**SEMESTER 10 – Master Thesis**

**RISK AND SAFETY MANAGEMENT**

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# Simulation of Emergency within the Municipality of Esbjerg

## Abstract

The purpose of this report is to look into a simulation of emergency within the Municipality of Esbjerg and evacuation training, which is done in order to analyse hazards and implement improvement to the new general emergency plan done by Esbjerg Municipality.

Going through different regulations, standards, evacuation training at the Municipality and discussions the group's members had with representatives from the Safety Council at Esbjerg Municipality and fire department, it was concluded, that the evacuation training will be done in the civil service, where people can enter directly from the street, and is the area with the highest risk for fatalities in case of a fire, because it can be the most populated area and the visitors don't necessarily know the escape routes and doors, therefore the main problem is raised: *How is the new general emergency plan of the Municipality built to face the hazard of fire?*

To do so, training was done at the municipality and simulations models are developed in 3Ds Max and Simulex, computing different scenarios in which the searchers did their job as intended or not are assumed. The focus will be on fire in the civil service, at Esbjerg Municipality Afterwards, the critical time for an evacuation was assumed and, plus the evacuation time was calculated compared to the actual evacuation time from the training and the result from the two simulation software.

The report will then conclude with the advised improvement on the new general emergency plan and layout of the civil service, in order to reduce consequences in case such an event took place.

The report will end with concluding remarks.

## Preface

This thesis ”Simulation of Emergency within the Municipality of Esbjerg” is written by RISK4-2 as a mandatory part of the 10th semester master thesis project at the University of Aalborg-Campus Esbjerg, department of civil engineering, master of Risk and Safety Management.

The idea for the report came with the help of Aalborg University, Esbjerg Municipality and its representatives therefore a special thanks to these representatives is required.

The report was written in the period from the 1st of September 2016 until 10th of January 2017. The thesis contains information about the municipality of Esbjerg, its new general emergency plan, amount of employees, everyday operations and layout of the 1st floor. The main chapters of the report are making simulations and evacuation training at the municipality, in case of a fire in the civil service area. The research was accomplished with the help of different other relevant articles, reports and given material from Esbjerg Municipality, plus plot plans.

The report is divided into 7 chapters. A list of relevant acronyms and their names are provided in the beginning of the report and a list of sources used for the making of this report can be found in the bibliography. The report uses the Harvard referencing style for the sources in the bibliography. The in-text references are seen as numbers in brackets [X] and refer to the corresponding reference in the bibliography section. For a visual imagine of the written text, tables and figures are provided also. These were numbered in an ascending order with the caption for the figure being done at the bottom of the figure, whereas the numbering for the table was done at the top of the table.

Authors’ signature:

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## Acronyms

3ds max - Three-dimensional max studio

UK – United Kingdom

IES VE – Integrated Environmental Solutions virtual environment

E.U. – European Union

DST – Dansk statistik / Danish statistic

NFPA – National fire protection association

PVC - Polyvinylchlorid

CAD – Computer-Aided Design

DXF – Drawing Exchange format

TV – Television

HVAC – Heating, ventilation and air conditioning

# Table of content

Chapter 1

# 1. Introduction

## 1.1 Aim

This report" Simulation of Emergency within the Municipality of Esbjerg" is intended as a review from an educational point of view of the new emergency management plan implemented in the Esbjerg municipality and the other depending municipalities and the new safety features and measures implemented, in order to reduce the probability for different hazards occurring, or the measure to reduce the spread of the hazards in order to reduce the risk of having injuries or fatalities. The present report will focus on the hazard of fire and its dangers since it is the main cause for accidents leading to fatalities in office spaces. The safety measures in buildings have a long history. The need to improve the safety and to save lives spans all the way back to the 12$^{th}$ century, when the first measures concerning protection against fire were implemented. In all honesty, it is considered that the romans were the first ones to implement safety measures against fire, but no significant evidence was found to prove this. The fire safety in offices starts somewhere in the late 1800s and the beginning of 1900s when the Select Committee in UK and other committees in France, released several documents concerning fire and methods to improve safety against fire and to save lives. This is due to some events that have led to a large number of fatalities. After this inception, safety measures were added constantly in humanity's fight against fire. However, as it can also be seen in the following chapters, office fires still occur, quite frequently, despite all efforts to combat it, hence the need to have a plan to evacuate the workers in case a fire occurs.

The bulk of this report will revolve around the Esbjerg Municipality and its new emergency management plan by constructing two simulations into different software's, 3DS Max and IES VE Simulex, which then will be compared to a real life exercise. The improvements follow the safety regulations proposed by the European Commission in regards to safety in office buildings, and this is also a good way to notice possible flaws in the regulations.

An old Chinese saying dictates: "Fire is a good servant, but a hard master" so based on this saying the main hazard on which this project focuses was raised. Based on these simulations of different scenarios and by checking different articles and reports, the report will check if the main hazard which is fire/explosion is treated as best as possible in the Municipality of Esbjerg in order to reduce as much as possible the loss of lives.

## 1.2 Esbjerg Municipality-Short history

In order to start this project a short history about the Esbjerg Municipality is required and its construction, as well as all the renovation steps that have led to the present day building.

Until 1967 there was no building where all the governmental bodies that form the present day municipality could work. In 1967 a decision was made to start the construction for a new building which would combine all the major governing bodies from the city and an auction was arranged. By the end of April 1967, the area was fenced and the foundation was about to be started.

**Figure 1 The foundation for the new municipality [1]**

In the autumn of 1970 the project was completed and on the 31st of October, the opening ceremony was held. A building made out prefabricated elements and reinforced concrete with a façade covered in bronze was unveiled.

**Figure 2 the old facade of the building [2]**

The building was kept more or less the same until 1989. By that time, new regulations regarding safety in concern to fire were implemented by the EU. The building was not in accordance to the new regulations so a large renovation was required.

Besides the safety measures that were implemented, the largest and noticeable change observed was the façade which was completely changed, from the old façade which was covered in bronze to a new and modern one covered in glass. The roof was also renovated as well as safety features such as improved fire cells and fire sections were installed in accordance to the new standards.

**Figure 3 the building renovated after 1991 [3]**

Between 2004 and 2006 another renovation of the building was implemented in which the interior atrium was covered, the cantina was renovated and most importantly, the sprinkler and fire sensors were updated.

The last renovation was in 2007 when some security cameras were updated, some fire sensors were also updated and a couple of doors and walls were moved or closed. After the renovation from 2007, small changes were done to the structure, without significant changes to the structure or the safety features.

After these changes, the emergency evacuation plan was concluded with focus on several hazards and on several regions, in and outside the municipality which was updated to its final form in March 2016. Based on this update, the report will be constructed, testing its capacity to save lives and improve safety.

## 1.3 Problem identification and analysis

The found data for this subpart was provided by the Danish Emergency Management Agency and DST (Danmarks Statistik/Denmark statistic).

The purpose of this section is to identify the main causes for fatal accidents and further look into the main causes for fatal accidents caused by fire, identify the most hazardous places and causes for fatal fire.

Table 1, shows total fatal accidents from Denmark in 2014

**Table 1 Causes for fatal accident in Denmark 2014 [4]**

| **Causes** | **Fatalities** |
|---|---|
| Motor Vehicle Accidents | 201 |
| Other accident | 1053 |
| Fire | 84 |

A total of 1.338 fatalities, were caused by accidents. Of them 201 fatalities were caused by motor vehicle accidents, 1053 caused by other accidents for example work related, sport, spare time activities, etc. and 84 fatalities were caused by fire in 2014.

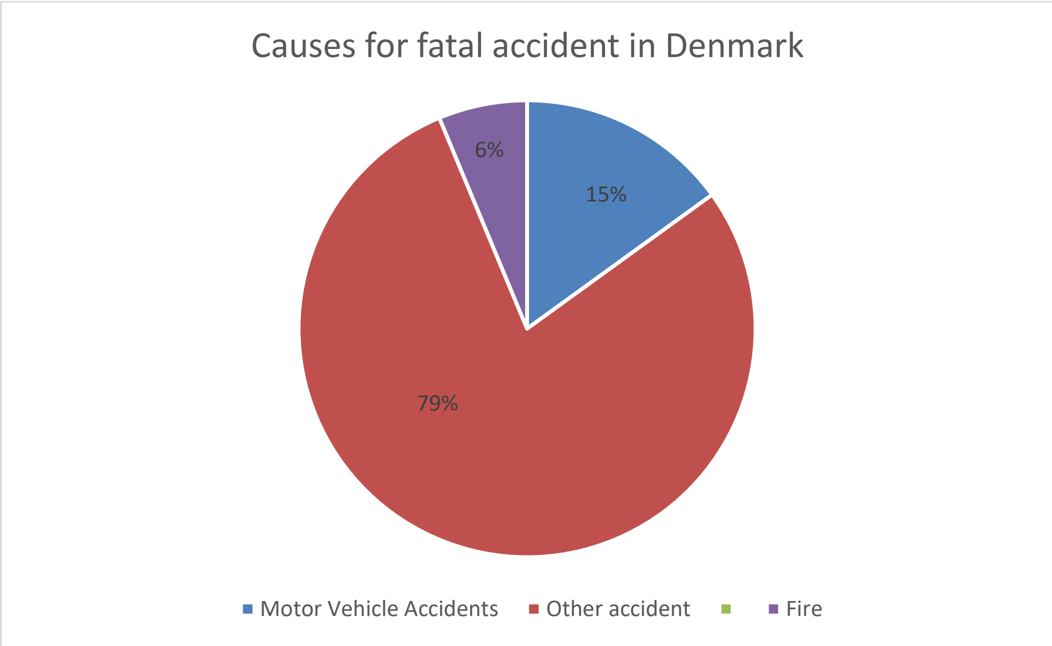



**Figure 4 Causes for fatal accident in Denmark 2014 [5]**

A fatality caused by fire is represented by 6 % of all fatalities caused by an accident in Denmark in 2014, which is illustrated in Figure 4, the main cause being motor vehicle accidents, represented by 15 %. Other accident is divided into many types of accidents and therefore cannot be mentioned as a main cause for a fatal accident.

The Danish Emergency Management Agency is monitoring the numbers of fatal fire accidents which is an ongoing process throughout the whole year, year after year. A fatality caused by a fire, is a person that will perish under a fire or latest 30 days after the fire as a consequence of fire effects – smoke inhalation or combustion.

The statistic shows that in the last 25 years, there had been an average 78 fatalities in 74 fire accidents pr. year [6]. Table 2 below illustrates the numbers of fatalities from 2010 to 2015, caused by fire accidents, on different age groups.

**Table 2 Fatalities caused by fire, divided by age**

| **Fatalities caused by fire** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ages** | **Fatalities and %** | | | | | | | | | | | |
| | **2010** | **%** | **2011** | **%** | **2012** | **%** | **2013** | **%** | **2014** | **%** | **2015** | **%** |
| < 15 | 1 | 1,4 | 0 | 0,0 | 0 | 0,0 | 2 | 2,9 | 0 | 0,0 | 4 | 5,9 |
| 15-29 | 6 | 8,1 | 7 | 10,9 | 3 | 4,5 | 2 | 2,9 | 3 | 3,6 | 1 | 1,5 |
| 30-49 | 10 | 13,5 | 6 | 9,4 | 10 | 15,2 | 6 | 8,6 | 13 | 15,5 | 9 | 13,2 |
| 50-66 | 21 | 28,4 | 20 | 31,3 | 28 | 42,4 | 24 | 34,3 | 23 | 27,4 | 14 | 20,6 |
| 67-79 | 18 | 24,3 | 14 | 21,9 | 14 | 21,2 | 19 | 27,1 | 23 | 27,4 | 26 | 38,2 |
| 80-89 | 14 | 18,9 | 15 | 23,4 | 9 | 13,6 | 9 | 12,9 | 16 | 19,0 | 10 | 14,7 |
| ≥ 90 | 4 | 5,4 | 2 | 3,1 | 2 | 3,0 | 8 | 11,4 | 6 | 7,1 | 4 | 5,9 |
| Total | 74 | 100,0 | 64 | 100,0 | 66 | 100,0 | 70 | 100,0 | 84 | 100,0 | 68 | 100,0 |

According to the statistics, people from 50-79 years are in the highest risk zone, due to the fact that there have been 244 fatalities from 2010 to 2015, in this age group, which represents 57 %, over half of all fatalities during that time. The lowest risk zone is <15 years, where there had only been 1.16 fatalities pr. year. The intervals 15-29 and 30-49 is neither in the lowest or highest risk zone, but more or less in the middle, people from 15-29 year had in average 3,15 fatalities and people from 30-49 had in average 7,8 fatalities caused by a fire accident.

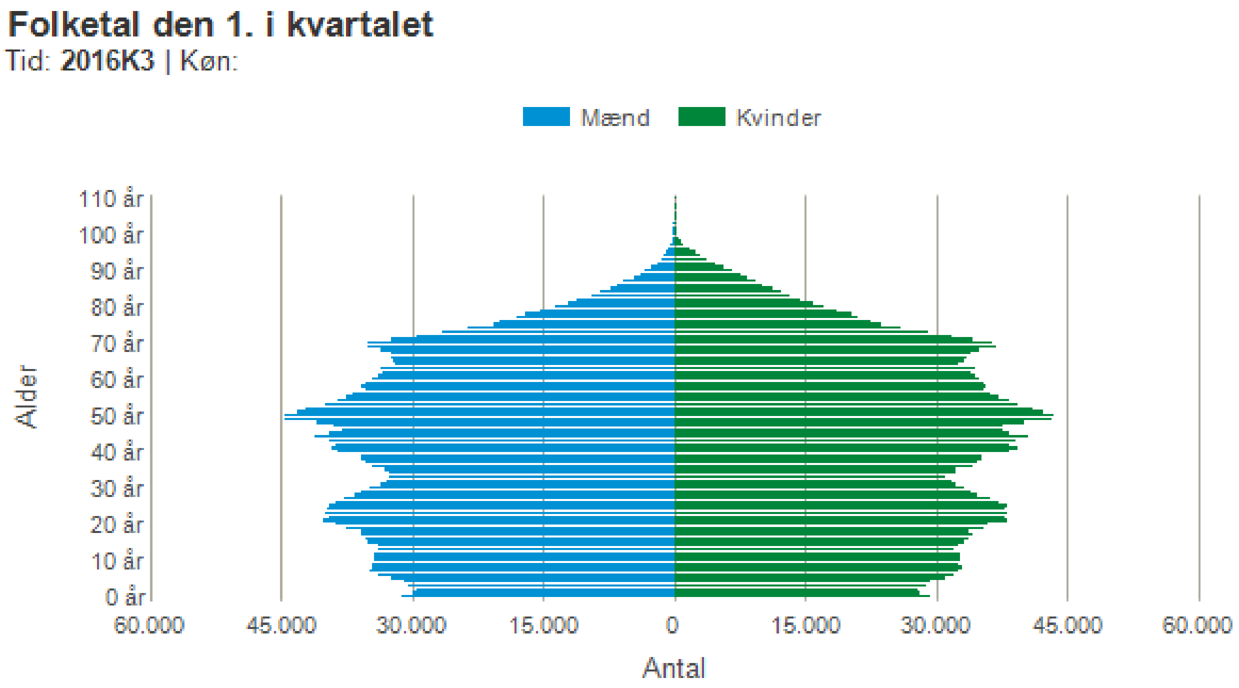



**Figure 5 Population divided in age in Denmark, 2016 [7]**

Considering the life expectancy in Denmark is 82, 5, we consider ≥ 90 also to be in the high risk zone, because this group of people is at least 7, 5 years older than the life expectancy in Denmark, and the population in this group is small, seen also in Figure 5. The population group from 80-89 could also be a part of the highest risk zone, as Figure 5 shows, considering that the number of people in that age group decreases massively, whereas the risk of fire is the same as for the 50-79 years groups. Why are these numbers relevant? Considering that the Municipality of Esbjerg deals with every aspect related to government, all these age groups can be present, and most likely are present in the building sometime during the working hours, hence the risk is present.

The next step was to look into fire causes in Denmark from different years, how many fatalities were there in Denmark from 2010 to 2015 caused by fire. This is shown in the two tables, Table 3 and 4.

**Table 3 Fire causes from 2010 - 2012**

| **Fire causes** | **2010** | | **2011** | | **2012** | |
|---|---|---|---|---|---|---|
| | **Fatalities** | **Fire** | **Fatalities** | **Fire** | **Fatalities** | **Fire** |
| Smoking | 25 | fire | 20 | 20 | 17 | 17 |
| Smoking in bed | 12 | 11 | 9 | 9 | 9 | 8 |
| **Total smoking** | **37** | **11** | **29** | **29** | **26** | **25** |
| Defect el component | 4 | 4 | 4 | 4 | 2 | 2 |
| Error in el-installation | 1 | 1 | 0 | 0 | 0 | 0 |
| Other | 3 | 3 | 1 | 1 | 3 | 3 |
| **Total electrical** | **8** | **8** | **5** | **5** | **5** | **5** |
| arson | 1 | 1 | 4 | 2 | 3 | 3 |
| Suicide | 4 | 4 | 1 | 1 | 4 | 4 |
| Car fire | 2 | 2 | 5 | 3 | 4 | 4 |
| Cooking | 4 | 4 | 7 | 7 | 5 | 5 |
| Carelessness | 2 | 2 | 5 | 5 | 6 | 6 |
| Candles | 0 | 0 | 5 | 5 | 4 | 4 |
| wood burning | 3 | 3 | 1 | 1 | 1 | 1 |
| Explosion | 0 | 0 | 0 | 0 | 2 | 2 |
| Unknown | 13 | 13 | 2 | 2 | 6 | 6 |
| **Total** | **74** | **48** | **64** | **60** | **66** | **65** |

**Table 4 Fire causes from 2013 - 2015**

| **Fire causes** | **2013** | | **2014** | | **2015** | |
|---|---|---|---|---|---|---|
| | **Fatalities** | **Fire** | **Fatalities** | **Fire** | **Fatalities** | **Fire** |
| Smoking | 18 | 18 | 29 | 28 | 28 | 28 |
| Smoking in bed | 16 | 14 | 19 | 18 | 11 | 11 |
| **Total smoking** | **34** | **32** | **48** | **46** | **39** | **39** |
| Defect el component | 3 | 3 | 3 | 2 | 1 | 1 |
| Error in el-installation | 2 | 2 | 2 | 2 | 2 | 2 |
| Other | 0 | 0 | 3 | 3 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Total electrical** | **5** | **5** | **8** | **7** | **3** | **3** |
| arson | 1 | 1 | 1 | 1 | 0 | 0 |
| Suicide | 5 | 5 | 5 | 5 | 2 | 2 |
| Car fire | 1 | 1 | 0 | 0 | 0 | 0 |
| Cooking | 4 | 4 | 2 | 2 | 4 | 4 |
| Carelessness | 1 | 1 | 0 | 0 | 0 | 0 |
| Candles | 3 | 3 | 2 | 2 | 8 | 4 |
| wood burning | 6 | 6 | 1 | 1 | 1 | 1 |
| Explosion | 1 | 1 | 3 | 3 | 0 | 0 |
| Unknown | 9 | 9 | 14 | 14 | 11 | 11 |
| **Total** | **70** | **68** | **84** | **81** | **68** | **64** |

As seen throughout all causes from Table 3 and 4, the risk for fatalities or injuries is the highest due to smoking in general, especially smoking in bed. There had been 182 fire accidents caused by smoking, which caused 213 fatalities. In average 35, 5 fatalities every year are caused by smoking, which is the most common fire cause in Denmark. The other common cause is the electrical hazard as defect electrical component, error in el-installation and other electrical related accident, 34 fatalities in six years, which is in average 5, 66 person pr. years. Other fatalities caused by a fire accident are: suicide, arson, car fire, cooking, carelessness, candles, wood burning, explosion and unknown, has combined cause in total from 2010-2015 179 fatalities in Denmark, which is in average 29,8 fatalities every year. Combined fire accidents have caused 426 fatalities from 2010-2015 in Denmark, in average 71 every year. Most of these causes can be also a main cause for fire in the office buildings, in Denmark and everywhere else. More causes for fires will be given in the next section which focuses specifically on office fires.

For a better visual representation for fatalities caused by a fire accident, the numbers from the tables are plotted into a diagram, which is shown below in Figure 6.

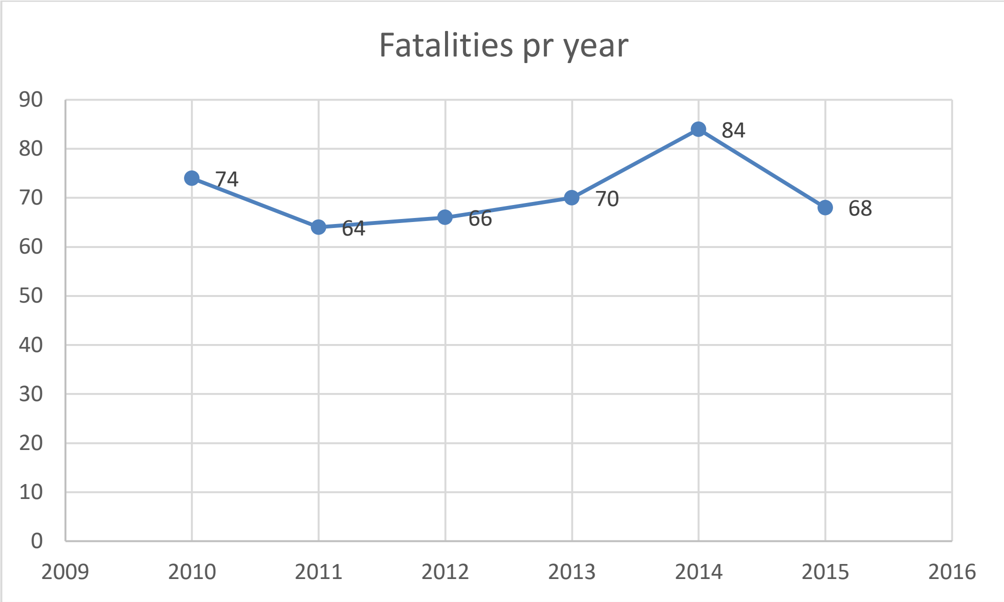



**Figure 6 Fatalities per year 2010-2015**

In 2010 there were in total 74 fatalities and from 2010 to 2011 it decreased to 64 fatalities. From 2011 to 2014 the fatalities had an ongoing increase from 64 fatalities to 84, and decreased by 16 fatalities from 2014-2015, where there were 68 fatalities. The slope is going up and down, and nothing shows that there has been some improvement to reduce the numbers of fatalities; it looks more as a coincidence that the slope is increasing and decreasing from year to year. This shows that although safety measures are implemented constantly, the fatalities do not necessarily change; therefore evacuation exercises need to be conducted to ensure the safety of the people working in office buildings.

## 1.4 Causes

The previous section showed that fire is one of the main reasons for fatalities in Denmark. This section will focus on the causes that can lead to a fire strictly in office buildings, since the report will focus on Esbjerg Municipality, an office building, and are in accordance to the main causes reported by the NFPA.

**Table 5 Potential causes for fire in an office environment [8]**

| Causes | Causes |
|---|---|
| **A) Cooking equipment** | **E) Intentional fires** |
| Faulty Microwave | Arson |
| Damaged coffee machine | Terrorist attack |
| Stove fires | **F) Smoking** |
| **B) Electrical fires** | **G) Proximity hazards** |
| Faulty wires | Outside fuel tanks |
| Overload of the electrical grid | Outside dumpsters |
| Improperly maintained equipment | Neighbouring buildings |
| Damaged equipment | **H) Human error** |
| **C) Heating equipment** | Faulty use of machine |
| Improperly installed | Leaving machines unattended |
| Wrongly operated | Throw rubbish in dangerous areas |
| Lack of maintenance | Improper storage of office materials |
| **D) Mechanical friction** | **I) Special hazards** |
| Improperly maintained equipment | Flammable materials |
| Improperly cleaned equipment | Glues/solvents |

More than that, it was concluded that the major causes of fires in an office environment have nothing to do with the age of the building or the type of business conducted in it, as they can occur both in old buildings as well as new buildings and they can also occur in a company focused without significant knowledge about the dangers of a fire as well as in a company with many experts in regards to fire hazards.

Knowing the major causes for fire in a building, the next section will look into the major consequences that are an aftermath of a fire exposure in an office environment.

## 1.5 Consequences

As seen throughout the previous sections, fire is seen as one of the most dangerous hazards that can occur, whether it is fire in private homes or in commercial establishments such as office buildings.

There are many consequences related to office fires, the most obvious one being the damage and destruction to the property itself. Depending on the intensity of the fire and its length, the damages can span anywhere from minor destruction of an office up to the total incapacitation of the entire structure, if not its total collapse.

This consequence gives in term another consequence from an economical point of view. Most of the companies or buildings that provide public services are self-contained, meaning that if the building where the business or processes take place is damaged, the production and normal operations cease completely or partially. This leads to a business loss or downtime. A downtime is a period of time in which an asset, a department or a building is unavailable to use. This, in business terms, translates into loss of revenue. For every day in which the building is incapacitated, there is average revenue that is not generated. In the case of a municipality, this case can be even more severe due to its importance for the citizens of the area and due to the fact that important documents are present in the building. Also, in order to bring the building back to its functional state, additional revenue needs to be spent in order to fix the building or, in more severe cases, to build a new building.

The third category of consequences that has to be looked into is the one that affects the health and safety of the office workers. The fire can kill in numerous ways, but probably the most common ones are due to the heat and due to the killing fumes. Most deaths are not caused due to the heat of the fire but rather due to the killing fumes which tend to act and affect immediately the human body. According to the NFPA, as a fire grows inside a building, it will consume most of the available oxygen, slowing the burning process. This incomplete combustion leads to toxic gases.

Smoke is made out of three major components that can each be deadly in their own way:

- Particles: which in essence are unburned, partially burned or completely burned substances which are so small that they can penetrate the lungs` filters and lodge in the lungs. Some are toxic; others can affect the eyes or the digestive system.
- Vapours: Small drops of liquid that can be inhaled or absorbed through the skin.
- Toxic gases: the most common toxic gas is carbon monoxide can be deadly even in the smallest quantities as it replaces oxygen in the bloodstream. Another toxic gas is hydrogen cyanide which results from the burning of plastics, such as PVC pipes and the last gas which can be lethal is the phosgene, formed from the burning of vinyl products such as linoleum floors. [9]

In addition to producing this toxic smoke, fire can paralyze or kill by reducing the level of oxygen, either by consuming it or by replacing it with smoke and deadly fumes. To give a better understanding of the effects the lack of oxygen has on the human body, Table 6 is presented.

**Table 6 Different level of oxygen and the effects of it [10]**

| When oxygen level is at…. | … a person experiences: |
|---|---|
| 21% | Normal outside air |
| 17% | Impaired judgement and coordination |
| 12% | Headache, dizziness, nausea, fatigue |
| 9% | Unconsciousness |
| 6% | Respiratory arrest, cardiac arrest, death |

As seen in this section, the consequences for a fire are quite considerable, both from an socio-economic point of view as well as from a health and safety point of view, therefore the relevance for choosing the fire hazard as the main hazard for the present report and the next section with introduce the reader into the problem formulation, with a keen aspect on fire hazard.

Chapter 2

## 2. Problem formulation

Up to this point, the purpose of this entire introduction was to introduce the reader into the office fire accidents and their rate of occurrence. Causes and consequences were also presented for the fire hazard regarding office buildings. Based on this information and a discussion the project`s members have had with the representatives from the municipality of Esbjerg, the main question was raised:

**How is the new general emergency plan of the Municipality built to face the hazard of fire?**

In order to answer this question simulations are required. In order to check the feasibility of this emergency plan, the reaction of the personnel has to be compared to something and for the present report it will be compared to two simulations using different software available on the market. The aftermath of the fire and from the simulations will be compared to articles and books and are used to define the conclusions. Also, to help answer the main problem, several sub-questions need to be raised.

**How is a simulation using Simulex representing the personnel and what are the outcomes of it?**

*One software that will be used is entitled Simulex from IES VE. This software is specially designed for the purpose of representing emergency evacuations and it is therefore very relevant for this present project.*

**How is a simulation in 3Ds Max representing the personnel and what are the outcomes of it?**

*In order to answer this question, a simulation using the software entitled 3Ds Max from Autodesk will be constructed, by implementing different behaviours to the personnel present in the building. From this simulation some pros and cons will be extracted to give a relevance to this project.*

*After the representation from 3DS Max will be concluded the two programs will be compared and pros and cons between them will be presented in order to have a better understanding of which software is best for the situation presented.*

**How will the personnel and the visitors react and evacuate in a real life simulation, and what possible improvements can be implemented?**

*For this question, the project`s members have had discussions and meetings with the safety representatives from the Esbjerg Municipality and have agreed to create a real life simulation where the staff from the civil service and the visitors present will conduct an experiment and their behaviour will be observed and possible improvements will be presented, based on the simulations created in the two programs.*

**Could the mitigation measures implemented by the municipality of Esbjerg reduce, if not completely avoid the present situation and its consequences?**

*In the last chapter the mitigation measures will be described, and their importance to show that most, if not all safety measures to reduce the risk and the consequences of a fire are implemented, and that the most significant safety feature that could be used is given by the emergency evacuation exercises.*

## 2.1 Problem delimitation

Since the ground floor plan of the municipality is quite vast, it would be almost impossible to do a simulation that would engulf the entire personnel with the limited resources that the group members had; ergo the simulation plan from the software and the real life simulation will only focus on the civil service area (Borgerservice). Also due to limited resources and time, the real life simulation will take place only one time, so the personnel present might not be the one at full capacity. Due to limited time, in the software, the figures will not be represented in detail or with moving limbs.

## 2.2 Outline

This report is furthermore divided into five sections representing simulations and safety measured. Chapter 3 will focus on the simulation from Simulex software, including the detailed explanations and the positive and negative aspects of this software. Chapter 4 is more or less the same, apart from the fact that it focuses on 3DS Max. At the end of this chapter, the comparison between these two programs will be presented. Chapter 5 will be the one that will explain the real life simulation that will take place within the Esbjerg municipality. Chapter 6 will focus on the safety measures already implemented, their probability of failure and the possible improvements that could be added, if needed. The final chapter gives concluding remarks to the report.

Chapter 3

# 3. Simulation using Simulex

## 3.1 Introducing Simulex

**What is Simulex?**

Simulex is a sub-software, part of the much larger IES Virtual Environment, which enables you to define a building, no matter how comes or large it might be, and to define its occupants and simulate how they move and act in the building in case of an emergency.

**What is it good for?**

Simulex allows you to identify any problematic areas and evaluate possible solutions for a large variety of buildings such as: schools, hospitals, conference centres, airports, train stations, large office buildings etc. [11]

According to IES official website there are a few steps that need to be taken in order to achieve a proper simulation model that could be used as a future reference and be compared to a real life simulation and these steps are, as follow: [12]

a) Model Set-Up
   - Use VE or CAD generated DXF files to create and define each floor plan.
   - In case of a multi-storey building, create staircases to connect the floor plans together
   - Define and position the exits from the building and their sizes.
   - In case of a multi-storey building link each staircase with a specific doorway from a floor plan.

b) Building Set-Up
   - Define the building fabric with exactly the same accuracy as DXF files
   - Simulex automatically generates a 0.2*0.2 spatial mesh, overlaid onto the DXF files.
   - Generate and calculate a distance map which calculates the total distance-to-exit for every point on the spatial mesh.
   - In wanted, display the distance map graphically as distance contours

c) People Set-Up
   - Define different population groups or individuals with different behaviours.
   - Body, shape and size.
   - Define walking speeds.
   - Define time to respond to alarm.

d) Evacuation simulation
   - Once the simulation model has been built and populated the simulation can be calculated.
   - Simulex will complete all the needed calculation and display the evacuation time.
   - The calculation is done in 2D, but if the user wants it, afterwards, with a simple click, the model can be transferred into a 3D model.
   - The population will evacuate in accordance to their behaviours assigned.
   - The evacuation proceeds until all occupants have left the building.

e) Outputs
   - The simulation can be recorded and played back in real time.
   - Creates a text file of general occupant flow details.
   - Can create a text file of every individual's movements, every 0.1 seconds.
   - Creates a text file that shows how many people go through each exit.

As a last thing to be stated, it has to be mentioned that Simulex provides a large variety of behaviours for the population that is to be included in the simulation model. The algorithms for the movement of individuals are based on real-life data, collected by using computer-based techniques for the analysis of human movement, observed in real-life footage.

Now that the reader has had a short introduction into Simulex, it is time for the software to be implemented for the actual theme of this report.

### 3.2 Simulation using Simulex

For the present report, the members of the group that was responsible with this report, followed the five different steps provided by the official website of IES in order to achieve a proper simulation model, which could be used as a comparison with a real-life model.

a) Model Set-Up

To do such, the first step was to do the set-up of the model. As mentioned before, the floors can be represented either by using VE or by using CAD software and then exporting it into a DXF file which can then be imported into Simulex.

The chosen option by the group members was the second one, considering their past experience with the Autodesk package and of their knowledge with Revit and AutoCAD, both CAD software. Their option was to use the Revit software to design the floor plan. As stated in the earlier chapter, due to limited time and resources, it was impossible to create a simulation for the entire building; therefore, the design focused on the civil service area (Borgerservice).

Using Revit, the civil service area was designed. For a proper result, all the small offices and other related rooms in that area were represented. All other information such as door swing lines, text and other irrelevant lines had to be deleted in advance; otherwise the simulation could not proceed. Simulex uses the wall lines to define the physical space available for evacuation. The text can be present but not in the area were the people are to be added because Simulex will read the text as obstruction and the evacuation time will be extended and an incorrect result will be obtained.

The end result obtained in Revit can be seen in the picture below. In order to understand the importance of Simulex, two different simulations will be conducted with the same number of people, but with small changes in the layout. This is to show that a small change in the layout can bring improvement in the evacuation process.

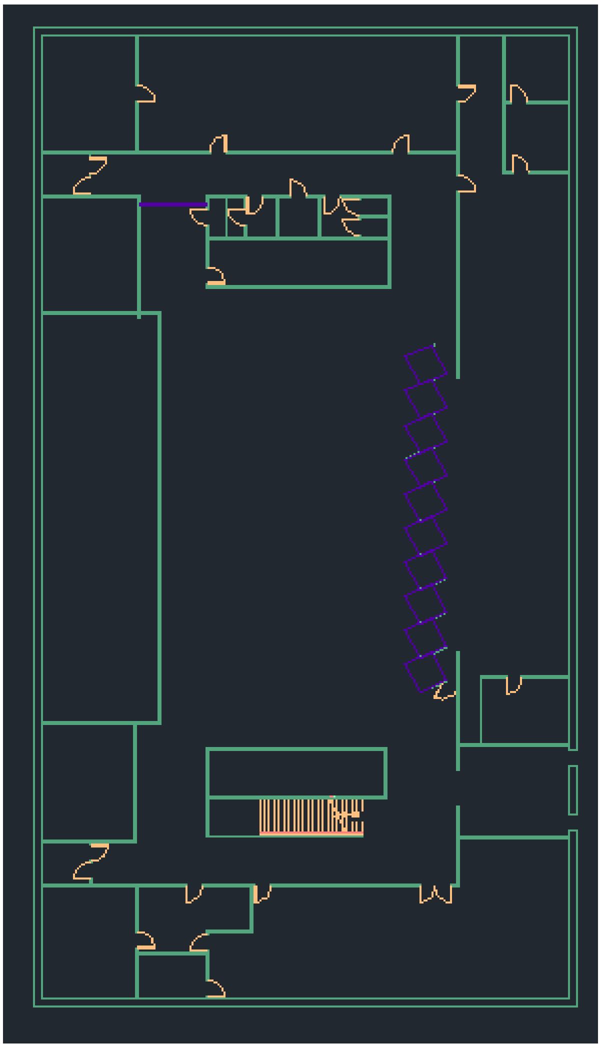


**Figure 7 The Revit model for the current layout**

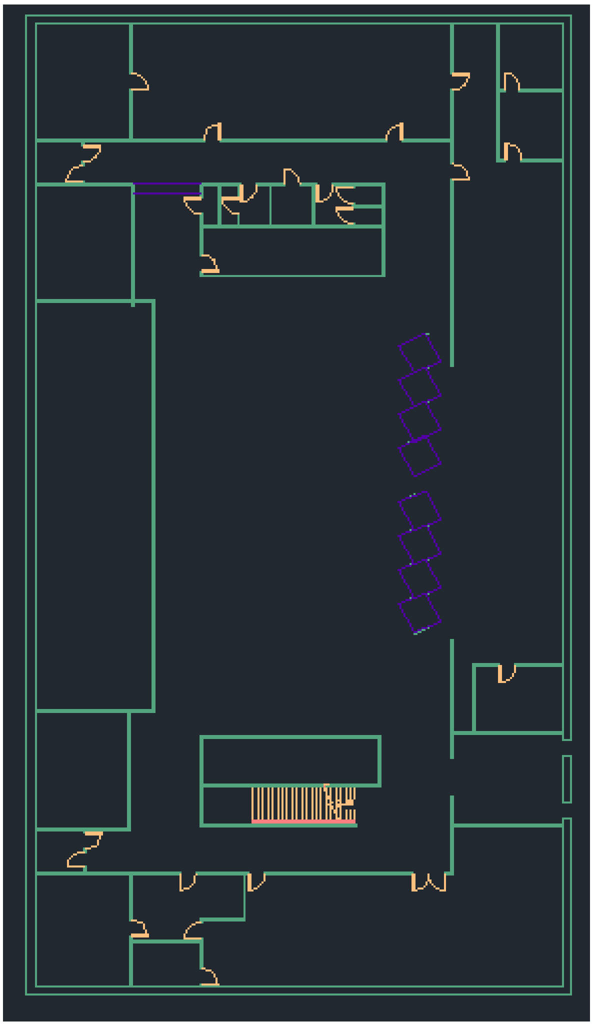


**Figure 8 the Revit model for the improved layout**

With the model designed in Revit, it was time to import it into Simulex. To do such thing, Simulex was opened and then the by clicking the Menu item> Add floor, were the DXF filter was activated, the floor was added. The software will analyse the design and then ask for the units, which cannot be specified in the DXF file. For the present report, millimetres were used so they were also selected in the dialog box that opened, as it can be seen in the following picture.

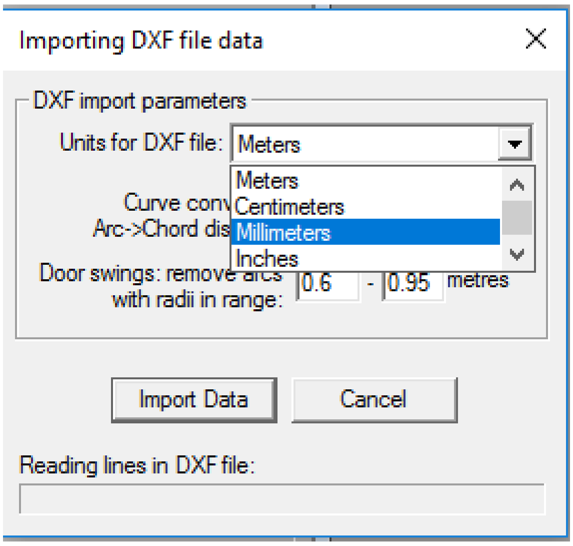



**Figure 9 Units choice for the present report.**

Afterwards, the software also asks about the elevation of the floor, but this is more relevant for multi-storey projects, and since this project had only one level, the chosen elevation was zero.

With the layout of the building imported in the software, the next stage was to assign the exits and their sizes and, if needed the links connecting the different floors. As previous mentioned, since only one floor exists in this project, only the exits and their sizes had to be implemented.

Each exit has to be assigned individually. For the present project, two exits exist and they were implemented as follows. From the Menu item: Building> Add exit. A dialogue box will appear asking for the location of the exit, floor wise, and the size of the exit. Location wise, the exits were placed on the only existing floor, Floor 0, and size wise, according to the drawings, a 0.9 metre exit was implemented. The dialogue box can be seen in the following picture.

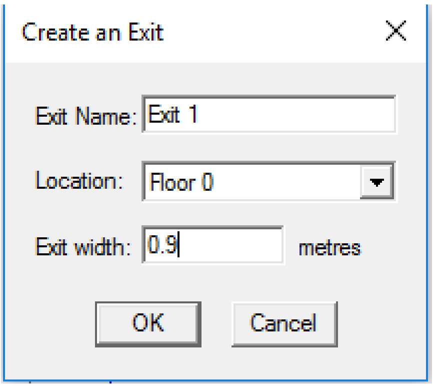



**Figure 10 Dialogue box for exits**

Afterwards, with a simple click, on the position were the exit is needed, the software will implement the exit. If the position is not the one wanted, it can be simply dragged and dropped to the desired position. The exits for the present report can be seen in the picture below.

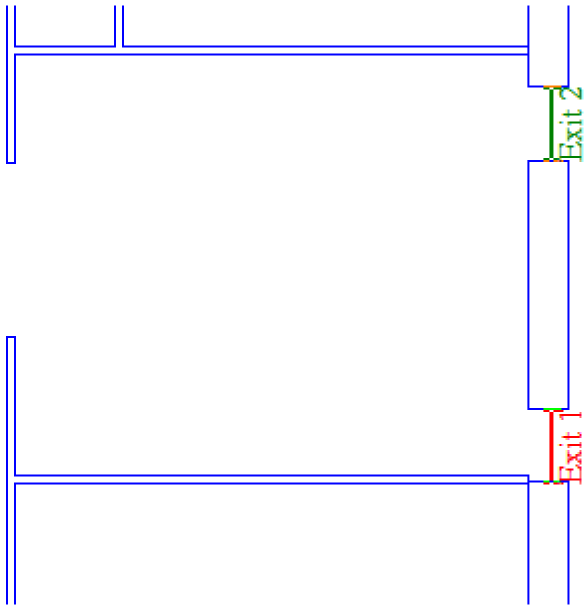



**Figure 11 Positioning of the two exits for the present report.**

With the exits created and no existing links or need for staircases and other floors, the first step of the simulation process was concluded and the second step could be started.

b) Building Set-Up

The next step proposed by the official website of IES was to do the building set-up. Defining the building fabric with exactly the same accuracy as DXF files was already done when the Revit model was imported into Simulex and the correct units were chosen.

Next the distance map had to be generated and calculated. According to official users guide manual the definition for a distance map is the following:" A 'distance map' consists of a mesh of 0.2 by 0.2m spatial blocks, which is used to represent a 'low-resolution' form of the total building space. The numerical value assigned to each block is equal to the total travel distance to an exit from that block. Simulex is able to calculate a distance map when at least one exit has been defined for a building." [13]

To put it into simple terms, the distance maps are calculated in order to direct the occupants to the closest exits. The software also provides the opportunity to calculate more than one distance map in case the designer would like to test the evacuation time for only a certain exit. A total of ten distance maps can be calculated for the different exits of a building. This will allow finding certain problems concerning certain exits.

For the present report, the distance map can be seen in the below figure. The green areas show that the flow of occupants is normal and steady whereas the areas where the colour is red represent the area where a chance of an overcrowding might be present.

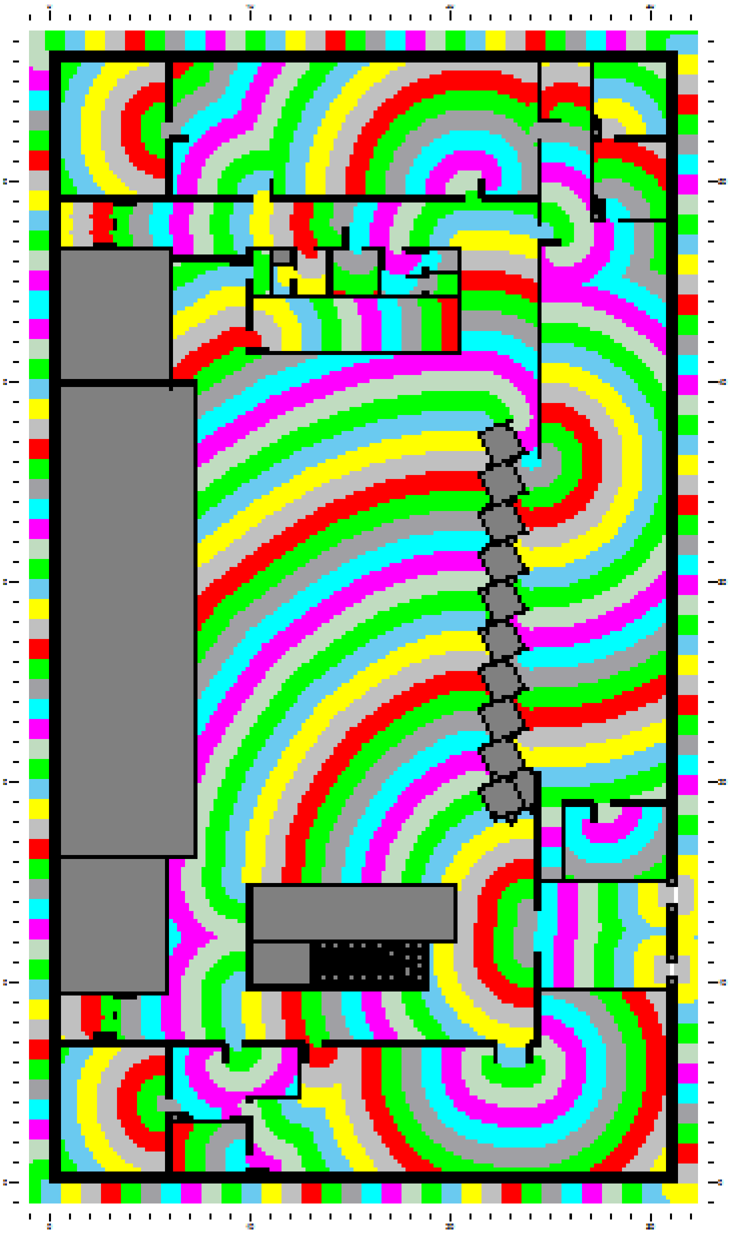


**Figure 12 The distance map for the case of the Esbjerg City Hall**

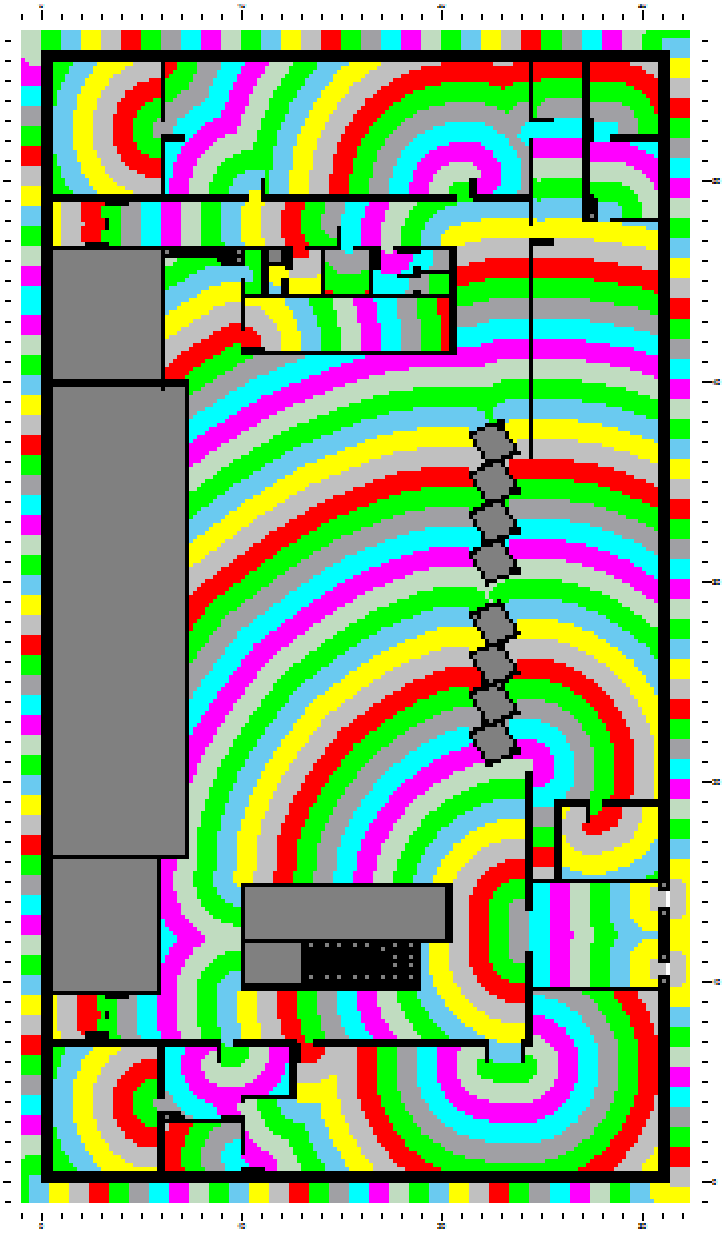


**Figure 13 the Distance Map for the improved layout**

c) People Set-Up

The next step in designing the software simulation was the people set-up. For this, the different population groups had to be defined and their behaviours. A total of 51 figures were implemented with several behaviours.

For the present report, six different types of behaviours were chosen, based on the research from prior similar simulation models and the possibility of meeting these people in the environment presented in the project (the civil service area from the city hall). Also, as previously mentioned, the same number of people and the same behaviours will be implemented for the two layouts.

These behaviours were selected from the vast list provided by Simulex and are as follow:

- Office staff. This behaviour goes from the assumption that they are well acquainted with the work environment and that they all know the exits and the escape routes, the gathering point and they do not need to gather as a group in order to evacuate the building.

- Commuters. These are the visitors that come to the building, either as a group or as individuals and they are not well acquainted with the evacuation plan or the layout or the building. These individuals will tend to move slower as they are further from the exits and they will tend to walk in groups or follow someone and might create overcrowding.

- Elderly: these are older people that are the same as visitors, but which will move slightly slower, but in good order.

- Children: this behaviour was natural to use, since in a public building there are bound to be children, ideally with their parents. The properties of this behaviour is that the members will move slightly slower and will tend to join a larger mass of other individuals, most likely adults, therefore there is a risk of overcrowding.

- All 1, 4 m/s: these people are more or less as the previous ones, being part both of the office staff, but also of the visitors and have the normal average speed of a person walking.
- Disabled: the last behaviour that was assigned took into consideration the old people in wheelchairs or any other disabled people. They have the lowest speeds and might increase the evacuation time if only one exit would be available, the visitors and personnel having to wait for the evacuation. However, the behaviour of disabled will not have any other effect on the other population. For example, the personnel will not go and try and help them or offer their assistance.

Having defined the behaviours the bodies, shapes and sizes were already defined also, since they are already implemented in the design of the multitude of behaviours. So, the male adults are considered to have larger body sizes than the female and the elderly. This influences the turn speed or the distances between two individuals and ads up to the total evacuation time.

Concerning the walking speeds they are also pre-implemented in the behaviours design. Besides the one behaviour which focused on the speed only, the other speeds are as follow. The office staff, considering is acquaintance with the building, will have a normal average walking speed which is 1, 4 m/s and possibly above for those that are further from the exits.

The commuters will tend to walk slowly due to the fact that they are not very informed about the layout of the building and the exit routes; therefore their speeds will be somewhat lower than the average normal walking speed. 1, 3 m/s is the speed of the commuters.

The children will tend to act as the commuters, with their assigned speed of 1, 3 m/s which is slightly below average, but this is only natural, going by the premises that they might be confused and panicked.

The elderly are more or less the same as the commuters in regards to them knowing the layout of the building; therefore the walking speed is already reduced from the start. Considering their old age, the walking speed is even more reduced so that the average walking speed for the elderly behaviour was assigned 1, 1 m/s.

The last behaviour, the disabled, is, as expected, the slowest one. The average speed of this behaviour is 1 m/s.

The final stage in this step was to define the respond time to alarm. The respond time to alarm was based on the fire standards that are currently in play and with the help of the book entitled ”Fire-safety engineering and performance-based codes” from professor Lars Schiøtt Sørensen, this response time was concluded to be: 2 minutes.

d) Evacuation simulation

Once the design of the building was created, its routes were calculated and it was populated with occupants and their different behaviours, the simulation can finally be calculated. For the simulation concerning the Esbjerg city hall, the following screenshot shows us how the building looks like and how it is populated.

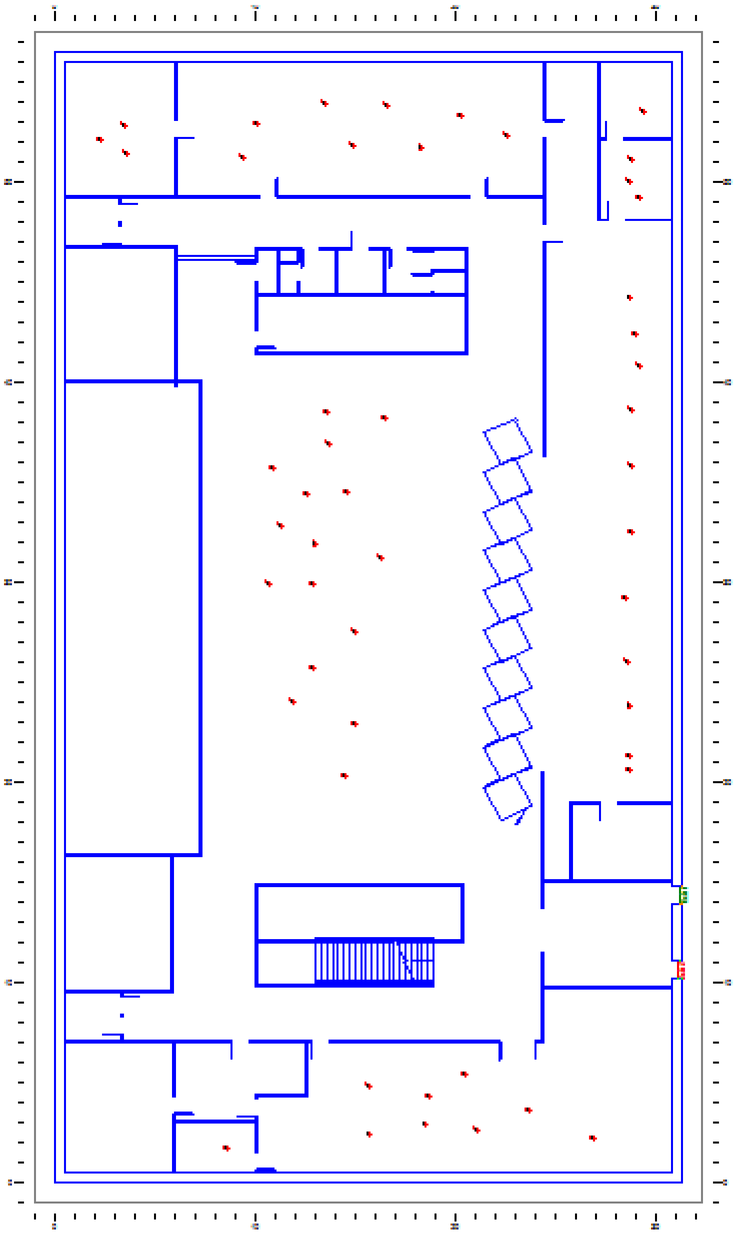


**Figure 14 Screenshot from the simulation model concerning the Esbjerg Town Hall**

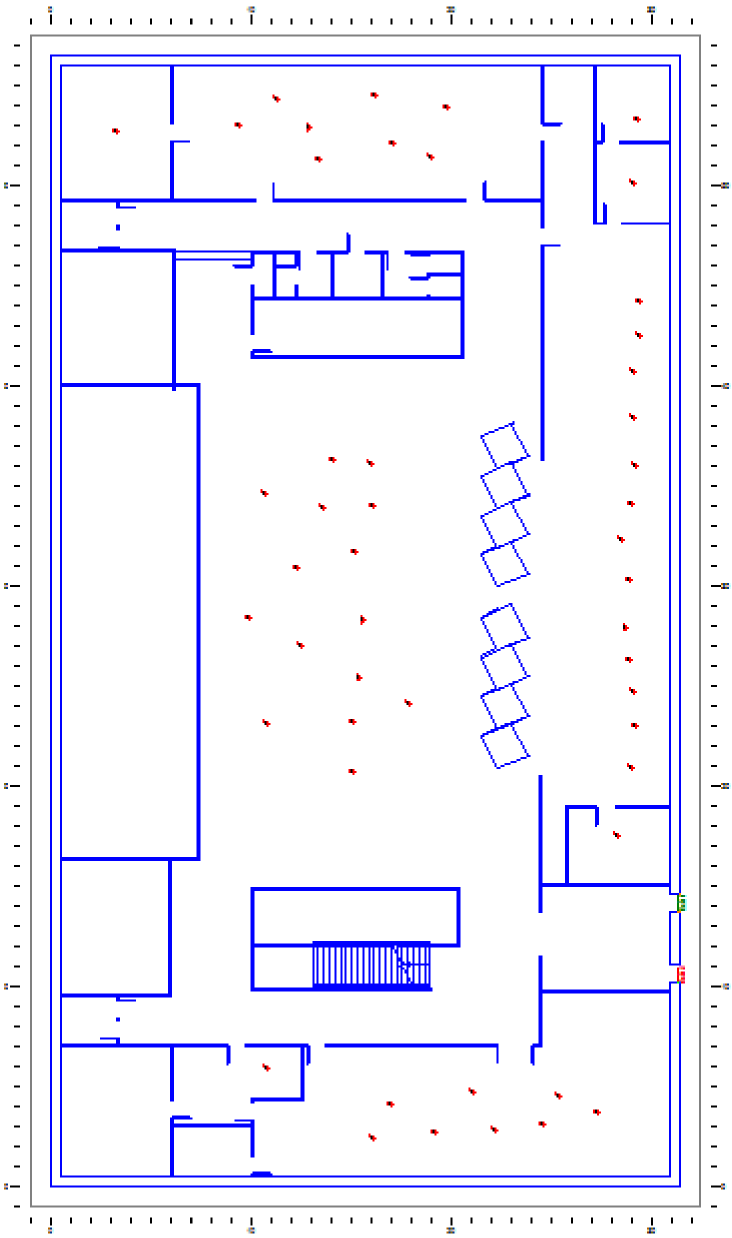


**Figure 15 Screenshot from the improved layout**

This is done simply by clicking on the simulate menu option and then click begin, as shown in the picture.

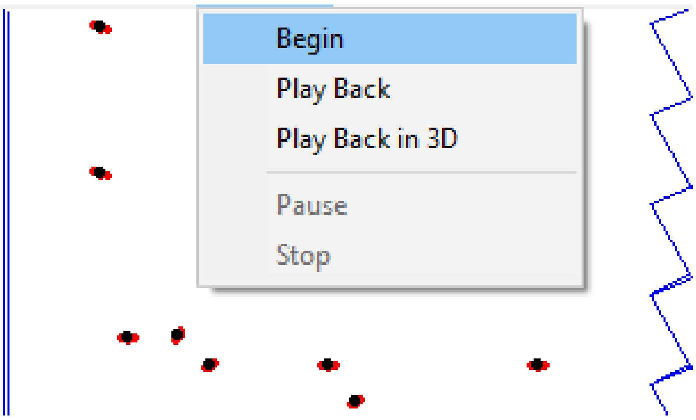



**Figure 16 How the simulation model is tested.**

Afterwards, the software runs the simulation and does the necessary calculation for every individual that was assigned a position on the floor and the total evacuation time is obtained and presented.

After this, the results are saved and then the evacuation can be observed into a 3D model, as in can be seen also in" Previous figure".

For the present result, the 3D is as it can be seen in the following pictures.

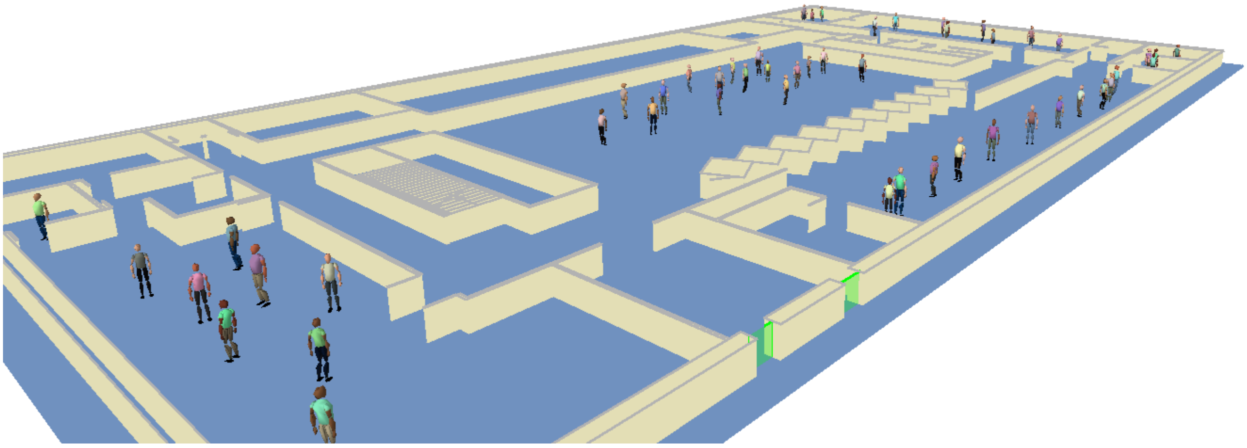


**Figure 17 Positioning of the individuals prior to the evacuation**

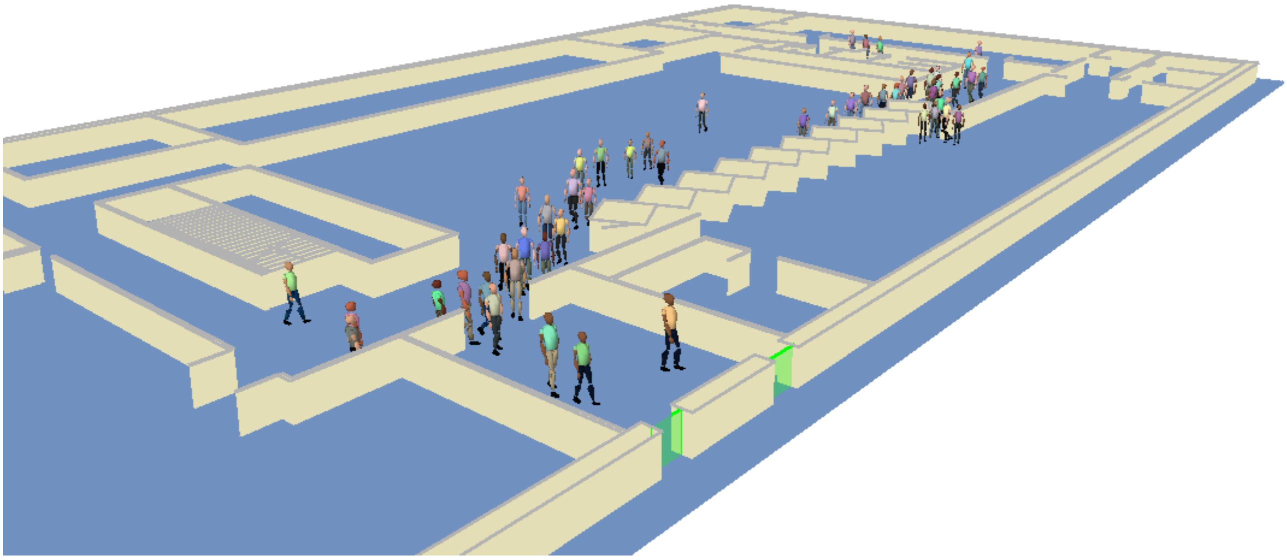


**Figure 18 Individuals evacuating the premises.**

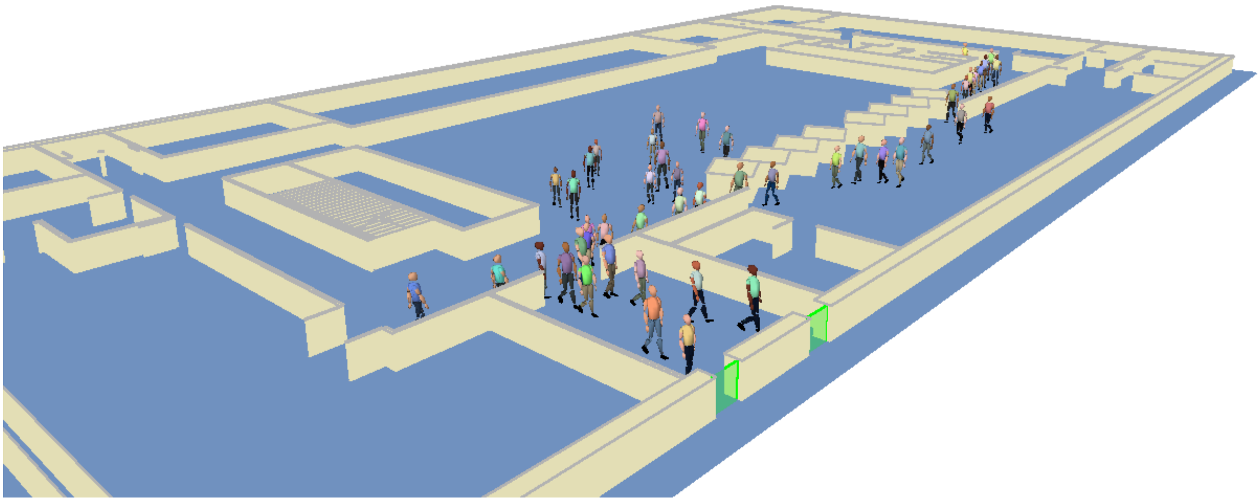


**Figure 19 Individual evacuating the premises in the improved layout**

e) Outputs

- The simulation can be recorded and played back in real time.
- Creates a text file of general occupant flow details.
- Can create a text file of every individual's movements, every 0.1 seconds.
- Creates a text file that shows how many people go through each exit.

This subpart is basically the end result of the entire simulation. Once the simulation is designed with all the necessary information and then we ran the model, the software will first give us on the screen the total evacuation time for the entire population introduced in the simulation as it can also be seen in the following picture.

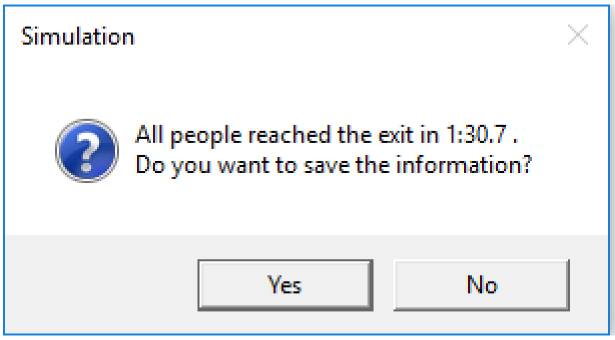



**Figure 20 Evacuation time calculated by Simulex for the current layout at the Municipality**

The purpose of Simulex is to bring improvements in the layout of the building by analysing the evacuation time for different layout. The time for the improved layout can be observed in the following picture, and it can be seen that it depicts massive improvement in the evacuation time.

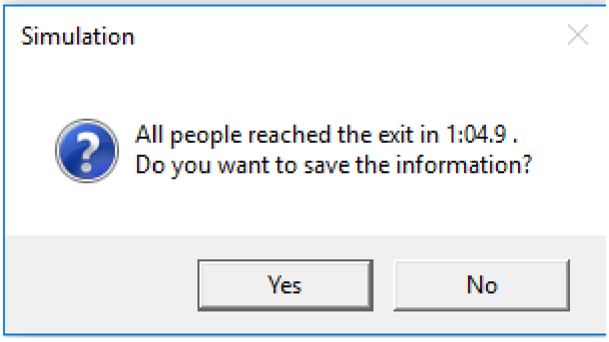



**Figure 21 Evacuation time for the improved layout**

Afterwards, the software saves the rest of the information in a text file. The information provided in that text file is basically a summary of the entire process and the evacuation time. It states the number of people evacuating the building, for this project, every 5 seconds, firstly through both of the exists and then the next two columns show represent the number of people evacuating the building every 5 seconds for each exit individually. This is made to give a better understanding about the behaviour of the people during the evacuation and the evacuation process. To summarise the results for the reader of this project, the results are introduced in the following table.

**Table 7 The end result of the simulation for the current layout of the Municipality**

| Number of Floors = 1 | Number of people through all exits over 5-second periods | | Number of people through Exit 1 over 5-second periods | | Number of people through Exit 2 over 5 second periods | |
|---|---|---|---|---|---|---|
| | Time(s) | N (People) | Time(s) | N (People) | Time(s) | N (People) |
| Number of Staircases = 0 | 5 | 0 | 5 | 0 | 5 | 0 |
| | 10 | 0 | 10 | 0 | 10 | 0 |
| | 15 | 0 | 15 | 0 | 15 | 1 |
| | 20 | 4 | 20 | 1 | 20 | 3 |
| | 25 | 6 | 25 | 2 | 25 | 4 |
| Number of Exits = 2 | 30 | 8 | 30 | 4 | 30 | 4 |
| | 35 | 4 | 35 | 3 | 35 | 1 |
| | 40 | 5 | 40 | 4 | 40 | 1 |
| | 45 | 6 | 45 | 6 | 45 | 0 |
| | 50 | 3 | 50 | 3 | 50 | 0 |
| | 55 | 2 | 55 | 2 | 55 | 0 |
| Number of Links = 0 | 60 | 3 | 60 | 2 | 60 | 1 |
| | 65 | 4 | 65 | 4 | 65 | 0 |
| | 70 | 5 | 70 | 5 | 70 | 0 |
| Number of People = 51 | 75 | 0 | 75 | 0 | 75 | 0 |
| | 80 | 0 | 80 | 0 | 80 | 0 |
| | 85 | 0 | 85 | 0 | 85 | 0 |
| | 90 | 0 | 90 | 0 | 90 | 0 |
| All people reached the exit in 1:30.7 | 95 | 1 | 95 | 1 | 95 | 0 |

The above table shows the results from the actual layout of the Esbjerg municipality, whereas the table below depicts the results from the improved layout.

**Table 8 the results from the improved layout**

| Number of Floors = 1 | Number of people through all exits over 5-second periods | | Number of people through Exit 1 over 5-second periods | | Number of people through Exit 2 over 5 second periods | |
|---|---|---|---|---|---|---|
| | Time(s) | N (People) | Time(s) | N (People) | Time(s) | N (People) |
| Number of Staircases = 0 | 5 | 0 | 5 | 0 | 5 | 0 |
| | 10 | 0 | 10 | 0 | 10 | 0 |
| Number of Exits = 2 | 15 | 2 | 15 | 2 | 15 | 0 |
| | 20 | 4 | 20 | 2 | 20 | 2 |
| | 25 | 9 | 25 | 6 | 25 | 3 |
| Number of Links = 0 | 30 | 4 | 30 | 4 | 30 | 0 |
| | 35 | 6 | 35 | 4 | 35 | 2 |
| | 40 | 6 | 40 | 6 | 40 | 0 |
| Number of People = 51 | 45 | 6 | 45 | 6 | 45 | 0 |
| | 50 | 4 | 50 | 4 | 50 | 0 |
| | 55 | 3 | 55 | 3 | 55 | 0 |
| All people reached the exit in 1:04.9. | 60 | 5 | 60 | 5 | 60 | 0 |
| | 65 | 2 | 65 | 2 | 65 | 0 |

Based on these results, a notable difference can be observed in the evacuation time, which sparks from minor changes but with a very relevant impact.

### 3.3 Concluding remarks

As seen in the detailed explanation, the process of creating a simulation using Simulex can be divided into 5 different steps, each with its own complexity, but the end result is the one that matters and based on different studies, with the help of the different behaviours implemented into this software, the evacuation time for a building can be calculated with quite good accuracy, the behaviour of the people can be also observed, and possible areas where there is a danger for over-crowding can be noticed and, if needed, can be corrected.

There are several advantages to using this software and they are the following:

- The exact shape of the building can be designed
- The exact number of the workers can be introduced
- All the exits and staircases can be represented and, if needed, some of them can be blocked.
- There is a large variety of behaviours one can choose from and they are based on prior analysis of human behaviour during an emergency.
- It can give a 3D simulation model, for a better visual representation
- It can also be played in real-life speed.
- The software itself is not very demanding.
- Helps in finding the best layout in order to reduce the evacuation time.
- Calculates the evacuation time and gives it in a text document and provides information every 5 seconds or, if needed, it can provide every 1 second, and it also gives information about the number of people evacuating of each of the exits.

Granted, there are also a few downsides to this software, which might end up giving some error between the evacuation time provided by the software and the evacuation time from a real-life simulation. Some of the downsides of this software are:

- Although it provides a large list of behaviour, you are limited to them and cannot add any new ones.
- The software itself is not very demanding, but usually is comes as a sub-part of a larger software entitled Virtual Environment and that software is quite demanding.
- There is no free student license provided, so if anyone wants to use the software, even if it is for academic purpose, has to pay.
- With newer versions of Autodesk related software, there are some problems when it comes to reading the entire information, therefore it is advised to save the information as an older version; however it is stated that this small upset will soon be mended.

Chapter 4

# 4. Simulation using 3DS Max

## 4.1 Introduction to 3DS Max

3DS Max is a software created by the Autodesk team, the same team that created design software such as AutoCAD, ArchiCAD or Revit. It is a 3D software for modelling, animation, and rendering that allows the creation of stunning scenes for design visualization. [14]

It is frequently used by video game developers, TV studios to create commercials and by architects to provide a 3D video of their soon-to-be project. Due to its complexity and vast amount of tools provided, it can also be used for visual representation of an emergency situation and its adhering events and elements.

The steps that are to be followed for a proper representation of the evacuation are as follow:

a) Model and building set-up.
    - Use a CAD generated layout which would represent the structure.
    - Represent the exists
    - If a multi-storey building is being represented, include the staircases in order to achieve a proper evacuation model.

b) People set-up
    - Create a figure to represent the average human being.
    - Implement different behaviours by auto keys.
    - Assign different walking speeds by auto keys.

c) Simulation of the evacuation
  - The evacuation will proceed with the assigned behaviours
  - The evacuation stops once every occupant has left the building.
  - It renders the evacuation into a video which can be presented for everyone, regardless if they possess of not the license for the software and provides good learning tool.
  - The evacuation time can be observed in the video.

As a side note, 3DS Max does not provide an output as Simulex does, in which the occupant flow and other relevant details are provided. The only output provided by 3DS is the video and the behaviours can be seen and observed in the video.

## 4.2 Constructing the simulation

After the input from the Esbjerg's municipality was received, which stated which area should be in the simulation model and the number of people, the simulation model could be constructed.

a) Model and building set-up

The first step to be taken, as it can be seen in the above section, was the model and building set-up in the program Revit. Basically in this model the floor plan was created to represent the area where the evacuation will be conducted. Being a CAD based software, the floor plans can be created in 3DS Max also but since the group's members have a better know-how in other related CAD software, such as AutoCAD and Revit, they opted for those instead, precisely for Revit. The exact parameters of the building, such as measures of the rooms, walls and any other object in the layout, are done easier in Revit and AutoCAD, than 3DS Max, hence the usage of Revit to represent the layout.

This was a single storey floor so additional staircases were not needed, but the two exits had to be represented. They were represented as normal doors and the revolving door was left aside, since it does not work during the evacuation procedures and is meant to be locked since it might impair the movement.

After the model was constructed in Revit, true to its form as observed from the plans received from the members of the council in the municipality, it was imported into 3DS Max, where the next two stages of the process would be followed.

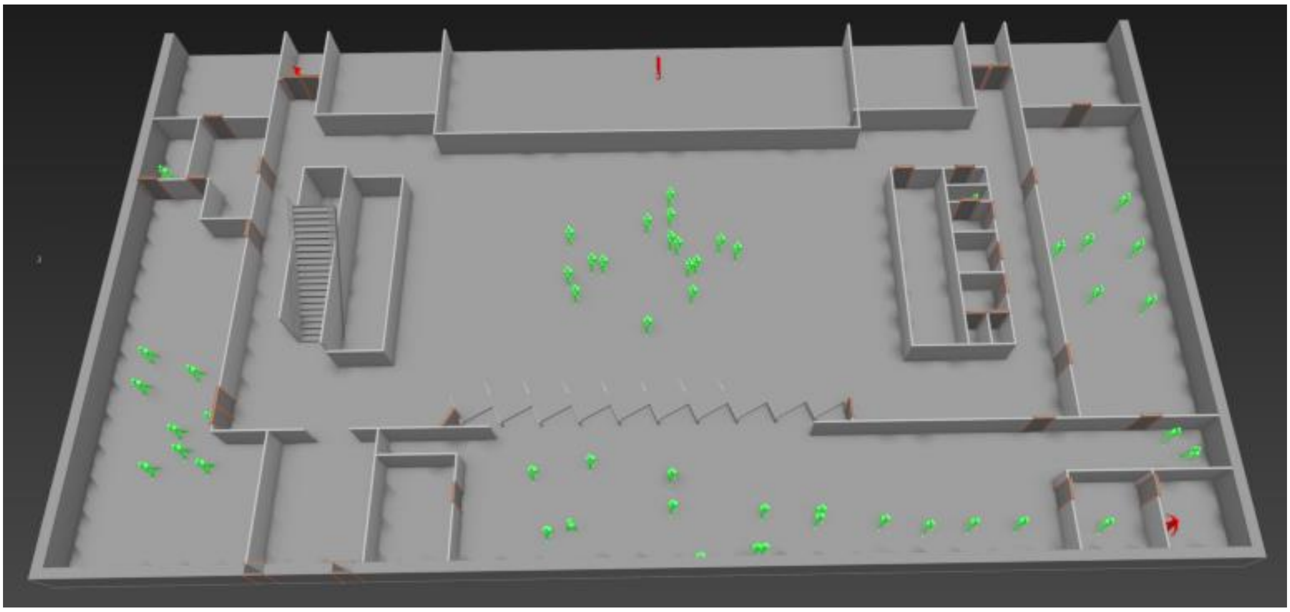


**Figure 22 The floor plan for the citizen service area.**

After the floor plan was imported, the first step of the process was also completed and the next step could be followed.

b) People set-up

This was the most time consuming part of this simulation process using 3DS Max. First, as mentioned before, 3DS Max provides a large variety of tools in order to design complex elements; therefore there is no figure implemented to represent a person, unless if the ”Crowd” function is used, but that function was redundant for this report, hence a figure representing a human being had to be created.

This was done by following the tutorials provided by Autodesk, at the same time as the other group member was constructing the layout of the building. It has to be stated that no movements for the legs or arms was implemented as it would have been too time demanding; therefore the figure’s arms and legs will be static. In the end, the figure that was obtained can be seen in the following figure.

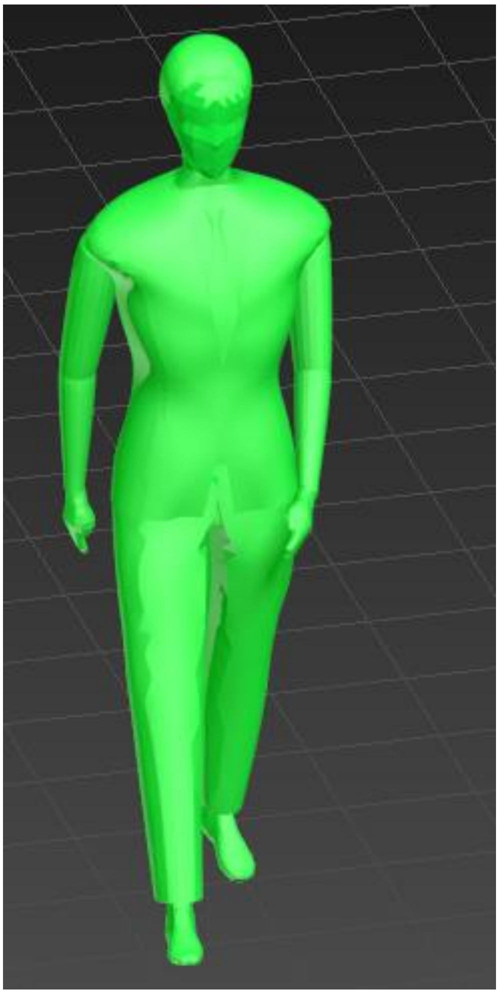


**Figure 23 Representation of a human in 3DS Max**

After the figure was constructed, the next step was to implement the behaviours. 3DS Max does not come with already implemented behaviours as Simulex does, so these had to be implemented by hand for each figure individually, by the members of the project. Three different types of behaviours were implemented and are as follow.

- Visitors/Students' behaviour. These are meant to represent the students that were part of the real life exercise, but can also represent the day to day visitor. They are represented as figures that stand together in smaller groups and who are unaware of the situation and the upcoming events. They have a slower reaction time and will tend to follow the instructions of the coordinators. They will also move in groups, following each other. They have also had assigned faster walking speeds, signifying that they might panic; therefore they would try to evacuate as fast as possible.

- Municipality workers. These represent the second behaviour and are meant to represent the workers that were aware of the situation, know the surrounding environment and have had prior training in this situation and environment. They will wait calmly until all the students/ visitors have evacuated and only after that they will start their evacuation. They have had assigned a slower walking speed, due to the fact that, by knowing the situation and the environment, they will not panic and will walk calmly towards the exits.
- The search behaviour. This is the last behaviour assigned in this simulation and is meant to represent the three workers that are meant to ensure that everyone reached safety and, afterwards they are meant to search throughout their assigned area in order to make sure there is nobody left behind. They have had assigned a slightly faster walking speed to ensure that the evacuation time is made as small as possible and that all the areas are checked. They have also had assigned a different colour (red) to make sure that they stand out of the crowd during the evacuation process, making it easier to follow their movement. For this behaviour, two simulations were constructed. One were the search behaviour does the job as its intended, whereas in the other one, the search behaviour does only part of its job.

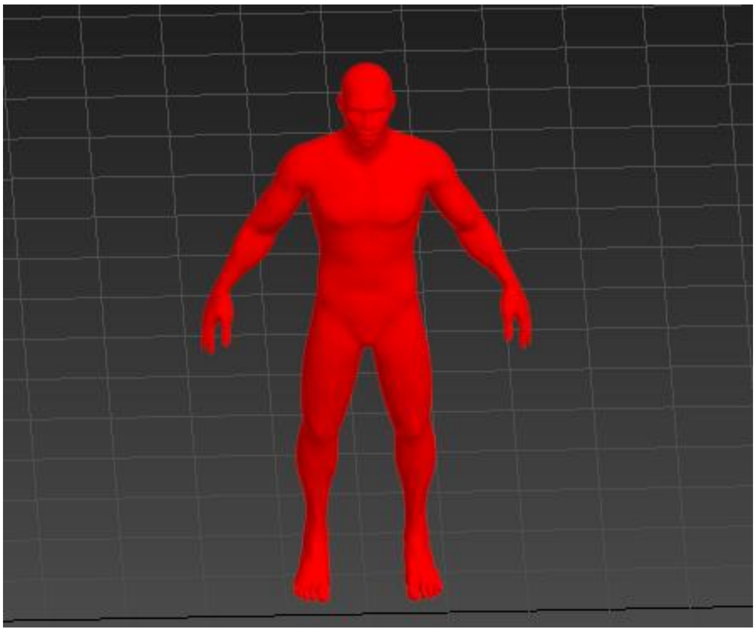


**Figure 24 Representation of the workers assigned with searching the premises.**

In a place as the municipality, it is important, that the searchers do their job as intended. When a place as the municipality has visitors as they normally have, the visitors don't necessarily have knowledge of the building section, and can't help themselves safely out without help. Especially deaf, handicapped and old people can have trouble moving themselves out on a safe route. In Denmark there are approximately 4.000 deaf people, 16,6 % under 75 year have impaired hearing and 50 % over 75 have impaired hearing [15], so the chance for a deaf person is low but the for a person with impaired hearing is high, and this person could be at the toilet when the evacuation alarm start, and not hear it. Due to this information, the search behaviour was implemented and, it can be seen in the videos, its importance is undeniable.

In the end, to give a better picture of the event, an image of the fire was represented to show were the fire occurs and which of the areas might be impaired for evacuation due to this.

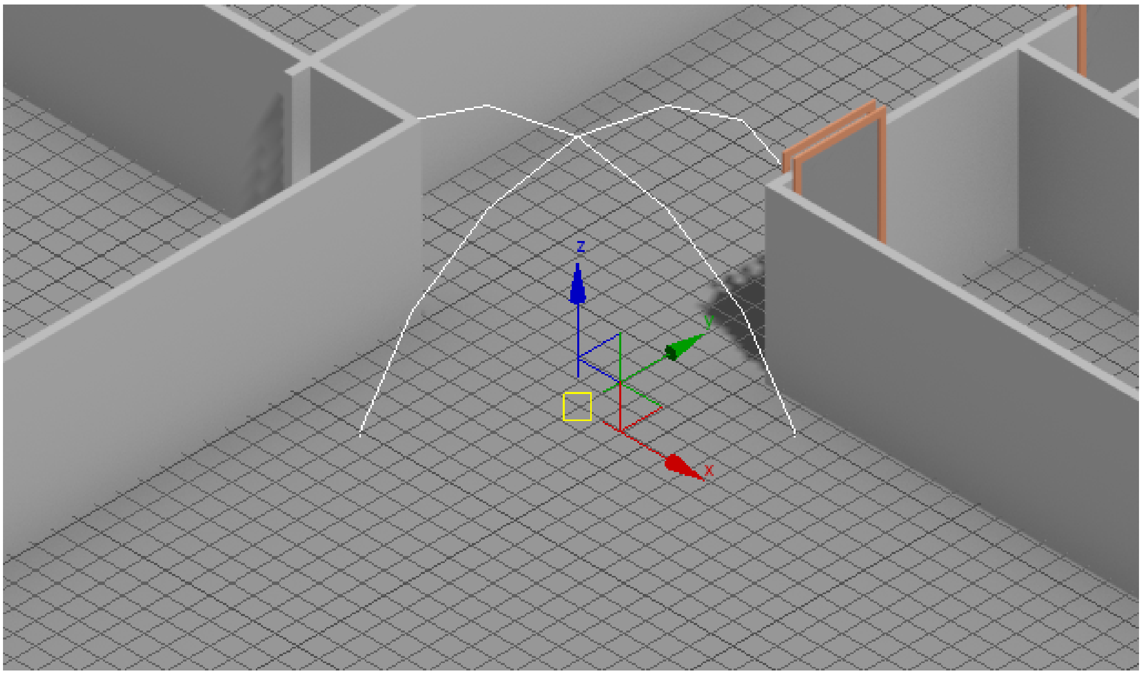



**Figure 25 Still of the fire skeleton. (Before the rendering process)**

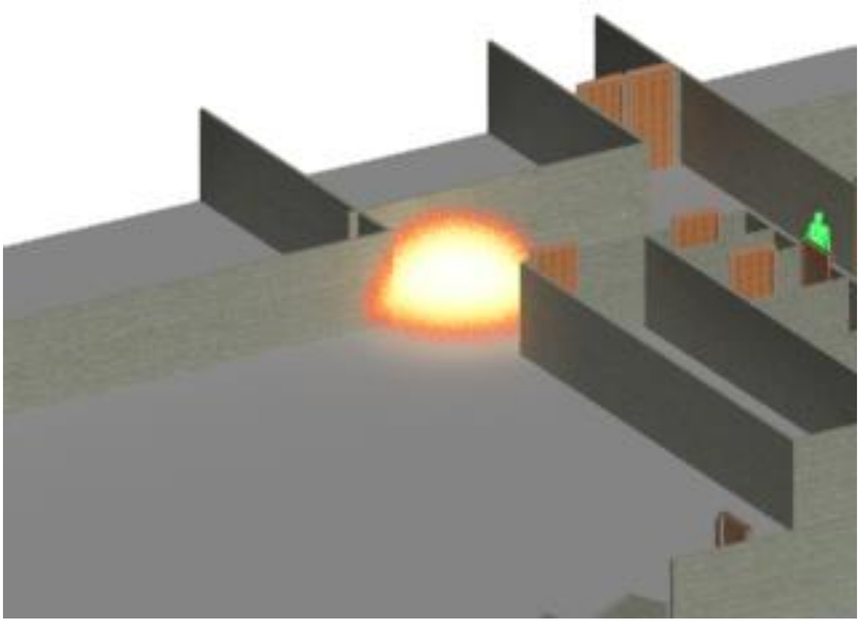


**Figure 26 Still of the fire after the rendering process**

With the behaviours implemented the next and last stage of the simulation process could be conducted.

c) Simulation of the evacuation

This process was just a matter of assigning different keys to each of the characters in order to represent their movement. They were represented taking into account their assigned behaviours. The evacuation was then rendered into a video. This was done both in order to represent the fire, which would only appear in the rendering process, but also to make it easier to play. Once the rendering process is done, the full scale of the simulation model can be observed and noticed, and possible knowledge could be deducted from this. The following pictures show a still of the fire after the rendering process was conducted, as well as a still from the evacuation model and the roles of each occupant and their different behaviours.

## 4.3 Concluding remarks

As seen in the detailed explanation, 3DS Max is a very complex software, providing a large variety of tools at the user’s disposal. It was not designed specifically for creating evacuation simulation processes, but for graphic representation, nevertheless is can also be used to create a simulation of an emergency with the provided tools, giving a better understanding of the evacuation process, helping in understanding where possible improvements might be needed.

There are several advantages to using this software and they are as follow:

- Provides an exact, scalable replica of the building.
- It gives the opportunity to display the workers in the layout as they would be in a real life situation
- Can also represent a fire or other adverse situations, showing where the hazard is.
- Different behaviours can be implemented, not directly from the software, but by the users.
- The relevance of different behaviours in an evacuation process can be observed.
- It displays a video of the simulation, showing when and where everything is happening.
- Provides a free student license for 3 years.
- Only the fantasy sets limits for 3d effects.

Admitted, there are also a few challenges and downsides with this software and they are as follow:

- The software is very demanding.
- Does not provide any calculation.
- It is time-consuming since all the behaviours need to be added manually for each individual and the program have thousands of features and is really large.

The next section will focus on providing a comparison between the two programs, emphasizing on their pros and cons, trying to decide which one is more suitable for the task at hand.

## 4.4 Comparison between Simulex and 3DS Max

As seen in the above sections, both Simulex and 3DS Max are tools that can be used to properly create a simulation of an emergency. However, both programs have disadvantages as well as advantages. But which one is better?

It is difficult to make a decision, but some aspects can be compared. For example Simulex, as seen in its section, provides a large variety of behaviours which are already implemented, thus making it less time-consuming than 3DS Max. However, it does not provide" search" behaviour, as this project would require, nor does it have the option to add extra behaviours. This is a disadvantage, but overall, due to its large variety of Simulex, and the complexity that was put into analysing these behaviours by the developers, Simulex is an excellent tool.

On the other hand, 3DS Max does not provide any type of behaviour pre-installed, hence all the needed behaviour has to be implemented by hand. This is, as stated above, a very time-consuming process. But, on the other hand, by using 3DS Max and implementing the behaviour that one requires, for this specific case the ”search” behaviour, one is not confined by the limited behaviours as he might be by using Simulex.

Another good comparison between the two programs is their size and how demanding they are. This is where Simulex has an advantage since it is optimised to work on older platforms, whereas 3DS Max is a software that demands a very potent platform to operate.

When it comes to license, 3DS Max is the one that has an advantage since they offer free student license for up to 3 years and the process is very easy and done in a short amount of time, whereas Simulex, although they provide a student license it is not free and it is only for up to one year.

Another advantage that 3DS Max has, is the fact that, in essence, is a CAD software, meaning that any other software from the Autodesk package or any other software is used, the layout will be compatible, while with Simulex it tends to be a little more complicated and sometimes errors in units might occur, destroying the end result.

But when it comes to results, Simulex has a large advantage. As stated before, 3DS Max only provides a video overview of the situation and, afterwards experts are supposed to draw additional conclusions from this. Simulex on the other hand, does a thorough analysis of the area and the evacuation routes, and in the end provides a text document with the results in detail about the evacuation process. This is quite helpful, as even people without a background in this field, can draw conclusions from the process. More than that, one of the most important features that Simulex provides is the distance map, where area with potential of overcrowding are represented and additional knowledge can be taken from that, if a need to reshape the structure appears.

3DS Max is a more complex software, and by saying this, additional features can be added to the simulation, such as a fire or any other hazard in order to represent the severity of the situation and how the hazard and risk might expand.

To summarize this section, both of these programs are very useful and have a large variety of features, and each have advantages and disadvantages. While Simulex is a better tool for this type of simulation, considering it is a software specially design for this especially, you are somewhat confined by the behaviours which are pre-installed in the software and you do not have the ability to add new ones, whereas you can do that with 3DS Max. Simulex is also less demanding but more expensive to use on a short term basis, such as a student project or a student license. Both programs can represent the evacuation in 3D which is very useful in this case both of them are more or less demanding. Granted, Simulex is only demanding until all its features are turned on, while 3DS Max is demanding throughout the time.

As a personal choice, for this project, the members of the group have concluded that Simulex is a better option, since it is strictly made for this type of events and since it provides a larger output in the end, although additional features would be useful.

Chapter 5

# 5. Evacuation exercise

This chapter focuses on the real life evacuation drill that was carried out at Esbjerg's municipality. The entire idea for this project came from the members of the city council who were keen to test their new evacuation plan. Since the evacuation had to be compared to something, the two previous programs were used to see if their evacuation methods are working as they should or, if not, what possible improvements could be added. This is the purpose of this coming chapter: to describe the exercise, the environment and the possible improvements, if needed.

The idea was simple. Test both the workers and the visitors and observe the possible improvements that could be added to this specific building, based on past, similar exercises.

Besides the two software simulations, there is one more way to compare the reaction of the workers to the actual standards and that is by calculating the total egress time of the people in the building. These calculations can be seen in the following section where they are also described in more detail.

## 5.1 Description of the evacuation time

The total evacuation time (egress time) is calculated according to the European Standards and the group members followed the book of Lars Schiøtt Sørensen where each step is explained in detail and the process that needs to be followed. [16]

The initial formula is: $t_{evac} = t_{wa} + t_{rd} + t_w$ where:

$t_{evac}$-total evacuation time

$t_{wa}$-represents the warning time and is taken as standard 1 minute.

$t_{rd}$-represents the response and decision time and is a standard 1 minute.

$t_w$-represents the walking and flow time

Since the other two elements of the formula are given as standard, the walking and flow time is the formula that needs to be calculated and it is as follows:

$$t_w = t_{walk} + t_f = \frac{L}{V} + \frac{N}{F_a}$$

Before we go in any more details, some information needs to be provided, which will represent the data for the following calculations.

There were 35 workers from the municipality and 16 students to represent the visitors. These combined add up to a total of 51 people to include in the formulas.

Additional information required is the size of the area that needs to be calculated. This resulted into an area of 1379 square metres to be included in the future calculations. The area is needed to calculate the density which is: Density=$\frac{number\ of\ people}{area} = \frac{51}{1379} = 0{,}036$ which is then rounded to the closest number, different from zero, therefore it is 1.

Finally, the last information required is the number of doors which would be used during the evacuation process and these are two doors with a width of 0,9m.

Now that the information is known, the formulas can be further on calculated and explained.

$$t_{walk} = \frac{L}{V};\ L = walking\ distance, V = walking\ speed$$

$t_f$ = flow time through doors

Concerning the walking distance, the worst case scenarios has to be taken, meaning that into the calculation the longest distance that has to be travelled must be taken. This was observed to be 73,025 metres, value which will be included in the formula.

The walking speed, since the density is smaller than 1, can be taken directly from a Table 17.1, page 462, from the book ”Fire Safety Engineering” by Lars Schiøtt Sørensen, and is equal to 1.3 m/s or 75 m/minute.

However, around the evacuation doors, the density will increase, as it is normal, so around the evacuation doors a density of 3 people per square meter is taken, therefore the formula that needs to be used is the following:
$V_{exit} = k_t(1 - 0.266 * D)$ where $k_t$ is a factor equal to 84 given the fact that the formula concerns corridor and doorways, and not stairs.

By that, with the assumed density, the speed around the exits will be:
$V_{exit} = 16.97\ mImin$

As mentioned earlier in this section $t_w$ has two components, one related to length and speed that is just explained whereas the second component is about the flow of the occupants through door that is explained in the following lines.

The time, $t_f$, used for a number of people, N, passing a doorway is as follows:

$t_f = N/F_a$ Where N represents the number of people, equal to 51 for this case, and $F_a$ represent the actual flow.

The actual flow, $F_a$, is calculated as follows:
$F_a = F_s * W_e$ where $F_s$ represents the specific flow and $W_e$ represents the effective width designed.

In this formula, $F_s$ is calculated by using the formula: $F_s = V_{exit} * D$, where D is the density at the exit, taken as 3, and $V_{exit}$ is the speed at the exits which was calculated previously, so by using this data as input, the final result is $F_s = 16.97 * 3 = 50.91\ persons/min$.

$W_e$ is calculated for any door with a given width and it is calculated as follows: $W_e = W - BL$ where W is the given width, for this case 0.9 metres, and BL represent the boundary layer, which corresponds to 0.15 metres on each side of the door. So the final result for the effective width designed is: $W_e = 0.9 - 2 * 0.15 = 0.6\ m$

By having the specific flow, $F_s$, and the effective width designed, $W_e$, the actual flow can be calculated.

$$F_a = 50.91 * 0.6 = 30.546\ persons/min$$

Having calculated the actual flow, the flow time through doors can be calculated. As mentioned earlier the formula is a division of the total number to the actual flow. The number 51 has to be divided by two, given the fact that there are two exit doors available, so the results are:

$$t_f = \frac{26}{30.546} = 0{,}85 = 1\ minute\ 25\ seconds$$

The data is all known now, so they can be simply included into the formula and the $t_w$ can be obtained:

$$t_w = t_{walk} + t_f = \frac{L}{V} + \frac{N}{F_a} = \frac{73.025}{75} + \frac{26}{30{,}546} = 183\ seconds = 3\ minutes\ 5\ seconds$$

Having obtained $t_w$ the total evacuation time can be calculated. As a reminder, this is the formula of the total evacuation time: $t_{evac} = t_{wa} + t_{rd} + t_w$ in which all the information is known, so the result is$t_{evac} = 1 + 1 + 3.05 = 5\ minutes\ 5\ seconds.$

## 5.2 Description of the evacuation process

This section is meant to describe the evacuation drill and the steps that were followed. There were several meetings that have led to this evacuation drill and how to conduct it. It was agreed from the beginning that the resources and time to evacuate the entire building would be too demanding and that the loss of time would lead to a large loss of capital so it was decided that only one area of the building should be evacuated, more specifically the citizen service area.

The initial idea was to test the evacuation plan during the working hours, but it was later agreed that panic might ensure; therefore this idea was left aside. Afterwards, the members of the council came with the idea that only the workers should be tested, but that would mean that only a part of the evacuation plan would be tested as well, hence the need for visitors was considered necessary.

The final idea, and the one that was put into play, was that some students from Aalborg University could serve as the" visitors". They were only announced that there will be a meeting with the safety council from the municipality, so they were unaware of the evacuation drill that was about to commence. This would be done in order to achieve better results, trying to make the students act as close as possible to victims of a real fire, which was the chosen hazard.

Due to security reasons, the workers from the municipality would be informed of this event, so their reaction time and coping of the situation might be altered a little.

The idea of the simulation was that at an agreed time, the workers would go to their normal places in the designated areas, while one member from the safety council would greet the students outside of the building, invite them inside, and introduce them to the safety measures installed at the municipality. Again, this was done to make sure that the students act as the perfect" victims". Afterwards, the safety council member left the students in the area, saying that he will return. This was done in order to make sure that the students spread out in the area, filling the room.

A smoke machine would be then turned on, engulfing the area in smoke, trying to recreate the actual effects of a building fire.

The alarm would start, announcing an emergency, and then everything would go by the evacuation plan principles. The fire evacuation coordinators would grab their jackets, one of them would lead the students/visitors to safety, whereas the others ones would announce the workers to prepare for evacuation.

When most of the students were evacuated, the workers would commence their evacuation, followed closely by the fire evacuation coordinators, who need to ensure that everyone has evacuated safely.

Once everyone is outside, a counting should be concluded to make sure that all the people that were present in the building, were also evacuated.

During this whole time, a firefighting vehicle would come to the municipality, being announced by the alarm signal, which starts at the same time as the speakers from the municipality.

If not all the people present in the building are outside after the counting, the firefighting department should be notified and a search should be conducted.

Once the missing person/ persons is/are found, the fire drill should be stopped everyone can go to their normal job.

## 5.3 The actual evacuation process

On Friday the 2$^{nd}$, at 8 o'clock in the morning, the student from Risk 2 and Risk 4 from Aalborg University gathered in front of the city hall, where they were met by the chief of the Safety Council from the municipality of Ebjerg. At 8:15 they were called inside and received a brief introduction about the safety measures implemented in the municipality.

Afterwards, according to the discussion, the chief of the Safety Council left saying he will return. This was an excuse to give enough time for the students to accommodate with the surroundings and to spread out in the building, as it was wanted that the students should act as normal visitors. During this time, a member from the fire department was heating up a smoke machine and at 8:35, he received a signal that the exercise could commence, and the building was engulfed in smoke.

**Figure 27 the use of the smoke machine and the commencement of the exercise.**

When this happened, the alarm noise was started and a voice message was sent through the speakers, while at the same time a signal was sent to the firefighting station. During this time, the fire evacuation coordinators took their high visibility jackets, as it is expected, in order to be easily observable.

All these events, if we were to compare them to the calculation of the evacuation time, represent the warning time and response and decision time. According to the videos that the municipality provided this time was around 1 minute and 10 seconds which is way lower than the 2 minutes provided by the standards. But it has to be taken into consideration that this was a known exercise, so the warning time is somewhat downsized. In a real life event detecting and providing the warning might not be increased. Nevertheless, for the present exercise, this time was 1 minute and 10 seconds, well under the standards. Also, we can see that the result from the survey, which was presented to the students after the exercise, dictates that the safety measures were useful, as it can be seen in the following picture.

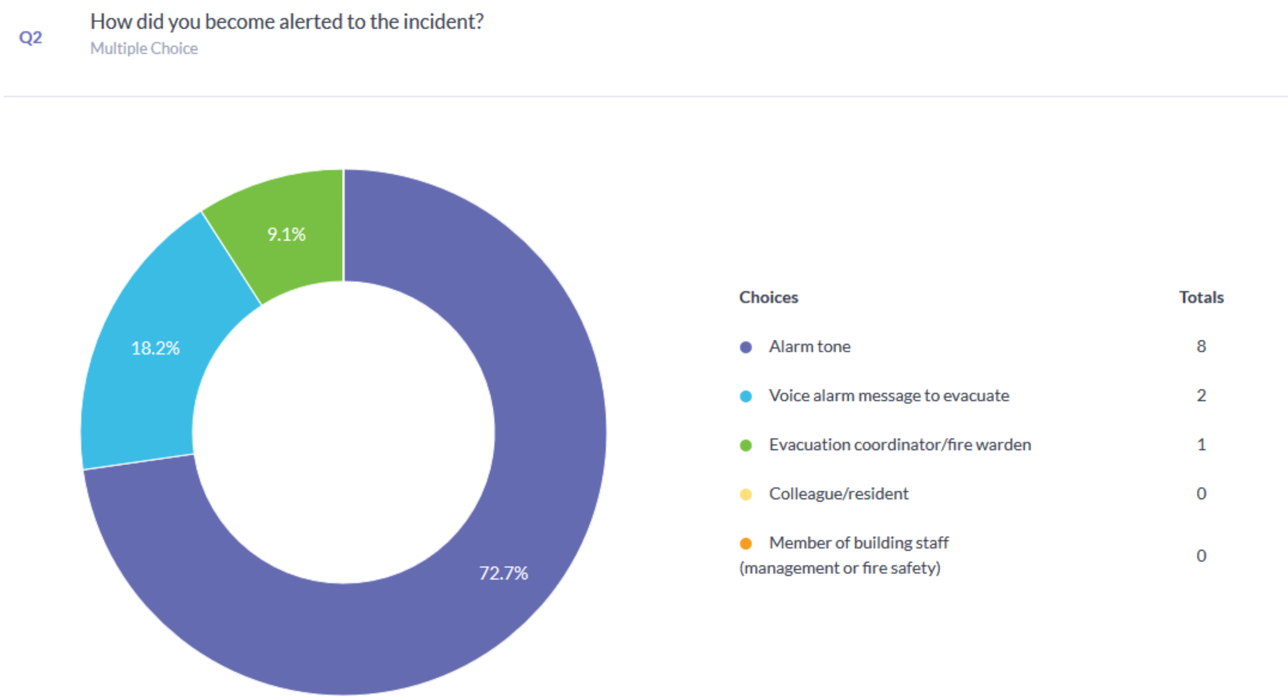



**Figure 28 the answers of the students regarding the alerting methods.**

Once the alerting measures were started, the fire evacuation coordinators made their appearance, some of them directing the student to the exits, whereas the other ones were informing the workers about the evacuation procedures.


**Figure 29 Fire evacuation coordinator directing the students towards the exits**

According to the evacuation procedures, the students were the first ones to be evacuated, and once, most of the students were out, or close to the exit areas, the workers started evacuating also, as it can be seen in the following two figures.

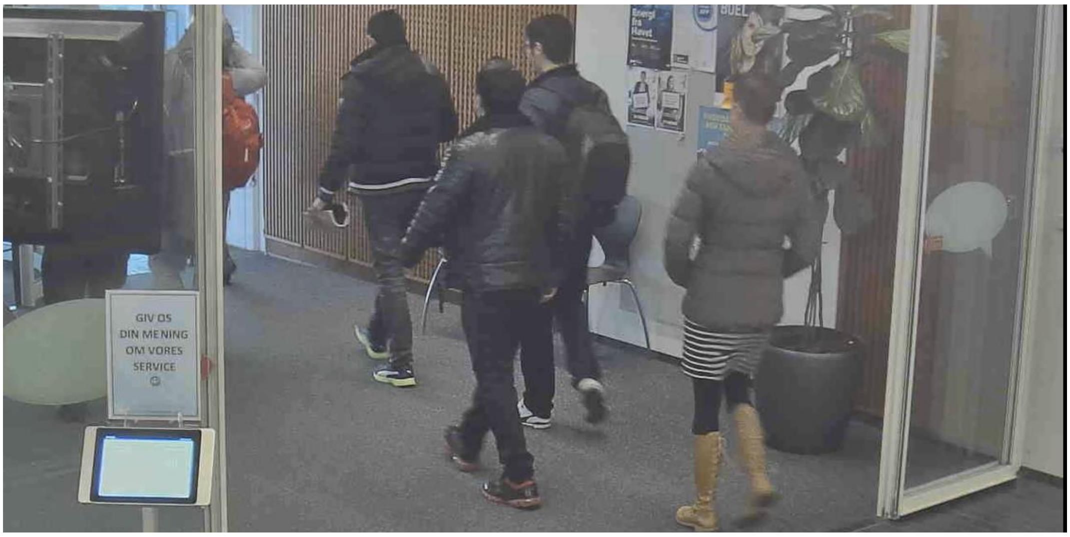



**Figure 30 this picture shows that the students/visitors evacuated first**


**Figure 31 Followed by the workers**

The total time for the walking and flow, according to the videos provided by the municipality was found to be 2 minutes and 23 seconds, way below the margin provided by the standards.

In total, an evacuation time of 3 minutes and 33 seconds was obtained, much smaller than the time calculated according to the European standards.

Once outside, everyone was aware of the gathering area and they waited patiently there, until everyone was evacuated. Meanwhile, during the evacuation, a firefighting vehicle from the fire station arrived in less than 4 minutes, from the time they received the signal until they parked the vehicle. This time would help a lot in an actual event where fighting the flames would be necessary and also in a search and rescue operation.

**Figure 32 people gathering at the gathering point and the firefighting vehicle in the back.**

When everyone evacuated, the alarms were turned off and the smoke dissipated, the exercises was concluded, the students were asked to fill out a short survey, a short meeting between the members of the safety council from the municipality and the group members for this report took place and the necessary materials for the writing of this report were gathered.

The next section will focus on the comparison between the two simulations from the two programs and the real life exercise, presenting possible improvements for the municipality and their evacuation procedures.

## 5.3 Comparison and possible improvements for the Esbjerg Municipality

Based on the research from the two software programs used to create the simulations, several additions and improvements can be brought for the Municipality of Esbjerg, all of them concerning the exercises.

From Simulex, based on the first simulation which mimicked the actual layout of the Esbjerg Municipality, it was deducted that the evacuation time for the real life situation was longer than the evacuation time provided by the software. The software provided an evacuation time of 1:30.7 whereas from the footage provided by the Municipality, is was deducted that the evacuation time was 2 minutes and 23 seconds; hence a difference of 53 seconds is observed in between the two.

Although the evacuation time from the Municipality is lower than the time provided by the standards, the software shows that possible improvements can be added, especially that in the software, behaviour such as disabled was added increasing the evacuation time, behaviour which was not in the real life exercise. This time can be downsized, by repeating the exercises every year, if not every half a year. Practice makes perfection as a saying dictates.

Simulex was also used to observe possible improvements in the layout and based on some small changes in the layout, was observed that the evacuation time can be downsized even more.

The second simulation built in Simulex, with an improved layout, showed that the evacuation time can be downsized by increasing the evacuation routes for the workers in the civil service area. A time of just 1:04.9 was obtained with the improved layout. This improved layout basically refers to clearing the other two possible routes, making them according to the standards.

An evacuation route must be a permanent part of the workplace, without being obstructed by other objects, impairing the evacuation process and increasing the time. An evacuation route should be at least 1.3 metres according to the Danish regulations. [17]

As seen in the first evacuation layout, the workers behind the desk have access to only one escape route, increasing the evacuation time. But there are two other escape routes which can be normally used but they are impaired in the Municipality. These routes can be seen in the following pictures.

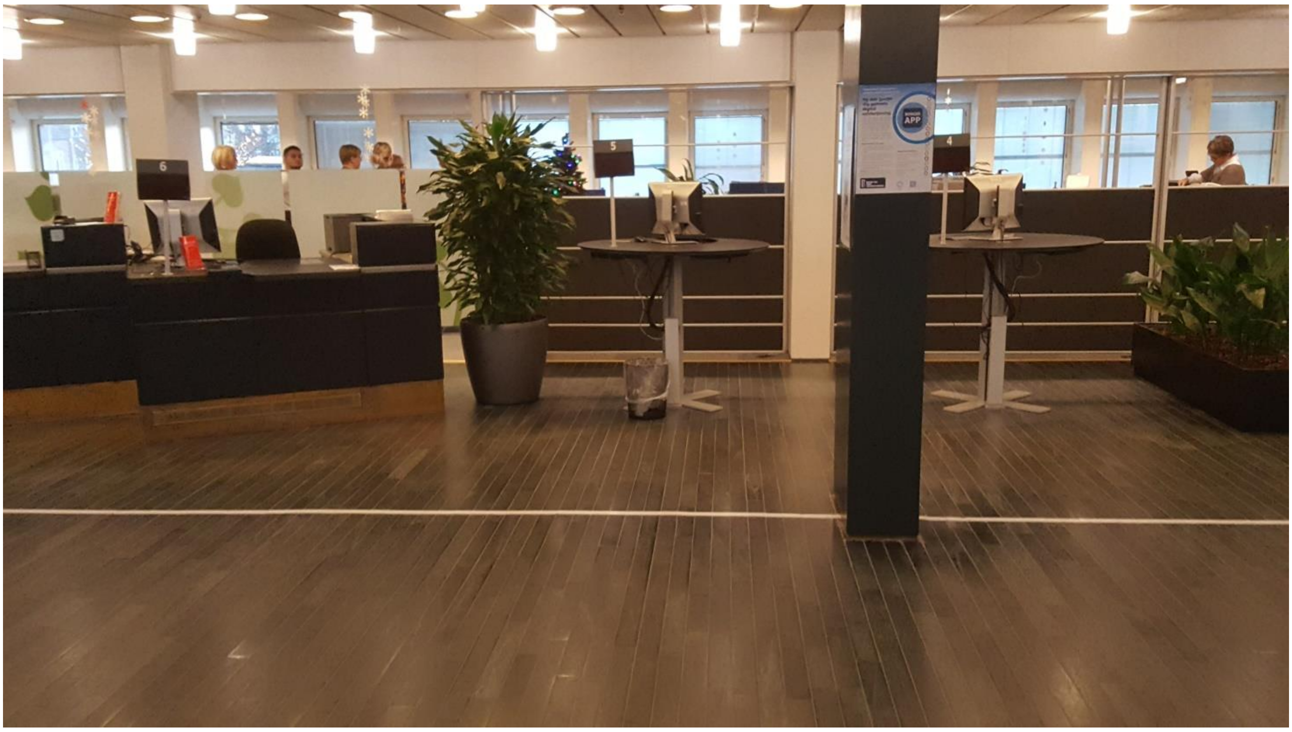



**Figure 33 the middle escape route in the Municipality of Esbjerg.**

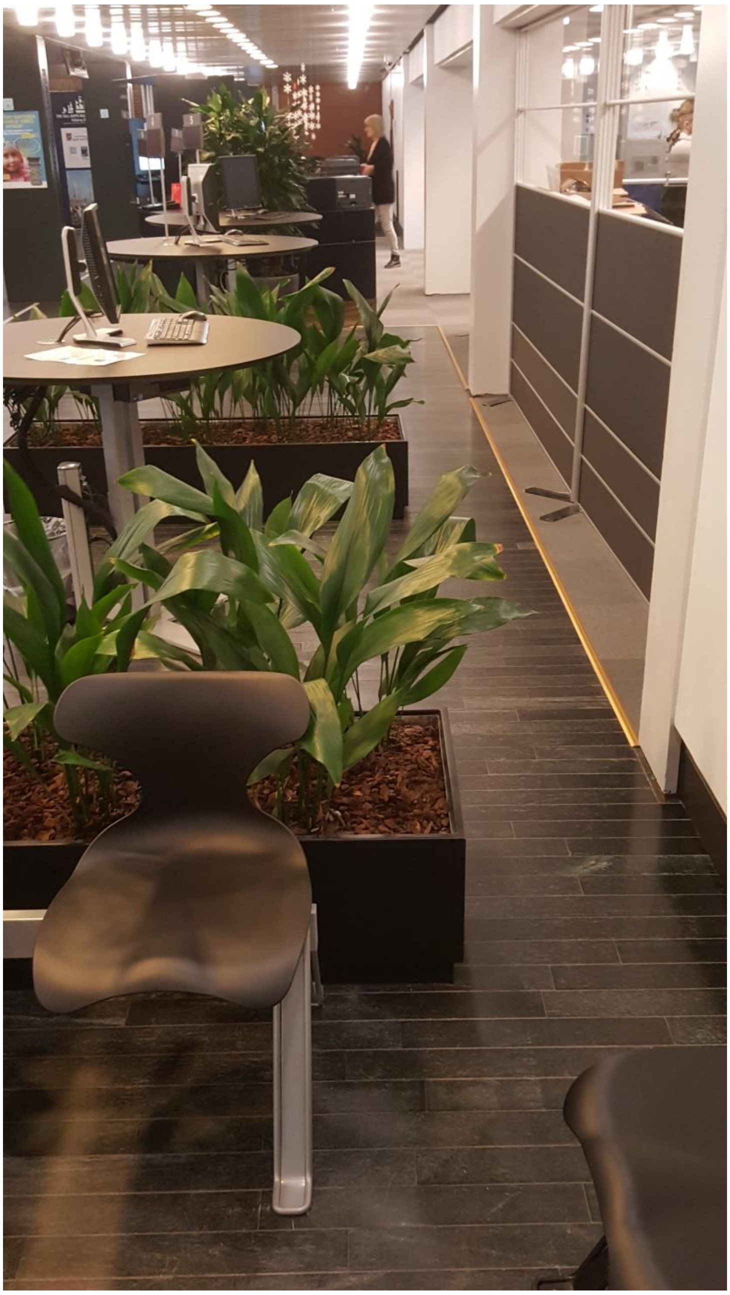


**Figure 34 the right escape route in the Municipality of Esbjerg.**

As it can be seen in the pictures, there are additional routes which could be used in case of an evacuation procedure but they are impaired. The first one is obstructed by an obstacle which makes the route completely unusable, whereas the second one in too narrow according to the Danish regulations. Although in the real life simulation it was observed that the route from the second picture was used, it should not be used in the state that it currently is in. This is because possible injuries might occur because of rushing or panicking. After the exercise was done, the evacuation route, seen in the second picture was measured and the size was of only 70 cm. According to the Danish regulation this is not the size for an evacuation route. But these are small improvements which could mitigate the risk of injuries and fatalities during an actual danger and decrease the evacuation time; therefore the plant pot should be removed completely to get access to that exit, and the benches seen in the other picture should be slightly moved to the left, to increase the size of the escape route. Based on the second simulation from Simulex, the people tended to follow the evacuation route closest to the evacuation doors, in these pictures, represented by the second picture, and the time was reduced with more than 40 seconds; therefore their importance cannot be overlooked.

Another improvement obtained from both Simulex and 3DS is the one concerning the path finding. In both programs, either an obstacle or a fire was placed close to the bathroom area, where it was agreed from the beginning that the hazard should be. In all four simulations, created in the two programs, the individuals avoided the area were the hazard was, which is what a normal situation would dictate. In the real exercise it was observed that some individuals, while trying to evacuate, followed the easiest path, even though that path would mean that they should go through the smoke. As seen in the beginning of this report, the effects of a smoke are very severe for the human body; hence these situations should be completely avoided. This is a good outcome noticed from the two programs and should be implemented in the real life situation.

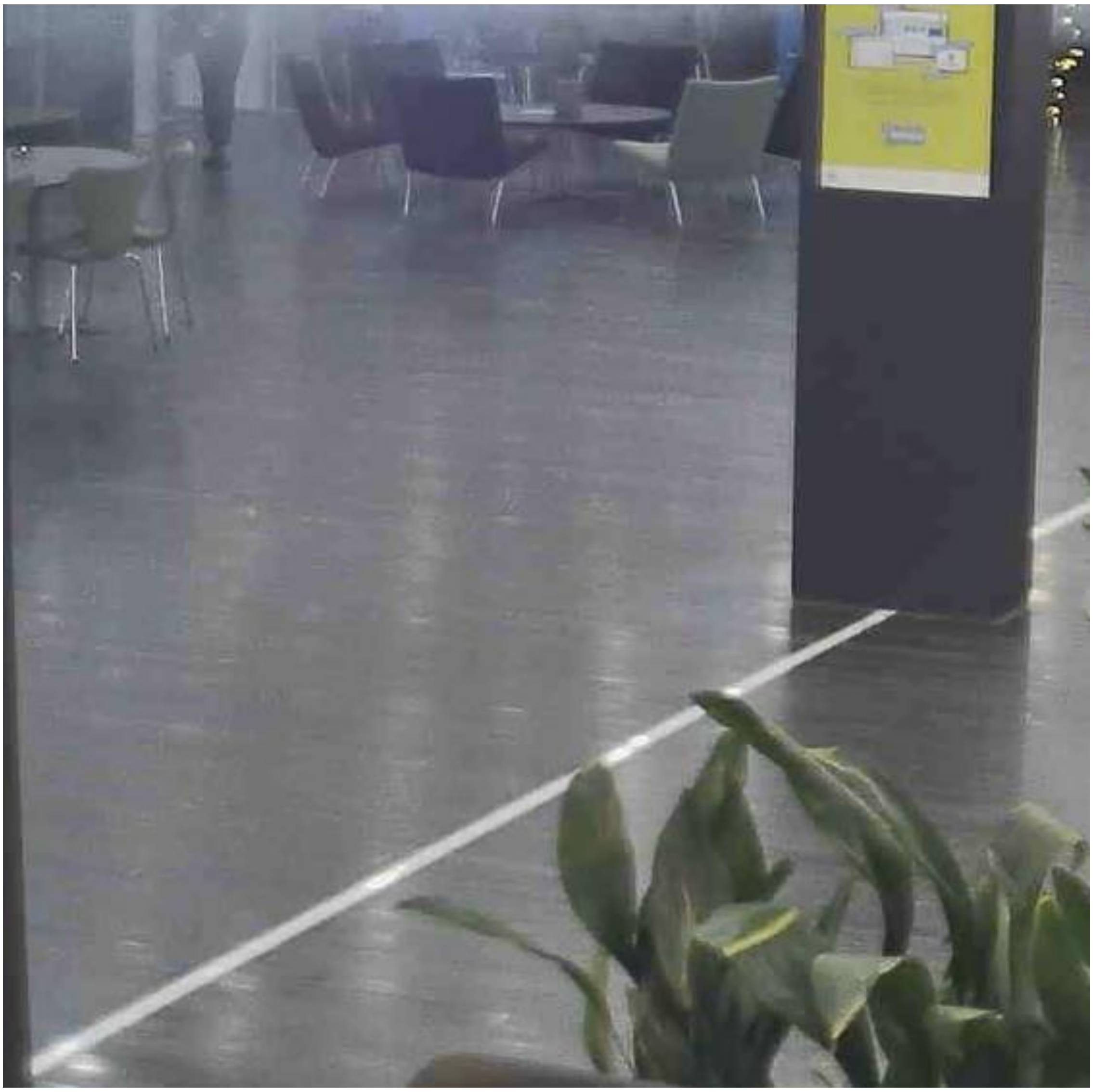


**Figure 35 People running through the smoke. (Top left corner of the picture)**

Concerning 3DS Max, the most important comparison between the software and the real life simulation is represented by the search behaviour. This was implemented only in 3DS Max and it represents the three people which are meant to search the premises to find people that are stranded and cannot reach safety. In 3DS Max this behaviour was implemented and it can be seen that it searches throughout the entire area, looking for people, finding one person in the bathroom, evacuating it to safety. During the evacuation exercise at the municipality, the search was conducted but not in a thorough manner as it should have been done, resulting in a person not being found. This happened because during the exercise, one member from the visitors, who was aware of the events that would take place, was asked to stay in the bathroom and wait for rescue. Although the alarm can be heard in the bathroom area, that person acted as a person with a hearing problem. And since, as seen also in the chapter dedicated to 3DS Max, there are 4.000 deaf people, 16,6 % under 75 year have impaired hearing and 50 % over 75 have impaired hearing and since, 38% of the population in Denmark is above 50 years old, the risk of having impaired hearing is quite possible; therefore the case at the Municipality cannot be ignored. [18]

Another aspect which might be improved concerning the search behaviour in a real life simulation is given by the area that the designated people with the search aspect have to search. It was calculated for this report that the 3 people, destined to search the premises, have to search an area of approximately 8900 square metres and 132 rooms, on four different levels. This might be too challenging in a real life simulation when people have to search the other levels, not only the ground floor, and since a fire hazard might become too dangerous for them to search the premises, not all the rooms would be checked. Although according to researchers, people do not generally panic in dangerous situations, and even if they do, they only become fearful and do not act crazy or irrational, if a fire spreads too fast, it might endanger the searcher's life, hence he should evacuate even though not all the areas have been searched.[19] The search behaviour, as it can also be seen in the simulations, is the last one to evacuate, as it should be, but it is also the one that increases the evacuation time; therefore if a large number of people are assigned with the search operations, the evacuation time might be decreased.

Other improvements that were found necessary are the one concerning the emergency evacuation system, the emergency evacuation lights and the exit doors, the counting and the gathering point.

An improvement in the system, which would aid deaf people or with hearing impairments, would be installing the safety lights, which flicker when an emergency alarm sounded alerting the people that an emergency situation is occurring.

**Figure 36 Emergency evacuation light**

These lights should help the people evacuate, but since the other systems are already installed, it might not be very cost effective to install these safety lights. Also this cost can be avoided completely if the search is conducted as it should be.

One improvement deemed necessary for the Municipality is the one concerning the emergency evacuation lights. During the multiple visits in the building, it was observed that the emergency evacuation lights are, although installed, not visible from many angles in the building. This was noticed also by some of the people that took part in the exercise. This finding was also presented to the members of the council and it was agreed that these lights should be installed so that they are visible from every corner of the building.


**Figure 37 Figure depicting that the emergency lights are not visible everywhere.**

Another improvement found necessary in the evacuation process was the one concerning the evacuation doors. According to the EU regulations, a door used for emergency evacuation should be a swinging door, which should open or close automatically upon the sounding of a fire alarm or an employee alarm. [20]

During the evacuation process, it was noticed that although the doors would open automatically, they would not stay open during the entire evacuation process, as they are supposed to, locking in front of the fleeing people. In order to improve this situation a small change in the sensors should be done, but which could lead to a decreased evacuation time.


**Figure 38 Picture depicting the doors closing on people evacuating.**

Concerning the counting and the gathering point, possible improvements in this area could be implemented. Firstly, the counting wasn’t done so nobody noticed that there is a person missing. This counting could be done if the workers would gather on one side of the entrance, whereas the visitors would gather on the other side. By doing this, the missing of a visitor should be noticed. This method was implemented in several places in the USA and it was found to be very useful when it comes to counting people. This is where the improvement of the gathering point comes into play. As seen in the pictures, everyone gathered in front of the main entrance but the problem was that the entrance was impaired by doing so; therefore, the firefighters might have a hard time entering the building. It is therefore the advice of the authors and the chief of the firefighting divison that the gathering point should be clearly represented and put somewhere on the side of the entrance, not to prevent the firefighters from accessing the building.

The purpose of this section was to present a comparison between the two programs used and possible improvement learnt from the two soft wares, but also possible improvements needed which were observed during the real life exercise.

The next chapter will introduce the reader into the safety measures from the Municipality of Esbjerg.

Chapter 6

# 6. Measures and actions taken in order to reduce the risk

The purpose of this section is to demonstrate that:

- All possible measures to reduce the risk of a fire and its consequences are taken.
- Other ways of evacuation and extinguishing are available.
- The risk of failure is very small.

These will lead to the conclusion that the necessary safety measures were implemented according to the standards and regulations and that the only improvement available in the municipality is represented by regular fire drills and adjoined small safety measures, to increase the awareness of the situation and the surroundings.

The measures taken in order to mitigate, if not completely avoid, the risk for a fire and its consequences, are in accordance to the European standards regarding fire safety engineering and with the Danish standards and regulations.

To reach the conclusion of this chapter, all three sections need to be furthermore dissected, and to be looked into them in more detail.

## 6.1 All possible measures to reduce the risk of a fire are taken.

In order to prevent the risk of a fire and its consequences the municipality of Esbjerg is fitted with several safety measures such as:

- Structural safety measures( passive fire protection)
- Heat and smoke detectors.
- Alerting system
- Sprinklers and fire hoses.

Concerning the **structural safety measures**, there are a number of key elements that would influence the size of a fire, limiting its strength and its consequences. The most important structural element installed in the municipality, is given by the fire cells and fire sections. A fire cell is a preventing measure which prevents the spread of a fire during the evacuation and emergency work, whereas a fire section is meant to prevent the fire spread during its entire duration, securing values and ensuring safe emergency service work.

Basically a fire cell and a fire section are walls made out of sturdy materials which have a higher resistance to fire and who limit the spread of smoke in other areas, limiting the possibility of injuries and fatalities. [21] To ensure this, the walls are not built as in conventional buildings, where they end on the lower part of the floor, but they are extended all the way up to the upper part of the floor. For a better understanding, the following picture gives a visual imagine of what was just explained.

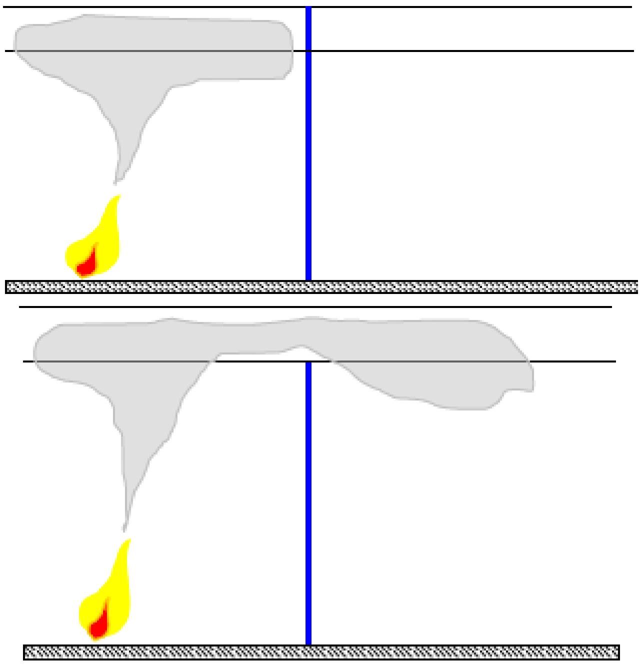


**Figure 39 on top, a fire cell wall which stops the smoke from spreading and on the bottom a normal wall.**

The fire sections are typically found in the staircases areas, which are meant to be used during fire evacuations, or the elevator shafts which are meant to be used by the firefighters during emergencies. They have heat resistant doors which also lock air tight and prevent the flow of smoke and other hazardous air-carried substances in the staircases, mitigating the effects of a fire.

Another element part of the passive fire protection system is given by the smoke exhaust system, which is, in essence a ventilation system that changes the flow of air during a fire emergency. [22] These systems can be programed in such a way that in case of a fire, they can reverse the flow so that the smoke that fills the room is evacuated outside, to limit the influences of it in a building, since smoke is one of the major culprits of injuries and fatalities in case of a fire.

Once the fire alarm starts, a sensor receives the information and gives the command to reverse the flow of oxygen.

The systems are line monitored, so any damage would be easily observable.

After the several renovations which took place at the municipality of Esbjerg these safety features were installed. The offices represent fire cells, whereas the fire sections are placed in some of the staircases area, which are supposed to be used during evacuation.

Several heat resistant doors are also placed in some of the areas of the municipality and they can lock air-tight in order to stop to smoke from spreading. Also since the building is made out of concrete, it has a good heat resistance.

The next safety measure implemented is represented by the **heat and smoke detectors**.

A heat detector is intended to minimize the property damage by reacting to the change in temperature caused by a fire. [23] They are used because of their lower costs. They need to be changed after one use.

A smoke detector is intended to protect the lives and property by providing with an early warning, in the start of a fire. Most of the people need time to react to a fire and some of them might panic, hence every second is crucial, therefore early detection is needed. [24] They have higher costs but can be used multiple times.

Since early detection of a fire is crucial and an office building has many areas where people might not be present at all time, the need to mitigate this risk was deemed necessary. This is where the heat and smoke detectors come into play. They are meant to be installed in every area of the building and provide early warning.

Both the heat detectors and the smoke detectors are connected to the alerting system and in case they will be activated, the alerting system will also be activated.

A failure in these detectors would mean that the warning time would be increased and the possibility of safely evacuating everyone from the building is reduced. Also, since the warning system is directly connected to the firefighting department, a failure in the system would lead to an increase response time from the firefighters, increasing the chances of high property damage and even fatalities.

**Figure 40 Picture of a heat detector on the left and smoke detector on the right.**

Another safety measure installed in the municipality that must be looked into is the **alerting system**. This system is a combination of three elements. The first one is represented by the high volume megaphone, attached to the ceiling, which make a high pitched noise to alert that there is an emergency situation in the building. They are normally started by the smoke sensors, once they have detected traces of smoke in the air, but they can also be started manually.

The second element in the alerting system is provided by the high volume speakers. They are placed in each corner of each section of the building and are meant to provide a pre-set message in Danish which informs the people about the dangers and asks them to evacuate. If the situation is unusual, the members from the safety council have the option to overwrite the message and to give the proper information about the hazard that is present.

The third element is represented by the Intranet, which is the local network that they have in the municipality. With this feature, members of the safety council can reach out with a message to all the members that are present in the building. The message will pop-up on everyone's desktop, informing them about the hazard. Combined, all these three measure represent one safety feature which is meant to reduce the loss of lives.

A problem with this element is that it is connected to the electricity grid, and although the megaphones and the speakers are connected to the secondary grid, the safety grid as it is called, the desktops are not working when there is a power outage; making the third element of this safety feature unusable in case of a power failure.

Another problem with this safety feature is that they are not heat resistant, so if the heat and smoke detectors fail, they might end up being affected by the heat of the fire, giving no chance to alert the workers and the visitors in some areas.

The last measure presented in this section is represented by the sprinkler system and the fire hoses.

A sprinkler system represents a system of pipes, which are typically supplied by two sources of water and which have heads, at recommended distances apart, which sprinkle the water on the fire once a signal was released. The water source can come from a water tank stored nearby, or from the town's main source, provided the flow is sufficient and can fill the pipes continuously. [25]

They are constantly filled with water and a glass bulb holds a plug in place, keeping the water from spilling all over. When heat is applied to the glass bulb, it shatters and the water starts spraying. Only the sprinklers that are affected by the heat of the fire start spraying water, limiting the consumption of water and also limiting the damages due to water exposure.

Once the water starts spraying, the system turns a warning bell which is operated by the force of water and not electricity, creating a strong noise informing people of the presence of a fire.

The sprinklers will limit the effects of the fire and stop it from spreading at a fast pace, and they will continue to sprinkle water until they are manually turned off.

In the municipality, the sprinklers are placed in all the areas, both in the small offices but also in the area where a large number of people are present. This is meant to reduce the possibility of occurrence of a fire and also the spreading of a fire.

The other safety feature is provided by the fire hoses, which are implemented in the building. They are mostly meant to assist the firefighter in their firefighting effort but they can also be used by the workers, in the initial stages of a fire. The hoses are connected to the main water grid and are turned on manually by using a lever. There are two hoses on each floor of the municipality.

This section had the purpose to depict the safety measures implemented in the municipality of Esbjerg, meant to reduce the risk of a fire presence and also to reduce the consequences of such an event.

The next section will be focusing on the other ways of evacuating and extinguishing the fire.

## 6.2 Other ways of evacuation and extinguishing are available

This section will present the features which are not fixed but can provide means of extinguishing the fire, and also some other paths of access that might be taken in case of a fire.

As in accordance to standards, the municipality has fire extinguishers every 40 metre since the building represents an office building with sprinkler system. They are placed to be easily accessible for everyone, but not to impair the movement of personnel or to represent a hazard themselves.

According to the legislation they are checked every year and every seven years they must be replaced.

Another safety feature provided is represented by the fire blankets and aluminium blankets. They are placed on all floors and in more than one location on each floor. A fire blanket is a piece of cloth used to extinguish small fires or to wrap a person whose clothes have caught fire. [26]


**Figure 41 Imagine of a fire blanket.**

The next safety feature meant to protect the lives is given by the other escape routes. This project focused on the citizen area and the fire was considered to start close to the bathrooms. In this way, the two exits were not impaired in any way, and since the gathering point for everyone is there, these two exits were used. In case there is a fire close to the main exits, there are additional paths one can follow to ensure he reaches safety. He can use the staircases which take to the underground car park, where there is a large exit. In the citizen area, there is such an exit close to the bathroom area, marked with green in the following picture.

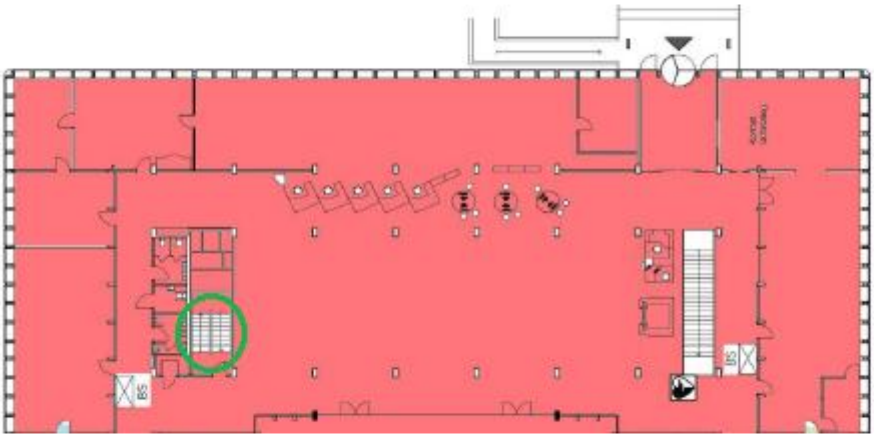



**Figure 42 the escape route if the main exits are impaired. (The fire is considered close to the main exits)**

Additionally, there are other escape routes one can take to ensure his/her safety and possible the safety of the colleagues. As mentioned before, there are several heat resistant doors which lock air-tight when the alarm signal has started. These doors can be opened manually by people, allowing the people to reach safety. Once everyone has escaped through the door, it will lock itself again air-tight, providing increased safety.

Once past the doors, the workers and the visitors can followed the hallways to the other staircases and evacuate through the underground parking lot. These paths can be observed in the following picture.

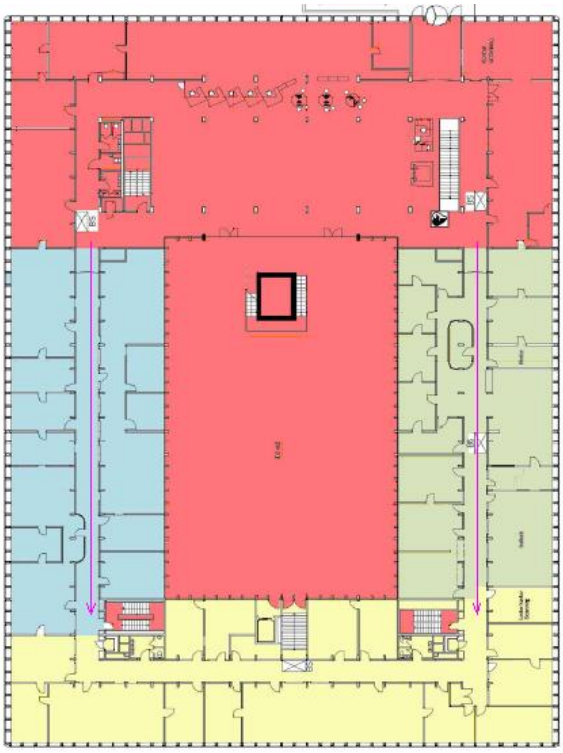


**Figure 43 the paths that might direct the workers to safety. (Marked with purple)**

The last safety feature installed in the municipality, which is in accordance to the standards and regulations of E.U and the Danish government, are the emergency exit windows which can be used as escape routes.

According to the regulations, a window is considered safe for evacuation if the width of it is larger or equal to 50 cm and if the height is larger or equal to 60 cm. Additionally, the sum between the height and the width has to be larger than 1,50 m. For a visual understanding the following picture depicts those that were written.

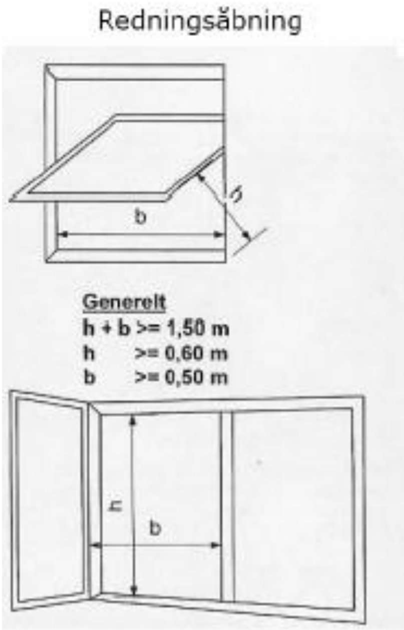



**Figure 44 the standard requirements for an emergency exit window.**

These escape windows were implemented throughout the building, even on the higher levels, to ensure that the workers that might be unable to escape through the other escape routes could be rescued by the firefighting ladders. On the ground floor, there is at least one escape window in each office and in the citizen service area every one in two windows represents an emergency escape window and can be used in case of emergency.

The purpose of this section was to present additional safety features that are implemented in the municipality and which would decrease the potential loss of life and reduce the hazard of a fire and its spreading.

The next section will focus on presenting the potential risk of failure for some of the installed devices and prove that the risk of failure is extremely small.

## 6.3 The risk of failure is very small

This section will focus on presenting the possibility of failure for the installed devices and demonstrate that the risk of a failure is extremely small.

Concerning the fire cells and fire sections, the risk is close to zero, if not zero. The structure is regularly maintained and after any renovation, a structural inspector is sent to assess the work that was done, afterwards giving a permit if the structure fills all the required demands, thus the risk of failure for these features is considered null.

Regarding the HVAC system, or the ventilation system, one failure option is represented by the system itself and its incapacity of working and reversing the flow of air, extracting the smoke filled air from the building. According to the researches, if a system is regularly maintained, there is a 0,002 probability that the system will not work, making it a very small probability, and since the ventilation system in the municipality is regularly maintained, this probability can be taken also for the present report. This probability includes also the compressor not working, which is considered the main element that could fail. [27]

Another failure concerning the ventilation system is provided by the back-up generator. This is the most likely element to fail out of all the safety features installed in the municipality. According to Arshad Mansoor, Senior Vice President for Research & Development with the Electric Power Research Institute, there is a 20-30% chance for a backup generator not working and this is due to the fact that they have many moving part which are supposed to move but are not, since a backup generator is kept only for backup. However, with proper maintenance the generator should work and since there are other safety features installed, this probability is also considered acceptable. [28]

Concerning the heat and smoke detectors, there is also a chance of them not working. However, the probability of them not working was computed, and a probability of 0, 06% per detector was found. [29]This risk is mitigated by implementing both heat detectors and smoke detectors in the same areas, so in case one of them fails, the other one should be functional, decreasing the risk significantly and increasing the chance for faster evacuation and lower property damage.

Regarding the alerting system, there are some elements that might fail, reducing the survivability rate. The first element that might fail is represented by the high volume megaphones. These are connected to the main grid and in case of power failure they are automatically assigned to the back-up system. The chance of a megaphone not working is not computed, but is considered very small. And in case one of them is not working, the other ones are not affected by that breakdown, so, even though, the noise would be reduced, the system should do its job. One problem that might incapacitate all of them would be if the electrical wires are affected, but since regular maintenance is provided, this event is deemed impossible to happen.

The other element that might fail is represented by the high volume speakers which pass the message throughout the building. For the speakers also there is no probability computed for their chance of failure, but only the reasons that might lead to failure and among them are glue failure of the voice coil attachments, mechanical failure of the cone, foreign object in the magnet gap and many others. However, these apply for each speaker individually and not for all at the same time and if a failure occurs in one of them, the other ones will work as it should be. The only cause that would incapacitate all of them is the faulty electrical wire but, again, since the maintenance is done frequently this fault is seen as impossible to happen.

The third failure that might occur in the alerting system is the failure of the Intranet service. This is probably the most problematic, since the Intranet is used on desktop devices and other wireless devices and it requires internet access and electricity. A failure in the electrical grid would lead to its incapacity, and thought the system might be connected to the back-up generator, the desktop devices might turn off before and then, once the back-up generator was started, they might be restarted, losing crucial time in case of an emergency. However, the Intranet is just another safety measure which should send an e-mail to all the employees informing them about the hazard, but the speakers and the megaphones will work even without this third measure, so per total, the failure of the alerting system is close, if not completely, zero.

Coming to the sprinklers, the risk of them not working is close to null. According to the safety ministry of New Zeeland, the sprinklers were effective and operating in 99, 7% of the cases, so there is only a 0, 3% probability that they will not work, a very small probability indeed. Not only that, but the losses in buildings protected by sprinklers were found to be 1/10 than those in buildings unprotected by sprinklers and 99% of the fires were controlled by sprinklers alone, 60% of the fires being controlled by the spray from no more than 4 sprinklers. [30] Based on these researches, and since the Municipality of Esbjerg is protected by sprinklers, it can be concluded that the failure for sprinklers is very low, while the protection is increased massively.

The last two elements which could go wrong are the extinguishers and the fire-hoses. However, since there are multiple fire extinguishers in the building, one at every 40 metres, another one can be easily obtained. Plus they also have to be changed every seven years, even though they are still functional and have not been used. This is a safety measure implemented to ensure that they will be in working conditions once the task demands it. The fire hoses are typically needed by the firefighting teams that would come to extinguish the fire, and the failures that might occur are that broken valves and the insufficient water. The probability of failure for a valve is 0,009% which is considered almost null and even if the water from the hoses is deemed insufficient, the sprinklers and the firefighting vehicles should provide enough water to extinguish the fire, reducing the chance of a fire from spreading even more.

The purpose of this chapter was to present that the probabilities of failures are very low for all of the safety features installed and that, with all of them combined, the risk of failure is close to null; therefore the only improvement that can be added to this situation is represented by the emergency fire drills.

**Chapter 7**

# 7. Conclusion

This report" Simulation of Emergency within the Municipality of Esbjerg" was meant to test the new emergency evacuation plan from the municipality of Esbjerg, which was updated and released in March 2016, and compared with software simulations and the standards provided by the European Union.

Firstly, a short history is provided and relevant data about fires in buildings is given. This is meant to emphasize on the fact that fire is still a very deadly hazard in our modern times, even after the many safety improvements that were developed throughout the years. It shows that even though that safety measures and constantly developing, there is not real decrease in the fatality rates, from year to year. They just fluctuate around the same figures. Possible causes for office fires and the consequences are then provided, showing the possible perils that a person can suffer during a fire.

The second chapter focused on the problem formulation according to the Aalborg Model and presented some additional sub-questions which helped in solving the main problem.

Chapter 3 focused on presenting a software simulation by using Simulex, which is a software specially created for the purpose of simulating evacuations. This software provides calculations and a visual overview of the situations. To get a better understanding of the importance of this software two different simulations were conducted. One with the current layout at the municipality, whereas the second one had an improved layout where minor changes in the design were presented, which gave a significant decrease in the total evacuation time. The results are presented in a table and the chapter ends with pros and cons of this software.

Chapter 4 presents the software entitled 3DS Max and focuses on creating a simulation in this software. Technically, there were two different simulations where the difference was given by the" search" behaviour which was manually implemented by the group's members. In the first scenario the" search" behaviour does the job as is happened at the municipality during the real life evacuation, whereas in the second scenario it does the job completely. The end results can be compared and although the second scenario gives an overall larger evacuation time, all the people were rescued, while in the first scenario one person was still missing. At the end of the chapter, pros and cons of this software are presented and a comparison between the two programs is given.

Chapter 5 focused on presenting the real life simulation and how the exercise was conducted. It also gives a calculation of the evacuation time according to the European standards which can be then compared to the actual evacuation time obtained in the real life exercises. A detailed description of the real life simulation process is provided and a comparison between the real life exercises and the two programs is conducted, focusing on possible improvements for the future. Also, additional improvements in the layout of the structure and safety features are presented which should help in decreasing the evacuation time and increasing the survivability rate of the workers and the visitors in case a fire occurs.

Chapter 6 is the one that presents the current safety features implemented in the municipality and provides the failure probabilities for most of the elements installed, showcasing the fact that most of the safety features have a very low probability of failure and that these safety features are more than sufficient for an office building such as the municipality is. The purpose of this chapter was to show that these safety features are more than sufficient and that the only improvement possible is the one that concerns the evacuation time and the behaviour during the evacuation.

Final conclusion suggests that all safety measures are installed and that the risk management plan from that point of view is built in accordance to the standards; proving once again that the only area were possible improvements can be added is the one which concerns evacuation exercises and that improvements can be obtained in that field, based on the research from two software compared to the real life exercise.

[1] Esbjerg Kommune (2009) *Rådhusets historie* [online] Available from: http://www.esbjergkommune.dk/om-kommunen/tal--fakta-og-historie/r%C3%A5dhusets-historie.aspx

[2] Esbjerg Kommune (2009) *Rådhusets historie* [online] Available from: http://www.esbjergkommune.dk/om-kommunen/tal--fakta-og-historie/r%C3%A5dhusets-historie.aspx

[3] Esbjerg Kommune (2009) *Rådhusets historie* [online] Available from: http://www.esbjergkommune.dk/om-kommunen/tal--fakta-og-historie/r%C3%A5dhusets-historie.aspx

[4] Danish statistic (2015) [online] Available from: https://www.dst.dk/da/Statistik/emner/doedsfald-og-middellevetid/doedsfald

[5] Danish statistic (2015) [online] Available from: https://www.dst.dk/da/Statistik/emner/doedsfald-og-middellevetid/doedsfald

[6] The Danish Emergency Management Agency(2015) [online] Available from: http://brs.dk/viden/statistik/doedsbrande/ Pages/doedsbrande.aspx

[7 Danish Statistic (2015) [online] Available from: https://www.dst.dk/da/Statistik/emner/befolkning-og-befolkningsfremskrivning/folketal

[8] http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/fires-by-property-type/business-and-mercantile/us-structure-in-office-properties

[9] National Fire Protection Association, August 2013, *U.S. Structure Fires in Office Properties* [online] Available from**:** http://www.nfpa.org/news-and-research/news-and-media/press-room/reporters-guide-to-fire-and-nfpa/consequences-of-fire

[10] National Fire Protection Association, August 2013, *U.S. Structure Fires in Office Properties* [online] Available from: http://www.nfpa.org/news-and-research/news-and-media/press-room/reporters-guide-to-fire-and-nfpa/consequences-of-fire

[11] IESVE for Engineers Support, *Simulex* [online] Available from: https://www.iesve.com/software/ve-for-engineers/module/Simulex/480

[12] IESVE for Engineers Support, *Simulex* [online] Available from: https://www.iesve.com/software/ve-for-engineers/module/Simulex/480

[13] IESVE for Engineers Support, *Simulex* [online] Available from: https://www.iesve.com/software/ve-for-engineers/module/Simulex/480

[14] Autodesk, 3DS Max Overview, [Online] Available from: http://www.autodesk.com/products/3ds-max/overview

[15] The Danish building Regulations, 31.12.2014, *Common escape routes 3.2.2* [Online], Available from: http://bygningsreglementet.dk/br10_05_id53/0/42

[16] Polyteknisk Boghandel og Forlag, September 2014, Lars Schiøtt Sørensen, *Fire-safety engineering and performance-based codes*

[17] The Danish building Regulations, 31.12.2014, *Common escape routes 3.2.2* [Online], Available from: http://bygningsreglementet.dk/br10_05_id53/0/42

[18] Hearing statistic, *Hver sjette dansker hører dårligt* [online] Available from: http://hoerelse.info/hver-sjette-dansker-horer-darligt

[19] American Psychological Association, September 2004, *Fighting fire with psychology* [Online], Available from: http://www.apa.org/monitor/sep04/fighting.aspx

[20] Occupational Safety and Health Administration, *Design and Construction Requirements for Exit Routes* [Online] Available from: https://www.osha.gov/SLTC/etools/evacuation/egress_construction.html

[21] European Association for Passive Fire Protection, *Fire Resisting Partitions* [Online] Available from: http://www.eapfp.com/fire_resisting_partitions.php

[22] Vysakh Manohar, 7th June 2011, *Smoke extraction in buildings* [Online] Available from: http://de.slideshare.net/vysakhmanohar/smoke-extraction-in-buildings

[23] System Sensors, 28th August 2015, *Heat Detectors vs Smoke Detectors: What's the Difference?* [Online] Available from: https://www.systemsensorblog.com/2015/08/heat-detector-vs-smoke-detector/

[24] System Sensors, 28th August 2015, *Heat Detectors vs Smoke Detectors: What's the Difference?* [Online] Available from:
https://www.systemsensorblog.com/2015/08/heat-detector-vs-smoke-detector/
[25] Fire Safety Advice Centre, 18th December 2015, *Industrial Fire sprinklers* [Online] Available from: http://www.firesafe.org.uk/industrial-fire-sprinklers/

[26] Department of Fire & Emergency Services, *Fire Blankets and Extinguishers* [Online] Available from:
https://www.dfes.wa.gov.au/safetyinformation/fire/fireinthehome/pages/fireblanketsandextinguishers.aspx

[27] Sweden, Dep. of Build. Serv., 4th October 2007, Sonny Myrefelt, *RELIABILITY AND FUNCTIONAL AVAILABILITY OF HVAC SYSTEMS* [Online] Available from:
http://oaktrust.library.tamu.edu/bitstream/handle/1969.1/5031/ESL-IC-04-10-07.pdf?sequence=4&isAllowed=y

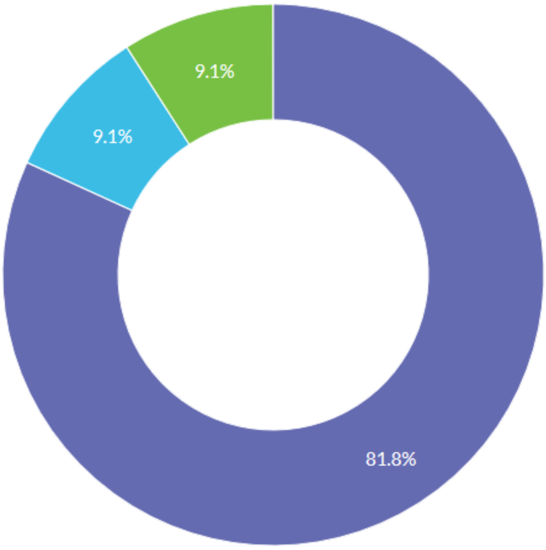
[28] Boingboing, 2nd November 2012, In backup generators we trust? [Online] Available from:
http://boingboing.net/2012/11/02/in-backup-generators-we-trust.html

[29] MAERSK OIL DK. *QRA of Tyra East following facilities optimization Main Report February 2012*

[30] Fire Safety Advice Centre, 18th December 2015, *Industrial Fire sprinklers* [Online] Available from: http://www.firesafe.org.uk/industrial-fire-sprinklers/

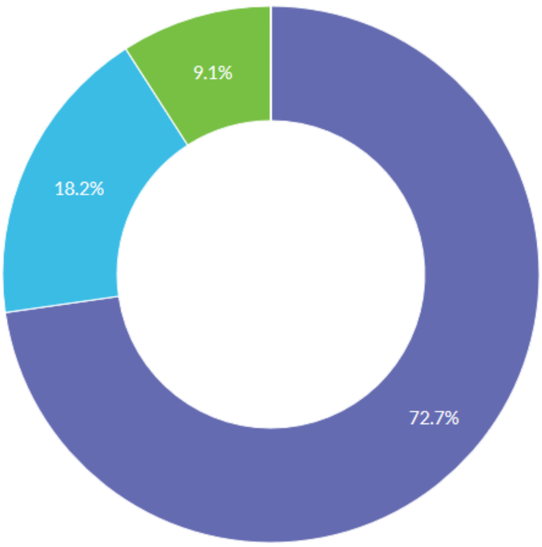
# Appendix

**Q1** Where were you when you first became alerted (e.g., from an alarm) to the incident in this building?
Multiple Choice



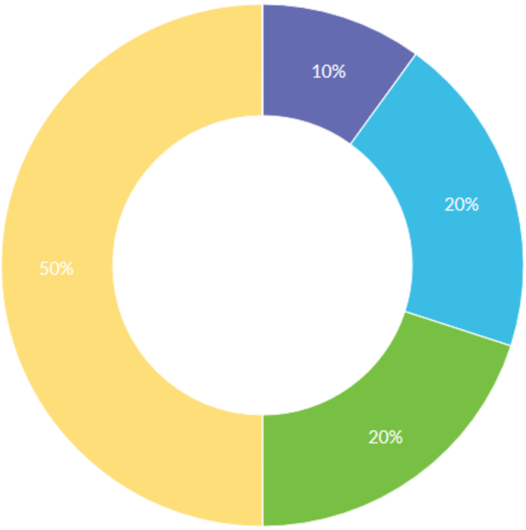

| Choices | Totals |
|---|---|
| First floor lobby | 9 |
| Office | 1 |
| Restroom | 1 |

**Q2** How did you become alerted to the incident?
Multiple Choice



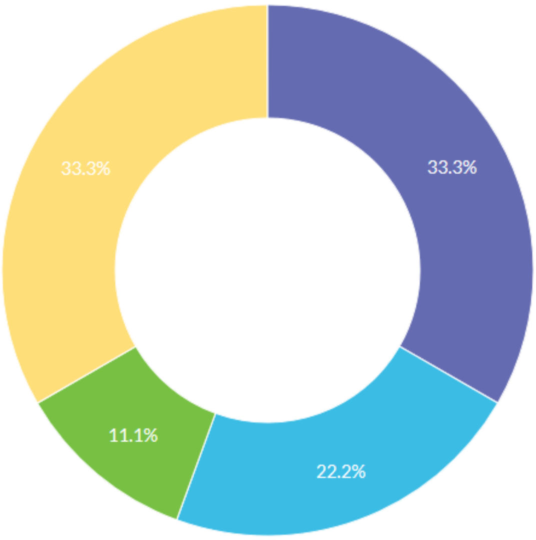

| Choices | Totals |
|---|---|
| Alarm tone | 8 |
| Voice alarm message to evacuate | 2 |
| Evacuation coordinator/fire warden | 1 |
| Colleague/resident | 0 |
| Member of building staff (management or fire safety) | 0 |

Q3 What did you think was going on?
Multiple Choice



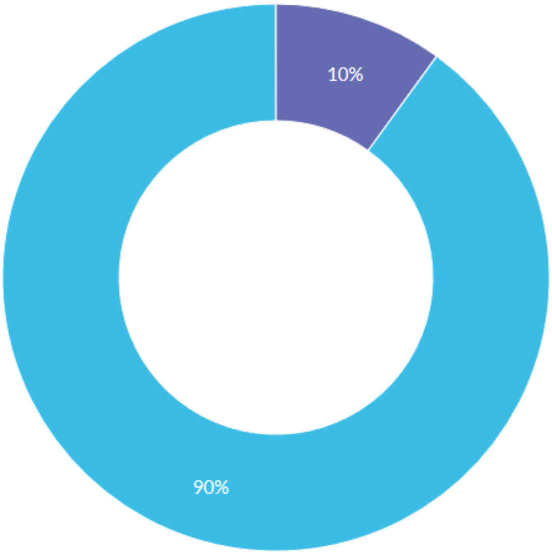

| Choices | Totals |
|---|---|
| Real fire emergency | 1 |
| False alarm (the alarm is sounding by mistake) | 2 |
| Test of equipment | 2 |
| Regularly scheduled fire drill | 5 |
| I didn't know what was going on | 0 |

Q4 Once you were alerted to the incident, did you receive any instructions on where to go or what to do from one of the following?
Multiple Choice



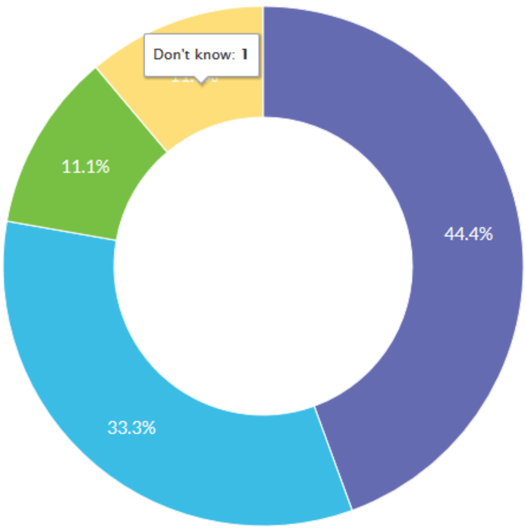

| Choices | Totals |
|---|---|
| Voice alarm message | 3 |
| A member of building staff (management or fire safety) | 2 |
| A colleague | 1 |
| An evacuation coordinator/fire warden | 3 |

Q5 Did you feel at risk (in danger) at any time before exiting the building?
Multiple Choice



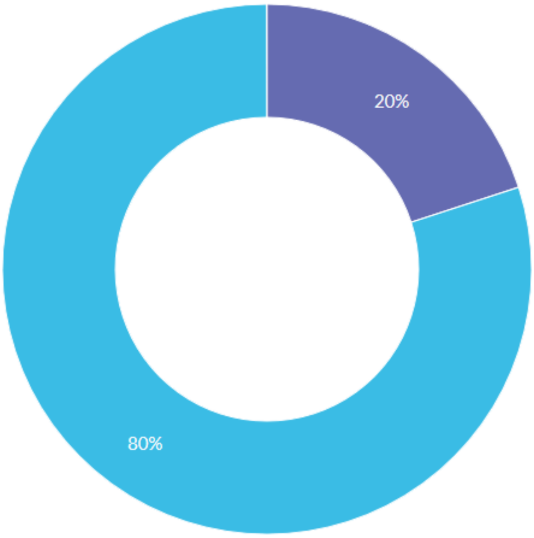

| Choices | Totals |
|---|---|
| Yes | 1 |
| No | 9 |

Q6 How much time passed from the moment that you became alerted to the incident until you started moving towards the exit
Multiple Choice



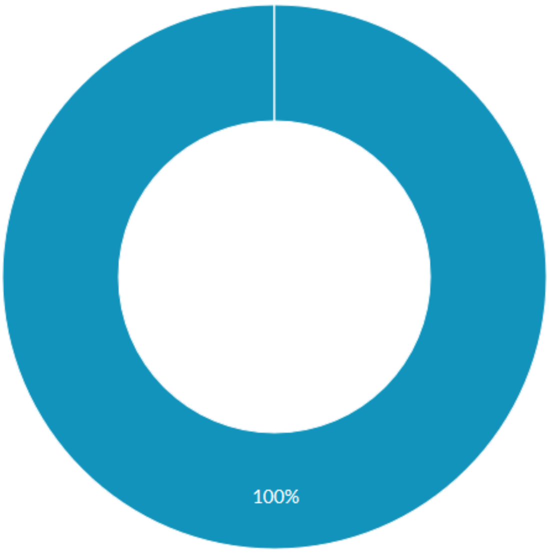

| Choices | Totals |
|---|---|
| 1 minute | 4 |
| 2 minutes | 3 |
| More than 2 | 1 |
| Don't know | 1 |

**Q7** Did you receive information or instructions that influenced your behavior while evacuating?
Multiple Choice




| Choices | Totals |
|---|---|
| Yes | 2 |
| No | 8 |

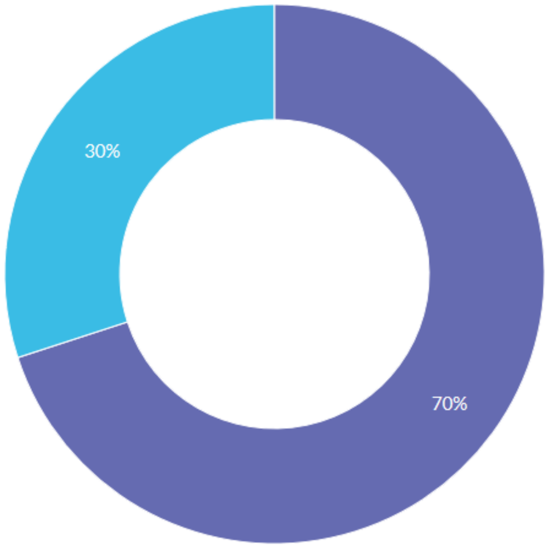
**Q8** Did any of the following conditions make your evacuation more difficult?
Multiple Choice




| Choices | Totals |
|---|---|
| Temporary injury/condition | 0 |
| Medical condition | 0 |
| Hearing impairment | 0 |
| Vision impairment | 0 |
| Mobility impairment/disability | 0 |
| Pregnancy | 0 |
| Other | 0 |
| Not applicable | 8 |

**Q9** Have you ever been in a building fire before (where you saw smoke or flames and/or you felt at risk)?

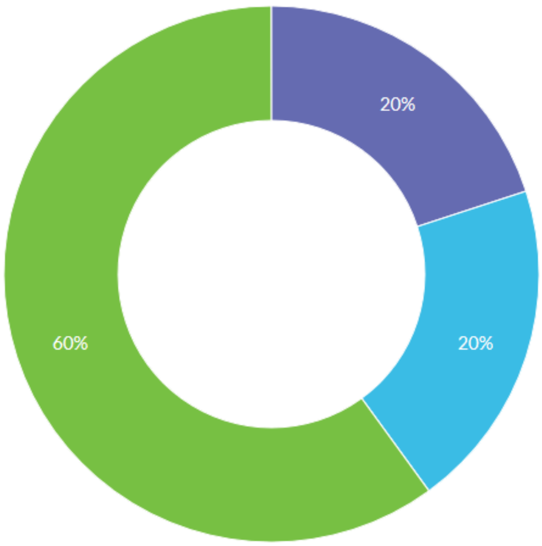
Multiple Choice




| Choices | Totals |
|---|---|
| No | 7 |
| Yes | 3 |

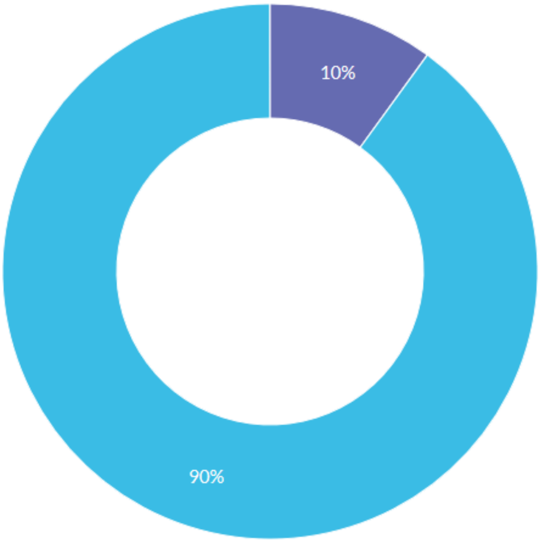
**Q10** How many fire drills have you participated in during your lifetime?

Multiple Choice



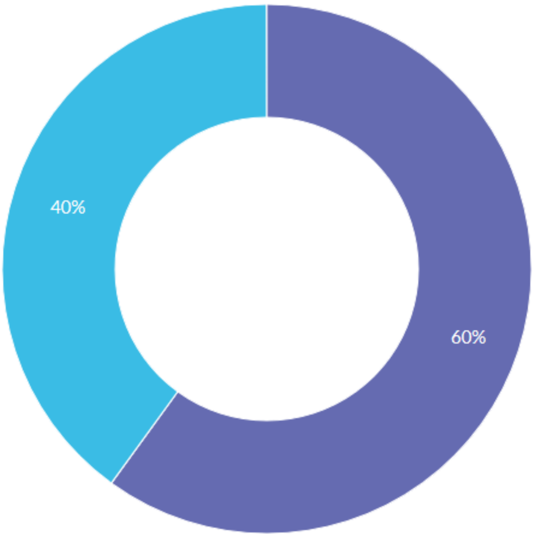

| Choices | Totals |
|---|---|
| None | 2 |
| 1 or 2 | 2 |
| 3+ | 6 |

Q11 Were you aware of the fire evacuation procedure for this building?
Multiple Choice




| Choices | Totals |
|---|---|
| Yes | 1 |
| No | 9 |

Q12 Are you a native danish speaker?
Multiple Choice




| Choices | Totals |
|---|---|
| Yes | 6 |
| No | 4 |