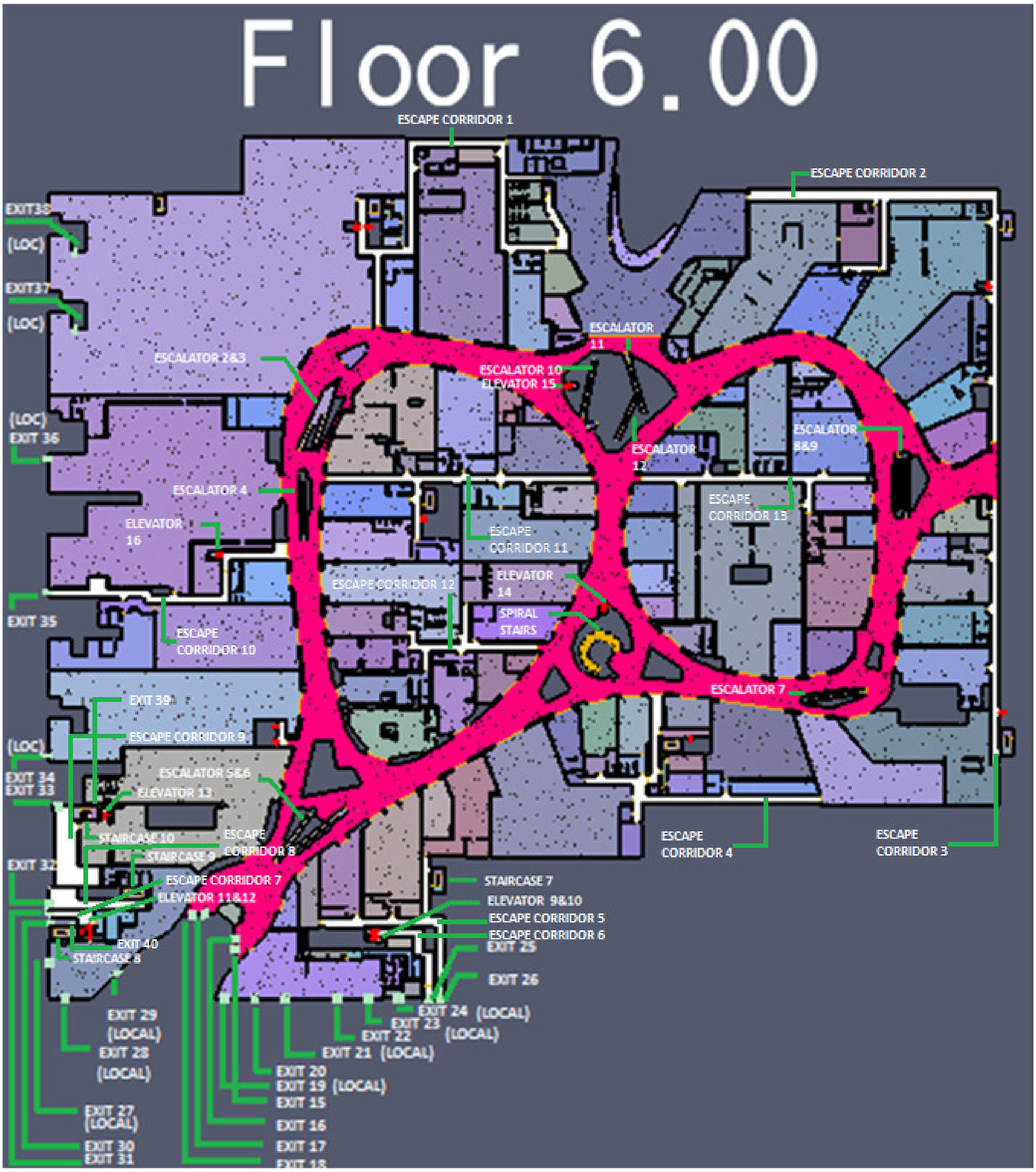

Figure 9. Top view of upper ground floor

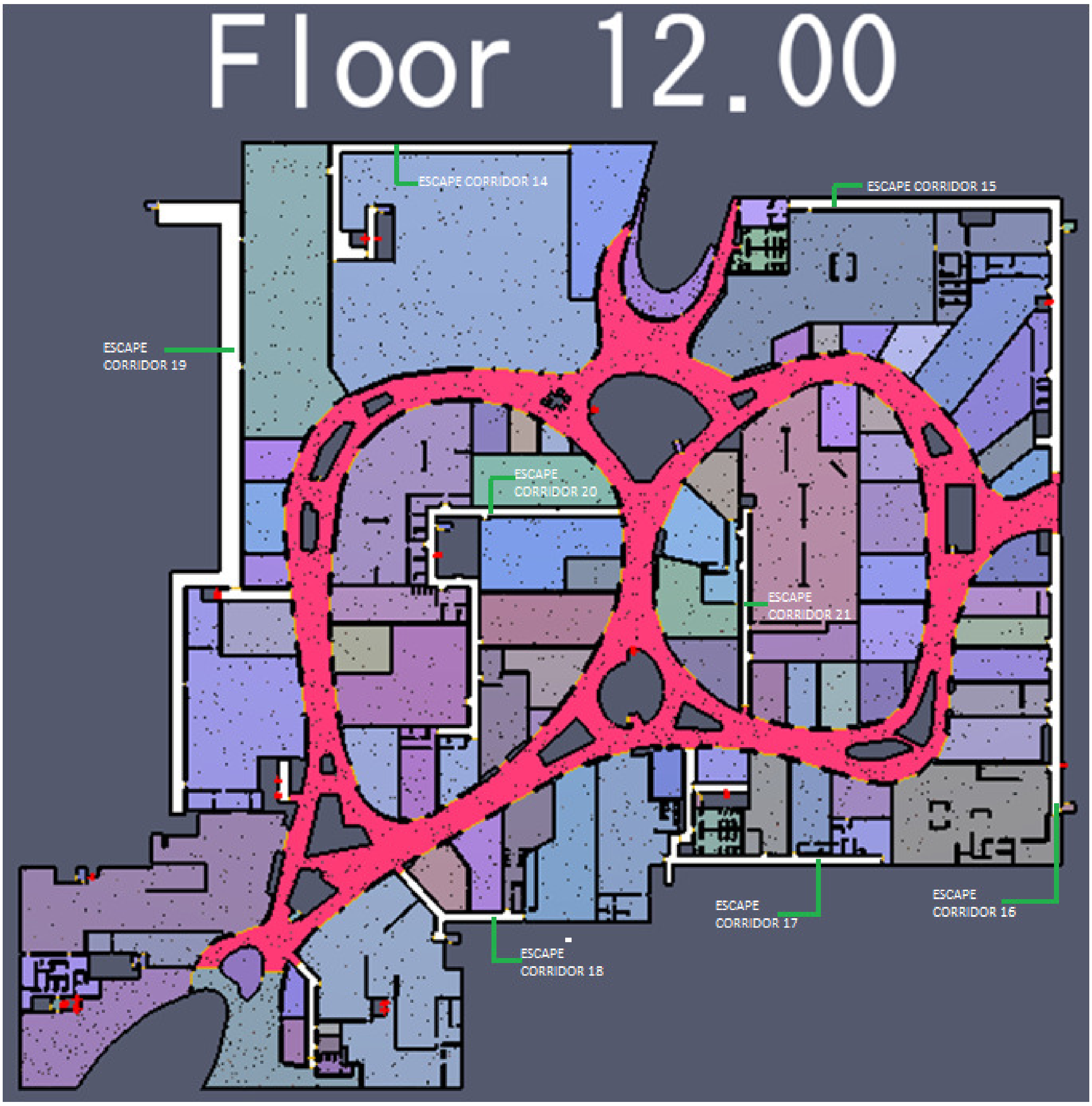

Figure 10. Top view of Level 1

4.9.1 Simulation of Scenario 1

Scenario 1 refers to the occupants using the locally quickest path as explained in Section 4.6. Since Pathfinder has by default a locally quickest route algorithm, any instructions, e.g. wait, go to a certain room, use the specified exit, etc. were not given to the occupants except for the people with movement disabilities. These people, i.e. disabled and elderly people with movement impairments, on the upper ground floor and Level 1 were directed to the elevators within the circulation spaces or escape corridors (some stores also have their own elevators inside). However, there are some stores which have exit doors opening directly outside, e.g. a few stores located on the upper ground floor. These people in such a room were directed to these exit doors if they were somewhere close to these exits. On the contrary, the nearest doors opening to the circulation areas or escape corridors were chosen by them in order to proceed to the elevators on condition that they were far from the exits opening to outside area.

People with disabilities in the circulation places or stores close to the main exits of the building were directed to these doors, otherwise they would have gone to the elevators, which means an unnecessary movement despite their current positions close to the main exits.

All the occupants will be able to change their routes taking into account the queuing time in this scenario.

4.9.2 Simulation of Scenario 2

A set of simulations for this case were carried out to demonstrate a worst-case scenario. In line with Sime's affiliation theory [36] , this hypothetical scenario considers that many occupants may want to leave the building through the familiar routes and main exits on the lower and upper ground floor. In this scenario, the occupants in the building were assumed to use the stairs in circulation spaces since the familiar routes in circulation areas are considered to go to the main exits positioned on both lower and upper ground floor. All doors used to get into the escape corridors were blocked changing direction of the doors or removing them. Figures 11, 12 and 13 illustrate a simple schematic map for each floor showing the familiar routes that occupants follow. Additionally, the whole people in stores were directed to store doors to the circulation spaces. In order to do that, emergency exit doors in stores were removed or the direction of those were changed to the inside the room as shown in Figure 14 so that occupants could not use the emergency corridors. In this scenario, all disabled and elderly people were assumed not to be directed to the elevators and they were assumed to use the stairs with the aid of evacuation staff in Emporia Mall who would take care of costumers in the wheelchair as well as elderly people with movement disabilities.

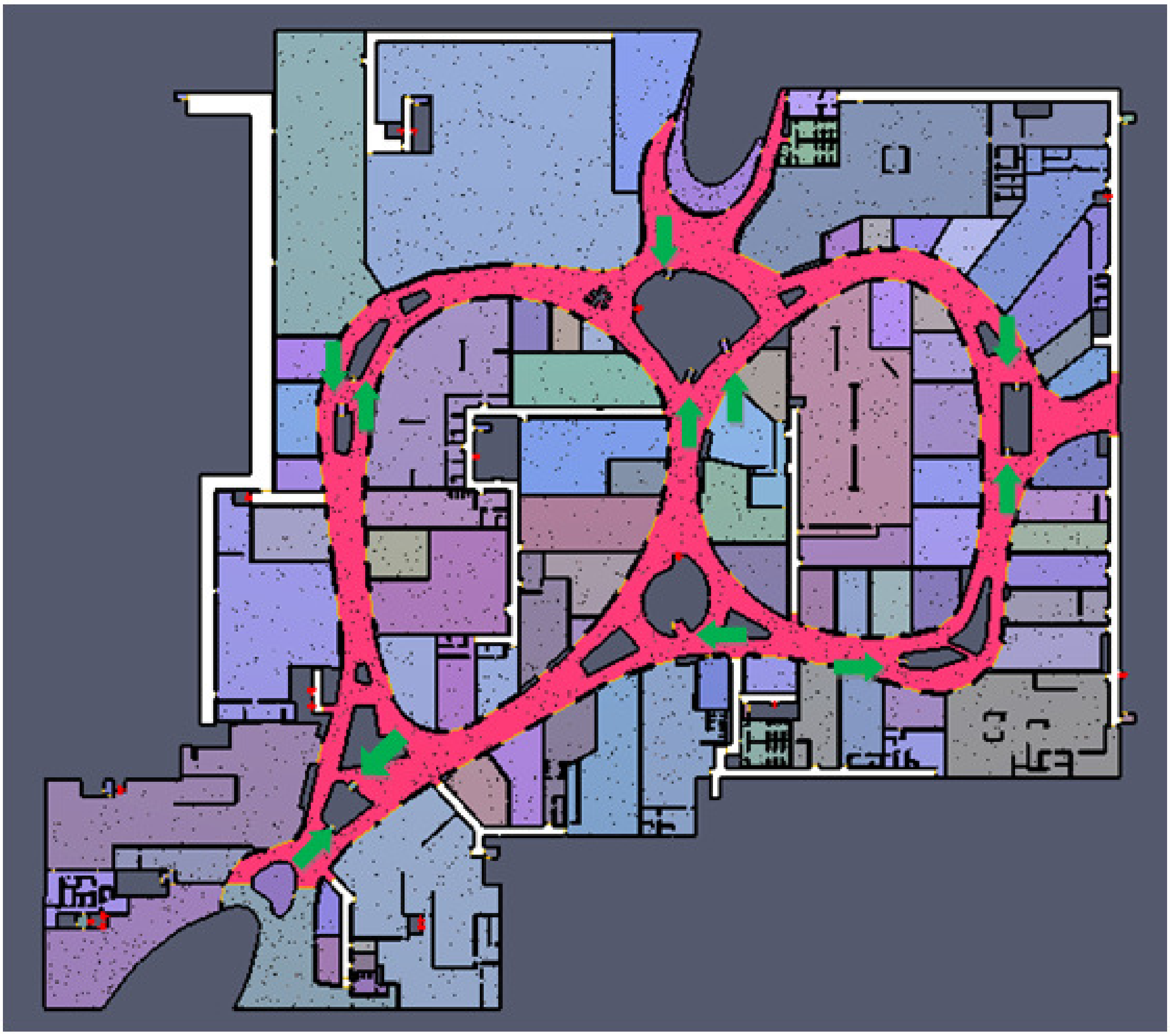

Figure 11. Schematic Map on Level 1 based on Scenario 2

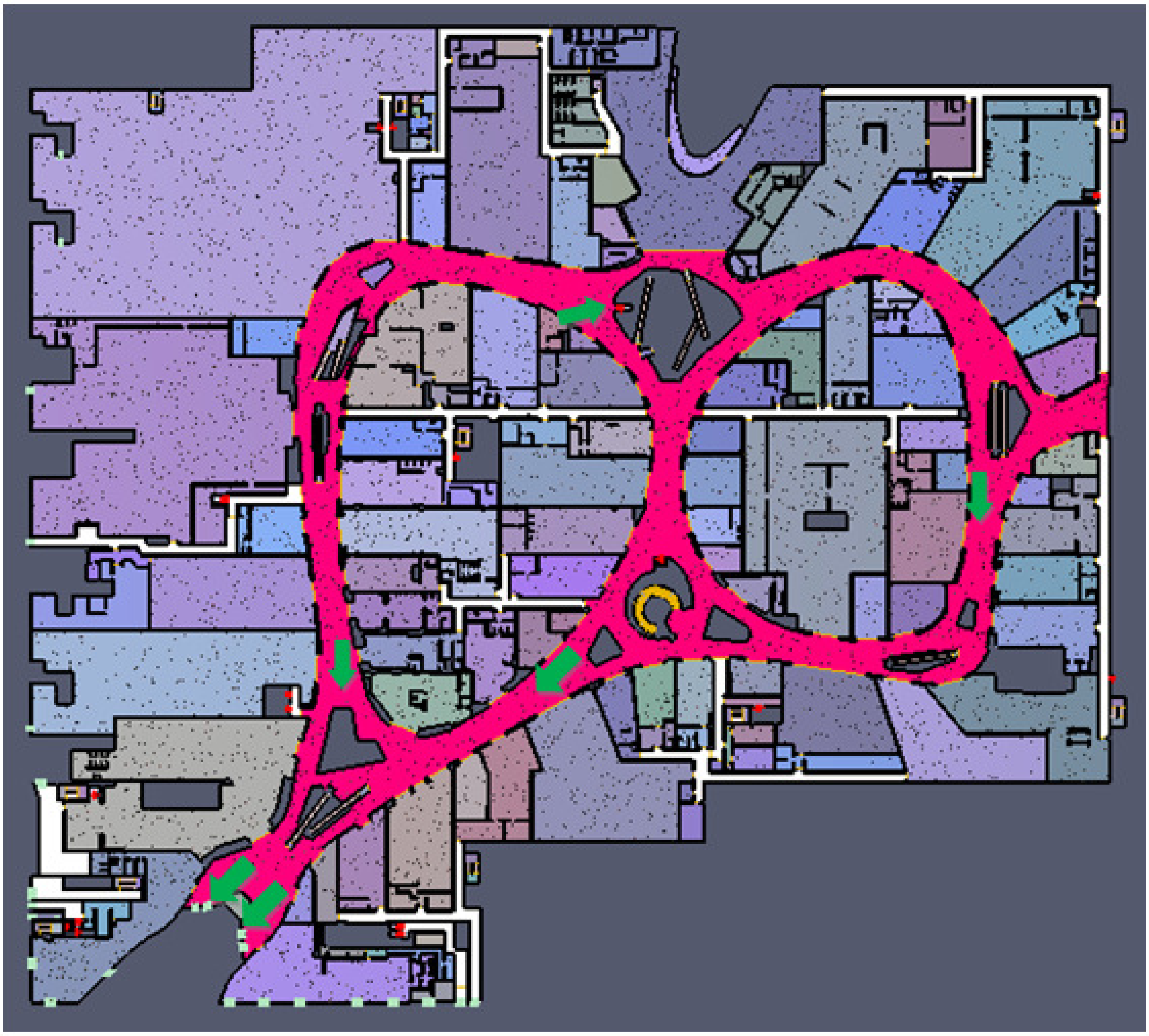

Figure 12. Schematic Map on the upper ground floor based on Scenario 2

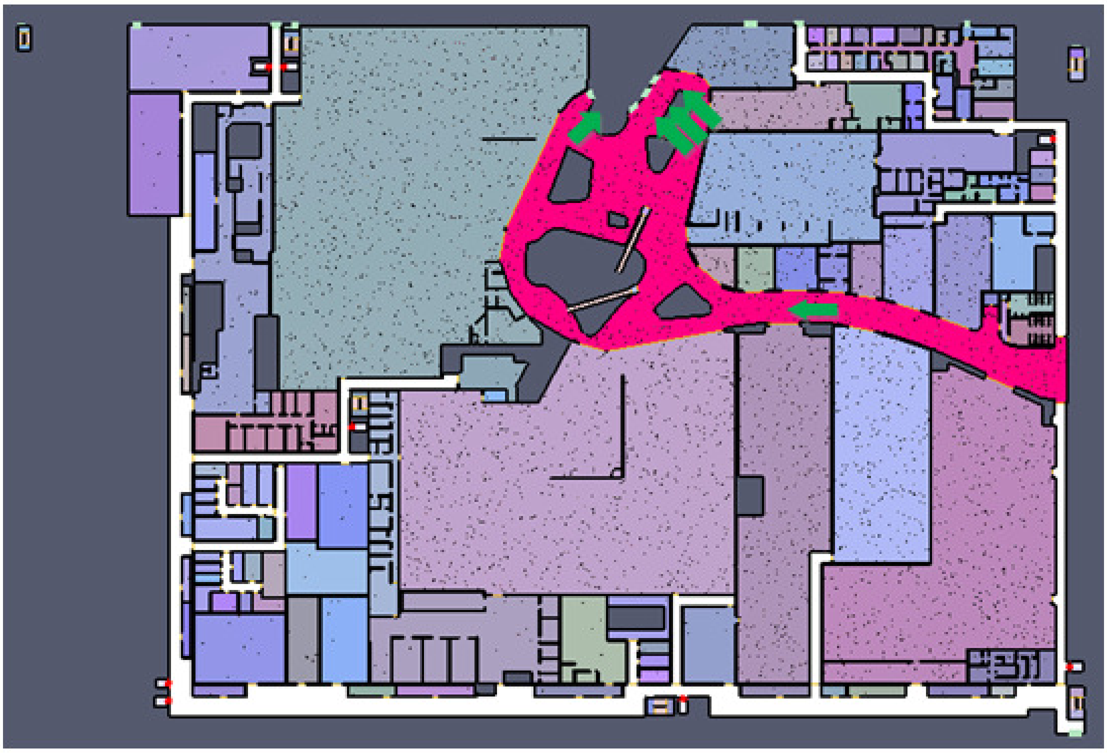

Figure 13. Schematic Map on the lower ground floor based on Scenario 2

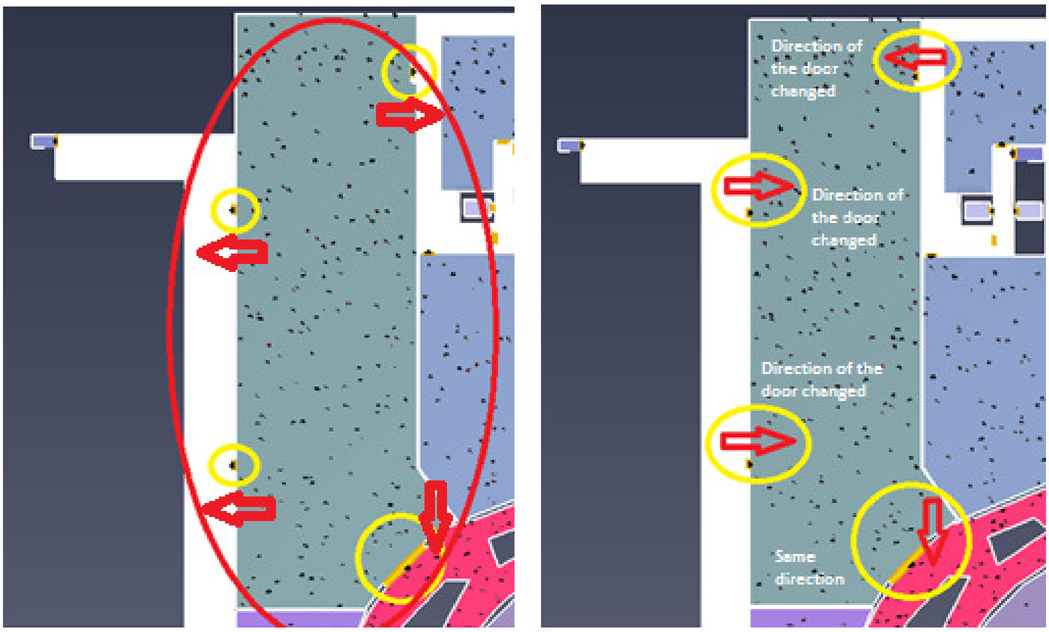

Figure 14. Old and new version of sample room on Level 1 from left to right based on Scenario 2

4.9.3 Simulation of Scenario 3

The nearest emergency exits in a set of pre-defined rooms (not the entire building) were used by all occupants within the building based on Scenario 3. In order to do that, a behaviour was defined in the model, namely 'go to the nearest exit'. There is also another method to make the occupants use the nearest exits. It can be achieved by artificially modifying the room shape, i.e. dividing a room into pieces so that occupants will be forced into going to the closest exits. Figure 15 shows the old and new version of a sample room on Level 1. As there are 4 doors in the room, the shape of it has been modified and divided into 4 pieces as shown in Figure 15. The results of Simulation 1 and Simulation 3 are expected to be similar since shortest way and quickest way can be the same most of the time. However, it should be borne in mind that due to a possible presence of congestion in the shortest way, another route might be the quickest path.

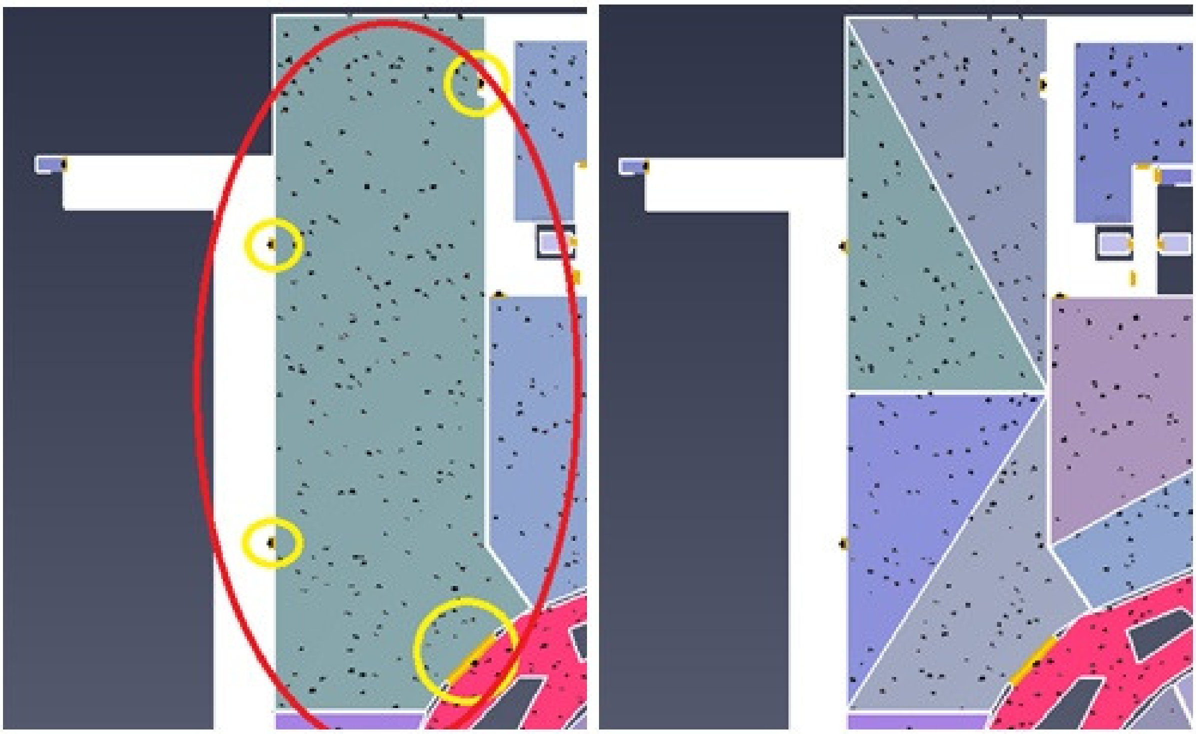

Figure 15. Old and new version of a sample room on Level 1 from left to right based on Scenario 3

4.9.4 Simulation of Scenario 4

In order to design an optimal evacuation scenario, initially, the areas where congestion emerged should be analysed carefully. Simulations of the previous scenarios show that the highest level of congestion occurred on the upper ground floor due to the greatest crowd on this floor, especially in the escape corridors where common staircases used by the occupants on the upper ground floor and the first floor are located, e.g. on the top-right side and bottom-right side. Additionally, considerable high level of congestion was detected in the circulation spaces near the escalators. Figure 16 and Figure 17 illustrate the highest level of congestion on the upper ground floor.

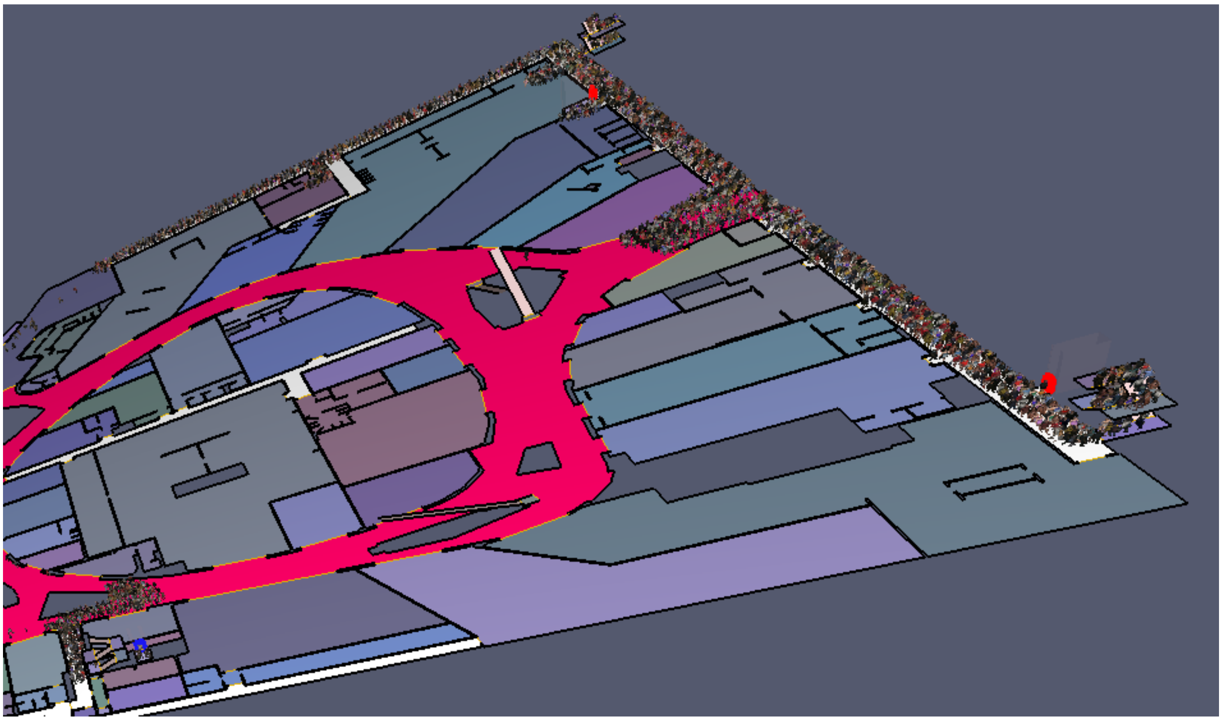

Figure 16. Highest level of congestion in the escape corridors on the upper ground floor

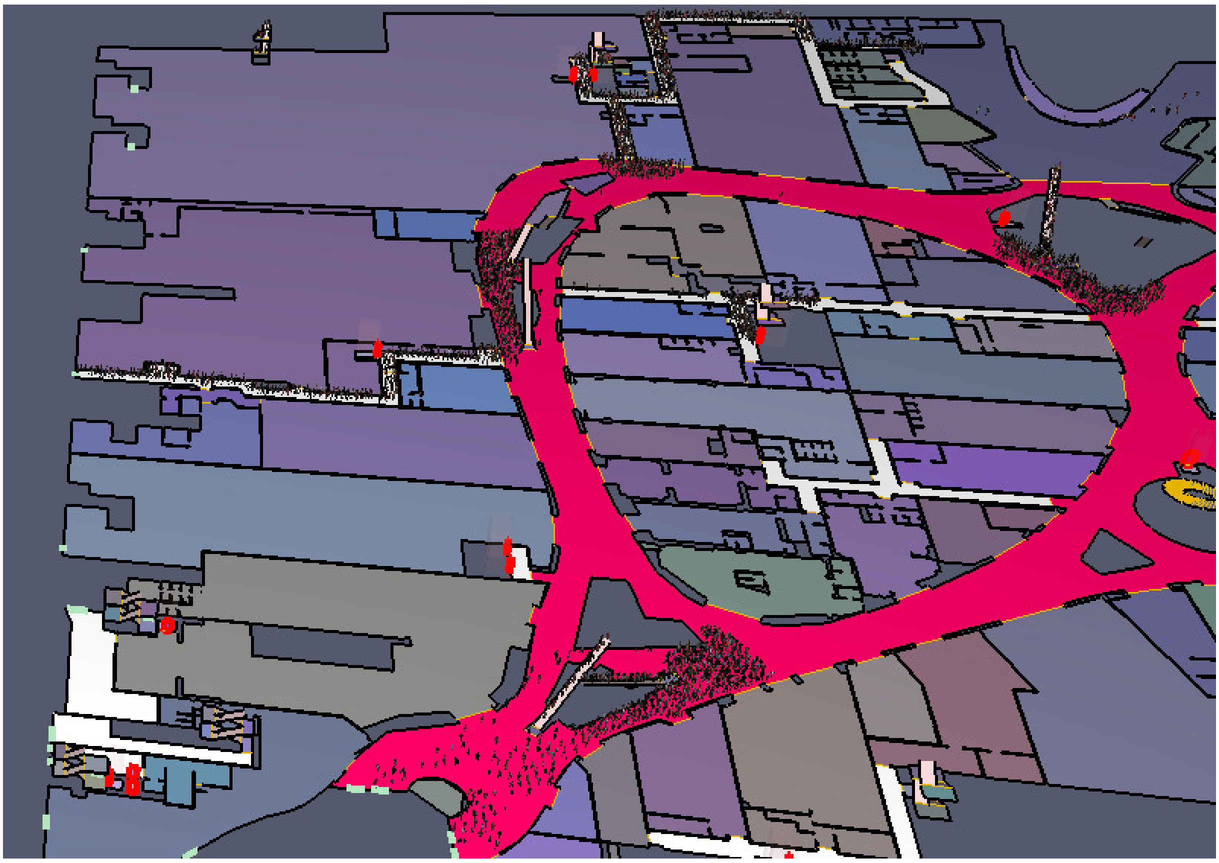

Figure 17. Highest level of congestion in the escape corridors and circulation spaces near the staircases on the upper ground floor

Considering the areas where the congestion occurred, a proper optimal scenario was constituted in a way to reduce the level of crowdedness. The purpose of this scenario is to shorten evacuation time by means of successful crowd management techniques. Additionally, phased evacuation strategy was also employed in this scenario. All the strategies implemented for this remarkable scenario are as follows:

- Since the most crowded floor is the *upper ground floor (Level +6)*, all stairs between this floor and first *floor (Level +12)* have been removed or blocked in the model so that additional congestion to upper ground floor was avoided. People on the first floor used only the stairs in escape corridors or the single staircase going down directly to the *lower ground floor (Level 0)*.

- Occupants in the lower ground floor and the first floor evacuated at the same time. Locally quickest route algorithm defined by Pathfinder by default was applied to the occupants on these floors. The occupants were able to change their routes considering the queuing time.

- All occupants in the upper ground floor stores with the exits opening directly to the outside, evacuated the stores using only these exits (not going to the circulation areas).
- Occupants in the circulation space in the upper ground floor marked with red areas and stores without any doors opening to the escape corridors evacuated the building via main exits or the escape corridors at which there is a door to outside at the end. The access to escape corridors on this floor was blocked.
- All the occupants in the upper ground floor stores with a door(s) opening to escape corridors evacuated via these exits. However, they were instructed to wait for all the occupants upstairs (Level +12) to complete the evacuation to go down the stairs in the escape corridors. The stairs marked in red circle and used by the occupants in both Level +6 and Level +12, which correspond to Staircase 2,3,4,5 and 6 can be seen in Figure 18,19 and 20. However, people with movement disabilities were instructed to go to the elevators located at the escape corridors without waiting.

Figures 18,19 and 20 show a simple schematic map for each floor showing the routes that occupants follow based on the strategies of Scenario 4. White arrows show the routes followed by the occupants in the upper ground floor stores with the exits opening directly to the outside. These occupants evacuated the stores using only these exits (i.e. they did not go to the circulation areas). Yellow arrows show the emergency exits used by the occupants in the upper ground floor stores with a door(s) opening to escape corridors. Green arrows point to the routes that occupant in the circulation spaces can use.

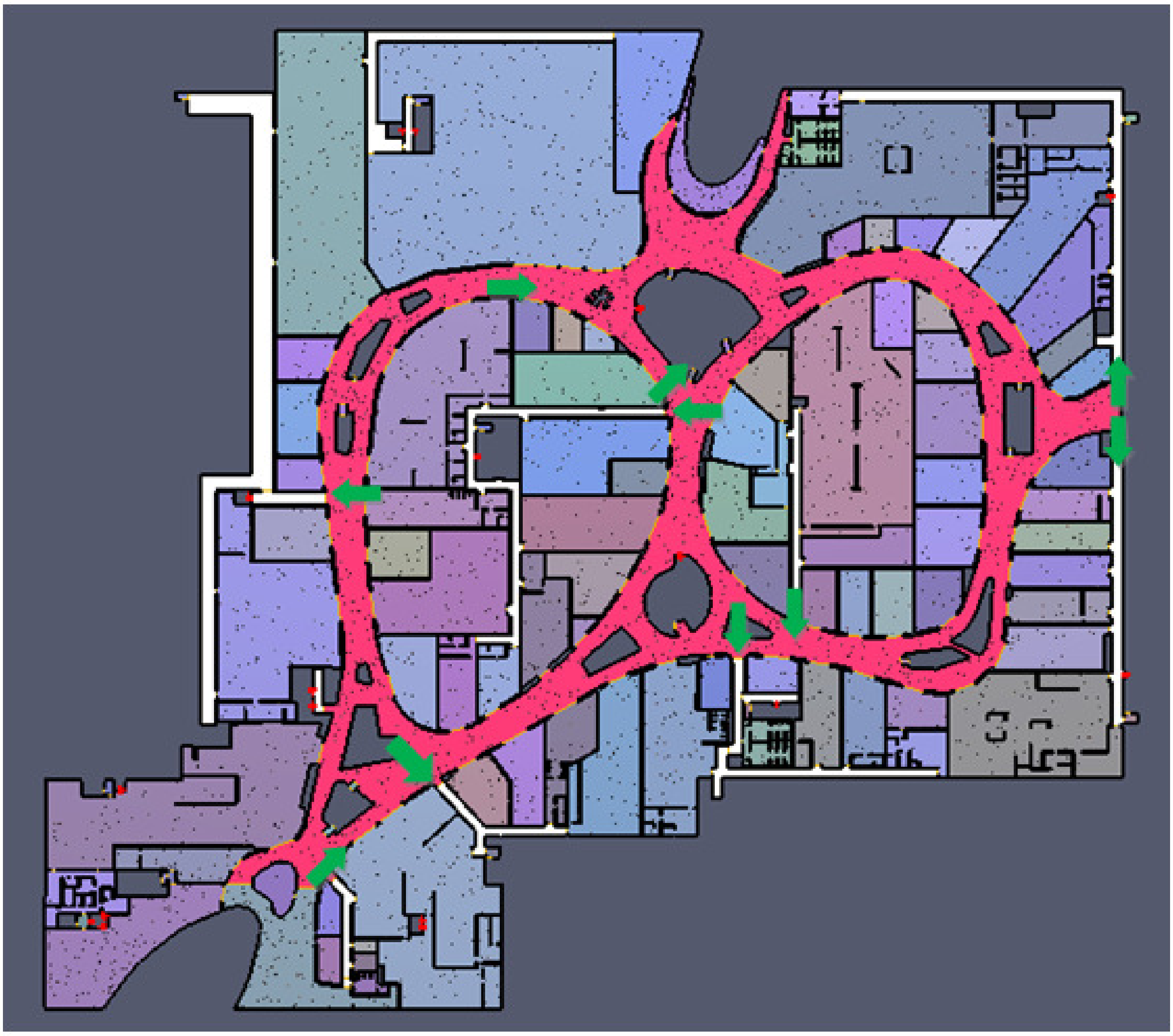

Figure 18. Schematic Map on Level 1 based on Scenario 4

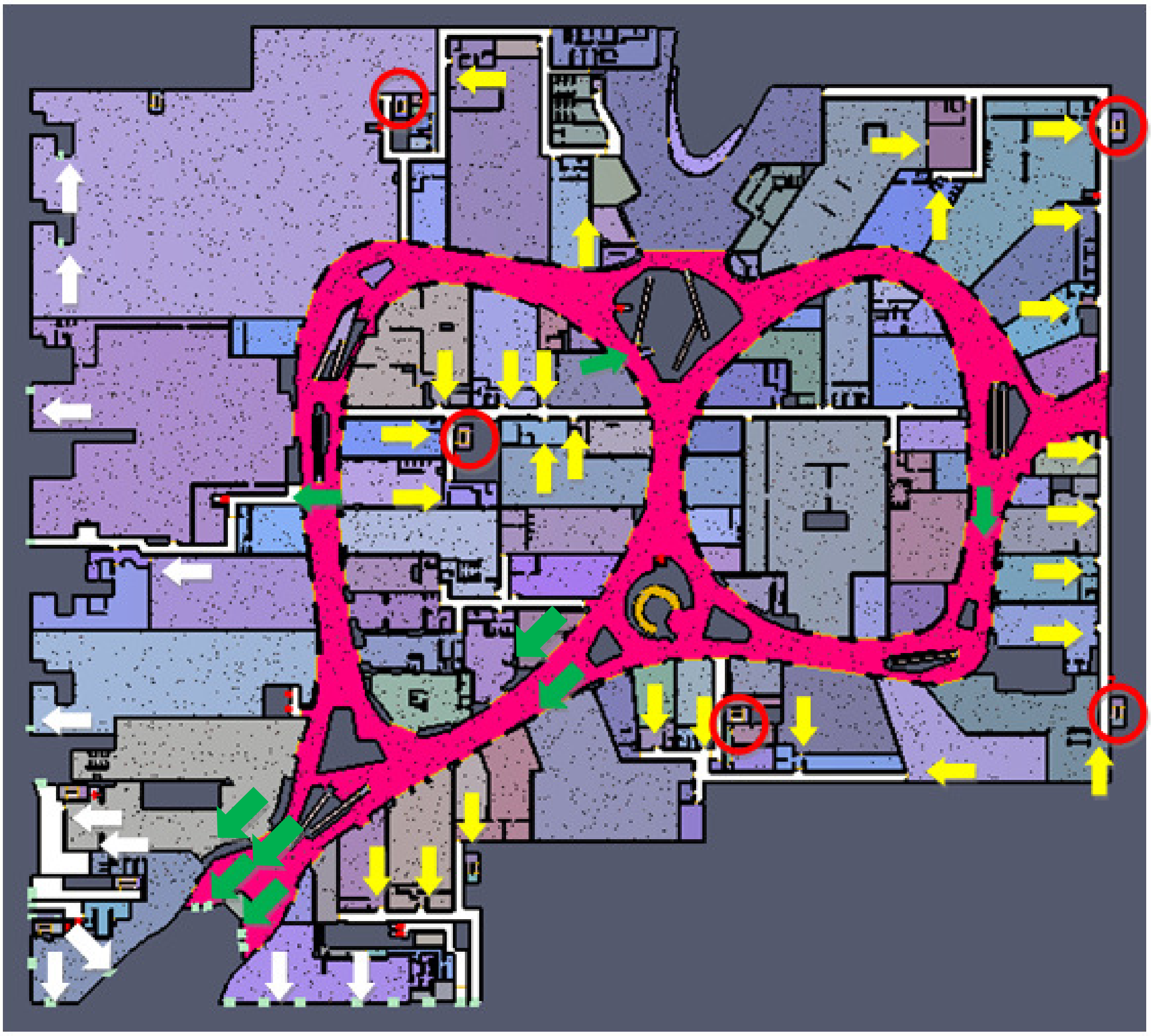

Figure 19. Schematic Map on the upper ground floor based on Scenario 4

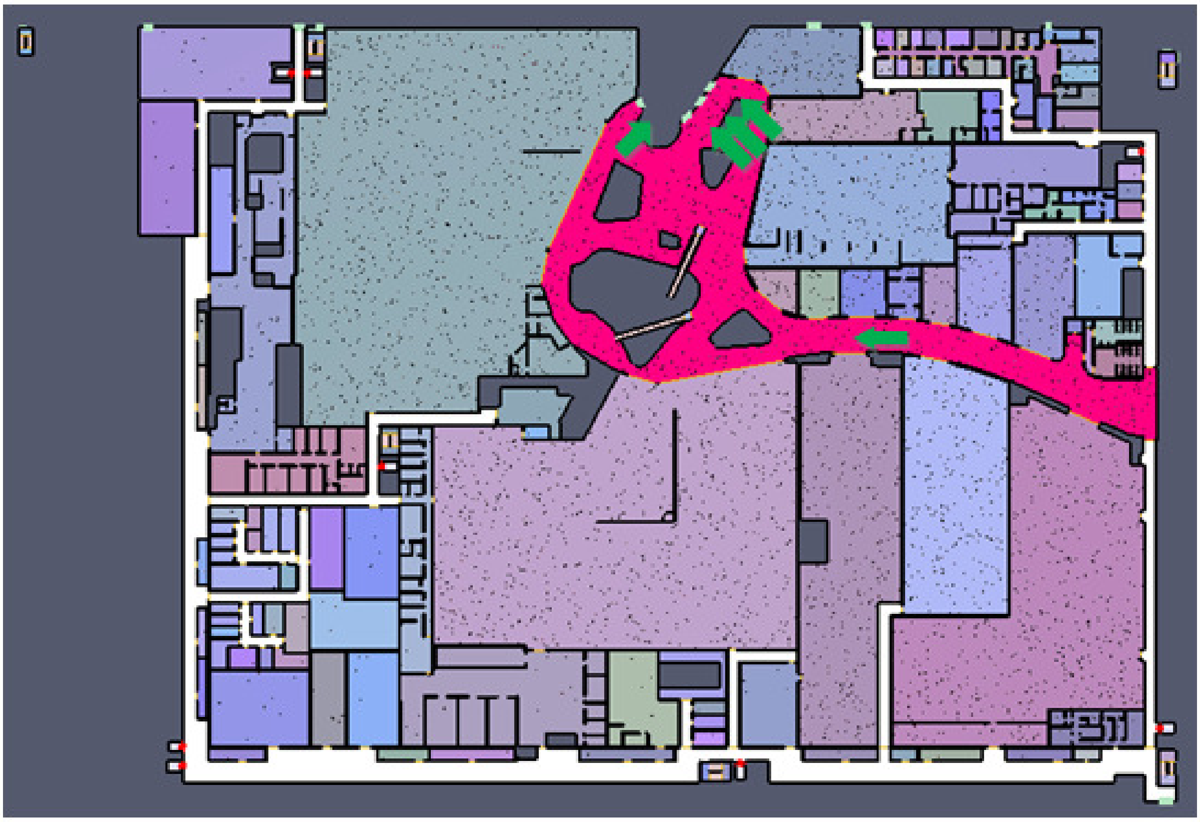

Figure 20. Schematic Map on the lower ground floor based on Scenario 4

4.9.5 Simulation of Scenario 5

Scenario 5 is basically the same scenario as Scenario 4. The only difference is that occupants in the stores on the upper ground floor with a door(s) opening to escape corridors were instructed to go down the stairs in the escape corridors together with the occupants on the first floor simultaneously. That means there is no phased evacuation implemented for this scenario.

5. RESULTS

Evacuation models generally use distributions or stochastic variables in order to simulate the variability of behaviours [8], thus a simple method called convergence based on simple acceptance criteria was implemented to decide the required number of runs for the same scenario. This method corresponds to the second method discussed in Section 4.7.

In this study, the following acceptance criteria (threshold values) have been assumed, as explained in Section 4.7:

- $TET_{convj} < 0.01$ (1%) for 10 consecutive number of runs
- $SD_{convj} < 0.05$ (5%)for 10 consecutive number of runs

Tables from number 6 to number 10 show the results for 20 Runs of each scenario (From Scenario 1 to Scenario 5, respectively). If the box in the tables points out 'FAILED', it means the test has been failed. If the test is passed, the box has been left empty. After 10 consecutive runs, when the test is passed, the box shows 'OK', i.e. the acceptance criteria have been realized. However, it should be noted that both criteria for TET and SD should be met. For instance, in the first scenario, TET converges at 14th run, while SD meets the criteria at 20th run, which means at least 20 runs are required. In order to exemplify this, some examples have been explained below:

In order to calculate these variables, the respective equations have been explained in Section 4.7.

For instance, if column '4' in Scenario 1 (Table 6) is analysed,

$TET_{av1} = TET_1 = 2277.0$

$TET_{av2} = (TET_1+TET_2)/2 = (2277+2258)/2 = 2267.5$

$TET_{av3} = (TET_1+TET_2+TET_3)/3 = (2277+2258+2253)/3 = 2262.7$

$TET_{av4} = (TET_1+TET_2+TET_3+TET_4)/4 = (2277+2258+2253+2168)/4 = 2239.0$

and

$TET_{conv2} = \left|\frac{TET_{av2} - TET_{av1}}{TET_{av2}}\right| = \left|\frac{2267.5 - 2277.0}{2267.5}\right|$ = 0.0042 (PASSED, 0.0042 < 0.01)

$TET_{conv3} = \left|\frac{TET_{av3} - TET_{av2}}{TET_{av3}}\right| = \left|\frac{2262.7 - 2267.5}{2262.7}\right|$ = 0.0021 (PASSED, 0.0021 < 0.01)

$TET_{conv4} = \left|\frac{TET_{av4} - TET_{av3}}{TET_{av4}}\right| = \left|\frac{2239.0 - 2262.7}{2239.0}\right|$ = 0.0106 (FAILED, 0.0106 > 0.01)

Standard deviation is calculated by the following equation:

$$\sigma = SD = \sqrt{\frac{(X_1 - X_{average})^2 + (X_2 - X_{average})^2 + \dots + (X_n - X_{average})^2}{n-1}}$$

For instance,

$$SD_2 = \sqrt{\frac{(TET_1 - TET_{av2})^2 + (TET_2 - TET_{av2})^2}{2-1}} = \sqrt{\frac{(2277 - \left(\frac{2277+2258}{2}\right))^2 + (2258 - \left(\frac{2277+2258}{2}\right))^2}{1}} = 13,44$$

In a similar manner,

$SD_3 = 12.66$

$SD_4 = 48.45$

and

$SD_{conv3} = \left|\frac{SD_3 - SD_2}{SD_3}\right| = \left|\frac{12.66 - 13.44}{12.66}\right|$ = 0.0610 (FAILED, 0.0610 > 0.05)

$SD_{conv4} = \left|\frac{SD_4 - SD_3}{SD_4}\right| = \left|\frac{48.45 - 12.66}{48.45}\right|$ = 0.7386 (FAILED, 0.7386 > 0.05

In this case, TET converges at 14th run, whereas SD fulfils the criteria at 20th run.

In order to have a single representative simulation, average of a certain number of simulations at which acceptance criteria have been met was calculated, e.g. average of 20 simulations and 19 simulations for Scenario 1 and Scenario 2, respectively, as shown in Table 6 and Table 7.

Table 6. RESULTS for 20 Runs of Scenario 1*

RESULTS for 20 Runs of Scenario 1							
Run (n)	**TET_j**	**TET_{avj}**	**TET_{convj}**	**Consecutive runs for TET**	**SD_j**	**SD_{convj}**	**Consecutive runs for SD**
1	2277	2277.0	/	/	/	/	/
2	2258	2267.5	0.0042		13.44	/	/
3	2253	2262.7	0.0021		12.66	0.0610	FAILED
4	2168	2239.0	0.0106	FAILED	48.45	0.7386	FAILED
5	2149	2221.0	0.0081		58.14	0.1667	FAILED
6	2184	2214.8	0.0028		54.15	0.0737	FAILED
7	2099	2198.3	0.0075		66.03	0.1799	FAILED
8	2299	2210.9	0.0057		70.75	0.0666	FAILED
9	2209	2210.7	0.0001		66.18	0.0690	FAILED
10	2211	2210.7	0.0000		62.40	0.0607	FAILED
11	2158	2205.9	0.0022		61.29	0.0181	
12	2162	2202.3	0.0017		59.80	0.0250	
13	2209	2202.8	0.0002		57.28	0.0439	
14	2220	2204.0	0.0006	OK	55.23	0.0372	
15	2180	2202.4	0.0007		53.58	0.0308	
16	2216	2203.3	0.0004		51.88	0.0327	
17	2171	2201.4	0.0009		50.85	0.0203	
18	2215	2202.1	0.0004		49.44	0.0285	
19	2174	2200.7	0.0007		48.47	0.0199	
20	2153	2198.3	0.0011		48.36	0.0024	OK

Scenario 1: Pathfinder default algorithm-locally quickest*

Table 7. RESULTS for 20 Runs of Scenario 2*

RESULTS for 20 Runs of Scenario 2							
Run (n)	TET_j	TET_{avj}	TET_{convj}	Consecutive runs for TET	SD_j	SD_{convj}	Consecutive runs for SD
1	2863	2863.0	/	/	/	/	/
2	2799	2831.0	0.0113	FAILED	45.25	/	/
3	2830	2830.7	0.0001		32.01	0.4140	FAILED
4	2869	2840.3	0.0034		32.41	0.0124	
5	2817	2835.6	0.0016		29.93	0.0828	FAILED
6	2919	2849.5	0.0049		43.31	0.3090	FAILED
7	2787	2840.6	0.0031		46.06	0.0596	FAILED
8	2905	2848.6	0.0028		48.34	0.0473	
9	2850	2848.8	0.0001		45.22	0.0690	FAILED
10	2805	2844.4	0.0015		44.83	0.0088	
11	2893	2848.8	0.0016		44.98	0.0034	
12	2885	2851.8	0.0011	OK	44.14	0.0190	
13	2890	2854.8	0.0010		43.57	0.0132	
14	2868	2855.7	0.0003		42.01	0.0371	
15	2900	2858.7	0.0010		42.06	0.0013	
16	2822	2856.4	0.0008		41.66	0.0096	
17	2879	2857.7	0.0005		40.70	0.0236	
18	2829	2856.1	0.0006		40.07	0.0158	
19	2855	2856.0	0.0000		38.94	0.0290	OK
20	2842	2855.3	0.0002		38.04	0.0238	

Scenario 2 Worst case-familiar routes*

Table 8. RESULTS for 20 Runs of Scenario 3*

RESULTS for 20 Runs of Scenario 3							
Run (n)	**TET_j**	**TET_{avj}**	**TET_{convj}**	**Consecutive runs for TET**	**SD_j**	**SD_{convj}**	**Consecutive runs for SD**
1	2075	2075.0	/	/	/	/	/
2	2057	2066.0	0.0044		12.73	/	/
3	2073	2068.3	0.0011		9.87	0.2901	FAILED
4	2035	2060.0	0.0040		18.51	0.4670	FAILED
5	2121	2072.2	0.0059		31.64	0.4150	FAILED
6	2125	2081.0	0.0042		35.59	0.1109	FAILED
7	2135	2088.7	0.0037		38.36	0.0724	FAILED
8	2086	2088.4	0.0002		35.53	0.0797	FAILED
9	2045	2083.6	0.0023		36.25	0.0197	
10	2097	2084.9	0.0006		34.44	0.0526	FAILED
11	2073	2083.8	0.0005	OK	32.87	0.0478	
12	2053	2081.3	0.0012		32.58	0.0089	
13	2034	2077.6	0.0017		33.83	0.0371	
14	2051	2075.7	0.0009		33.27	0.0168	
15	2096	2077.1	0.0007		32.49	0.0242	
16	2076	2077.0	0.0000		31.39	0.0351	
17	2074	2076.8	0.0001		30.40	0.0324	
18	2059	2075.8	0.0005		29.79	0.0206	
19	2114	2077.9	0.0010		30.28	0.0161	
20	2104	2079.2	0.0006		30.05	0.0074	OK

Scenario 3: shortest in the room*

Table 9. RESULTS for 20 Runs of Scenario 4*

RESULTS for 20 Runs of Scenario 4							
Run (n)	**TET_j**	**TET_{avj}**	**TET_{convj}**	**Consecutive runs for TET**	**SD_j**	**SD_{convj}**	**Consecutive runs for SD**
1	1795	1795.0	/	/	/	/	/
2	1780	1787.5	0.0042		10.61	/	/
3	1795	1790.0	0.0014		8.66	0.2247	FAILED
4	1795	1791.3	0.0007		7.50	0.1547	FAILED
5	1805	1794.0	0.0015		8.94	0.1615	FAILED
6	1817	1797.8	0.0021		12.34	0.2749	FAILED
7	1801	1798.3	0.0003		11.32	0.0893	FAILED
8	1787	1796.9	0.0008		11.22	0.0095	
9	1815	1798.9	0.0011		12.12	0.0748	FAILED
10	1789	1797.9	0.0006		11.85	0.0230	
11	1781	1796.4	0.0009	OK	12.35	0.0400	
12	1787	1795.6	0.0004		12.08	0.0222	
13	1789	1795.1	0.0003		11.71	0.0317	
14	1785	1794.4	0.0004		11.57	0.0122	
15	1789	1794.0	0.0002		11.23	0.0298	
16	1787	1793.6	0.0002		10.97	0.0236	
17	1797	1793.8	0.0001		10.67	0.0289	
18	1794	1793.8	0.0000		10.35	0.0308	
19	1793	1793.8	0.0000		10.06	0.0289	OK
20	1791	1793.7	0.0001		9.81	0.0253	

Scenario 4:Optimal evacuation strategy-1*

Table 10. RESULTS for 20 Runs of Scenario 5*

RESULTS for 20 Runs of Scenario 5							
Run (n)	**TET_j**	**TET_{avj}**	**TET_{convj}**	**Consecutive runs for TET**	**SD_j**	**SD_{convj}**	**Consecutive runs for SD**
1	1683	1683.0	/	/	/	/	/
2	1714	1698.5	0.0091		21.92	/	/
3	1683	1693.3	0.0031		17.90	0.2247	FAILED
4	1772	1713.0	0.0115	FAILED	41.96	0.5735	FAILED
5	1693	1709.0	0.0023		37.42	0.1212	FAILED
6	1696	1706.8	0.0013		33.89	0.1042	FAILED
7	1689	1704.3	0.0015		31.66	0.0703	FAILED
8	1655	1698.1	0.0036		34.10	0.0715	FAILED
9	1673	1695.3	0.0016		32.98	0.0340	
10	1701	1695.9	0.0003		31.15	0.0589	FAILED
11	1713	1697.5	0.0009		29.99	0.0384	
12	1732	1700.3	0.0017		30.29	0.0097	
13	1679	1698.7	0.0010		29.60	0.0234	
14	1703	1699.0	0.0002	OK	28.46	0.0400	
15	1676	1697.5	0.0009		28.06	0.0142	
16	1670	1695.7	0.0010		27.98	0.0027	
17	1713	1696.7	0.0006		27.41	0.0207	
18	1738	1699.0	0.0013		28.30	0.0314	
19	1704	1699.3	0.0002		27.53	0.0282	
20	1684	1698.5	0.0004		27.00	0.0195	OK

Scenario 5:Optimal evacuation strategy-2*

As it can be seen in the figures below (From Figure 21 to Figure 25) , Total Evacuation Time (TET) converge relatively fast, Standard Deviation (SD) converge significantly slowly. However, 20 runs for each scenario were sufficient in this study. If the defined acceptance criteria had not been fulfilled, additional runs would have been required. As seen in the figures below, SD fluctuates considerably until the 10th run for all cases and starts to remain steady. In contrast, TET converges very quickly and there is no dramatic change throughout the running process.

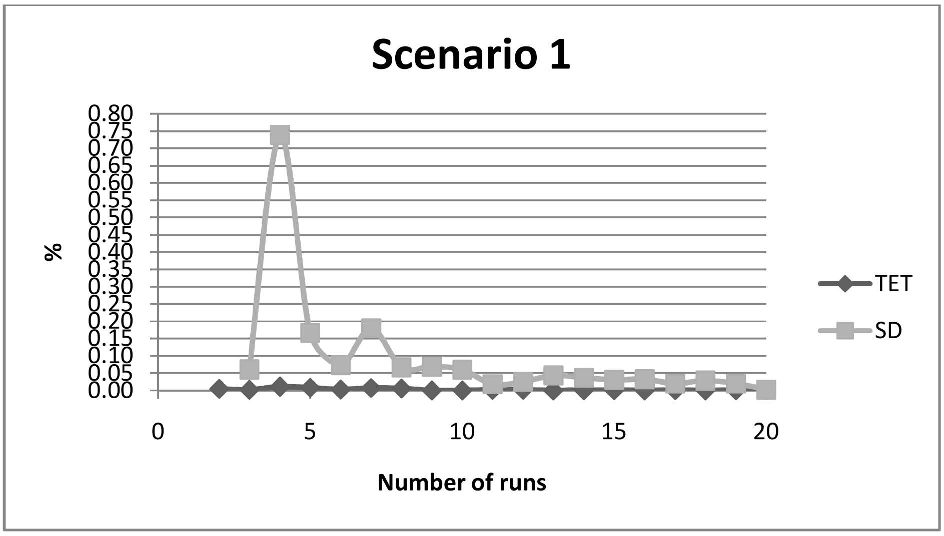

Figure 21. Convergence of model results for Scenario 1

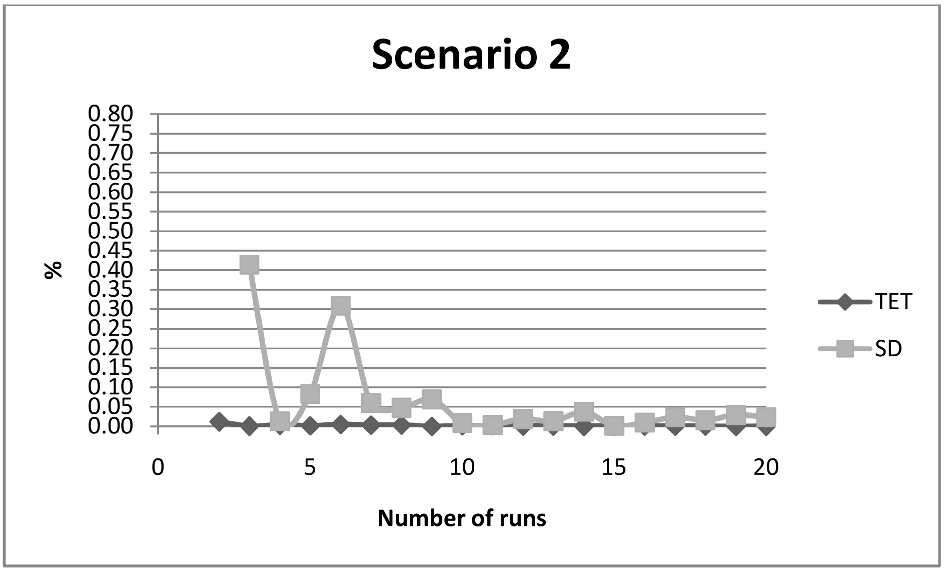

Figure 22. Convergence of model results for Scenario 2

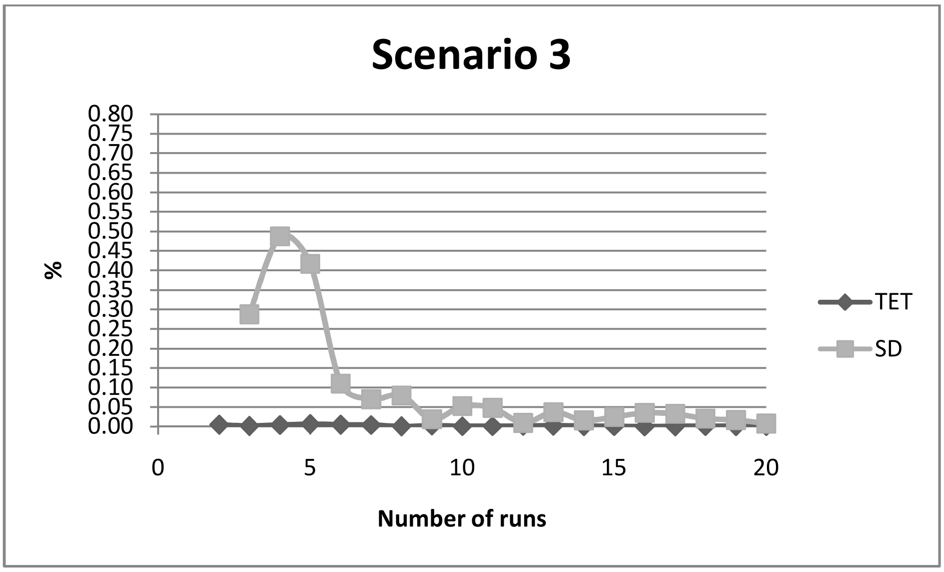

Figure 23. Convergence of model results for Scenario 3

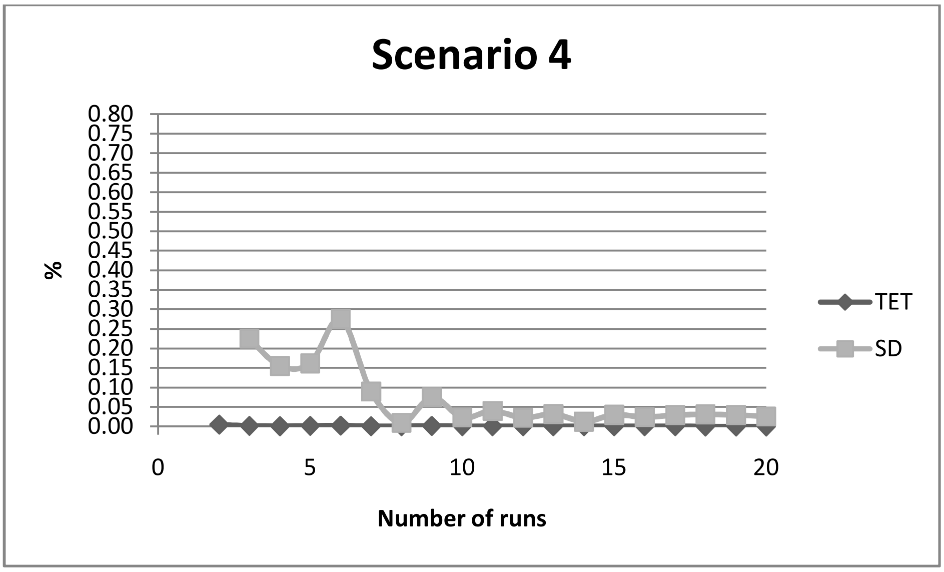

Figure 24. Convergence of model results for Scenario 4

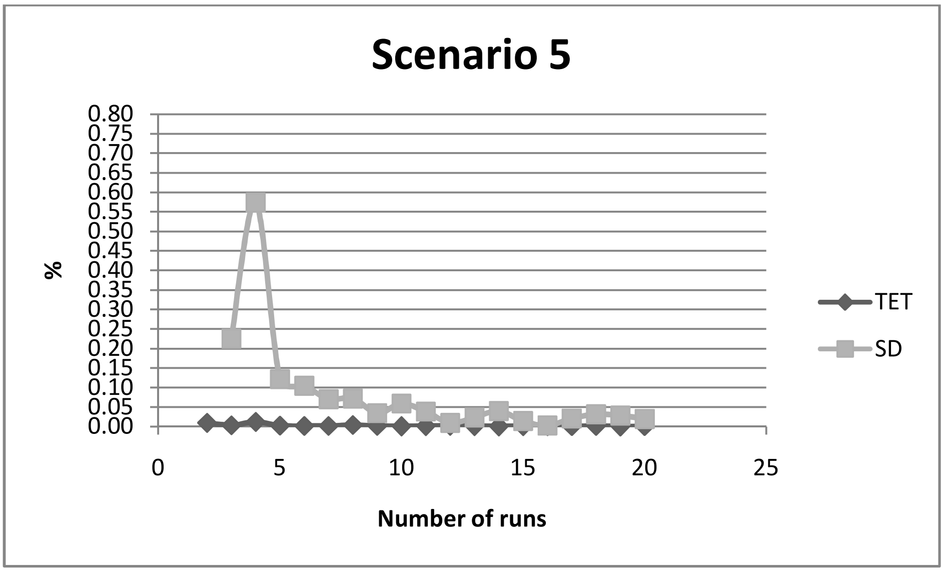

Figure 25. Convergence of model results for Scenario 5

Table 11 shows the percentages of evacuees and corresponding evacuation times for each scenario. The results are given as mean, minimum and maximum values. The evacuation process as well as the effect of the slow occupants on evacuation time can be evaluated easily be means of the different percentages of the occupants introduced. Figure 26 illustrates the comparison of arrival time curves.

Table 11. Percentages of evacuees against time for each scenario (mean [min-max])

% of Evacuees	Corresponding Occupant	Evacuation Time (s)				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
1st Evacuee out	1	7 [4-9]	6 [5-8]	6 [5-7]	6 [5-9]	6 [5-8]
25% of Evacuees out	5387	167 [165-169]	242 [237-246]	176 [174-177]	179 [178-181]	176 [175-178]
50% of Evacuees out	10774	375 [370-383]	578 [570-584]	420 [415-428]	364 [361-366]	357 [354-359]
75% of Evacuees out	16161	683 [676-695]	1143 [1132-1153]	771 [761-778]	656 [649-662]	639 [634-646]
98% of Evacuees out	21117	1837 [1729-1922]	2158 [2096-2214]	1761 [1673-1853]	1530 [1506-1558]	1419 [1405-1450]
100% of Evacuees out	21548	2198 [2099-2299]	2856 [2787-2919]	2079 [2034-2135]	1794 [1780-1817]	1699 [1665-1772]

Scenario 1: Pathfinder default algorithm-locally quickest

Scenario 2 Worst case-familiar routes

Scenario 3:Shortest in the room

Scenario 4:Optimal evacuation strategy-1

Scenario 5:Optimal evacuation strategy-2

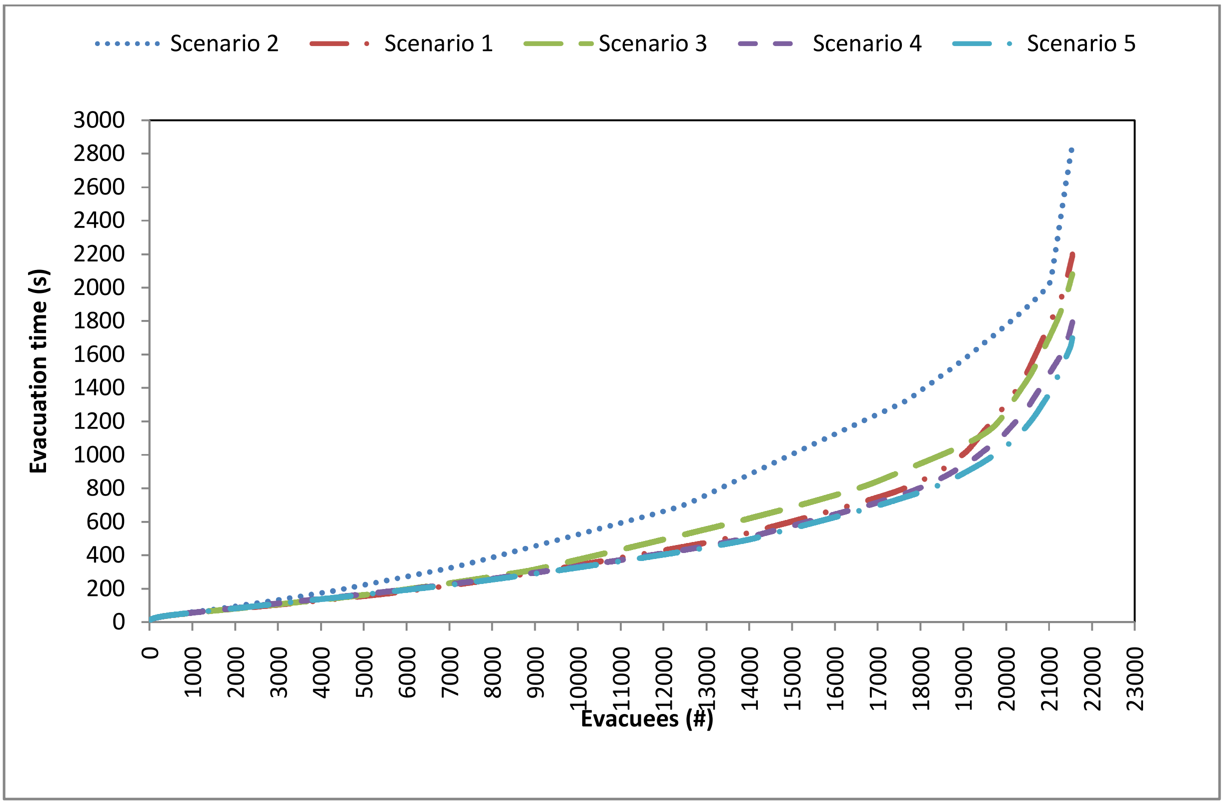

Figure 26. Comparison of arrival time curves

As can be seen in Table 11 and Figure 26, there is no significant difference in the evacuation times of 25% of evacuees between the scenarios, except for the worst-case scenario, which corresponds to Scenario 2. The difference of evacuation times between all the scenarios increases in direct proportion to the number of occupants. Unsurprisingly, Scenario 2-worst case scenario has the highest evacuation time with 2856 seconds (47 minutes 36 seconds) due to the disuse of emergency exits as well as following the familiar routes whereas Scenario 5 which points out the optimal evacuation strategy has the lowest time with 1699 seconds (28 minutes 19 minutes) to complete the evacuation of all the occupants within the building. There is a dramatic difference between the results of these 2 scenarios (19 minutes 17 seconds), i.e. Scenario 2 has 40.5% higher evacuation time than Scenario 5. It demonstrates that evacuation time can be reduced considerably by means of successful evacuation strategy using proper crowd management techniques. The figures for both Scenario 4 and Scenario 5, which include the optimal evacuation strategy are quite similar. These numbers are 1794 (29 minutes 54 seconds) and 1699 seconds (28 minutes and 19 minutes) for Scenario 4 and Scenario 5, respectively. Due to the slight difference between these scenario, it can be interpreted that occupants in the stores on the upper ground floor with a door(s) opening to escape corridors do not have to wait for all the occupants upstairs (Level +12) to completed to go down the stairs in the escape corridors (See 4.8.4), i.e. there is no need for partial evacuation. If the occupants on both floors go down the stairs simultaneously, evacuation will be completed slightly earlier, around 90 seconds, which refers to Scenario 5. Similarly, the difference in the arrival times of all the occupants is relatively low between Scenario 1 and Scenario 3, which refer to the cases of locally quickest and locally shortest algorithm, respectively. These numbers are 2198 (36 minutes 38 seconds) seconds for the Scenario 1 and 2079 (34 minutes 39 seconds) seconds for Scenario 2. Therefore, evacuation time of Scenario 3, which points to the locally shortest evacuation strategy is relatively lower than the one in the case of using locally quickest algorithm. As seen in Figure 26, the lines become steeper after about 19.500 evacuees leaves the building for all the scenarios excluding Scenario 2, which means that occupants slow down due to the congestion caused by queuing. Therefore, evacuation time started to go up remarkably from this point.

Apart from the comparison of arrival time curves, this section also includes a critical analysis of the interpretation of the data by comparing with two different benchmark scenarios. Considering that people may not effectively use emergency exits, Scenario 2 has been chosen in a way to be a representative case of today's worst case conditions as the first benchmark scenario. In addition, Scenario 5 including optimal evacuation strategy has been chosen as the second reference scenario since it represents an ideal crowd management strategy. In order to compare these scenarios with the others, a set of functional analysis operators, Euclidean Relative Distance (ERD), Euclidean Projection Coefficient (EPC) and Secant Cosine (SC), which have been explained in Section 4.7 should be employed. Previous applications of these operators for the analysis of evacuation model results are available in the literature for different fields of application [37].

In the case of the value of ERD close to '0' and EPC close to '1', that refers to good agreement between the curves of benchmark and compared scenario since ERD indicates the differences and EPC presents the similarities [8,37]. In the case of the value of SC close to 1, that points to similarities in the shape of curves of benchmark and compared scenario.

The results have been given for 2 different cases: Scenario 2, i.e. worst case scenario and Scenario 5, i.e. optimal scenario as the benchmark scenario, respectively.

Using the equations above, the values shown in Table 12 have been obtained for the first case. While $\vec{x}$ corresponds to the worst case scenario, i.e. Scenario 2, $\vec{y}$ points to the other scenarios to be compared.

Table 12. Calculated values for the operators 'ERD', 'EPC' and 'SC' comparing the benchmark scenario (Scenario 2) with the others

Scenario	ERD	EPC	SC
Scenario 2 vs. Scenario 1	0.46	1.42	0.85
Scenario 2 vs. Scenario 3	0.40	1.39	0.87
Scenario 2 vs. Scenario 4	0.60	1.59	0.85
Scenario 2 vs. Scenario 5	0.68	1.68	0.90

Scenario 1: Pathfinder default algorithm-locally quickest
Scenario 2 Worst case-familiar routes
Scenario 3:Shortest in the room
Scenario 4:Optimal evacuation strategy-1
Scenario 5:Optimal evacuation strategy-2

Considering the reference scenario as the worst case scenario, i.e. Scenario 2, the values for ERD, EPC and SC have been obtained. To clarify once again, this hypothetical case is caused by the following assumptions:

- Sub-optimal use of emergency exits
- Occupants use only familiar routes
- Insufficient staff management

As shown in Table 12, the values of ERD are not close to '0' in all the cases and also EPC values are far from '1'. It demonstrates that evacuation time decreases using different strategies, i.e. locally quickest, locally shortest and optimal strategies. As expected, the greatest difference between the scenarios, i.e. Scenario 2 and the compared scenarios, has been observed in the comparison of worst case scenario, i.e. Scenario 2 vs. Scenario 5 including optimal evacuation strategy. Results correspond to 0.68 and 1.68 for ERD and EPC, respectively. Since Scenario 4 and Scenario 5 are quite similar, the second greatest difference has been observed in the comparison of Scenario 2 and Scenario 4. The closest values to Scenario 2 are those for Scenario 3 with 0.40 for ERD and 1.39 for EPC. These figures for Scenario 1 are a little higher for ERD and slightly lower for EPC. Nevertheless, taking into account the worst case scenario as a benchmark scenario, all the values of each scenario are considerably far from '0' for ERD and far from '1' for EPC. There is no great difference between the values of SC taking into account the assumed values for the skip 's' in the equation of SC. It means that the curve shape of the all scenarios are quite similar, i.e. the overall evacuation process does not change to a great extent, but it is the reduced congestion which makes certain scenarios faster. While Scenario 5 is the one which is the closest to '1' with the value of '0.9', Scenario 1 and Scenario 4 is the furthest to '1' with the figure of '0.85'. However, as can be seen, there are no remarkable differences between each of them.

Using the equations for the operators explained before, the values in Table 13 have been calculated for the second case. $\vec{x}$ corresponds to the optimal scenario, i.e. Scenario 5 while $\vec{y}$ points to the other scenarios to be compared.

Table 13. Calculated values for the operators 'ERD', 'EPC' and 'SC' calculated comparing the benchmark scenario (Scenario 5) with the others

Scenario	ERD	EPC	SC
Scenario 5 vs. Scenario 1	0.17	0.85	0.96
Scenario 5 vs. Scenario 3	0.18	0.83	0.97
Scenario 5 vs. Scenario 4	0.06	0.95	0.97
Scenario 5 vs. Scenario 2	0.41	0.59	0.90

Scenario 1: Pathfinder default algorithm-locally quickest
Scenario 2 Worst case-familiar routes
Scenario 3:Shortest in the room
Scenario 4:Optimal evacuation strategy-1
Scenario 5:Optimal evacuation strategy-2

To remind once again, the optimal case can be achieved by appropriate staff crowd management considering the following assumptions:

- All the stairs between upper ground floor (Level +6) and first floor (Level +12) have been removed to avoid additional congestion on the ground floor. People on the first floor used only the stairs in escape corridors or the single staircase going down directly to the lower ground floor (Level 0). All the occupants in the stores on the upper ground floor with a door(s) opening to escape corridors were directed to go down the stairs in the escape corridors together with the occupants on the first floor simultaneously.
- Occupants in lower ground floor and the first floor evacuated at the same time.
- All the occupants in the upper ground floor stores with the exits opening directly to the outside, evacuated the stores using only these exits.
- Occupants in the circulation space in the upper ground floor and stores without any doors opening to the escape corridors evacuated the building via main exits or the escape corridors at which there is a door to outside at the end.
- All the occupants in the upper ground floor stores with a door(s) opening to escape corridors evacuated via these exits. However, they were instructed to wait for all the occupants upstairs (Level +12) to be completed before going down the stairs in the escape corridors. However, people with movement disabilities were instructed to go to the elevators positioned at the escape corridors without waiting.

As shown in Table 13, unsurprisingly, the greatest difference has been observed in the comparison of worst case scenario, i.e. Scenario 2 and optimal case scenario, i.e. Scenario 5. This figure is 0.41 and 0.59 for ERD and EPC, respectively. As Scenario 4 and Scenario 5 are quite similar, no great difference has been observed in the comparison of the results of these scenarios. These figures are 0.06 for ERD and 0.95 for EPC. The values of Scenario 1 for ERD and EPC are relatively close to 0 and far from 1, which are 0.17 and 0.85, respectively. These numbers for Scenario 3 are slightly different from Scenario 1. As seen in the first case, there is also no great difference between the values of SC in this case given the assumed values for the skip 's' in the equation of SC. The greatest difference between the curve shapes has been observed between Scenario 5 and scenario 2 with the value of '0.90'. The other curve shapes are quite similar to each other. Respective numbers of SC for Scenario 1, Scenario 3 and Scenario 4 are 0.96 , 0.97 and 0.97, respectively.

6. DISCUSSION

Performance-based design (PBD) is getting more and more important and being implemented for different types of buildings. Evacuation models, which are one of the main applications of PBD, are used for shopping malls at the present time. The availability of data for calibration of the input, which is quite important to obtain reasonable results and to make an appropriate technical analysis, is one of the main difficulties encountered. Shopping malls are quite different from other buildings since they are multifunctional complexes and comprise different areas of usage, e.g. food courts, stores, storages, restaurants, etc. which means that different approaches for the evaluation of evacuation process are required. Evacuation model results can provide useful and important information in order to make a reasonable analysis of evacuation process, e.g. evacuation times, flow constraints, congestion levels, etc. In this way, some precautions can be taken to reduce the traffic level or shorten the evacuation time.

The current model in this case study exemplifies hypothetical evacuation scenarios in an existing shopping mall. However, further research comprising the investigation of different building configurations, e.g. different location and configuration of egress components such as design and location of stairs, escalators, elevators, etc., building heights, number of floors, etc. is required [34].

As customers in shopping malls are likely to be unfamiliar with the building and fire safety system, pathfinding and crowd management can be considered to be fundamental issues for the evacuation process. It should be taken into consideration a team of staff can lead to an efficient evacuation as explained in Section 2.2. An analysis carried out about staff behaviour in unannounced evacuations for retail stores showed that almost 80% of staff affected customer behaviour positively [2]. Successful strategies, e.g. shortest route choice, optimal evacuation strategy, etc. employed in the scenarios within the scope of this study can be achieved by successful staff management. It can be interpreted that one of the main reasons of the occupant behaviours observed in the worst-case scenario arise from poor staff management, i.e. they could have chosen shorter or quicker routes rather than familiar routes by means of guiding of staff. Shorten evacuation times obtained by successful scenarios are in good agreement with the analysis in the relevant paper (Samochine DA, Boyce K, Shields TJ 2005) [2]. Therefore, investment in the training of staff, which must be periodically conducted and should address the duties explicitly, may have a significant positive impact on evacuation.

The pre-evacuation times in the paper of Shields and Boyce [30] reported in this paper are the actual ones observed in unannounced evacuations in large retail stores. Since the values for pre-evacuation times in this paper were lower than 1 minute, these figures and those observed in the drill and the data in the fire drill report [32] are a good match. It can be undoubtedly said that lower evacuation times can be achieved by trained staff and a successful fire alarm system accompanied by a proper voice message system.

Even though the mall staff in the present case study was given training, it was observed that some of them did not use the emergency exits during the drill, unlike those working for Mark and Spencer reported in the paper of Shields and Boyce [30]. In other words, staff and customers may use familiar routes and exits, i.e. main exits on the lower and upper ground floor. In order to shorten evacuation time and have a successful evacuation, a set of requirements, e.g. an appropriate training, monitoring staff training and behaviour, continuous training, etc. (as explained in Section 2.2 [2,12]) should be met.

One of the greatest differences between this study and Shields and Boyce's paper is the proportion of the occupant types. Since this paper represents a large number of elderly people as well as considerably small number of children, another study has been utilized as a reference paper [31] in order to present more realistic distribution of occupants. The numbers of occupants in these papers are remarkably low compared to the figures for the people in Emporia. Occupant load factor given in NFPA-101 Life Safety Code has been used for the occupant distribution in a way to represent maximum allowable occupant number rather than the observation data in the relevant papers [30,2].

Future research in these areas is needed in order to assess the overall evacuation process much better. First, more drills can be performed to observe occupant behaviour as well as obtain some valuable data, e.g. pre-evacuation times, occupant speeds in different egress components such as ascending stairs, spiral stairs, etc. Additional evacuation scenarios could also be quite helpful, e.g. scenarios including shopping malls with car parks. Multi-storey car park in Emporia has been out of the scope of this thesis. It could be advantageous to simulate it together with the shopping mall. Additionally, some scenarios containing a failure of some systems, e.g. fire alarm systems, elevators, etc. could be simulated.

7. CONCLUSIONS

Evacuation modelling has been used to simulate the evacuation of shopping malls analysing the case study of Emporia Mall located in the city of Malmö (Sweden). A set of procedures, e.g. the routes and exits used by the occupants, pre-movement times, etc. by means of the observed information obtained by the drill held in Emporia have been employed into the model. However, it is not reasonable to compare the results of evacuation times achieved by the simulations with those observed in the drill since there is a remarkably great difference in the number of the occupants in the model and the participants attending the drill. Instead, the results have been compared with different hypothetical benchmark scenarios as the primary objective of this study which was to show the factors that might influence evacuation times and procedures in shopping malls. Additionally, convergence of the simulation results has been checked using a simple method called convergence based on simple acceptance criteria.

The results of the study have fulfilled its purpose and objectives which was to investigate the use of evacuation modelling for analysing egress strategies in shopping malls as well as specify and carry out simulations of the shopping mall 'Emporia' by means of evacuation modelling. Therefore, a set of evacuation case studies in which complex way-finding takes place have been provided. Comparing the impact of wayfinding and exit choices in complex shopping malls in relation to different crowd management and evacuation strategies, the evacuation times for each scenario have been analysed. One of the main objectives of the study was to check if there was a way to shorten evacuation time by means of efficient crowd management techniques. As shown in the previous sections, the evacuation time can be reduced by different evacuation strategies. In this case study, the shortest evacuation time has been obtained by using a detailed evacuation strategy which has been identified. It should be noted that this strategy would require a high level of training by the staff that will conduct it. This study showed that lower evacuation time can also be achieved compared to those obtained by the worst-case scenario using either locally quickest routes to evacuate, i.e. Pathfinder default algorithm or shortest routes in the current locations of occupants by means of directing occupant to the nearest emergency exits.

A set of recommendations on the use of evacuation modelling and some measures which can be taken in order to enhance the evacuation conditions for the study of shopping malls are as follows:

7.1 Recommendations on the use of evacuation modelling

- The selected model is not the only model that can be used to simulate evacuation for shopping malls. Therefore, it should be considered that additional models adopting different modelling assumptions should be tested in order to evaluate the variability in the model results.
- The calibration of the modelling input has been carried out using the available data, e.g. pre-movement times (Shields TJ, Boyce KE 2010) , velocities (Korhonen T, Hostikka S 2009; IES Virtual Environment 2014), occupant distribution (Liang Qiang, JIN Hong-yu 2011), etc. Further experiments regarding evacuation of shopping malls can be useful for the modelling studies.
- Since it was not possible to observe the effects of fire and smoke on the occupant behaviours directly by using Pathfinder (2015 version), it would be quite useful to model evacuation also by means of the other models to evaluate how fire and smoke may directly affect the occupants in the building.
- Due to the lack of drawings of shelves in the stores in the layouts, simulations were carried out without them. It might be considerably beneficial to carry out the simulations with shelves to see how much this highest level of detail in the geometry representation may influence the results.

7.2 Recommendations for improving evacuation conditions

- Since staff behaviours have a dramatic impact on evacuation of the all occupants, lower evacuation time could be achieved by successful crowd management. Therefore, training of staff is enormously vital. They should guide the customers to evacuate safely in the case of emergency situation. In particular, the use of evacuation exits within the stores and the circulation spaces should be encouraged. Staff should also be present near the exits without blocking them.
- Once the fire alarm is activated, staff should take their responsibilities immediately ensuring the evacuation of the customers safely. This will enable to reduce the pre-evacuation time.
- Exit signs and evacuation signage in general should be placed correctly and the number of these signs should be sufficient. This is deemed to increase the usage of emergency exits and decrease evacuation time.
- Putting any obstacles, e.g. shelves, boxes, etc. near the exits should be avoided.

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9. APPENDICES

9.1 APPENDIX A

Figure A-1, A-2 and A-3 show the number of rooms for each floor. Since some rooms are quite small, the sum of those was given as a single room representing one single number. Some rooms located in the circulation areas, e.g. toilets, very small offices, etc. were included in the number of circulation spaces.

Table A-1, A-2 and A-3 give information about the areas of rooms and occupant numbers.

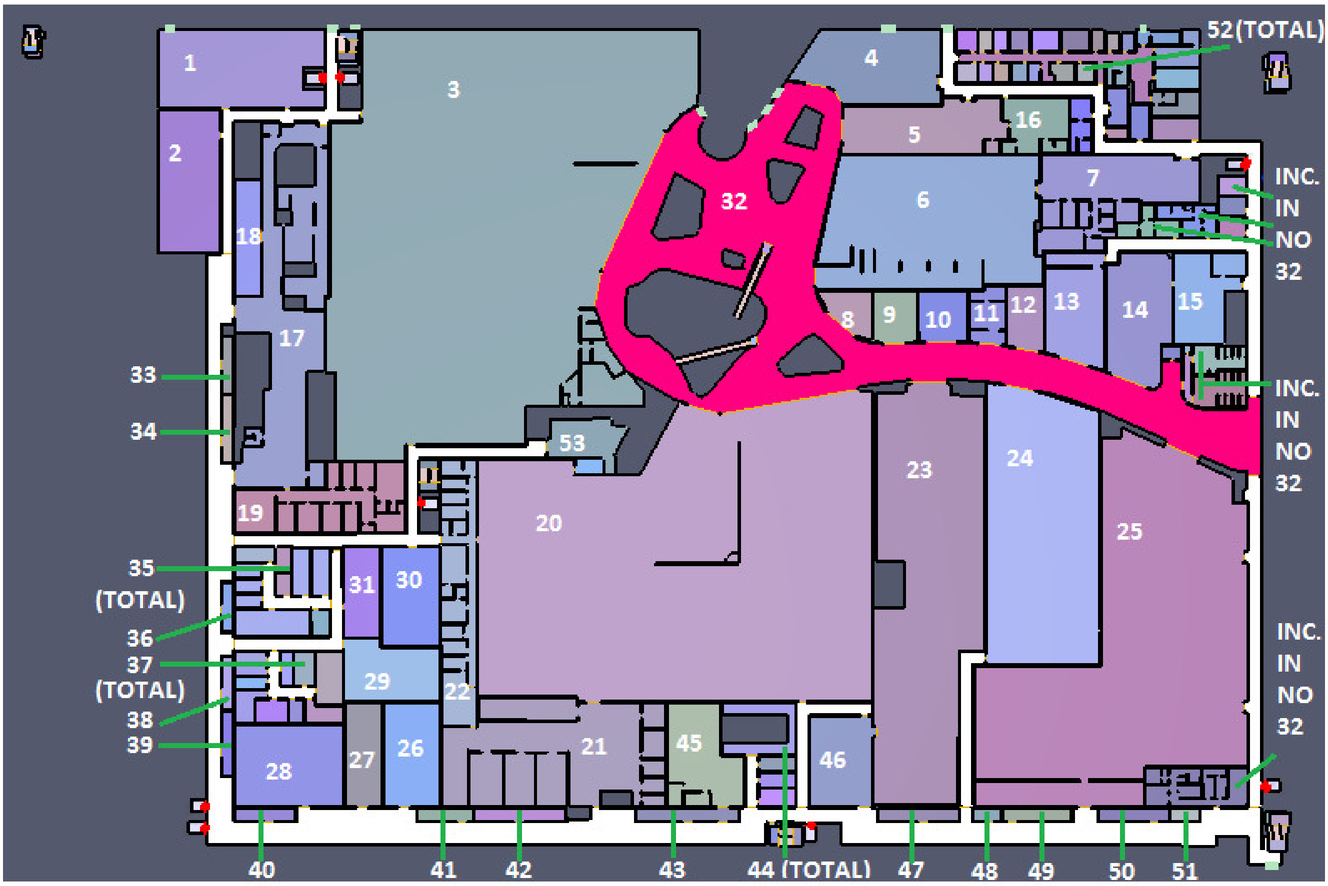

Figure A-1. The number of rooms located on the lower ground floor

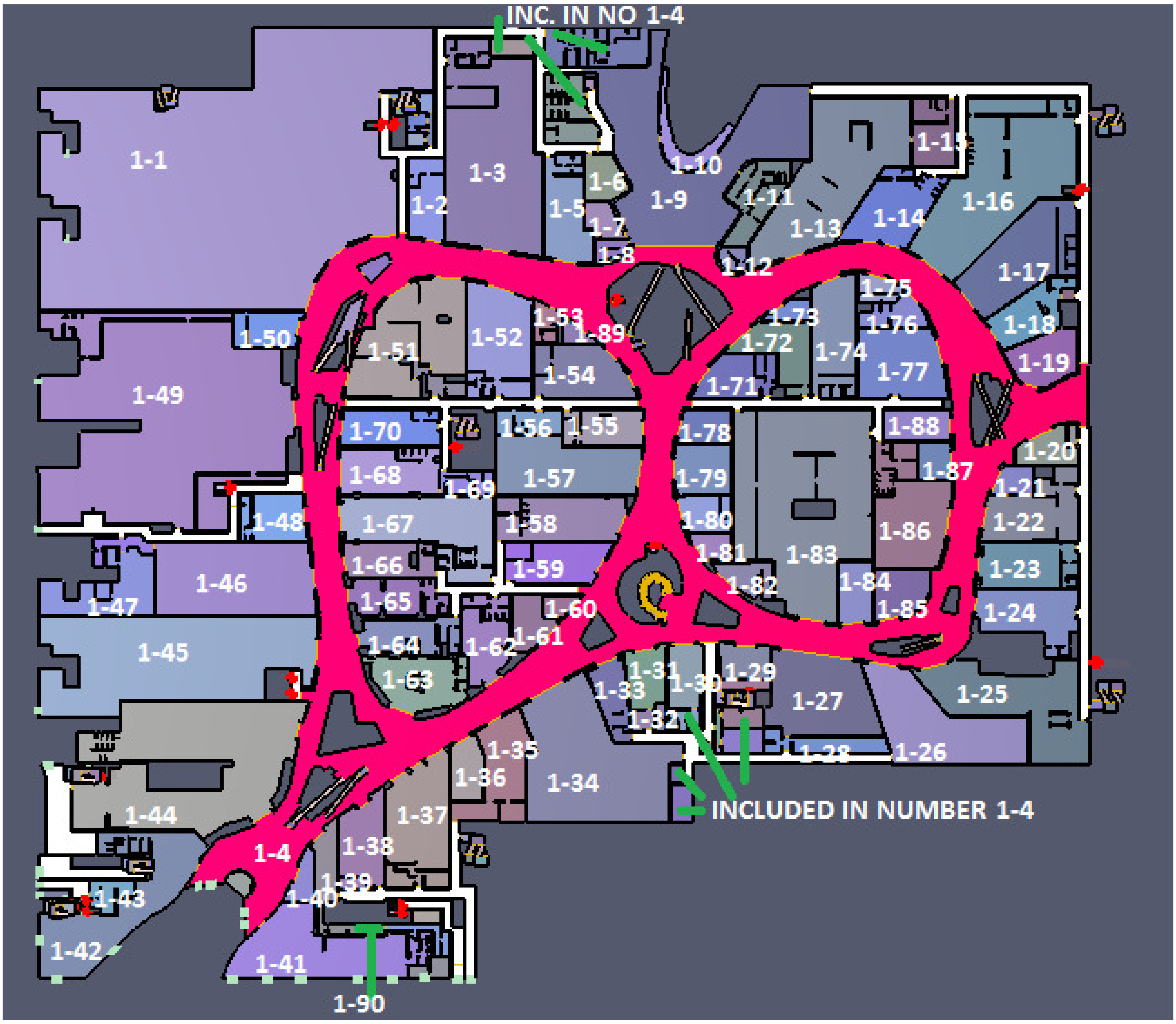

Figure A-2. The number of rooms located on the upper ground floor

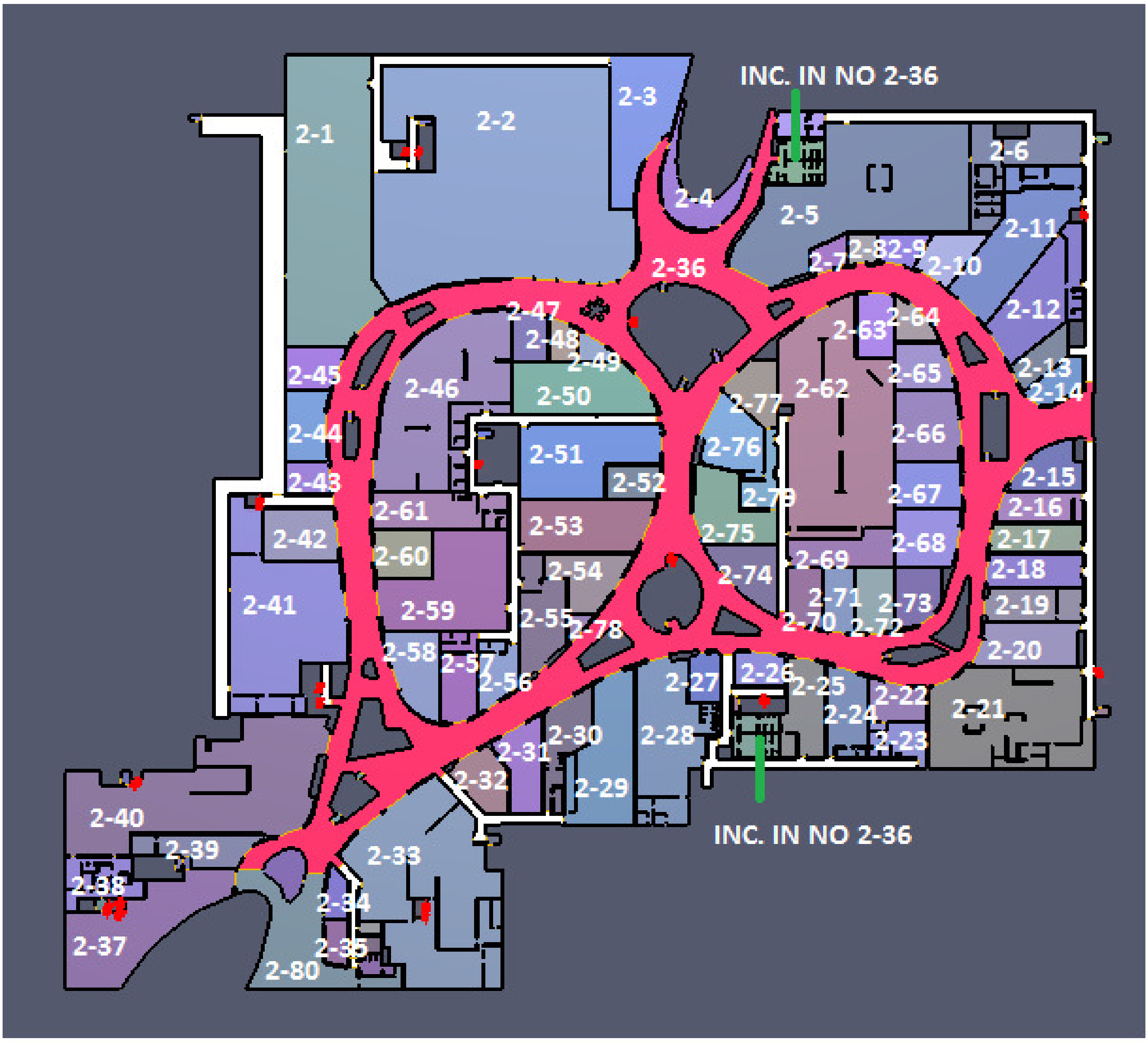

Figure A-3. The number of rooms located on the first floor

Table A-1. Areas of the rooms located on the lower ground floor and number of occupants

Room areas and number of occupants - Lower Ground Floor						
Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
1	Storage	In mercantile occupancies	Gross	27.9	322	12
2	Storage	In mercantile occupancies	Gross	27.9	228	8
3	Mercantile	Sales area on street floor	Gross	2.8	3149	1130
4	Assembly	Less concentrated use, without fixed seating (Restaurant)	Net	1.4	150	107
5	Mercantile	Sales area on street floor	Gross	2.8	211	76
6	Mercantile	Sales area on street floor	Gross	2.8	723	259
7	Storage	In mercantile occupancies	Gross	27.9	290	10
8	Mercantile	Sales area on street floor	Gross	2.8	46	17
9	Mercantile	Sales area on street floor	Gross	2.8	60	21
10	Mercantile	Sales area on street floor	Gross	2.8	66	24
11	Mercantile	Sales area on street floor	Gross	2.8	50	18
12	Mercantile	Sales area on street floor	Gross	2.8	60	21
13	Mercantile	Sales area on street floor	Gross	2.8	169	61
14	Mercantile	Sales area on street floor	Gross	2.8	203	73
15	Storage	In mercantile occupancies	Gross	27.9	138	5
16	Storage	In mercantile occupancies	Gross	27.9	91	3
17	Assembly	Kitchen	Gross	9.3	538	58
18	Storage	In mercantile occupancies	Gross	27.9	79	3
19	Storage	In mercantile occupancies	Gross	27.9	235	8
20	Mercantile	Sales area on street floor	Gross	2.8	2703	970
21	Storage	In mercantile occupancies	Gross	27.9	556	20
22	Storage	In mercantile occupancies	Gross	27.9	230	8
23	Mercantile	Sales area on street floor	Gross	2.8	1037	372
24	Mercantile	Sales area on street floor	Gross	2.8	790	284
25	Mercantile	Sales area on street floor	Gross	2.8	1659	594
26	Storage	In mercantile occupancies	Gross	27.9	148	5
27	Storage	In mercantile occupancies	Gross	27.9	100	4
28	Storage	In mercantile occupancies	Gross	27.9	226	8
29	Storage	In mercantile occupancies	Gross	27.9	144	5
30	Storage	In mercantile occupancies	Gross	27.9	152	5
31	Storage	In mercantile occupancies	Gross	27.9	87	3

Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
32	Mercantile	Circulation areas + other small areas (WC, etc.)	Gross	2.8	1664	594
33	Storage	In mercantile occupancies	Gross	27.9	15	1
34	Storage	In mercantile occupancies	Gross	27.9	18	1
35	Storage	In mercantile occupancies	Gross	27.9	194	7
36	Storage	In mercantile occupancies	Gross	27.9	14	1
37	Storage	In mercantile occupancies	Gross	27.9	167	5
38	Storage	In mercantile occupancies	Gross	27.9	15	1
39	Storage	In mercantile occupancies	Gross	27.9	18	1
40	Storage	In mercantile occupancies	Gross	27.9	20	1
41	Storage	In mercantile occupancies	Gross	27.9	19	1
42	Storage	In mercantile occupancies	Gross	27.9	30	1
43	Storage	In mercantile occupancies	Gross	27.9	34	1
44	Storage	In mercantile occupancies	Gross	27.9	155	5
45	Storage	In mercantile occupancies	Gross	27.9	172	6
46	Storage	In mercantile occupancies	Gross	27.9	145	5
47	Storage	In mercantile occupancies	Gross	27.9	27	1
48	Storage	In mercantile occupancies	Gross	27.9	9	0
49	Storage	In mercantile occupancies	Gross	27.9	23	1
50	Storage	In mercantile occupancies	Gross	27.9	24	1
51	Storage	In mercantile occupancies	Gross	27.9	9	0
52	Business	Offices	Gross	9.3	487	52
53	Storage	In mercantile occupancies	Gross	27.9	77	3
					TOTAL	***4881***

Table A-2. Areas of the rooms located on the upper ground floor and number of occupants

Room areas and number of occupants - Upper Ground Floor						
Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
1-1	Mercantile	Sales area on street floor	Gross	2.8	3656	1314
1-2	Mercantile	Sales area on street floor	Gross	2.8	128	46
1-3	Mercantile	Sales area on street floor	Gross	2.8	833	299
1-4	Mercantile	Circulation areas + other small areas (WC, etc.)	Gross	2.8	4889	1746
1-5	Mercantile	Sales area on street floor	Gross	2.8	199	71
1-6	Assembly	Kitchen	Gross	9.3	78	8
1-7	Assembly	Kitchen	Gross	9.3	50	5
1-8	Assembly	Kitchen	Gross	9.3	26	3
1-9	Assembly	Less concentrated use, without fixed seating (Food Courts)	Net	1.4	532	380
1-10	Assembly	Less concentrated use, without fixed seating (Food Courts)	Net	1.4	49	35
1-11	Assembly	Kitchen	Gross	9.3	146	16
1-12	Assembly	Kitchen	Gross	9.3	28	3
1-13	Mercantile	Sales area on street floor	Gross	2.8	640	228
1-14	Mercantile	Sales area on street floor	Gross	2.8	227	81
1-15	Storage	In mercantile occupancies	Gross	27.9	132	5
1-16	Mercantile	Sales area on street floor	Gross	2.8	765	274
1-17	Mercantile	Sales area on street floor	Gross	2.8	360	129
1-18	Mercantile	Sales area on street floor	Gross	2.8	148	53
1-19	Mercantile	Sales area on street floor	Gross	2.8	139	50
1-20	Mercantile	Sales area on street floor	Gross	2.8	81	29
1-21	Mercantile	Sales area on street floor	Gross	2.8	46	16
1-22	Mercantile	Sales area on street floor	Gross	2.8	235	84
1-23	Mercantile	Sales area on street floor	Gross	2.8	202	73
1-24	Mercantile	Sales area on street floor	Gross	2.8	222	78
1-25	Mercantile	Sales area on street floor	Gross	2.8	446	161
1-26	Mercantile	Sales area on street floor	Gross	2.8	428	153
1-27	Mercantile	Sales area on street floor	Gross	2.8	363	130
1-28	Storage	In mercantile occupancies	Gross	27.9	98	4
1-29	Mercantile	Sales area on street floor	Gross	2.8	77	28

Room Number	Use	Type	Gross/Net Area (m^2)	Occupant Load Factor (m^2/p)	Area (m^2)	Number of occupants
1-30	Mercantile	Sales area on street floor	Gross	2.8	100	36
1-31	Mercantile	Sales area on street floor	Gross	2.8	104	37
1-32	Storage	In mercantile occupancies	Gross	27.9	35	2
1-33	Mercantile	Sales area on street floor	Gross	2.8	97	34
1-34	Mercantile	Sales area on street floor	Gross	2.8	706	253
1-35	Mercantile	Sales area on street floor	Gross	2.8	231	84
1-36	Mercantile	Sales area on street floor	Gross	2.8	87	30
1-37	Mercantile	Sales area on street floor	Gross	2.8	347	125
1-38	Mercantile	Sales area on street floor	Gross	2.8	173	62
1-39	Mercantile	Sales area on street floor	Gross	2.8	77	28
1-40	Mercantile	Sales area on street floor	Gross	2.8	46	17
1-41	Assembly	Less concentrated use, without fixed seating (Restaurant)	Net	1.4	260	185
1-42	Assembly	Less concentrated use, without fixed seating (Restaurant)	Net	1.4	280	200
1-43	Assembly	Kitchen	Gross	9.3	51	6
1-44	Mercantile	Sales area on street floor	Gross	2.8	1010	360
1-45	Mercantile	Sales area on street floor	Gross	2.8	1012	361
1-46	Mercantile	Sales area on street floor	Gross	2.8	515	185
1-47	Storage	In mercantile occupancies	Gross	27.9	263	9
1-48	Mercantile	Sales area on street floor	Gross	2.8	136	49
1-49	Mercantile	Sales area on street floor	Gross	2.8	1964	705
1-50	Mercantile	Sales area on street floor	Gross	2.8	105	38
1-51	Mercantile	Sales area on street floor	Gross	2.8	458	164
1-52	Mercantile	Sales area on street floor	Gross	2.8	311	111
1-53	Mercantile	Sales area on street floor	Gross	2.8	44	16
1-54	Mercantile	Sales area on street floor	Gross	2.8	210	75
1-55	Mercantile	Sales area on street floor	Gross	2.8	128	46
1-56	Storage	In mercantile occupancies	Gross	27.9	74	3
1-57	Mercantile	Sales area on street floor	Gross	2.8	342	123
1-58	Mercantile	Sales area on street floor	Gross	2.8	255	92
1-59	Mercantile	Sales area on street floor	Gross	2.8	180	65
1-60	Mercantile	Sales area on street floor	Gross	2.8	26	9
1-61	Mercantile	Sales area on street floor	Gross	2.8	84	30
1-62	Mercantile	Sales area on street floor	Gross	2.8	166	60

Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
1-63	Mercantile	Sales area on street floor	Gross	2.8	200	72
1-64	Mercantile	Sales area on street floor	Gross	2.8	144	52
1-65	Mercantile	Sales area on street floor	Gross	2.8	143	51
1-66	Mercantile	Sales area on street floor	Gross	2.8	136	49
1-67	Mercantile	Sales area on street floor	Gross	2.8	402	142
1-68	Mercantile	Sales area on street floor	Gross	2.8	199	71
1-69	Storage	In mercantile occupancies	Gross	27.9	56	2
1-70	Mercantile	Sales area on street floor	Gross	2.8	199	71
1-71	Mercantile	Sales area on street floor	Gross	2.8	136	49
1-72	Mercantile	Sales area on street floor	Gross	2.8	153	55
1-73	Mercantile	Sales area on street floor	Gross	2.8	34	12
1-74	Mercantile	Sales area on street floor	Gross	2.8	235	84
1-75	Mercantile	Sales area on street floor	Gross	2.8	46	17
1-76	Mercantile	Sales area on street floor	Gross	2.8	72	26
1-77	Mercantile	Sales area on street floor	Gross	2.8	260	93
1-78	Mercantile	Sales area on street floor	Gross	2.8	79	28
1-79	Mercantile	Sales area on street floor	Gross	2.8	128	46
1-80	Mercantile	Sales area on street floor	Gross	2.8	80	29
1-81	Mercantile	Sales area on street floor	Gross	2.8	44	16
1-82	Mercantile	Sales area on street floor	Gross	2.8	66	24
1-83	Mercantile	Sales area on street floor	Gross	2.8	1066	383
1-84	Mercantile	Sales area on street floor	Gross	2.8	94	34
1-85	Mercantile	Sales area on street floor	Gross	2.8	111	40
1-86	Mercantile	Sales area on street floor	Gross	2.8	359	129
1-87	Mercantile	Sales area on street floor	Gross	2.8	54	19
1-88	Mercantile	Sales area on street floor	Gross	2.8	96	34
1-89	Mercantile	Sales area on street floor	Gross	2.8	21	8
1-90	Assembly	Kitchen	Gross	9.3	89	9
					TOTAL	***10747***

Table A-3. Areas of the rooms located on the first floor and number of occupants

Room areas and number of occupants - First Floor						
Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
2-1	Mercantile	Sales area on floors above street floor	Gross	5.6	1188	213
2-2	Mercantile	Sales area on floors above street floor	Gross	5.6	2385	428
2-3	Mercantile	Sales area on floors above street floor	Gross	5.6	397	71
2-4	Assembly	Less concentrated use, without fixed seating	Net	1.4	98	70
2-5	Mercantile	Sales area on floors above street floor	Gross	5.6	1088	195
2-6	Storage	In mercantile occupancies	Gross	27.9	299	11
2-7	Mercantile	Sales area on floors above street floor	Gross	5.6	49	9
2-8	Mercantile	Sales area on floors above street floor	Gross	5.6	42	8
2-9	Mercantile	Sales area on floors above street floor	Gross	5.6	67	12
2-10	Mercantile	Sales area on floors above street floor	Gross	5.6	110	20
2-11	Mercantile	Sales area on floors above street floor	Gross	5.6	464	83
2-12	Mercantile	Sales area on floors above street floor	Gross	5.6	341	61
2-13	Mercantile	Sales area on floors above street floor	Gross	5.6	86	15
2-14	Mercantile	Sales area on floors above street floor	Gross	5.6	83	15
2-15	Mercantile	Sales area on floors above street floor	Gross	5.6	129	23
2-16	Mercantile	Sales area on floors above street floor	Gross	5.6	123	22
2-17	Mercantile	Sales area on floors above street floor	Gross	5.6	127	23
2-18	Mercantile	Sales area on floors above street floor	Gross	5.6	154	28
2-19	Mercantile	Sales area on floors above street floor	Gross	5.6	151	27
2-20	Mercantile	Sales area on floors above street floor	Gross	5.6	204	37
2-21	Mercantile	Sales area on floors above street floor	Gross	5.6	742	133
2-22	Mercantile	Sales area on floors above street floor	Gross	5.6	105	19
2-23	Storage	In mercantile occupancies	Gross	27.9	103	4
2-24	Mercantile	Sales area on floors above street floor	Gross	5.6	169	30
2-25	Mercantile	Sales area on floors above street floor	Gross	5.6	193	35
2-26	Mercantile	Sales area on floors above street floor	Gross	5.6	79	14
2-27	Mercantile	Sales area on floors above street floor	Gross	5.6	73	13
2-28	Mercantile	Sales area on floors above street floor	Gross	5.6	472	85
2-29	Mercantile	Sales area on floors above street floor	Gross	5.6	399	71
2-30	Mercantile	Sales area on floors above street floor	Gross	5.6	176	31
2-31	Mercantile	Sales area on floors above street floor	Gross	5.6	160	29
2-32	Mercantile	Sales area on floors above street floor	Gross	5.6	127	23

Room Number	Use	Type	Gross/Net Area (m^2)	Occupant Load Factor (m^2/p)	Area (m^2)	Number of occupants
2-33	Mercantile	Sales area on floors above street floor	Gross	5.6	1097	199
2-34	Assembly	Kitchen	Gross	9.3	49	5
2-35	Assembly	Kitchen	Gross	9.3	49	5
2-36	Mercantile	Circulation areas + other small areas (WC, etc.)	Gross	2.8	4898	1749
2-37	Assembly	Less concentrated use, without fixed seating (Restaurant)	Net	1.4	280	200
2-38	Storage	In mercantile occupancies	Gross	27.9	143	6
2-39	Assembly	Less concentrated use, without fixed seating (Restaurant)	Net	1.4	95	68
2-40	Mercantile	Sales area on floors above street floor	Gross	5.6	1045	188
2-41	Mercantile	Sales area on floors above street floor	Gross	5.6	820	147
2-42	Mercantile	Sales area on floors above street floor	Gross	5.6	182	33
2-43	Mercantile	Sales area on floors above street floor	Gross	5.6	68	12
2-44	Mercantile	Sales area on floors above street floor	Gross	5.6	139	25
2-45	Mercantile	Sales area on floors above street floor	Gross	5.6	107	19
2-46	Mercantile	Sales area on floors above street floor	Gross	5.6	824	148
2-47	Mercantile	Sales area on floors above street floor	Gross	5.6	85	13
2-48	Mercantile	Sales area on floors above street floor	Gross	5.6	53	9
2-49	Mercantile	Sales area on floors above street floor	Gross	5.6	33	6
2-50	Mercantile	Sales area on floors above street floor	Gross	5.6	324	58
2-51	Mercantile	Sales area on floors above street floor	Gross	5.6	404	73
2-52	Mercantile	Sales area on floors above street floor	Gross	5.6	85	15
2-53	Mercantile	Sales area on floors above street floor	Gross	5.6	322	58
2-54	Mercantile	Sales area on floors above street floor	Gross	5.6	170	30
2-55	Mercantile	Sales area on floors above street floor	Gross	5.6	220	39
2-56	Mercantile	Sales area on floors above street floor	Gross	5.6	111	20
2-57	Mercantile	Sales area on floors above street floor	Gross	5.6	153	27
2-58	Mercantile	Sales area on floors above street floor	Gross	5.6	184	33
2-59	Mercantile	Sales area on floors above street floor	Gross	5.6	492	88
2-60	Mercantile	Sales area on floors above street floor	Gross	5.6	134	24
2-61	Mercantile	Sales area on floors above street floor	Gross	5.6	232	42
2-62	Mercantile	Sales area on floors above street floor	Gross	5.6	1074	193
2-63	Mercantile	Sales area on floors above street floor	Gross	5.6	115	21
2-64	Mercantile	Sales area on floors above street floor	Gross	5.6	61	11
2-65	Mercantile	Sales area on floors above street floor	Gross	5.6	121	22

Room Number	**Use**	**Type**	**Gross/Net Area (m^2)**	**Occupant Load Factor (m^2/p)**	**Area (m^2)**	**Number of occupants**
2-66	Mercantile	Sales area on floors above street floor	Gross	5.6	214	38
2-67	Mercantile	Sales area on floors above street floor	Gross	5.6	145	26
2-68	Mercantile	Sales area on floors above street floor	Gross	5.6	173	31
2-69	Storage	In mercantile occupancies	Gross	27.9	162	6
2-70	Mercantile	Sales area on floors above street floor	Gross	5.6	93	17
2-71	Mercantile	Sales area on floors above street floor	Gross	5.6	96	17
2-72	Mercantile	Sales area on floors above street floor	Gross	5.6	120	22
2-73	Mercantile	Sales area on floors above street floor	Gross	5.6	118	21
2-74	Mercantile	Sales area on floors above street floor	Gross	5.6	154	28
2-75	Mercantile	Sales area on floors above street floor	Gross	5.6	219	39
2-76	Mercantile	Sales area on floors above street floor	Gross	5.6	178	32
2-77	Mercantile	Sales area on floors above street floor	Gross	5.6	122	22
2-78	Mercantile	Sales area on floors above street floor	Gross	5.6	21	4
2-79	Storage	In mercantile occupancies	Gross	27.9	79	3
2-80	Assembly	Less concentrated use, without fixed seating (Food Courts)	Net	1.4	238	170
					TOTAL	***5920***
				TOTAL (ALL FLOORS)		***21548***

9.2 APPENDIX B

Table B-1 shows the exits opening directly to outside and corresponding widths giving the location of those.

Table B-1. Exits and corresponding widths

Exits and corresponding widths			
Exit Number	**Floor**	**Location**	**Width (cm)**
EXIT 1	Lower Ground Floor	Escape Corridor 1	190
EXIT 2	Lower Ground Floor	Staircase 5	155
EXIT 3	Lower Ground Floor	Main exit (Circulation spaces) / (Room 32)	195
EXIT 4	Lower Ground Floor	Main exit (Circulation spaces) / (Room 32)	195
EXIT 5	Lower Ground Floor	Main exit (Circulation spaces) / (Room 32)	195
EXIT 6	Lower Ground Floor	Main exit (Circulation spaces) / (Room 32)	195
EXIT 7	Lower Ground Floor	Escape Corridor 2	190
EXIT 8	Lower Ground Floor	Room 56 (Local exit)	95
EXIT 9	Lower Ground Floor	Staircase 2	190
EXIT 10	Lower Ground Floor	Staircase 2	190
EXIT 11	Lower Ground Floor	Escape Corridor 1	235
EXIT 12	Lower Ground Floor	Staircase 1	145
EXIT 13	Lower Ground Floor	Room 1 (Local exit)	170
EXIT 14	Lower Ground Floor	Room 4 (Local exit)	245
EXIT 15	Upper Ground Floor	Main exit (Circulation spaces) / (Room 1-4)	195
EXIT 16	Upper Ground Floor	Main exit (Circulation spaces) / (Room 1-4)	195
EXIT 17	Upper Ground Floor	Main exit (Circulation spaces) / (Room 1-4)	195
EXIT 18	Upper Ground Floor	Main exit (Circulation spaces) / (Room 1-4)	195
EXIT 19	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 20	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 21	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 22	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 23	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 24	Upper Ground Floor	Room 1-41 (Local exit)	235
EXIT 25	Upper Ground Floor	Escape Corridor 6	235
EXIT 26	Upper Ground Floor	Escape Corridor 5	190
EXIT 27	Upper Ground Floor	Room 1-42 (Local exit)	235
EXIT 28	Upper Ground Floor	Room 1-42 (Local exit)	235
EXIT 29	Upper Ground Floor	Room 1-42 (Local exit)	235
EXIT 30	Upper Ground Floor	Staircase 8	140
EXIT 31	Upper Ground Floor	Escape Corridor 7	140
EXIT 32	Upper Ground Floor	Escape Corridor 8	245
EXIT 33	Upper Ground Floor	Escape Corridor 9	250

Exit Number	Floor	Location	Width (cm)
EXIT 34	Upper Ground Floor	Room 1-45 (Local exit)	130
EXIT 35	Upper Ground Floor	Escape Corridor 10	130
EXIT 36	Upper Ground Floor	Room 1-49 (Local exit)	130
EXIT 37	Upper Ground Floor	Room 1-1 (Local exit)	130
EXIT 38	Upper Ground Floor	Room 1-1 (Local exit)	130
EXIT 39	Upper Ground Floor	Staircase 10	130
EXIT 40	Upper Ground Floor	Staircase 8	130