Escuela Técnica Superior de
Ingenieros de Caminos, Canales y Puertos.
UNIVERSITY OF CANTABRIA

TRABAJO FIN DE MASTER

UNDERSTANDING THE IMPACT OF SOCIAL INTERACTIONS AND COLLECTIVE BEHAVIOUR AMONG EVACUEES

(Comprender el impacto de las interacciones sociales y el comportamiento colectivo entre ocupantes durante la evacuación)

Student: Karen Rodríguez Puebla

Supervisor: Daniel Alvear Portilla

Co-Supervisor: Arturo Cuesta Jiménez

University Degree:

Master in Construction Research,
Technology and Management in Europe.
Master en Investigación, Tecnología y
Gestión de la Construcción en Europa.

Santander, 01 of August of 2017

ACKNOWLEDGMENTS

I would first like to thank my thesis tutors Daniel Alvear and Arturo Cuesta of the GIDAI group at University of Cantabria. Thank you for your patience, dedication, motivation, discretion and encouragement. Han made easy the difficult. It has been a privilege to have your guidance and help. Thank you to the GIDAI group for their collaboration, directly or indirectly, in the project, for all the support received during the training hours, for all the help received regarding the different problems, in general, thank you.

I would like to thank my fellow masters, without whom this experience would not have been the same. For having gone through the different stages and have all arrived here. For sharing talks about the different jobs and everything learned from them until today.

I would like to thank all those people who from the first moment have believed in me and those who do not, too. to my friends, to understand my absences during the holidays and to endure my long hours talking about work.

To my parents, who from the first moment have been there, unconditionally, both in the good times and in the adverse. For bearing the unfortunate moments, the distance and supporting me through every decision I have taken along this period. For all what I have been taught, but especially for all the support in each of the moments of this stage.

SUMMARY

The fire is able to cause enormous damaging consequences, especially in buildings occupied by many people, increasing the cost of the losses in both, human and economy. For that reason, during the last decades, numerous researches have been carried out about emergency evacuations and how they rely upon the social interactions between the evacuees. Nonetheless, not much is known about when and how they do so. This thesis is based on a specific case study of an emergency drill carried out in a sports centre. The aim of the thesis is to comprehend the different social interactions and collective behaviour that might affect the evacuees. On the other hand, the final part of the thesis presents different evacuation model simulations in order to figure out up until which level a specific software is able to perform the collective behaviour of the evacuees and how. The different studies of the impact of social interaction are going to be analysed by one quantitative method that already has been used in previous studies. With the method proposed, two different situations are going to be analysed: the time to response to the emergency and the time to exit. Later on, the comparison between the results obtained in the model simulation and the real results would be presented.

TABLE OF CONTENTS

FIGURES:

TABLES:

GRAPHS:

1. INTRODUCTION

During the last years, numerous researches have been carried out about the behaviour of the people in emergencies evacuations. However, most of them based their results on empirical studies or methods, and in the vast majority of the cases, on individual behaviours. For that reason, it is considered the necessity to carry out an analysis in which it might be possible to understand the degree and how much affects the collective behaviour and the social impact among the evacuees at the exact moment of the evacuation of a certain building. In this case, the thesis will be based on analysis in a sports centre, in which it might be considered that people's behaviour may become different than if they were in another building, such as a building of offices.

The purpose of the research is to identify which are the different aspects that may affect the evacuees in an emergency situation and how they should be considered when designing a building in future cases. It has been said that people under stressful or panic circumstances may act in different manner, as they would do in normal conditions. However, the scenario where the emergency happens has a big impact into their behaviour. For that reason, since most of the buildings that have analysed the collective behaviour or the evacuation in general are mostly buildings with a specific route or high-rise buildings. Because of that, in this case, the building in which the emergency drill is carried out is a sports centre, a very different scenario.

The thesis is going to be divided into different sections in order to identify different aspects of the behaviour of the evacuees in an emergency. It is going to use a quantitative method, which has been previously used in other researches (Cuesta, et al., 2016), in order to calculate the grade of collective behaviour of the different people in the building. With this calculation, it might be possible to understand different aspects of the behaviour of the evacuees in a certain emergency. On the other hand, this is going to be analysed in two different situations of the evacuation: the time response to the emergency and the time to exit the building, to see if the grade of collective behaviour varies between this two different situations and if it does, why. The last step of the thesis is to show a comparison, in a simulation model with the software Pathfinder in order to see if the virtual simulation of that specific software is able to calculate the collective behaviour in two different situations. The first situation is going to be a conventional, the same response time to everybody; meanwhile the other situation is going to be carried out with the specific times obtained in the videos from the case study.

2. STATE OF THE ART

The emergencies are events that do not occur daily in the cities where people live. However, the same day can occur different emergencies worldwide. A person can read about the different tragedies that happen daily and be aware of them. Nevertheless, they can never be involved in one them. For that reason, when that person is forced to face any situation like an emergency, the level of experience that they usually have, is quite limited. On the other hand, the circumstances when the different decisions have to be made are usually in an urgency, in which fear, stress, etc. are present. For that reason, the psychological and social capacity of the different people is one of the key points that the last researches about evacuation emergencies have been focusing on.

The majority of the emergencies have the characteristics of being rather ambiguous or, at least, at the beginning of them. For that reason, when a person has to face a situation so ambiguous, they have to make different decisions among which the most important is the one to consider if that specific situation they are involved in, is an emergency or not. At the same time, when making that kind of decision, it is very likely that the people could be influenced by the movements and decisions that other people who are around them make. For example, if that person takes part of a specific group that reacts to an emergency without moving, the person being analysed might not consider the specific situation as an important emergency, and would not react to the emergency as well.

The designers of the buildings, when trying to increase the ability of the occupants of the building to evacuate the building in case of an emergency, should have into consideration different social and psychologic aspects that are involved in the situation itself (Sime, 1983). However, Jones, B.K. and Hewitt, J.A. (1985) go beyond, proposing that, a part from the psychological aspects of the people, the social and organization of the different occupants have to be considered as well. Also, if they have any kind of knowledge about the specific situation they are involved in, may be because they already have faced another similar situation or if they take part of a group, should be considered as well. At the same time, up to this day, different researches have been carried out in which the leadership and decisions at the time of evacuating the building are analysed. According to Hollander (1971), who states that the leaders are made according to the circumstances and what they face, there have been found two different types of leadership people could have: imposed and emergent. The imposed leadership is the one that an authority somebody has in the hierarchy of any type of situation such as business, family, etc. On the contrary, the emergent leadership is something that occurs due to the circumstances of the specific moment, and it is something that it tends to be occasional. Another principle that fire safety engineers should have into consideration when designing buildings is the time available needed the occupants to escape in case of evacuation. It has to be smaller than the time available. The time required for occupants to escape is called RSET (Cuesta, et al., 2016).

On the other hand, social influence is not seeing only when an emergency occurs. Actually, it is appreciated every day how others influence people such as with the clothes tendencies, the music tendencies and many other examples. Based on a study, there has been identified two different social influences. The normative influence and the informational influence. The normative is the one that people do according to what is expected for them to do. However,

the informational influence is the one that is related with how the actions or inactions of the people around, when the emergency occurs, affect people's behaviour.

Other researchers, (Deustch, 1955), state that social influence for the evacuees might be more important when the emergency that they have to face is quite ambiguous. This is important in terms of the fire emergencies. For example, if the fire is clear, if there is black or white smoke, etc. would not lead the people to think about how important the emergency is and how they should or not evacuate. Therefore, they would not lose time of the reaction that can safe their lives. On the other hand, the type of alarm, if it has only sound in the message or if it goes with a message voice, is something helpful for the evacuees that will help the social influence. That is to say, that if the message says that the people should evacuate the building due to the emergency of fire, the people would not wonder what is going on or why the alarm sound is on. When the message voice does not occur, the social influence becomes important because their inactivity could be because they might think that nothing important is happening. For that reason, according to Kuligoeski (2016), there are statements and assumptions that stay the idea that when it is time to evacuate, people who go or are by themselves, end up making groups with other people, even though they do not know each other before evacuating. In addition, they will mostly maintain that group until they reach a safety place.

The agglomerations or crowds of people and its behaviour in hazard or emergency evacuations has been empirically studied for more than four decades. They were studied by analysing images from videos, interviews of survivors from different accidents or emergencies, and by applying the different quantitative methods found over the years. However, one of the main aspects that has still not be solved yet, despite the numerous researches that have been already carried about, is the behaviour of the people when they become or take part of a group. That is to say, the collective behaviour under stressful situations (Moussaïd, M. et al., 2016). It has been carried out empirical researches in several cases studies such as the September 11th attacks, (Johnson, C.W., 2005) or others. They have studied how the people evacuate under those circumstances of panic and stress and which are the different problems they could find along the evacuation. For example, the lack of information, the type of alarm, different emergency exits closed, etc. On the other hand, there are other researches that focus on how the people are affected by others or how people react to this stressful situations by leading this to different delays in the evacuation process. However, it has not been studied deep enough how important the collective behaviour in an evacuation is.

Other aspect that affects the social influence is the type of building where the emergency or the drills take place. This means that in places or buildings where the activities hold in them affect large groups of people, the social influence is not the same as in buildings where the rooms where the people are doing the different activities are smaller. This also leads to point out that, the social influence affects the people in terms of the people who are closer to them than the people who are further when it comes to evacuate or react to the emergency. In the case study of this research, this affects quite a lot since it is a public building, where the spaces inhabited by the people, are big. Other researchers have proved that people look or pay attention to people closer to them. At the same time, when you practice any sport, usually you know the other people who practice the same sport as you.

In sports centres, as well as in any public building where a crowd of people could occur for a period of time, there is a high risk that if there is not a propper evacuation plan, and an emergency occurs, there would be an enormous tragedy. For that reason, it is quite important to analyse how those situations could be faced from the evacuees. According to (Weeraskera, N.N., 2015), historically people had to face those situations and improve the different solutions as the tragedies were occuring. Nevertheless, nowadays the technology has improved up to a level were it is possible to have a simulation of a real case in 2D and 3D. The researches could take advantage of that by using the modelling and simulation tools to understand the social and pshychological behaviour of the people when a hazard situation occurs.

If the quantitative methods already proven, could be used with the evacution simulation models softwares, the numerical results and solutions would improve quite easily the evacuation plans. That is to say that by incorporating this new tools, the tragedies may be reduced since the power, the accuracy and ease the evacuation proccess would be increased. However, the researches are still concerned about the steadfatness of this modelling simulations due to the fact that the calculations are done in virtual conditions and not in real conditions.

This master thesis tries to understand which are the different impacts and how do they affect the social interactions and the collective behaviour among the evacuees in a specific situation. The project is based in a specific case study of an emergency drill carried out in one of the buildings of the campus of the University of Cantabria, the sports centre. The reason to analyse this particular building is due to the lack of information of this types of buildings. In which the group of people are not homogeneous and the people present different types of reactions to the emergency. On the other hand, this thesis is going to based it studies of the social influence and the collective behaviour according to the quantitative method proposed by Cuesta, A. et al., (2016). However, in this situation, only one of the methods proposed is going to be used since the sizes of the groups only fit with one of the methods. Furthermore, this thesis will try to investigate if the quantitative method can be used into the different model simulation programs that already exists, showing a comparison among the results.

3. METHOD

In this part of the thesis, the method that is going to be used to identify the collective behaviour is going to be presented. As mentioned before, the method has already been presented in other specific situation (Cuesta et al., 2016). However, they present two different methods that could be used depending on the size of the group to analyse. For that same reason, in this specific situation only one of them is going to be used since the size of the groups are not small enough to use both of them.

The collective behaviour (CB) is considered when the behaviour of the people evacuating a building, has few differences from each other. That is to say, when a group of people who stand in the same origin, react to the emergency or reach a safety place more or less at the same time. Let us consider X as a variable that measures a specific behaviour during the evacuation. Therefore, it could be pointed out the following statement: "*the smaller the division between the statistical dispersion of each group and the statistical division of the general group, the greater the collective behaviour is"* according to Cuesta et al., (2016).

There are different methods that could be applied to calculate the collective behaviour. However, there are several differences among them starting with the size of the groups. The first method should be used when the groups are N≥5. On the contrary, the other method should be applied when the number of the people of the group is N≤5. For that reason, since in this case more than five people form the groups identified in the images, the first method is the one that should be applied.

There are different values that are capable of measuring the statistical dispersion such as the mean difference, the standard deviation, the range, etc. Nevertheless, these estimations depend on different values such as the general tendency. There is another measure that estimates the dispersion of probability distribution. In other words, it measures the variability relative to the mean. It is called the Coefficient of Variation (CV) and it does not have units.

The formula used to calculate the Coefficient of Variation for a specific group is presented as follows:

$$CV_i = \frac{s_i X}{m_i X} \quad (1)$$

Where:

$s_i X$ → Standard deviation of the variable of the specific group

$m_i X$ → Mean estimation of the variable of the specific group

The Coefficient of Variation for the general group should use the following formula:

$$CV_t = \frac{s_t X}{m_t X} \quad (2)$$

Where:

$s_i X$ → Standard deviation of the variable of the specific group

$m_i X$ → Mean estimation of the variable of the specific group

The last step to carry out in order to see if there is collective behaviour is the following formula:

$$\gamma_{CBi} = 1 - \frac{CV_i}{CV_g} \quad (3)$$

Where:

CV_i → Coefficient of Variation of the Specific Group

CV_g → Coefficient of Variation of the General group

The closer the value of γ_{CBi} is to 1, the greater the collectiveness is. That is to say that if the results obtained are 1, we would have a perfect synchronization among the evacuees.

4. CASE STUDY

In this section, what is going to be presented is a case study that has been carried out by the GIDAI department at one of the buildings of the University of Cantabria, the sports centre. The evacuation drill took place on the 18th of May of 2015 during the afternoon since it was when more students were going to be at the building practicing some sports. The building has several floors where there are different rooms in which the different sports can be practiced. All of them are located under the main floor that is to say, under the ground (Figure 1). In the first level, -1, what can be found is the main sports court, the gym and different changing rooms and offices or storage rooms (Figure 2). Figure 1. At the same time, from the main floor, in the right side, a stair takes you to the floor -2. In that floor, there is another class to practice some sports or to perform any sports class. From that floor, there is another stair that will take to the last floor, -3, where the other sports rooms can be found as well as the squad rooms (Figure 3). In this case, as it had to seem to be a real emergency, there was only one type of alarm sound in order to warn the people. In the following sections, different aspects from the analysis of the data collection are going to be described.

Lay out

The sports centre has a total area of approximately 8500 m^2. Out of those 8500 m^2, 1779, 95 m^2 belong to the principal sports court. 247, 59 m^2, belong to the gym and 520, 32 m^2 for the rest of the classes. There are different exits along the building. In the first floor, 0, there are three, one as the main entrance and two others located on the sides of the building. In the level -1, one emergency exit has direct access from the main sports court. There are other two emergency exit located at the end of the stairs that take from level -2 from level 0.

In order to be able to collect the data in an easy manner, there were some cameras placed along the building. The number of the total cameras was eight. They were located at the top of the doors in order to see how the people evacuate the different rooms that were being used at that moment.

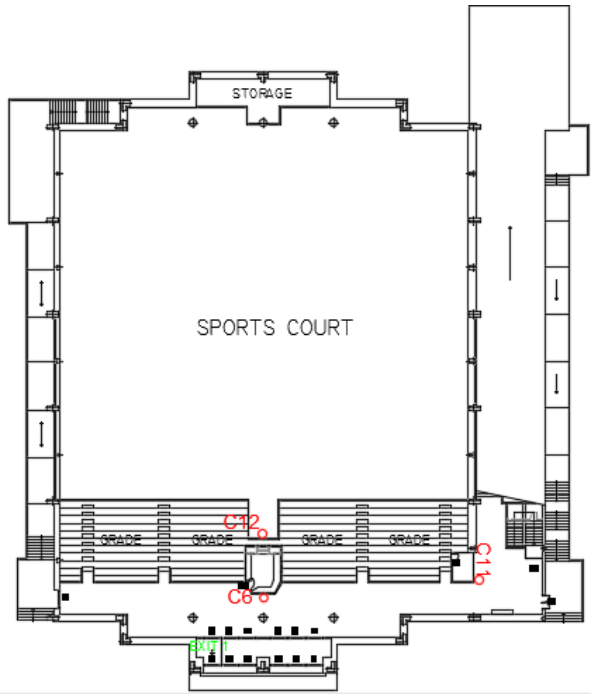


Figure 1 – Plan of the main floor of the Sports Centre of the UC – (University of Cantabria, 2016)

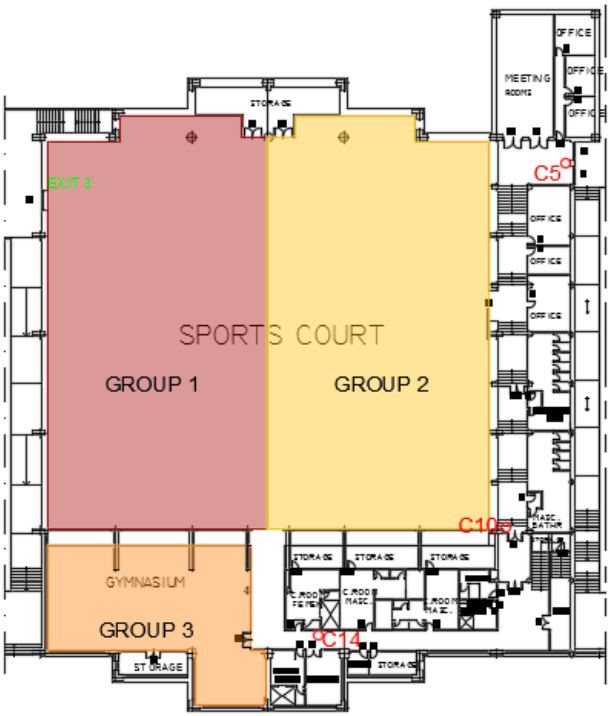


Figure 3 - Plan of the floor -1 of the Sports Centre of the UC – (University of Cantabria, 2016)

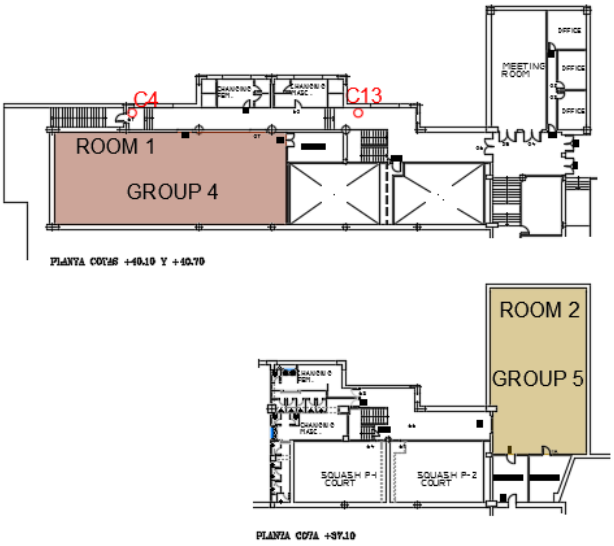


Figure 2 - Plan of the floor -2 and -3 of the Sports Centre of the UC – (University of Cantabria, 2016)

Locations of cameras:

The location of the different cameras can be seen in the figures shown above. In Figure 1, it is possible to see that there are located three different cameras. According to the recordings from that date, the numbers of the cameras are 6, 11 and 12. Each one of them give important information since they are located in front of three different emergency exits. In Figure 2, there are located three different cameras as well. Although they are not located in front of different emergency exit, they show important information. Number 14 is located in front of the gymnasium so it shows the different people who were inside that room. On the contrary, number 5 and number 10 show different information on how the people from the floors downstairs are evacuating the building or if there is somebody who leaves through a different door as the rest of the people. In Figure 3, there are only two cameras. Each of them are also important since they show how people evacuate from Room 1 and how many people come from the rooms downstairs, Room 2 and the Squash court.

Participants

Unlike other emergency drills, the participants who were involved on it did not know what was going to happen. They were just going to practice different sports and sportive activities as they normally do. For that reason, the participants were not chosen for the emergency drill so they were normal people in their normal routines in the building. At the same time, most of the people might go there to practice sport quite often so they might know the people around them a little bit more than in the rest of the drills that the people were volunteers. This last aspect has to be considered, as it will might affect the results by being influenced for the people who they already know.

As a sport centre, there are different spaces where various sports can be practiced at the same time. The different people, who were involved in the emergency drill, were located along the different spaces practicing different sports.

Trial

As previously mentioned, the emergency drill or trial was carried out without nobody knowing what was going to happen, not even the people who work at the sports centre. For that reason, the different results are going to be quite specific and real since this could be a real situation and that it would be how the people could react.

To have a clear view of how the emergency drill was carried out, how the people react to it and what happen in the building during it, it has been created a time line that includes the main aspects, Figure 4.

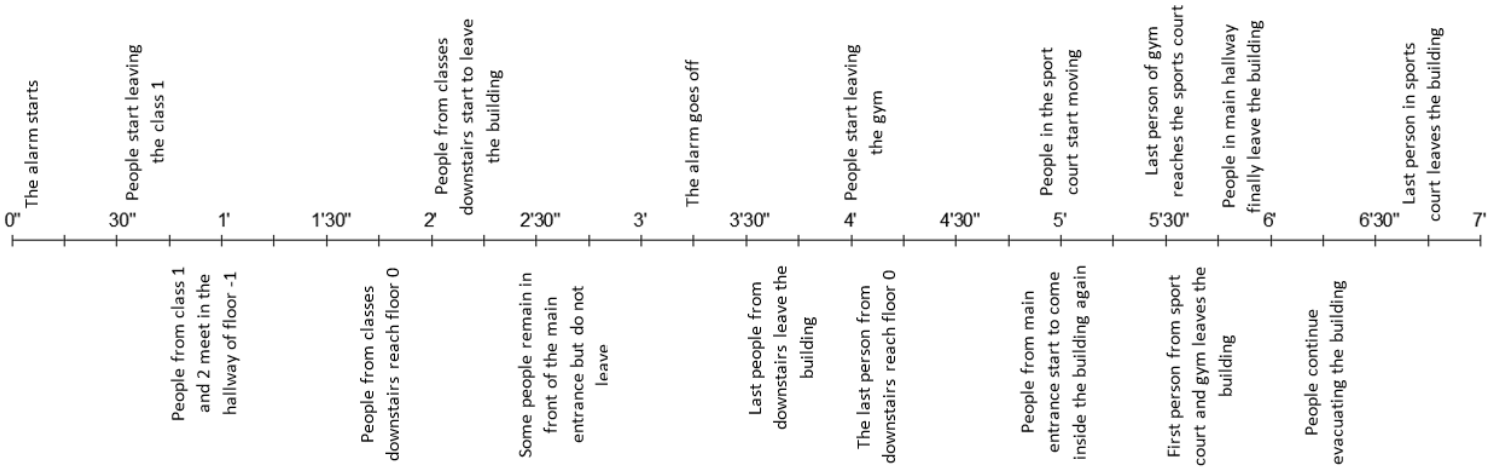


Figure 4 – Time line of the fire drill carried out in the building Sports Centre of the University of Cantabria – (Self production, 2017)

Data collection

For the data collection, the information has been taken from the eight cameras that were placed along the building. The following aspects were the ones that have taken into account in order to see if there is or not collective behaviour:

- The starting location → the exact point where people were when the evacuation drill started
- The final point → the exact point or exit that people used to leave the building
- The response time → the time each person needed to response to the emergency drill
- The exit time → the time each person needed to exit the building

The images were collected at a frequency of 29,970 frames/s and analysed using the Avidemux 2.5.2 software. With this software, it is possible to figure out the exact moment that people react to the emergency drill and the exact moment when they evacuate the building. Later on, with the application of the quantitative method previously explained, it is possible to find out the grade of collective behaviour of each group.

The response time was considered the time people needed to react and move towards the emergency exit. It was considered at the exact frame when each person started to move

toward their exit route. On the other hand, the exit time is taken at the exact frame when the people crossed the emergency exit.

In order to analyse if there is collective behaviour, there are different things that have to be considered:

1. The first thing that has to occur is to have different groups of people. Those groups of people have to be formed by at least five people each.
2. In case there are different groups in the drill, those groups of people have to be at the same place and doing the same activity when the alarm sound goes on and evacuate or reach a safety place through the same route of evacuation.

From the images obtained from the cameras, it was possible to see there were five different groups that accomplish the requirements previously mentioned. The different groups that were found are described as follows:

- Group 1 (G1) → this group was located on the left side of the main sports court. Around twelve people formed it. They were practicing indoor football by the time the alarm started to sound (Figure 2).
- Group 2 (G2) → on the contrary as the previous group, this was located in the right side of the main sports court. It was formed by nine people and were practicing badminton (Figure 2).
- Group 3 (G3) → this was the biggest group found. It was located at the gym and around thirty-one people formed it (Figure 2).
- Group 4 (G4) → this group was not a big group. It was located in one of the rooms located at the -2 floor (Figure 3). It was formed by eight people.
- Group 5 (G5) → the last group was formed by twelve people who were practicing any kind of sport in the room located in the last floor (Figure 3).

5. DATA COLLECTION AND APPLICATION OF METHOD

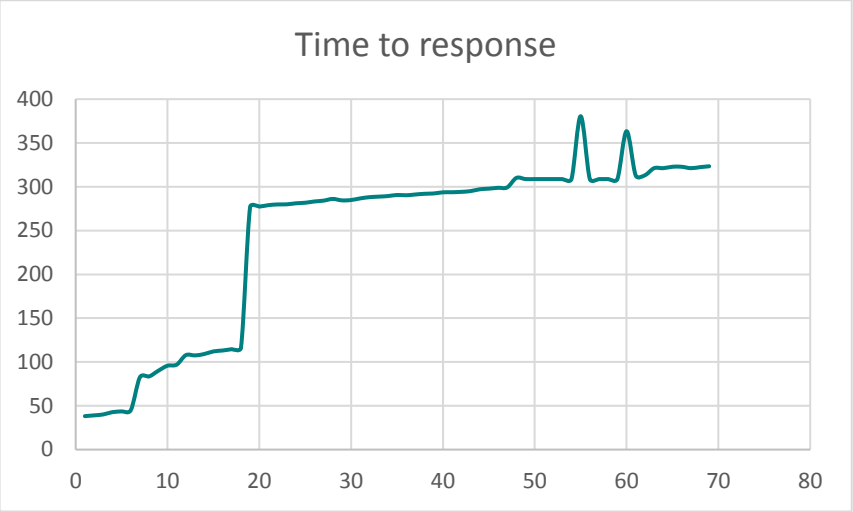
The data, once it has been collected, it needs to be analysed and prove if there is an existence of collective behaviour in this particular case. Therefore, the method explained previously is going to be applied in this section.

The method previously mentioned has been applied for each of the different groups found in the images obtained. From that, it was possible to detect if there is collective behaviour when reacting to the emergency and when leaving the building to a safety place.

In order to understand in an easy manner how the emergency drill occurred, it is suggested to present different graphs that show the different times in relation to the evacuees. In the following graphs, Graph 1 and Graph 2, what is going to be shown are the times compare to the people. This will help to see the differences of time between the evacuees in both situations that are going to be analysed, the time response and the evacuation time.

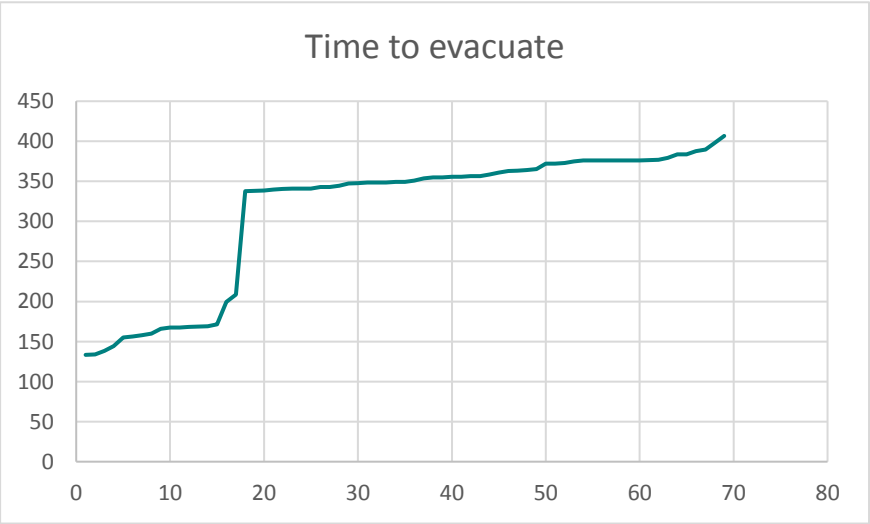
As it can be seen in Figure 4, the alarm started to sound two seconds after the videos from the different cameras started. However, not everybody took the same amount of time to react and to evacuate the building. Moreover, there were people who started at the same point and did not finish at the same emergency exit.

With the following graph, Graph 1, it is possible to see that, in terms of the time response, there is a big gap between the people responding to it. The first two groups to response to the emergency were the two located in the lower floors, group 4 and group 5. The difference that exits between the first two groups and the other to response is quite high, approximately more than twice the time the last person of the previous group needed to response. In general, the difference that exits between the first person that responded to the emergency and the last one is around 350 seconds, almost 6 minutes.



Graph 1 - Comparison between the people and the time to response to the emergency – (Self-production, 2017)

On the other hand, when talking about the time to evacuate the building, it also exits a big difference of time between the first person and the last to leave. Furthermore, the emergency exits chosen among the evacuees are not the same. Mostly, the group 4 and 5 evacuate through the main entrance meanwhile the rest of the groups left through the door located in the sports court that was closer to them. Since the people did not react to the emergency at the same time, the evacuation is going to be influenced for that. In the Graph 2, it can be appreciated that the gap where the people did not evacuate continuously is at the beginning, around the 15-18 person. This means that this happened when the two first groups, 4 and 5, reached the emergency exit. At the same time, the difference in this case between the first and the last person is around 273 second, almost 5 minutes.



Graph 2 – Comparison between the people and the time needed to evacuate the building – (Self-production, 2017)

5.1. DESCRIPTION AND OBTAINING THE TIMES FOR EACH GROUP

Group 1

As previously mentioned, the group one was formed by twelve people. The first thing that should be pointed out by analysing the images is that the group took quite long time to response to the emergency. Actually, when the group started to move towards the emergency exit was when somebody from the staff told them to quit the activity they were doing and the alarm had already went off. In the following table, the different frames and time that took them to leave the building can be seen:

Description of person	Location	Frame react.	Time react (s)
Boy, green shirt white shorts	Left side (-1)	9254	308,7754421
Boy, black shirt, black shorts, long black socks	Left side (-1)	9254	308,7754421
Boy, blue shirt white line on it	Left side (-1)	9254	308,7754421
Boy, white shirt black shorts	Left side (-1)	9254	308,7754421
Boy, orange shirt black shorts long white socks	Left side (-1)	9254	308,7754421
Boy black shirt red shorts	Left side (-1)	9254	308,7754421
Boy, white shirt white shorts	Left side (-1)	11406	380,5805806
Boy, black shirt and black shorts	Left side (-1)	9254	308,7754421
Boy brown shirt and black shorts	Left side (-1)	9254	308,7754421
Boy, dark blue shirt and blue shorts	Left side (-1)	9254	308,7754421
Boy, black t-shirt with yellow letters	Left side (-1)	9254	308,7754421
Boy, yellow shirt and black shorts	Left side (-1)	10892	363,4300968

Table 1 – Description, location and time of the participants of Group 1 of the response time (Self-production, 2017)

As it can be seen, most of the people in the group started the movement to the emergency exit at the same time since it was a group sport what they were practising. On the other hand, the people who had higher time was because they decided to pick up their belongings or because there were people who they knew, were coming behind them.

Figure 5 – Location of Group 1 and Group 2 in the sports centre (GIDAI group, 2015)

Group 2:

The group two was practicing badminton in the right side of the sports court and was formed by approximately 9 people. This group also took quite long time to response to the emergency drill, more or less the same as the group 1. This could be because they had the same impression as the previous group that nothing really important was going on. As same as the previous group, somebody else from the staff had to tell them to stop their activity and leave the building. They took a little bit more time than the previous group because the sports court was divided into two sections and the first person from the staff only advised the other group.

Description of person	Location	Frame reaction	Time to react. (s)
Boy orange shirt black shorts, orange shoes	Right side (-1)	9375	312,812813
Boy, orange shirt, black shorts	Right side (-1)	9385	313,14648
Girl, long hair, blue shirt half leg leggings	Right side (-1)	9627	321,221221
Boy, blue t-shirt and black shorts	Right side (-1)	9627	321,221221
Girl red UC shirt black pants	Right side (-1)	9675	322,822823
Boy, brown shirt white things and black shorts	Right side (-1)	9675	322,822823
Boy, black long sleeve shirt, white shorts	Right side (-1)	9627	321,221221
Boy, shirt and blue shorts (bold)	Right side (-1)	9662	322,389056
Girl, blue tank top and grey leggings	Right side (-1)	9692	323,390057

Table 2 – Description, location and time of the participants of Group 2 of the response time (Self-production, 2017)

As it can be seen in the table, the times to respond are quite different to be a group and being in the same spot and practicing the same activity. This is because the badminton is a sport that is practice in pairs and the people were reacting as the person was telling them to stop and leave. The pairs who were leaving did not influenced the rest of the pairs to respond to the emergency.

Group 3:

This group was the biggest one out of the five groups and was formed by thirty-one people. They were having different activities in the gym with an instructor. In addition, the instructor was the person who had to lead the group since he was part of the staff of the building. He also, was in charge to lead the people to choose the right direction and the closest emergency exit. This group was the one that leaded the group 1, previously described.

Figure 6 – Group 3 evacuating the gymnasium (GIDAI group, 2015)

Description of person	Location	Frame reaction	Time react.(s)
Boy, black shirt white sleeves	Gym	8303	277,04371
Boy, blue shorts, grey hoodie	Gym	8313	277,377377
Girl sports bra, shorts (black coat)	Gym	8362	279,012346
Boy, brown shirt, red shorts	Gym	8387	279,846513
Boy, red UC shirt, black shorts	Gym	8390	279,946613
Boy shirt with blue/white stripes (black jacket)	Gym	8426	281,147814
Boy, black shirt black shorts blue shoes	Gym	8444	281,748415
Boy long hair, white tank top (things on it)	Gym	8488	283,21655
Boy white UC shirt black shorts and shoes	Gym	8516	284,150817
Boy white UC shirt, black shorts orange shoes	Gym	8575	286,119453
Boy white shirt horizontal red line	Gym	8525	284,451118
Boy, black shirt and shorts white long sock	Gym	8537	284,851518
Boy, black shirt and blue shorts	Gym	8594	286,75342
Boy, red shirt white sleeves	Gym	8635	288,121455
Boy, white hair, blue shirt and black shorts	Gym	8653	288,722055
Boy, red shirt and white shorts green shoes	Gym	8672	289,356023
Boy, blue long sleeve shirt yellow things, black shorts	Gym	8710	290,623957
Girl pink UC shirt	Gym	8700	290,29029
Boy, black t-shirt white horizontal letters, black shorts	Gym	8727	291,191191
Boy, red jacket and yellow shirt	Gym	8751	291,991992
Boy, white UC shirt and black long pants	Gym	8762	292,359026
Boy, black t-shirt grey pants (black jacket blue things)	Gym	8801	293,660327
Boy, red shirt grey shorts	Gym	8804	293,760427
Boy grey tank top	Gym	8817	294,194194
Girl red UC shirt	Gym	8842	295,028362
Boy, grey shirt, blue gym gloves, black shorts	Gym	8904	297,097097
Girl, white tank top, grey leggings	Gym	8926	297,831164
Boy, blue shirt with yellow letters, black shorts	Gym	8955	298,798799
Boy, white tank top red shorts	Gym	8969	299,265933
Boy, blue UC shirt	gym	9294	310,11011

Table 3 – Description, location and time of the participants of Group 3 of the response time (Self-production, 2017)

As it can be seen, the time to react is quite different even though it was a group. This is because there were people who instead of going out directly, went to the changing rooms to take their belongings or other who were waiting for their friends to come out and leave all together towards the direction of the emergency exit.

Group 4:

This group was the smallest one and the only one that was not practicing any kind of sport activity as it can be seen in the way they were dressed. Unlike the previous groups described, this did not take that much time to leave. However, eight people formed this group, six of them left before, and the last two took more than one minute to leave since they were making sure everything was closed. For that reason, the last two people should not be considered as part of the group because of the difference of time. Furthermore, this group did not need anybody to lead them towards the exit.

Description of person	Location	Frame reaction	Time react.(s)
Boy, grey long sleeves and black long pants	Exit Sala 1	1144	38,1715048
Girl, blond with long pants and black shoes	Exit Sala 1	1171	39,0724057
Boy, jeans and brown and blue jacket	Exit Sala 1	1202	40,1067734
Girl, glasses, long hair, greenish purse jeans	Exit Sala 1	1281	42,7427427
Girl, black t-shirt with white letters, pants	Exit Sala 1	1307	43,6102769
Boy, white t-shirt and black long pants	Exit Sala 1	1345	44,8782115
Boy, dark long pants and shirt	Exit Sala 1	2478	82,6826827
Girl, red pants and white shirt	Exit Sala 1	2503	83,5168502

Table 4 – Description, location and time of the participants of Group 4 of the response time (Self-production, 2017)

The time of reaction in this case is more or less the same in two small groups as they were leaving the room in two different groups of three people each. However, they have to be considered as one group since they were practicing the same activity and in the same room when the drill started. Additionally, the difference of the time between them is quite short.

Group 5:

This last group was practicing something related to yoga or something like that in the last floor of the building, the -2. The size of the groups is around ten people. The group, as it can be seen in the Table 5, did not take a lot of time to react to the emergency simulation. They started to leave the room and the building as soon as they heard the alarm. In this case, there are people who walk along with the group but do not belong to it since they were in another room and therefore practicing other sport activity. At the same time, they did not need anybody to lead them to the emergency exit.

Figure 7 – Group 5 evacuating the building from floor -2 (GIDAI group, 2015)

Description of person	Location	Frame reaction	Time react. (s)
Woman, short blond hair, multicolour pants	Floor -2	2697	89,98999
Girl, pink t-shirt, grey leggings, black jacket	Floor -2	2869	95,7290624
Girl, red t-shirt, black leggings	Floor -2	2906	96,9636303
Girl, orange long sleeve shirt black pants	Floor -2	3231	107,807808
Girl, blond short hair, blue UC t-shirt	Floor -2	3221	107,474141
Girl, green t-shirt, black pants and jacket	Floor -2	3269	109,075742
Girl, red t-shirt, black leggings and jacket	Floor -2	3358	112,045379
girl, red UC t-shirt, black pants and jacket	Floor -2	3389	113,079746
Girl, blond and short hair, red jacket, black leggings	Floor -2	3435	114,614615
Boy, red shorts, blue jacket	Floor -2	3479	116,082749

Table 5 - Description, location and time of the participants of Group 5 of the response time (Self-production, 2017)

5.2. APPLICATION OF THE METHOD

In the following section, what is going to be developed and showed is how the method that has been described before, in the Method point, in each of the groups and the different results that are obtained.

At first, what the analysis is going to do is to see if there is collective behaviour when responding to the emergency and then when leaving the building. Later on, what is going to be done is to analyse if the collective behaviour has varied between the responding times and the evacuation time and why.

When talking about the reaction time, what should be done at first is to transfer the frames into time by dividing them by the frame rate. This can be done with the software Avidemux. In this case, the frame rate of the videos is 29,970.

Once that step has been done, what has to be done is to calculate the different values previously described in point three, Method, and analyse the different results. This process has to be done for each of the different groups. However, in order to see if there is collective behaviour or not, the value of the *Coefficient of Variation¸* of the groups is going to be calculated taking into account all the people that form part in each of the groups as if it was only one big group.

Once all the frames have been transformed into time, as it can be seen in the previous tables, the value of the Standard Deviation and the Mean Estimation of each group can be calculated. Then, with those two values the last value, the Coefficient of Variation can be calculated. In the following section, the different values for each group are going to be presented:

Group 1:

- Standard deviation = 24,88233
- Mean estimation = 319,3138

$$CVg1 = \frac{Sdv1}{Mes1} \rightarrow CVg1 = \frac{24{,}88233}{319{,}3138} \rightarrow CVg1 = 0{,}077924$$

Group 2:

- Standard deviation = 4,124853
- Mean estimation = 320,1164

$$CVg2 = \frac{Sdv2}{Mes2} \rightarrow CVg2 = \frac{4{,}124853}{320{,}1164} \rightarrow CVg2 = 0{,}012885$$

Group 3:

- Standard deviation = 7,643974
- Mean estimation = 288,9356

$$CVg3 = \frac{Sdv3}{Mes3} \rightarrow CVg3 = \frac{7{,}643974}{288{,}9356} \rightarrow CVg3 = 0{,}026456$$

Group 4:

- Standard deviation = 2,694217
- Mean estimation = 41,43032

$$CVg4 = \frac{Sdv4}{Mes4} \rightarrow CVg4 = \frac{2{,}694217}{41{,}43032} \rightarrow CVg4 = 0{,}06503$$

Group 5:

- Standard deviation = 8,944851
- Mean estimation = 106,2863

$$CVg5 = \frac{Sdv5}{Mes5} \rightarrow CVg5 = \frac{8{,}944851}{106{,}2863} \rightarrow CVg5 = 0{,}084158$$

To sum up, in the Table 6, the different values for the different groups can be found.

	Group 1	Group 2	Group 3	Group 4	Group 5
Standard deviation	24,88233	4,124853	7,643974	2,694217	8,944851
Mean estimation	319,3138	320,1164	288,3956	41,43032	106,2863
Coefficient variation	0,077924	0,012885	0,026456	0,06503	0,084158

Table 6 – Resume of the different values obtained in each group (Self-production, 2017)

Once all the different values for each group have been calculated, what has to be done next is to figure out if there is or not *Collective Behaviour.* For that, as mentioned before, the different groups that have been identified, they have to form a big group and then calculate the different values that have been previously calculated in the small groups. The frames and therefore the time is going to be the same as the one used before.

General group:

- Standard deviation = 99,83893
- Mean estimation = 244,3265

$$CVggr = \frac{Sdvg}{Mesg} \rightarrow CVggr = \frac{99{,}83893}{244{,}3265} \rightarrow CVggr = 0{,}408629$$

For the *Collective Behaviour*, all the data that was required to calculate it has been already computed. After that, what has to be done is to calculate the grade of collective behaviour by using, first the Coefficient of Variation for the general group and then the Collective Behaviour by applying the following formula:

$$CB = 1 - \frac{CVg1-5}{CVggr}$$

Where:

$CVg1-5$ → Coefficient of variation of each group (1 to 5)

$CVggr$ → Coefficient of variation of the general group

To analyse the grade of collectiveness that exists in the different groups, it is necessary to see how close the value is to 1. The closer the value is to 1, the greater the grade of collectiveness is in the group. In the following paragraphs, the different results that each group have obtained are going to be shown:

Group 1:

$$CBg1 = 1 - \frac{CVg1}{CVggr} \rightarrow CBg1 = 1 - \frac{0{,}077924}{0{,}408629} \rightarrow CVg1 = 0{,}809303$$

Group 2:

$$CBg2 = 1 - \frac{CVg2}{CVggr} \rightarrow CBg2 = 1 - \frac{0{,}012885}{0{,}408629} \rightarrow CBg2 = 0{,}968467$$

Group 3:

$$CBg3 = 1 - \frac{CVg3}{CVggr} \rightarrow CBg3 = 1 - \frac{0{,}026456}{0{,}408629} \rightarrow CBg3 = 0{,}935258$$

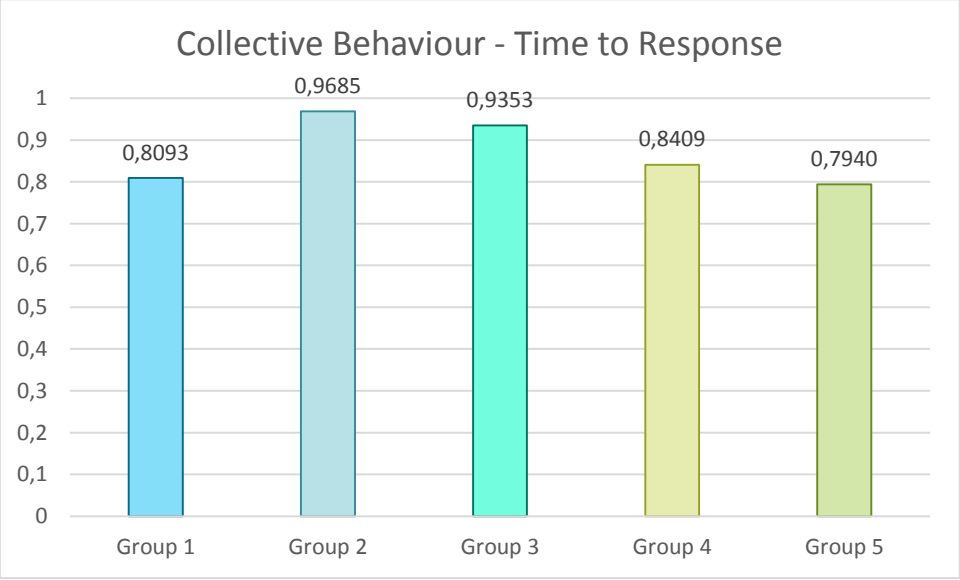
Group 4:

$$CBg4 = 1 - \frac{Sdv4}{CVggr} \rightarrow CBg4 = 1 - \frac{0{,}840858}{0{,}408629} \rightarrow CBg4 = 0{,}840858$$

Group 5:

$$CBg5 = 1 - \frac{Sdv5}{CVggr} \rightarrow CBg5 = 1 - \frac{0{,}084158}{0{,}408629} \rightarrow CBg5 = 0{,}794048$$

In the following graph, the different grades of Collective Behaviour of each group are shown in order to be able to compare which is the one that has higher grade and analyse why.



Graph 3 – Results of Collective Behaviour in terms of the time to response of the different groups of the evacuation drill - (Self-production, 2017)

When analysing the degree of collective in the behaviour of the people regarding the exit of the building, the same steps as when it has been calculated for the reaction time should be followed. For that reason, it is necessary to see if each group, at the end of the evacuation, also has the different characteristics that make possible the analysis of this method, as it is to have at least five people since it would not be considered a group. However, it is likely that throughout the evacuation, the size of the group is affected. That is to say, it might be possible that people from other groups or from other routes end up coming to a safety place together without being part of the same group. In this case, in one of the floors, it can be seen how the group is divided and they end up taking different emergency exits. Another step is to transform the frames into time. To do this, as mentioned before, we will use the software Avidemux 2.5. This software gives the exact data, being performed as in the previous cases. Subsequently, all the formulas that have been used previously have to be carried out, in order to find out if there is a degree of collective behaviour in each group.

As previously mentioned, once the frames are transformed into time, the following step is to calculate the Coefficient of Variation of the group. Later on, the coefficient of collective behaviour can be calculated with the general group values. For that, the first values to be shown are the ones that are related with the general group so as to be possible to calculate the rest of the values for each group.

General group:

- Standard deviation = 86,6636793
- Mean estimation = 316,369105

$$CVggr = \frac{Sdvg}{Mesg} \rightarrow CVggr = \frac{86{,}6636793}{316{,}369105} \rightarrow CVggr = 0{,}27393218$$

For the *Collective Behaviour*, all the data that was required to calculate has been already computed. After that, what has to be done is to calculate the grade of collective behaviour by using, first the Coefficient of Variation for the general group and then the Collective Behaviour by applying the following formula:

$$CB = 1 - \frac{CVg1-5}{CVggr}$$

Where:

$CVg1-5$ → Coefficient of variation of each group (1 to 5)

$CVggr$ → Coefficient of variation of the general group

Group 1:

The first group is the one that was located in the main sports court and that was practicing indoor football. In this case, as it can be seen in the Table 7, the amount of people that begin the evacuation and finish is the same. However, due to the time of response, the time of the people when reaching a safety place varies and it is going to be influenced for that reason. That is to say, even though there is collective behaviour when reaching a safety place and the size of the group does not vary, the grade of Collective Behaviour is going to be different from the

response time. This is because, despite the fact that the people started to leave to the safety place at the same time, through that evacuation route different circumstances happened. For instance, there might be people who found other people who were familiar to them and stop to talk to them, or at half way of the evacuation route, they find out something important for them was being left behind. Furthermore, people can find different obstacles when evacuating and they might not be the same for everybody.

Description of person	Location	Frame react.	Time to exit(s)
Boy, green shirt white shorts	Left side (-1)	10952	365,4320988
Boy, black shirt, black shorts, long black socks	Left side (-1)	10141	338,371705
Boy, blue shirt white line on it	Left side (-1)	11181	373,0730731
Boy, white shirt black shorts	Left side (-1)	11620	387,7210544
Boy, orange shirt black shorts long white socks	Left side (-1)	10407	347,2472472
Boy black shirt red shorts	Left side (-1)	10877	362,9295963
Boy, white shirt white shorts	Left side (-1)	12188	406,67334
Boy, black shirt and black shorts	Left side (-1)	10135	338,1715048
Boy brown shirt and black shorts	Left side (-1)	11272	376,1094428
Boy, dark blue shirt and blue shorts	Left side (-1)	11371	379,4127461
Boy, black t-shirt with yellow letters	Left side (-1)	10889	363,3299967
Boy, yellow shirt and black shorts	Left side (-1)	11925	397,8978979

Table 7 - Description, location and time of the participants of Group 1 of the evacuating time (Self-production, 2017)

Once the general Coefficient of Variation of the general group has been calculated, the different values of Collective Behaviour of each group could be estimated.

- Standard deviation = 21,7798241
- Mean estimation = 369,697475

$$CVg1 = \frac{Sdv1}{Mes1} \rightarrow CVg1 = \frac{21{,}7798241}{369{,}697475} \rightarrow CVg1 = 0{,}058912$$

Therefore, once this value of the Coefficient of Variation has been calculated, the Collective Behaviour in terms of the evacuation time has to be calculated with the value of Coefficient of Variation of the general group:

$$CBg1 = 1 - \frac{CVg1}{CVggr} \rightarrow CBg1 = 1 - \frac{0{,}058912}{0{,}27393218} \rightarrow CVg1 = 0{,}78493743$$

As it can be seen, the value obtained for this situation is higher than 0,5. That is to say, there is collective behaviour in the group 1 when the group reaches a safety place.

As it has been mentioned above, the size of the group has not vary. That is to say, everybody who was part of the group when starting the response process has evacuate the building through the same emergency exit. However, the value of the Collective Behaviour of these two different situations has fluctuate. In this case, the value is lower than the response time. In group 1, the value for the collective behaviour was 0,8093 and for the exit time is 0,7849. It is true to say that it has not barely decreased; nonetheless, something might affect the group. At the same time, it has been mentioned that this group was the one that did not react to the alarm and did not start the evacuation until somebody from the staff told them to do it. Because of that, since the group did not react to the emergency, they did not consider

something important was going on. That led them to react to the emergency and leave the building quite slow.

Group 2:

This group was also located in the main sports court when the alarm started to sound. Nevertheless, this group was practicing badminton instead of indoor football. On the other hand, it might be possible that this group does not vary its collective behaviour because they were playing in pairs and the group is not as crowded as the previous group. In the following table, it can be seen that the same amount of people that started in the group when calculating the time to response, finish and evacuate the building through the same emergency exit.

Description of person	Location	Frame reaction	Time to exit(s)
Boy orange shirt black shorts, orange shoes	Right side (-1)	11500	383,7170504
Boy, orange shirt, black shorts	Right side (-1)	11500	383,7170504
Girl, long hair, blue shirt half leg leggings	Right side (-1)	11151	372,0720721
Boy, blue t-shirt and black shorts	Right side (-1)	11282	376,4431098
Girl red UC shirt black pants	Right side (-1)	11267	375,9426093
Boy, brown shirt white things and black shorts	Right side (-1)	11267	375,9426093
Boy, black long sleeve shirt, white shorts	Right side (-1)	11230	374,7080414
Boy, shirt and blue shorts (bold)	Right side (-1)	11267	375,9426093
Girl, blue tank top and grey leggings	Right side (-1)	11148	371,971972

Table 8 - Description, location and time of the participants of Group 2 of the evacuating time (Self-production, 2017)

Once the frames are transformed into time, the collective behaviour is possible to be calculated.

- Standard deviation = 4,30119212
- Mean estimation = 376,717458

$$CVg2 = \frac{Sdv2}{Mes2} \rightarrow CVg2 = \frac{4{,}30119212}{376{,}717458} \rightarrow CVg2 = 0{,}01141755$$

Like in the previous group, with this value of Coefficient of Variation and the value of the Coefficient of Variation of the general group, the Collective Behaviour is calculated.

$$CBg2 = 1 - \frac{CVg2}{CVggr} \rightarrow CBg2 = 1 - \frac{0{,}01141755}{0{,}27393218} \rightarrow CVg2 = 0{,}95831978$$

In this group, the value obtained is higher than 0,5 as well. This means there is Collective Behaviour. However, this grade of collective behaviour is quite big since it is really close to 1. The closest the value is to 1, the greater the collective behaviour of the group is. At the same time, if this value, 0,95831978, is compared to the value of Collective Behaviour of the response time, 0,968467, what can be seen is that it has not lowered almost nothing. The reason why it has vary so little could be because when the group started to move towards the emergency exit, they did not stop at any point and finished crossing the emergency exit mostly together.

Group 3:

This group is the one that was practicing sports at the gym when the alarm went on. At the same time, this group has the same amount of people when analysing the response time and when they reach a safety place. As it could be seen previously, this was the biggest group found in the building, and this could lead to reduce the grade of collective behaviour.

Description of person	Location	Frame evacuation	Time to exit(s)
Boy, black shirt white sleeves	Gym	10126	337,8712045
Boy, blue shorts, grey hoodie	Gym	10281	343,043043
Girl sports bra, shorts (black coat)	Gym	10821	361,0610611
Boy, brown shirt, red shorts	Gym	10281	343,043043
Boy, red UC shirt, black shorts	Gym	10211	340,707374
Boy shirt with blue/white stripes (black jacket)	Gym	11267	375,9426093
Boy, black shirt black shorts blue shoes	Gym	10682	356,4230898
Boy long hair, white tank top (things on it)	Gym	10211	340,707374
Boy white UC shirt black shorts and shoes	Gym	10211	340,707374
Boy white UC shirt, black shorts orange shoes	Gym	10449	348,6486486
Boy white shirt horizontal red line	Gym	10200	340,3403403
Boy, black shirt and shorts white long sock	Gym	10449	348,6486486
Boy, black shirt and blue shorts	Gym	10449	348,6486486
Boy, red shirt white sleeves	Gym	10465	349,1825158
Boy, white hair, blue shirt and black shorts	Gym	10319	344,3109776
Boy, red shirt and white shorts green shoes	Gym	10465	349,1825158
Boy, blue long sleeve shirt yellow things, black shorts	Gym	10637	354,9215883
Girl pink UC shirt	Gym	10637	354,9215883
Boy, black t-shirt white horizontal letters, black shorts	Gym	10178	339,6062729
Boy, red jacket and yellow shirt	Gym	11267	375,9426093
Boy, white UC shirt and black long pants	Gym	10662	355,7557558
Boy, black t-shirt grey pants (black jacket blue things)	Gym	11267	375,9426093
Boy, red shirt grey shorts	Gym	10662	355,7557558
Boy grey tank top	Gym	10604	353,8204872
Girl red UC shirt	Gym	10418	347,6142809
Boy, grey shirt, blue gym gloves, black shorts	Gym	11300	377,0437104
Girl, white tank top, grey leggings	Gym	10745	358,5251919
Boy, blue shirt with yellow letters, black shorts	Gym	10512	350,7507508
Boy, white tank top red shorts	Gym	10686	356,5565566
Boy, blue UC shirt	Gym	10911	364,0640641

Table 9 - Description, location and time of the participants of Group 3 of the evacuating time (Self-production, 2017)

With the frames transformed into time, the next step is to calculate the grade of collective behaviour and see if it has lowered quite a lot or not compared to the response time of the emergency. For that, the first value to calculate is the Coefficient of Variation:

- Standard deviation = 13,106874
- Mean estimation = 350,038928

$$CVg3 = \frac{Sdv3}{Mes3} \rightarrow CVg3 = \frac{13{,}106874}{350{,}038928} \rightarrow CVg3 = 0{,}03744405$$

With the following formula and by using the value calculated before and the coefficient of variation of the general group, it is possible to figure out the valour of the collective behaviour.

$$CBg3 = 1 - \frac{CVg3}{CVggr} \rightarrow CBg3 = 1 - \frac{0{,}03744405}{0{,}27393218} \rightarrow CVg3 = 0{,}86330906$$

As it can be perceived, the value obtained for this group, 0,86330906, is higher than 0,50 which means that there is Collective Behaviour. Nonetheless, the value has been modified from the previous value of collective behaviour, when analysing the time response, 0,935258. In this case, the value has lowered a little bit more than the previous cases. In this case, as previously mentioned, the group is quite big since the number of people who form it was thirty-one. As it could be seen in the videos, there were people who after starting their way out to a safety place, did not consider the situation as an important emergency and took quite a lot of time to evacuate. On the other hand, there were other people who went back to wait for their friends and leave all together. Furthermore, there were people who thought that taking their belongings was important and went back to take them. For this reason, the group ended up being apart from what it started. Therefore, the result in this case has decreased more than what it should, since everybody in the group had a high grade of collective behaviour in the response time.

Group 4:

This group was located in the lower floors. They were not practicing any sports activity according to their clothes seen in the images of the cameras. At the same time, this group was not quite big, only formed by eight people compared to the previous one.

Description of person	Location	Frame evacuation	Time to exit(s)
Boy, grey long sleeves and black long pants	Exit Sala 1	3996	133,3333333
Girl, blond with long pants and black shoes	Exit Sala 1	4009	133,7671004
Boy, jeans and brown and blue jacket	Exit Sala 1	4141	138,1715048
Girl, glasses, long hair, greenish purse jeans	Exit Sala 1	5052	168,5685686
Girl, black t-shirt with white letters, pants	Exit Sala 1	5037	168,0680681
Boy, white t-shirt and black long pants	Exit Sala 1	5021	167,5342009
Boy, dark long pants and shirt	Exit Sala 1	-	-
Girl, red pants and white shirt	Exit Sala 1	-	-

Table 10 – Description, location and time of the participants of Group 4 of the evacuating time (Self-production, 2017)

As it can be realised in the Table 10, the last two people of the group do not have value in terms of frame and time to exit the building. This does not mean they did not leave the building, but they evacuate the building through a different door than the rest of the group. Because of this, they cannot be considered part of the group in terms of the evacuation process. This is going to affect the value of the Collective Behaviour as the group is smaller.

- Standard deviation = 18,1385342
- Mean estimation = 151,573796

$$CVg4 = \frac{Sdv4}{Mes4} \rightarrow CVg4 = \frac{18{,}1385342}{151{,}573796} \rightarrow CVg4 = 0{,}11966801$$

$$CBg4 = 1 - \frac{Sdv4}{CVggr} \rightarrow CBg4 = 1 - \frac{0{,}11966801}{0{,}27393218} \rightarrow CBg4 = 0{,}56314732$$

The value obtained is 0,5631 which is higher than 0,50 but not as high as the previous groups. That means the collective behaviour of this group is almost non-existent. One of the reasons of this low value is because the group in general did not leave through the first emergency exit it was available in their route. They went and evacuate through the main entrance. This means the distance they travelled to evacuate the building was long enough for the group to separate.

Group 5:

This last group is the other group that was located in the last floor of the building. It was also a small group and unlike the previous group, they were practising some kind of sport.

Description of person	Location	Frame evacuation	Time to exit (s)
Woman, short blond hair, multicolour pants	Floor -2	4649	155,1217885
Girl, pink t-shirt, grey leggings, black jacket	Floor -2	4689	156,4564565
Girl, red t-shirt, black leggings	Floor -2	4327	144,377711
Girl, orange long sleeve shirt black pants	Floor -2	4791	159,8598599
Girl, blond short hair, blue UC t-shirt	Floor -2	5135	171,3380047
Girl, green t-shirt, black pants and jacket	Floor -2	4736	158,0246914
Girl, red t-shirt, black leggings and jacket	Floor -2	5977	199,4327661
girl, red UC t-shirt, black pants and jacket	Floor -2	5016	167,3673674
Girl, blond and short hair, red jacket, black leggings	Floor -2	5063	168,9356023
Boy, red shorts, blue jacket	Floor -2	-	-

Table 11 – Description, location and time of the participants of Group 1 of the evacuating time (Self-production, 2017)

Like in the previous group, the last person shown in the Table 11 does not have values both for the frames and for the time to exit. This means that this person, like in the previous case, did not finish the evacuation with the rest of the group. He found another emergency exit in his way to the main entrance where he could leave the building. At the same time, he was leaving the building almost when the two people from the other group were too, so this boy might influence them since he left before and they saw him.

In terms of the value of the collective behaviour, in the following lines it is going to be calculated:

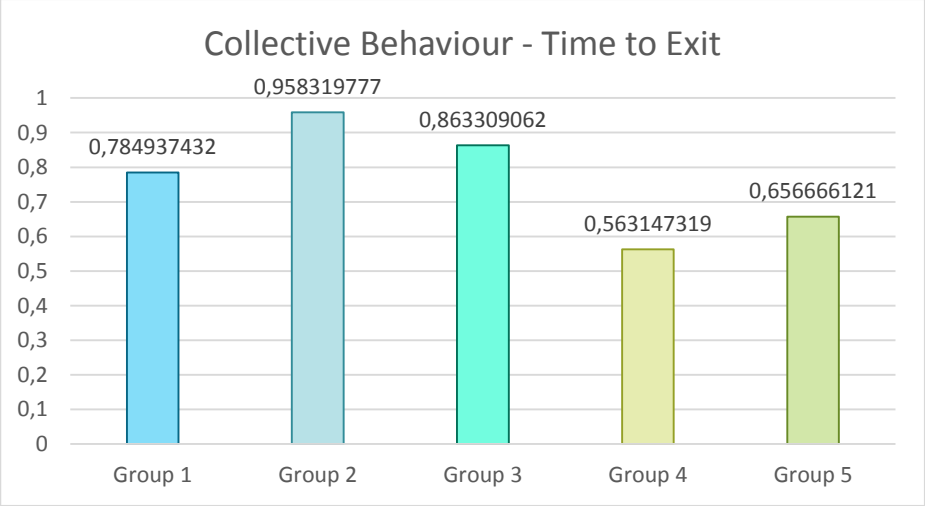
- Standard deviation = 15,4755865
- Mean estimation = 164,546028

$$CVg5 = \frac{Sdv5}{Mes5} \rightarrow CVg5 = \frac{15{,}4755865}{164{,}546028} \rightarrow CVg5 = 0{,}0940502$$

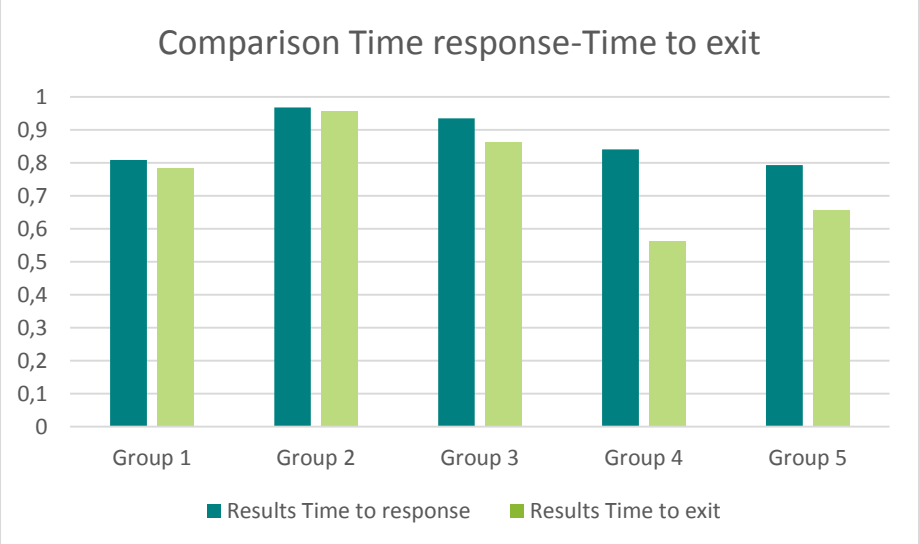
Applying this value to the formula of the collective behaviour, the following value is obtained:

$$CBg5 = 1 - \frac{Sdv5}{CVggr} \rightarrow CBg5 = 1 - \frac{0{,}0940502}{0{,}27393218} \rightarrow CBg5 = 0{,}65666612$$

In this case, the value obtained for the collective behaviour is 0,65666612. It is also higher than 0,50 which means that there is also collective behaviour. However, it is also quite low compared to the first three groups, which their values were higher than 0,75. The reason why this value is somehow low could be for the long distance they have to travel to get to the main entrance, the emergency exit they used to evacuate. At the same time, other people from this group tried to open some emergency doors, located in their evacuation route, and they were not open at that moment. Because of that, they lost some time and might affect the value. On the other hand, the last two groups had to travel a long distance and open several doors that were in their way out which affect also the time.



Graph 4 - Results of Collective Behaviour for time to exit of the evacuation drill – (Self-production, 2017)



Graph 5 – Results of the comparison between the time to response and the time to exit– (Self-production, 2017)

6. EVACUATION MODEL SIMULATION

According to fire evacuation experts, different evacuation techniques, methods and policies have been suggested over the years based on the buildings, the groups of people or situations. Nevertheless, they present different obstacles to carry out the experiments in order to prove the solutions. Hence, so as to experiment these proposals, the simulation of fire and the simulation of fire evacuation is an acceptable solution.

Lately, one of the most interesting topics to base the researches in, are the modelling and the simulation of the fire or emergency evacuation. Different models have been proposed, however, the most important are modelling and simulation based in agents. In this case, each agent is independent and it could move around the building to communicate with other in order to reach his or her goal. The most suitable part of the systems is that in the simulation of fire evacuation, the agents can play different characters. For example, they can be an evacuee in different situations or an object such as smoke, water, etc. Along the fire evacuation modelling simulation, the agents have to represent different movements and conducts such as how to avoid the smoke or fire, evacuate the building, collective behaviour among the groups or even follow different instructions to find the suitable evacuation, help other people, etc. The different activities or actions previously mentioned could be modelled and simulated by using different software technologies.

In this section, an evacuation model simulation is going to be presented about the case study that has been studied along the thesis. The reason of this section in the thesis is to prove if the evacuation model simulations are able to perform the collective behaviour or not. To do so, different simulations have to be performed. There is going to be two different simulations that are going to be compared among each other and with the results obtained with the empirical method previously described.

In this specific situation, the software chosen to simulate the behaviour and actions of the fire evacuation simulation is Pathfinder. Pathfinder is an agent based in evacuation and human movement simulator. It provides different tools such as the 2D and 3D visualization as well as a graphical user interface for results analysis. The graphical user interface was created in order to operate simulation models. Additionally to the 2D and 3D visualization and the graphical user interface, Pathfinder provides output in 2D and a text summary of the different rooms or evacuees with the times and doors flows rates.

The simulation of the evacuation model of the current case study with the program Pathfinder has been done in 2D instead of 3D. In order to do that, the plans of the building have been imported into the model to import the geometry. The plans are imported in *.dwx* format. Once this has been done, the different geometries of the plans are exported. The rooms and hallways where the people were located are the different geometries that have been exported to the file. At the same time, the different stairs, emergency exits and regular doors have to be settle in the geometry in order to allow the agents evacuate the building.

About the agents, what has been set in this case is that they are all the people who were in the sports centre the day of the emergency drill, located each of them in the different rooms according to the images from the videos. In the different situations presented, they will have different characteristics. In the two simulations that are going to be carried out the emergency

exits are going to be selected. However, the software gives the chance to perform a random simulation without selecting any of them.

In this case, there is going to be presented two different model simulations. The blind simulation and the real case. The blind simulation will perform a case with specific values for the occupants and it is more likely to the ones that are being done in every building simulation. The data that is going to be assigned for the evacuees is not completely real. This simulation is going to be done only with the first three groups in order to see if this type of simulation is possible to perform the collective behaviour. For this specific simulation, different data has been assumed, shown as follow.

As it can be seen in Figure 9, the values of the blind simulation has been set according to the BSi PD 7974-6:2004. In that standard is set, according to the type of building, type of alarm and the type of staff in the building the values which should be assumed for the model simulation. On the other hand, all of the occupants will evacuate through the same door, the one that is located in the main sports court.

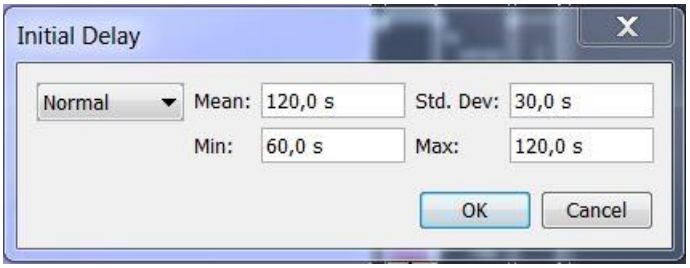


Figure 9 – Data assumed for the blind model simulation.

Once the simulation has been performed, the program gives as a result, different excel sheets with the results obtained. One of them present the different values of the evacuees with all the data needed in order to analyse if the program, with the data previously mentioned, takes the collective behaviour. The values that excel sheet of the occupants are, for example, the time to exit, the time active, etc. with the time to exit and using the formulas from the empirical method previously explained, Method. The following table, Table 12, shows the results obtained by applying the formulas.

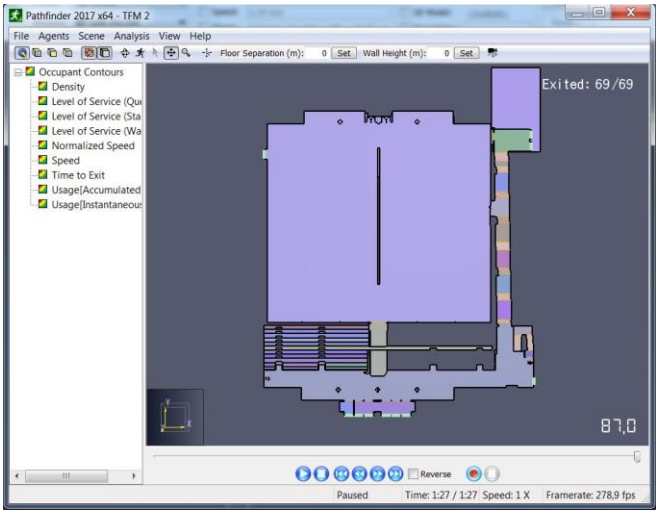


Figure 8 – Results of the blind simulation in Pathfinder (Self-production, 2017)

	General group	Group 1	Group 2	Group 3
Standard deviation	22,069	12,763	18,451	17,063
Mean Estimation	140,084	114,327	138,853	150,757
Coefficient Variation	0,158	0,112	0,133	0,113
Collective Behaviour	-	0,291	0,156	0,282

Table 12 – Results of the blind model simulation for the Collective Behaviour (Self-production, 2017)

As it can be seen, the values obtained for the Collective Behaviour are all under 0,500. As it was mentioned in the method, in order to have Collective Behaviour in the different groups, the values have to be higher than 0,500. For that reason, the blind simulation do not consider the collective behaviour. This is due to the fact that everybody is set with a specific delay, uniform, for everybody. However, even though the values are the same for all the evacuees, they will not evacuee at the same time; they will not react to the emergency at the same time.

The other simulation that is going to be presented is the one similar to the real case studied along the thesis. In this case, the data is not going to be assumed. On the contrary, the data will be taken from the videos previously analysed, shown in the Table 1, Table 2 and Table 3, shown in Figure 13, Figure 12 and Figure 11. In this case, each group have different data since the time to react to the emergency was different in each of them. At the same time, all of the evacuees, agents, will evacuate through the same door as the previous case, the exit located in the sports court.

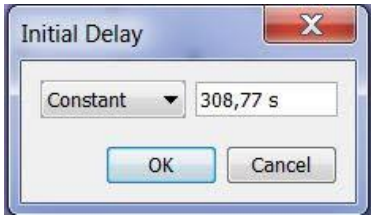


Figure 12 – Data for group 1 Real simulation.

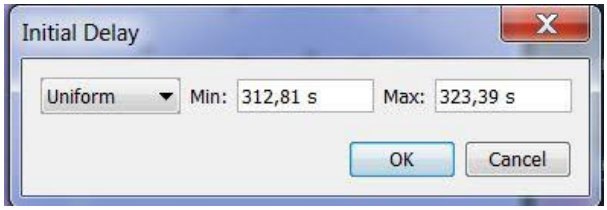


Figure 11 – Data for group 2 Real simulation

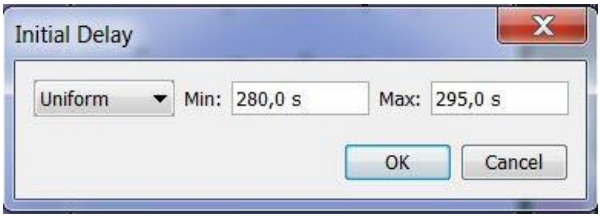


Figure 10 – Data for group 3 Real simulation

As the previous simulation, there is the necessity to analyse the collective behaviour, as the values obtained here will not be exactly the same as the real case. For that reason, the method will be also applied with the values obtained in this simulation. In the following table, the different results obtained are presented.

	Total group	Group 3	Group 1	Group 2
Standard deviation	12,275	5,965	3,568	2,795
Mean Estimation	342,942	347,013	323,727	355,128
Coefficient Variation	0,036	0,017	0,011	0,008
Collective Behaviour	-	0,520	0,692	0,780

Table 13 – Results obtained from the real model simulation for Collective Behaviour (Self-production, 2017)

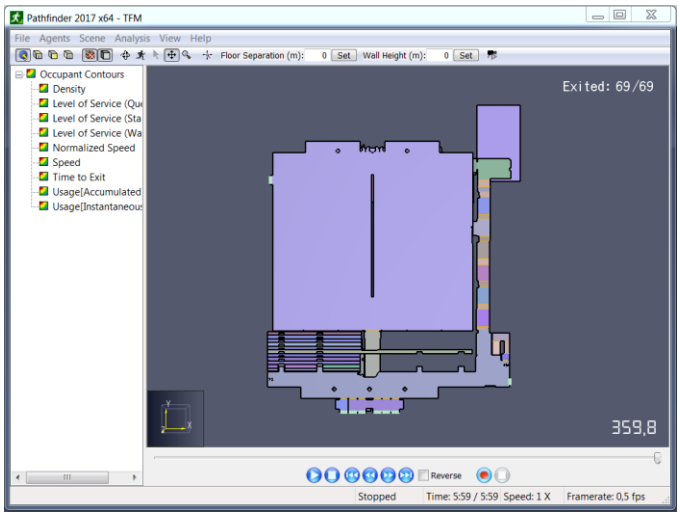


Figure 13 – Results of the blind simulation in Pathfinder (Self-production, 2017)

On the contrary as the previous simulation, the different values obtained for each group are higher than 0,500. For that reason, this case will have the Collective Behaviour. This is due to the fact that the values for this case are in a smaller variation so they will react to the simulation more or less at the same time, having a collective behaviour, as in the real case previously studied.

What can be understood from these two different simulations is that, as it can be seen in the different tables, the values of the Coefficient of Variation are very different one from another. In the first simulation, the values are higher than the second simulation. On the other hand, the other two values, the Mean Estimation and the Standard Deviation, also play an important role in the value of the Coefficient of Variation. However, what it can be state from this analysis is that: When simulations are used from the conventional point of view, as they are used a priori in many buildings, the collective behaviour is not represented

7. CONCLUSION

As a conclusion of what has been state along the thesis, there have been found different aspects that might affect the evacuees in terms of the collective behaviour and the social impact.

The collective behaviour is an aspect that greatly influences the evacuees when evacuating a building. It is important to consider the collective behaviour when evacuating a building as the people are going to be influenced by what people around them do. That is to say, if the people around them do not consider the alarm to be important, they might not react to it so it is probably that the rest of the people react in the same manner. On the other hand, there will be people who will always wait for their closest people, people they already know, in order to react to the emergency because they might feel more secure. However, it is a social behaviour that do not occurs in every evacuation of every building due to the fact that different aspects are needed to have that collectiveness. The first aspect is that it is needed different groups of people in that evacuation. At the same time, the groups have to be formed by, at least, five people. Those people have to be in the same origin when the evacuation process starts and go to the same destination, safety place or leave the building through the same emergency exit.

In addition, different aspects may affect when taking into account the collective behaviour in an evacuation process, apart from the evacuees. The type of building in which they are located is rather an important aspect because it may present a big complexity for the evacuees to leave it. Likewise, the grade of knowledge the evacuees have about the building, the location of its emergency exits, and the evacuation routes are relatively important as well. The activities that the building holds are also important, because the collective behaviour goes along with the type of social relation people may have during the activity.

It is possible to point out that even though the grade of collective behaviour might be high during the time response, it is not necessarily to be the same grade during the time exit. In fact, it is not usually the same due to the fact that there are different factors that influence such as the size of the group, the distance travelled to a safety place, etc. On the other hand, according to the results obtained in the thesis, it is possible to deduct that the longer the evacuation distance is, it is more likely that the degree of collective behaviour will be reduced one from another. Furthermore, it may also be probable that if along the evacuation route, there are people who evacuate through different routes as the ones they thought to be faster, people would follow their steps. Here it is a social aspect that affects the collective behaviour.

There are other aspects such as the grade of knowledge of the people about the building, the people from the staff or security in the building, the type of alarm, etc. that will create, directly or indirectly, an impact in the behaviour of the evacuees.

On the other hand, the evacuation model simulation is an innovative technology that is now starting to be more productive when analysing the evacuation of the buildings. However, according to the latest researchers, it is not completely reliable, as the simulations are done in virtual conditions. However, different progresses have been done during the last years in order to prove the advantage it can contribute to the society.

In the last episode of the thesis, two different simulations have been carried out. They are different from each other. The first one is a conventional simulation, as most of the ones carried out in the buildings, with data assumed for the evacuation of the agents according to BSi PD 7974-6:2004. The second one is a real case, the case study of a sports centre in which the values are not assumed. On the contrary, the values are obtained from an emergency drill carried out in the building.

As a conclusion of that section, if a general response is applied to an entire edification, according to the values of the law of response distribution, the software would not be able to reproduce a collective behaviour. Nonetheless, if different response ranks in different origin spots, those where is possible to identify a group of people, are applied to them, then it would be possible to obtain that collective behaviour.

8. REFERENCES

Aguirre, B.E., et al., 1998. A Test of the Emergent Norm Theory of Collective Behaviour. *Sociological Forum,* 13(2), pp. 301-320.

Banerjee, A., 1992. A Simple Model of Herd Behaviour. *The Quarterly Journal of Economics,* 107(3), pp. 797-817.

Bryan, J., n.d. Behavioural Response to Fire and Smoke. 3(12), pp. 315-341.

Cocking, C., et al., 2009. The Psychology of Crowd Behaviour in emergency evacuations: Results from two interview studies and implications for the Fire & Rescue Service.. *Irish Journal of Psychology,* 30(1), pp. 59-72.

Connell, R., 2001. Collective Behaviour in the September 11, 2001 Evacuation of the World Trade Centre. *University of Delaware Research Centre,* Volume 313, pp. 1-21.

Conradt, L. and Roper. T.J., 2003. Group decision-making in animals. *International weekly journal of science,* Volume 421, pp. 155-158.

Couzin, I. et al., 2005. Effective leadership and decission-making in animal groups on the move. *International weekly journal of science,* Volume 433, pp. 513-516.

Cuesta, A. et al., 2016. *Evacuation Modelling Trends.* First ed. Santander, Cantabria, Spain: Springer International Publising.

Cuesta, A. et al., 2016. Methods for measuring collective behaviour in evacuees. *Safety Science,* Volume 88, pp. 54-63.

Deustch, M. and Gerard, H.B., 1955. A study of normative and informational social influences uponindividualjudgement,. *Research Centre for Human Relations, New York University,* pp. 629-636.

Fahy, R., Proulx, G. and Aiman, L., 2011. Panic or not in fire: Clarifying the missconception. *Fire and Materials,* 36(5-6), pp. 328-338.

Guo, R., Huang, H. and Wong. S., 2011. Collection, spillback, and dissipation in pedestrian evacuation: A network-based method. *Transportation Research Part B,* Volume 45, pp. 490-506.

Guo, R., Huang, H. and Wong. S., 2012. Route choice in pedestrian evacuation under conditions of good and zero visibility: Experimental and simulation results. *Transportation Research Part B,* Volume 46, pp. 669-686.

Gwynne, S. Galea, E. and Lawrence, P., 2005. The introduction of social adaptation within evacuation modelling. *Fire and Materials,* Volume 30, pp. 285-309.

Helbing, D. et al., 2002. Simulation of Pedestrian Crowds in Normal and Evacuation Situations. *Springer Editors,* pp. 21-58.

Johnson, C., 2005. Lessons from the Evacuation of the World Trade Centre, September 11th 2001 for the Development of Computer Based Simulations.

Jones, B. and Hewitt, J.A., 1985. Leadership and Group Formation in High-Rise Building Evacuations. *Fire Safety Science - Proceedings of the first International Symposium,* Volume 1377, pp. 513-522.

Latané, B. and Darley, J.M., 1968. Group inhibition of bytstander intervention in emergencies. *Journal of Personality and Social Psychology,* 10(3), pp. 215-221.

Moussaïd, M. et al., 2016. Crowd behaviour during high-stress evacuations in an immersive virtual environment. *The Royal Society Publising,* Volume 13, pp. 1-8.

Nguyen, M. et al., 2015. Modeling and Simulation of Fire Evacuation in Public Buildings. *Advances in Computer Science: an International Journal,* 4(18), pp. 1-8.

Nilsson, D. and Johansson, A., 2009. Social influence during the initial phase of a fire evacuation - Analysis of evacuation experiments in a cinema theatre. *Fire Safety Journal,* Volume 44, pp. 71-79.

Sime, J., 1985. Movement towards the familiar: person and place affiliations in a fire entrapment setting. *School of Architecture, Portsmouth Polytechnic,* 17(6), pp. 100-109.

Sime, J., 1995. Crowd pshychology and engineering. *Safety science,* Volume 21, pp. 1-14.

Solomon, L., Solomon, H. and. Stone, R., 1978. Helping as a Function of Number of Bytstanders and Ambiguity of Emergency. *Personality and Social Psychology Bulletin,* 4(2), pp. 318-321.

Weeraskera, N., 2015. *Modeling and Simulation of Evacuation Plan for Hancock Stadium.* Illinois: s.n.