Taking into account groups for evacuation analysis

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ABSTRACT

Previous research has provided useful information to qualitatively interpret fundaments of social influence during evacuation. However, this performance needs to be quantified that it can be understood and considered in life safety calculations. We apply a quantitative method for assessing the behavioural cohesion among evacuees i.e. whether individuals respond and move together, as a group. Three evacuation scenarios are analysed: 1) a multimodal station, 2) a sports centre and 3) a library. Results suggested that proximity (visual/verbal contact) could be an important factor but not decisive in the formation of evacuation groups. Social ties and whether occupants share a target and/or an activity before the alarm are also deemed to be important factors. Overall, these results indicate that the proposed method can be used as a priori assessment to determine the presence of evacuation groups in fire safety engineering analyses.

1 INTRODUCTION

There is much work still to be done to improve our understanding of human behaviour in fire. One of the main issues in the field is the influence of groups dynamics on individual decision-making and group decision making [1]. A group can be defined as a number of people that behave and/or act together. In many evacuation scenarios occupants are likely to interact with others. That is why social influence should be considered in evacuation modelling and simulation calculations. Nevertheless, occupants (agents) are often simulated as if they were not influenced by others. An example can be found when implementing pre-evacuation time distributions to the population, as proposed in current fire safety engineering calculations [2, 3]. One agent can start the evacuation while others remain in the same room/place. While this could be assumed for some situations it could be less realistic for other situations thus leading to errors in evacuation predictions. Also, understanding social influence can help us to develop more effective evacuation procedures. For instance, staff members can be sent to certain places throughout the building to avoid the negative effects of social influence i.e. potential nonresponding of individuals seeing inaction of others [1].

Previous studies have reported different aspects of collective evacuation behaviour based on interviews and surveys to actual evacuees and/or theoretical frameworks [4]. The response of others has been proved to influence our own response to ambiguous threat cues [5]. This can also happen when the fire alarm is unclear [6]. In such conditions, we interact with others to decide what to do [7, 8]. Proximity also seems to be an important factor i.e. we are more influenced by people who are close than by those who are further away [6].

We also cooperate in emergencies [6-10]. Past incidents such as the Beverly Hills Supper Club fire have shown that social groups tended to escape or succumb together [11]. Evacuation groups can emerge spontaneously [7] or can be formed based on social ties [12] and the organizational/situational context [8]. Given this, evacuation can be also considered as a social process in that people are likely to make consensus decision, decide a plan of action and act together [8, 13, 14].

This paper presents a possible approach to determining the presence of groups during evacuation process. A simplified method derived from [15] is proposed and applied to a variety of evacuation scenarios to investigate group behaviour in emergencies, i.e. if and to which extend people respond and act together. The paper is organized as follows. Section 2 presents the proposed simplified method. Section 3 describes the evacuation scenarios considered for the analysis and presents results mainly focused on the identification of group behaviour among evacuees. Section 4 concludes the paper with some indications for future work.

2 METHOD

The method used here is a simplification of the Method 1 proposed in [15]. The philosophy behind it is that consensus and uniformity in individuals denotes a reduction in the behavioural variability. Let X be a continuous random variable that measures a behaviour during evacuation. Hence, the following postulate can be established: *The smaller the statistical dispersion of the variable X intragroup, compared to the statistical dispersion of the same variable X in all groups, the greater the cohesion among the members of an evacuation group.*

To measure the statistical dispersion, the method uses the coefficient of variation (*CV*) that is a dimensionless (unit-free). More specifically, it is a measure of variability relative to the mean. The coefficient of variation for a potential *i-th* evacuation group is:

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

where:

$s_i(X)$ = Standard deviation estimation of the variable X for the *i-th* group;

$m_i(X)$ = Mean estimation of the variable X for the *i-th* group.

The coefficient of variation for all potential evacuation groups in the evacuation scenario is:

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

where:

$s_t(X)$ = Standard deviation estimation of the variable X for all the groups in the scenario;

$m_t(X)$ = Mean estimation of the variable X for all the groups in the scenario.

Therefore, the degree of behavioural cohesion among individuals in a selected group can be calculated as follows:

$$\gamma_{B_i} = 1 - \frac{CV_i}{CV_t} \tag{3}$$

This coefficient approaches 0 when individuals behave differently (low cohesion) and 1 when all individuals behave together (high cohesion). In other words, the closer the γ_{B_i} value to 1, the greater the cohesiveness. For instance, a value of 1 would represent a perfect synchronization of group members. Results in [15] confirmed the presence of collective behaviour for γ_{B_i}values from 0.5 to 0.75 and a strong behavioural cohesion with γ_{B_i} values > 0.75.

It is also possible to introduce a new variable, the weighted coefficient $\tilde{\gamma}_B$ to characterize the degree of behavioural cohesion among evacuees in a given evacuation scenario:

$$\tilde{\gamma}_B = \frac{1}{n}\sum_{i=1}^{m} n_i \cdot \gamma_{B_i} \tag{4}$$

where:

n = The number of occupants in the scenario;
m = The number of groups in the scenario;
n_i = The number of group members for the i-th group.

It should be noted that the application of this method involves three main requirements. The first requirement is the proper definition of the continuous random variables for the analysis. Evacuation behaviour suitable for this king of analysis could be focused on two types of variables: 1) time variables and/or 2) movement variables. Time variables are those variables expressed in delays due to different reasons (seeking information, collecting belongings, waiting others, put on clothes, etc.). These variables allow us to know whether individuals respond together i.e. as a group. Movement variables are those variables related to purposive movement. These variables allow us to know whether individuals maintain cohesion with neighbours during the evacuation movements.

The second requirement is the appropriate identification and selection of the potential evacuation groups for the analysis. This relies on the analyst. Criteria of great weight could be, for instance, the specific location (room, zone, area, queue, etc.), the proximity where occupants are likely to interact each other (verbal and/or non-verbal communication) and/or whether they share a target and/or an activity before the alarm. The third requirement is that individuals of the selected potential group for the analysis must use the same evacuation route (i.e the same initial location and the same exit). This is a *conditio sine qua non* to use the method i.e. when movement variables are analysed.

3 CASES OF STUDY

The cases of application comprised three evacuation case studies in three buildings. The buildings were chosen to represent different configurations, population distributions and people activities. The findings from the application of the proposed method are presented below.

3.1 Case A: Evacuation trial in a multimodal station

The first case involved an evacuation experiment in an underground bus concourse of multimodal station in Madrid, Spain. The experiment took place on 17th July 2013. Several trials were conducted. Here we present results of one of these trials.

The building

Figure 1 shows the layout of the bus concourse. It consists of a waiting area with 10 boarding gates (BGs) to access the bus departure bays. The bus concourse has five emergency exits, a straight stair and an escalator that lead to the main entrance.

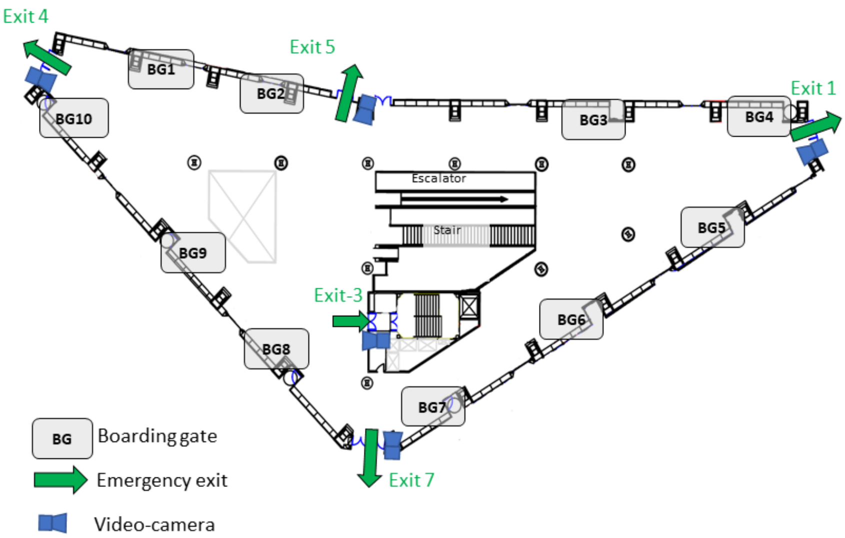
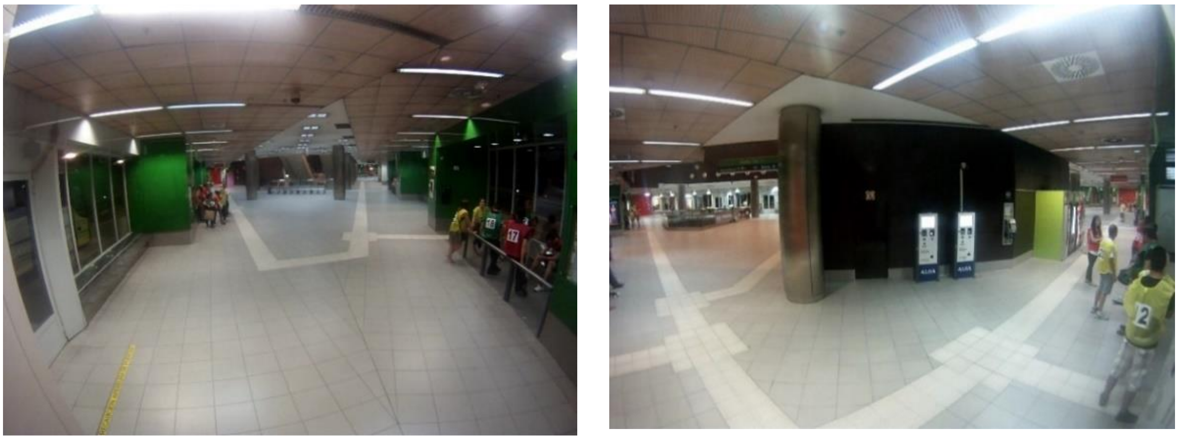


Figure 1. Layout of the bus concourse and boarding gates location.

The occupants

In total 75 subjects took part in experiment (32 female and 43 male). A deliberate effort was made to make the sample representative of the target population: 32 female and 43 male participants (age mean 40.7; standard deviation 14; range 17-73). Each participant was given a slip of paper with the number of a boarding gate (BG) to go and was instructed to remain there as if he/she were a passenger waiting the bus (see Figure 2). Table 1 shows the distribution of occupants within the concourse and the potential evacuation groups when the alarm sounded. It should be noted that this trial involved “pre-warned” participants who repeated test and were aware the of evacuation.



a) participants in BG4 and 5 *b) participants in BG7 and 6*

Figure 2. Snapshots of the location of participants within the concourse.

Building Level	Building area	Activity	Potential Group	# people
-1	Boarding Gate 1 (BG1)	Waiting	G1	6
-1	Boarding Gate 2 (BG2)	Waiting	G2	7
-1	Boarding Gate 3 (BG3)	Waiting	G3	6
-1	Boarding Gate 4 (BG4)	Waiting	G4	8
-1	Boarding Gate 5 (BG5)	Waiting	G5	8
-1	Boarding Gate 6 (BG6)	Waiting	G6	6
-1	Boarding Gate 7 (BG7)	Waiting	G7	9
-1	Boarding Gate 8 (BG8)	Waiting	G8	9
-1	Boarding Gate 9 (BG9)	Waiting	G9	7
-1	Boarding Gate 10 (BG10)	Waiting	G10	9

Table 1. Population distribution and activities when the alarm sounded during the evacuation experiment in a multimodal station.

The procedure

As explained, participants orderly accessed the concourse and went to the assigned boarding gate (BG). When all participants were at their respective BG, the alarm went off. The alarm consisted of a previous sound followed by a prerecorded voice message thought the PA system: *"Due to technical problems, we ask you to leave the station orderly. Follow the instructions of safety personnel"*. The alarm lasted 13 s. The trial was finished when all participants had evacuated the bus concourse trough the available emergency exits.

The data collection

For the data collection, five video-cameras were placed over the emergency exits (see Figure 1). The following variables were collected from each participant: 1) the response time (t_{res}) defined as the time from the sounding of the alarm to deliberate evacuation movement (s) and 2) the exit time (t_{exit}) defined as time from the sounding of the alarm to leave the concourse by an exit (s). The images were collected at a frequency of 29.97 frames/s and were analysed using the Avidemux 2.5.2 software.

The initial location (BG) and the exit used by each participant were identified and recorded. Therefore, it was possible to determine, for each individual, the route adopted during each evacuation trial. The measurements of response time and exit time variables were made as consistently as possible. The response time was taken at a specific frame when each individual move towards an exit. The exit time was taken at the specific frame when the body of the participant crossed a reference point at the exit doors. The frames associated then were noted and associated times logged to establish the variables t_{res} and t_{exit}.

Results

Table 2 displays the mean, standard deviation, maximum, minimum values of response time (t_{res}) and exit time variables (t_{exit}) and exit use observed for each potential evacuation group. Individuals from the same BG reached a consensus decision regarding the direction of evacuation i.e. they used the same exit. Figures 3 and 4 show the γ_{B_i} values obtained with the application of the proposed method. The behavioural cohesion among evacuees during the response phase of evacuation was confirmed for γ_{B_i} values >0.5 in G1(0.54) and G8 (0.62). Other potential groups produced γ_{B_i} values close to 0.5 G4(0.48), G5(0.48) and G7(0.44). These results should be considered as informative rather than definitive to confirm cohesion among evacuees. It should be noted that the response time variable (t_{res}) determines a specific action (i.e. from the alarm to starting to move) while the exit time variable (t_{exit}) covers all the evacuation process (i.e. from the alarm to exiting the enclosure).

When looking at results from Figure 4, the behavioural cohesion i.e. γ_{B_i} values >0.5 was confirmed in potential groups G1(0.73), G2 (0.53), G3 (0.84), G4 (0.53), G6 (0.59) and G9 (0.73). In these groups, despite some participants started evacuation movement individually, they tended then to move together and maintain the same speed throughout the entire evacuation movement (e.g. assuming the speed of the slowest member or increasing their speed to maintain the group).

Potential Group	# people	Response time (t_{res})				Exit time (t_{exit})				Exit use
		Mean	S.D.*	Min.	Max.	Mean	S.D.	Min.	Max.	
G1	6	8.82	1.99	7.03	12.23	20.67	2.02	17.80	23.03	4
G2	7	9.15	3.42	5.80	14.50	17.31	3.01	11.70	21.57	5
G3	6	3.63	1.65	1.83	5.57	22.89	1.33	21.00	24.93	1
G4	8	6.03	1.53	3.17	8.33	12.21	2.12	9.20	14.80	1
G5	8	10.11	2.58	7.27	13.57	23.36	4.56	17.70	28.17	1
G6	6	6.02	2.50	2.10	9.00	29.34	4.40	24.63	36.23	7
G7	9	9.22	2.53	5.00	12.00	18.72	3.81	11.47	24.73	7
G8	9	4.42	0.82	2.70	5.07	11.34	2.77	4.87	14.07	7
G9	7	6.11	2.49	2.03	9.73	28.14	2.73	23.67	32.37	3
G10	9	8.41	6.27	2.50	19.80	15.97	9.68	7.13	32.90	4
Overall	75	7.23	3.56	1.83	19.80	19.34	7.18	4.87	36.23	4
* Standard deviation										

Table 2. Response time (s), exit time (s) and exit used during the evacuation experiment in a multimodal station.

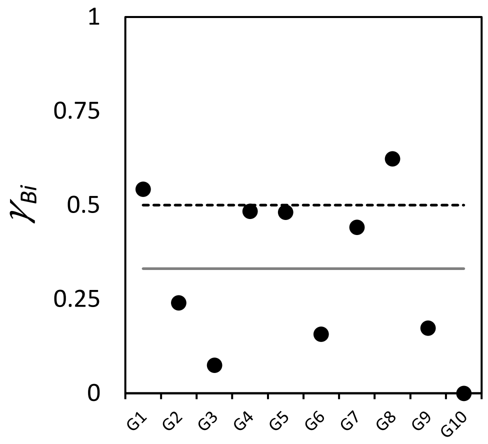


Fig. 3. γ_{B_i} *values for* t_{res} *variable during the evacuation of the bus concourse. Dashed line is the minimum threshold for group behavioural cohesion (*γ_{B_i} *=0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario(* $\tilde{\gamma}_B$*=0.33).*

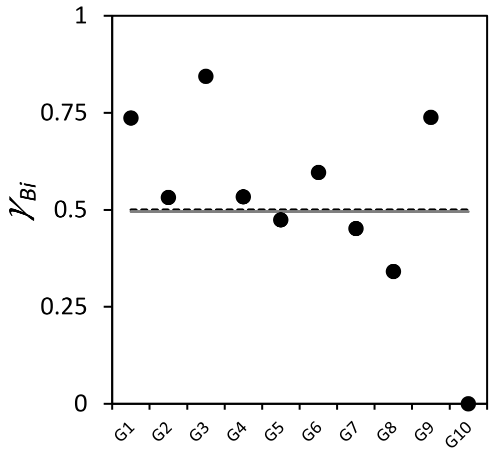


Fig. 4. γ_{B_i} *values for* t_{exit} *variable during the evacuation of the bus concourse. Dashed line is the minimum threshold for group behavioural cohesion (*γ_{B_i} *=0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario(* $\tilde{\gamma}_B$*=0.49).*

3.2 Case B: Evacuation drill in a sports centre

The second case involved an unannounced evacuation drill in a sports centre at the University of Cantabria, Spain. The evacuation drill took place on 18th May 2017.

The building
Figure 5 shows the layout of the building and the video-cameras location.

The occupants
In total 78 university students were involved in the evacuation. Occupants had no prior warning, while the two staff members had prior warning. The first staff member was in the office of level 0 in front of the Exit 1 (see Figure 5). The second one was in the gym of the Level -1 (he was the coach). The potential groups were predefined according to the specific location, the proximity where occupants were likely to interact each other and/or whether they share a target and/or an activity before the alarm. Table 3 shows the distribution of occupants within the building and the potential evacuation groups at the moment of the alarm. The first potential group G1 involved 11 occupants who were playing football in the Pitch 1 of the sport court. Other 9 occupants were playing badminton in the Pitch 2 of the sport court. Another potential evacuation group was defined for the analysis involving 11 occupants who were working out (CrossFit) in another area of the sport court (the Pitch 3). Figure 6 shows and snapshot of occupants in the sport court when the alarm went off. The rest of potential groups G4, G5 and G6 were defined since they were in separated enclosures within the building performing the same activity (G4 in the Gym, G5 dancing and G6 doing yoga).

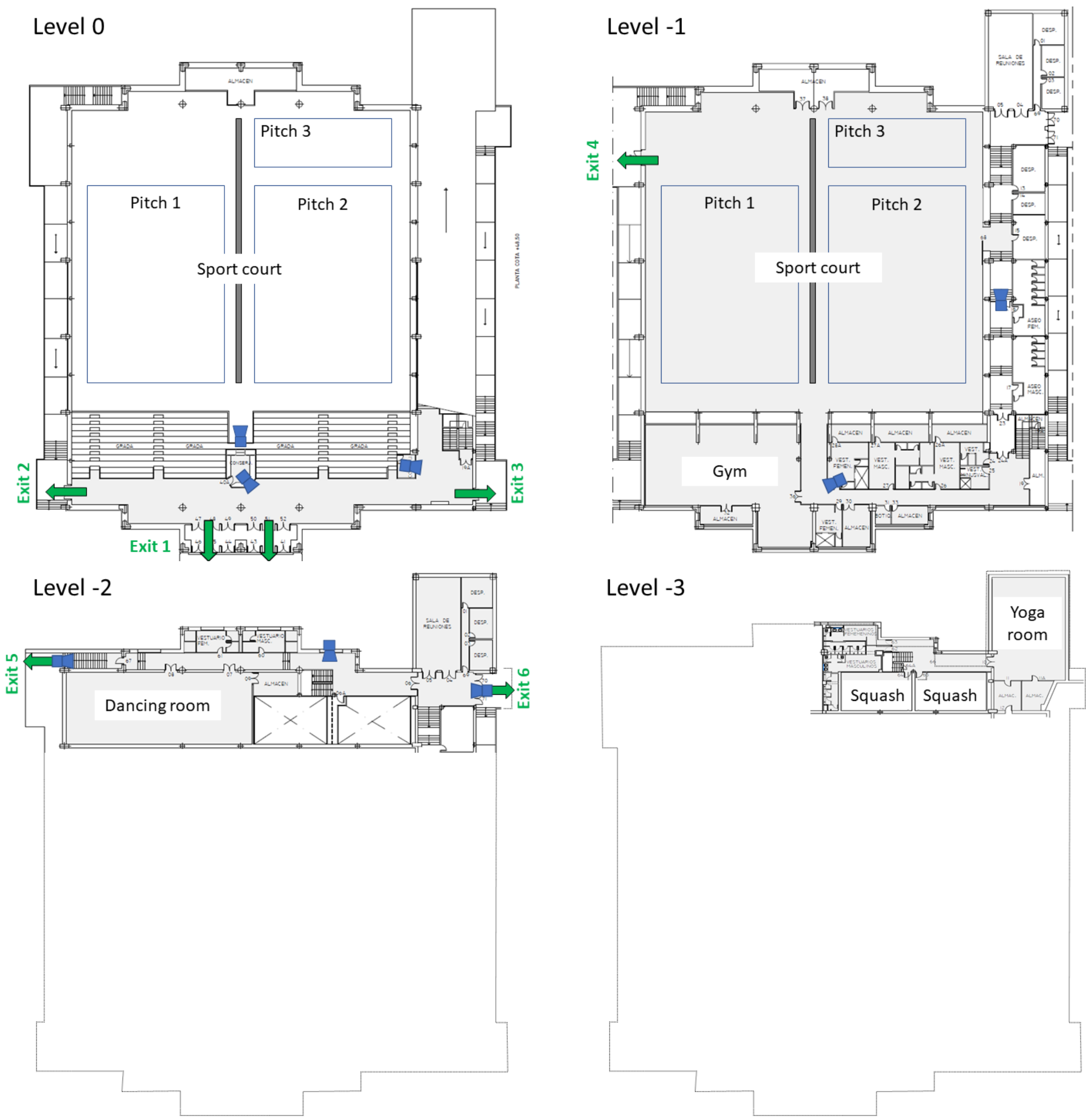


Fig. 5. Layout of the sport centre and video-cameras location.

Building Level	Building area	Activity	Potential Group	# people
-1	Sport court (pitch 1)	Football	G1	11
-1	Sport court (pitch 2)	Badminton	G2	9
-1	Sport court (pitch 3)	CrossFit	G3	11
-1	Gym	Exercise	G4	32
-2	Dancing room	Dance	G5	6
-3	Yoga room	Yoga	G6	9

Table 3. Population distribution and activities when the alarm sounded during the evacuation drill of the sports centre.

Fig.6. Initial location of occupants in the sport court when the alarm went off.

The procedure

The building has automatic fire detection and an alarm bell that was activated manually by the staff member on the Level 0 in front of the main entrance. The alarm lasted 3 min and 15 s before being switched off by the staff member. Then, staff members combed the building to warn occupants.

The data collection

Eight video-cameras were used for the data collection (see Figure 5). The video-cameras were installed as fast as possible 15 minutes before the alarm. As in Case A, the following variables were considered for the data collection of each occupant: 1) the response time (t_{res}) defined as the time from the sounding of the alarm to deliberate evacuation movement (s) and 2) the exit time (t_{exit}) defined as the time from the sounding of the alarm to leave the building by an exit (s). The data collection and processing was the same than Case A.

Results

Table 4 shows the observed values of the response time (t_{res}) and exit time (t_{exit}) variables and the exit use. Individuals from each potential evacuation group used the same exit. Potential groups G1, G2, G3 and G4 were warned by staff members. Potential groups G5 and G6 started evacuation by themselves. From Table 4 it is possible to see the differences between the lowest and highest values during the response and the movement phases of evacuation denoting a low dispersion of response time (t_{res}) and exit time (t_{exit}) variables in the potential evacuation groups.

Results from Figure 7 confirm behavioural cohesion during the response phase of evacuation with γ_{B_i} values >0.5 (G1=0.81; G2=0.93; G3=0.91; G4=0.83; G5=0.82; G6=0.77). Given this, it is possible to say that the occupants responded together, as a group. Figure 8 also shows γ_{B_i} values >0.5 representing behavioural cohesion during the movement phase (G1=0.76; G2=0.94; G3=0.93; G4=0.85; G5=0.53; G6=0.63). A decrease in the behavioural cohesion in groups G5 (from 0.82 to 0.53) and G6 (from 0.77 to 63) was observed during the movement phase. This was due to the longer distances that the occupants had to cover to leave the building i.e. some occupants moved faster than others.

Potential Group	# people	*Response time* (t_{res})				Exit time (t_{exit})				Exit use
		Mean	S.D.*	Min.	Max.	Mean	S.D.	Min.	Max.	
G1	11	329.14	23.00	306.31	379.68	358.62	21.72	337.20	406.01	4
G2	9	336.12	8.30	322.62	345.45	373.34	5.27	368.27	382.62	4
G3	11	366.48	12.31	355.96	395.53	389.97	7.18	381.78	406.77	4
G4	32	306.51	19.06	284.38	349.18	352.97	13.48	334.67	385.79	4
G5	6	41.43	2.69	38.17	44.88	151.57	18.13	133.33	168.57	1
G6	9	105.20	8.75	89.99	114.61	164.55	15.47	144.38	199.43	1
Overall		277.95	101.61	38.17	395.53	324.10	83.09	133.33	406.77	
* Standard deviation										

Table 4. Response time (s), exit time (s) and exit used during the evacuation in the sports centre.

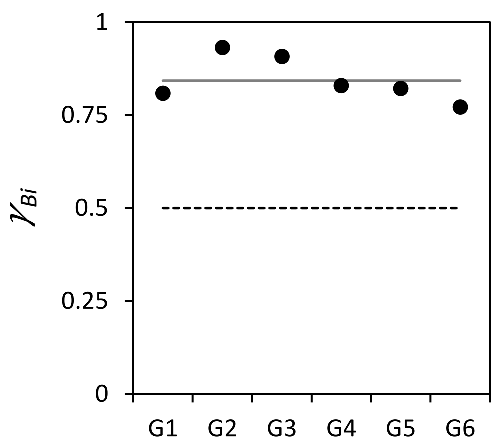


Fig. 7. γ_{B_i} values for t_{res} variable during the evacuation drill of the sports centre. Dashed line is the minimum threshold for group behavioural cohesion (γ_{B_i} =0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario($\tilde{\gamma}_B$=0.84).

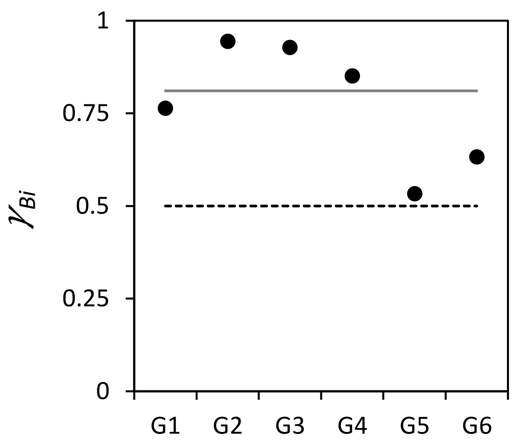


Fig. 8. γ_{B_i} values for t_{exit} variable during the evacuation drill of the sports centre. Dashed line is the minimum threshold for group behavioural cohesion (γ_{B_i} =0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario ($\tilde{\gamma}_B$=0.81).

3.3 Case C: Evacuation drill in a library

The third case involves a detailed analysis of the group behaviour in the library during an unannounced evacuation drill in the Faculty of Economics and Business at the University of Cantabria, Spain. The evacuation drill took place on 18th October 2016.

The library

Figure 9 shows the layout of the library and the tree areas analysed.

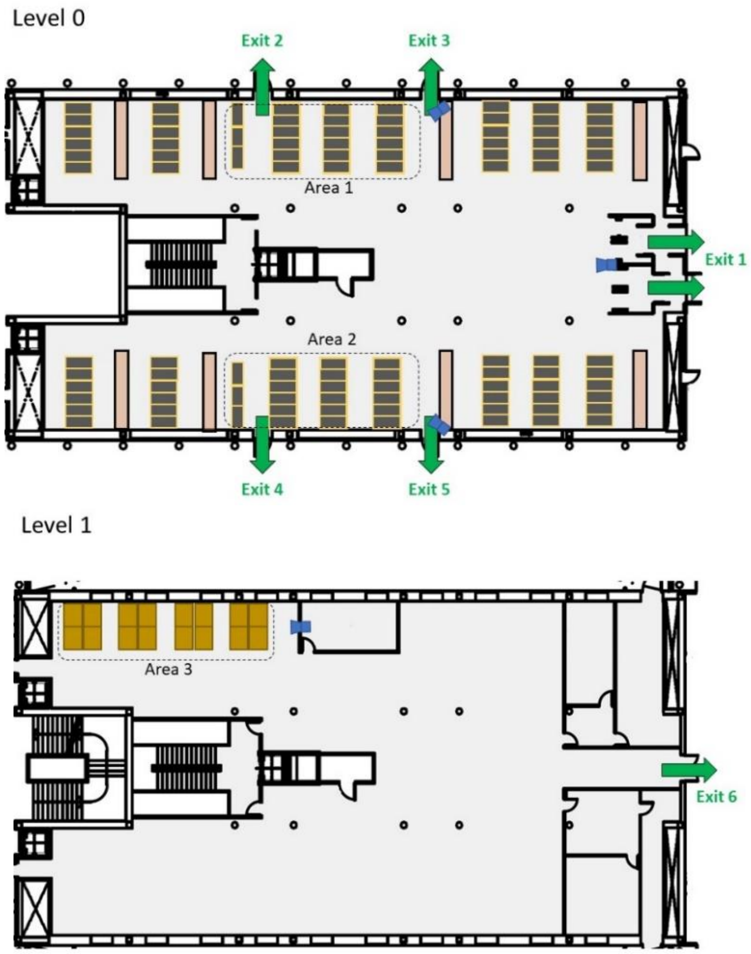


Fig. 9. Layout of the library, video-cameras location and areas for the study.

The occupants

The behaviour of 33 university students was analysed. They had no prior warning of the evacuation drill. There were two staff members: one staff member on Level 1 and one staff member on Level 0. Three potential groups were predefined according to proximity as occupants were likely to interact each other (visual/verbal) and also were doing the same activity before the alarm. Table 5 shows the location of the potential evacuation groups within the library and the number of occupants (the defined areas are shown in Figure 9).

Building Level	Building area	Activity	Potential Group	# people
0	Library (Area 1)	Studding	G1	10
0	Library (Area 2)	Studding	G2	10
1	Library-Computer room (Area 3)	Studding/using computers	G2	13

Table 5. Population distribution and activities when the alarm sounded during the evacuation drill of the library.

Figure 10 shows snapshots of occupants in Area 2 and 3. Table 5 shows the distribution of occupants within the library and the potential evacuation groups when the alarm sounded.

a) Area 2 *b) Area 3*

Fig. 10. Snapshots of Area 2 and Area 3.

The procedure

The building has automatic fire detection and an alarm bell that was automatically activated. Then, staff members combed the library to warn occupants.

The data collection

Four video-cameras were used for the data collection (see Figure 9). The video-cameras were installed as fast as possible 15 minutes before the alarm. However time constrains did not allow us to cover all available exits in the library with the video-cameras. Therefore, in this case only group behaviour during the response phase of evacuation was analysed through the following variables: 1) the recognition time (t_{rec}) defined as the time from the sounding of the alarm to the first response action such as collect belongings, shutdown lab top, stand up, put on jacket, etc. (s) and 2) the response time (t_{res}) defined as the time from the sounding of the alarm to deliberate evacuation movement towards the exit (s). As previous cases the images were collected at a frequency of 29.97 frames/s and were analysed using the Avidemux 2.5.2 software. The recognition time was taken at a specific frame when each individual started an activity to response the warning. The response time was taken at a specific frame when each individual started to move to a safe location.

Results

The recognition times (t_{rec}) and response times (t_{res}) observed are displayed in Table 6. Results show a wide dispersion of the variables. Given this, it is possible to say that occupants in the potential evacuation groups did not responded together, as a group.

Potential Group	# people	Recognition time (t_{rec})				Response time (t_{res})			
		Mean	S.D.*	Min.	Max.	Mean	S.D.	Min.	Max.
G1	10	289.81	90.49	118.95	354.99	225.16	76.68	193.59	398.20
G2	10	282.46	112.31	1.13	362.60	247.65	95.96	121.82	403.00
G3	13	316.93	61.83	193.69	384.98	271.83	56.00	225.83	394.76
Overall	33	298.26	86.75	1.13	384.98	336.78	73.79	121.85	403.00

* Standard deviation

Table 6. Recognition time (s) and response time (s) observed during the evacuation in the library.

Figures 11 and 12 show the γ_{B_i} values for recognition time and response time variables. Despite some occupants were together before the alarm forming smaller groups (two or three friends), results suggest that occupants behaved independently during the response phase of evacuation producing γ_{B_i} values < 0.5. While some occupants started evacuation activities some others ignored the alarm and continued with their activities as they did not recognize the alarm relevant to their situation. These occupants needed the staff intervention to physically undertake evacuation activities. Furthermore, 100 % of occupants performed different tasks before starting the purposive evacuation movement: shutting down laptops; packing work items; packing/collecting personal belongings; putting on jackets; physically moving to another location to perform an action. The time spent on these tasks varied considerably (G1 mean 46.81 s and standard deviation 19.37 s; G2 mean 47.61 s and standard deviation 32.80 s; G3 mean 25.12 and standard deviation 19.77 s) thus increasing the variability in the response phase of evacuation.

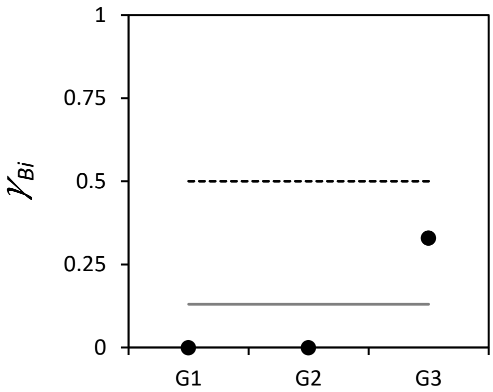


Fig. 11. γ_{B_i} values for t_{rec} variable during the evacuation drill of the library. Dashed line is the minimum threshold for group behavioural cohesion (γ_{B_i} =0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario($\tilde{\gamma}_B$=0.13).

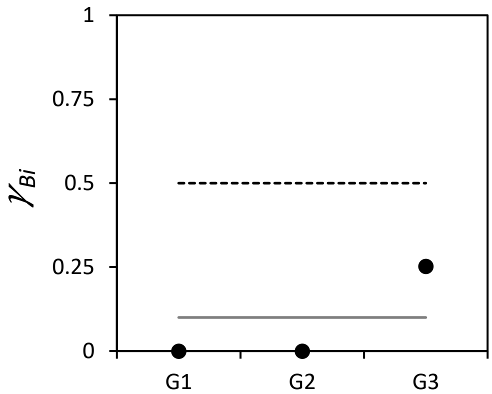


Fig. 12. γ_{B_i} values for t_{res} variable during the evacuation drill of the library. Dashed line is the minimum threshold for group behavioural cohesion (γ_{B_i} =0.5) and line in grey is the weighted coefficient to characterize the degree of behavioural cohesion of the evacuation scenario($\tilde{\gamma}_B$=0.10).

4 CONCLUDING REMARKS

Consensus and uniformity in individuals leads to a reduction in the behavioural variability. Based on this, a simplified method for measuring cohesion among evacuees has been implemented.

The method was used to determine quantitative evidences of collective behaviour in different evacuation scenarios: a bus concourse of a multimodal station (Case A), a sports centre (Case B) and a library (Case C). The analysis allowed us to determine whether participants responded and move together, as a group.

We found the presence of behavioural cohesion in 60% and 100 % of the potential evacuation groups for Case A and Case B respectively. But no evidences of behavioral cohesion were found for Case C. In this case, occupants responded independently and performed different tasks before start evacuation movements (collecting belongings, shutting down lab tops, etc.) thus increasing the behavioural variability. Overall, these results indicate that proximity could be an important factor but not decisive in the formation of evacuation groups. Social ties and whether occupants share a target and/or an activity before the alarm are also deemed to be important factors. This finding is an example of the importance of using the proposed method and the potential implications of taking into account groups for fire safety engineering analyses. For instance, implementing the same pre-evacuation time distribution to all occupants could be a good approach for evacuation scenarios similar to Case C (library) but potentially unrealistic for evacuation scenarios similar to Case B (sport centre).

The proposed method is intended for those who want to: a) increase the knowledge of collective behaviour in different evacuation scenarios, b) confirm theoretical frameworks and/or c) develop and validate new and current evacuation modelling and simulation tools.

Care is required when selecting the behavioural variables and defining the potential evacuation groups for the analysis. It is also noted that measurements are sensitive to extreme values (divergent behaviours) because they are based on the variability relative to the mean of data. For instance, given a defined group, it only takes an individual who acts separately to discard behavioural cohesion although the rest of group members behave as a group. This limitation may be solved through the application and inclusion of outliers detection methods. Nevertheless, this is very complicated for small sample sizes (N= [5-25]).

Further investigation and benchmarking of the method against other evacuation scenarios and experimental datasets is necessary. While the application of the method to three different evacuation scenarios is presented in this paper, the method in its generalised form has wider application.

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