Influence of information provided at the moment of a fire alarm on the choice of exit

Reference:
Peeters M., Compernolle Tine, Van Passel Steven.- Influence of information provided at the moment of a fire alarm on the choice of exit
Fire safety journal - ISSN 0379-7112 - 117(2020), 103221
Full text (Publisher's DOI): https://doi.org/10.1016/J.FIRESAF.2020.103221
To cite this reference: https://hdl.handle.net/10067/1751250151162165141

Influence of information provided at the moment of a fire alarm on the choice of exit

M. Peeters[a,b], T. Compernolle[b], S. Van Passel[b]

[a]Antwerp Management School Boogkeers 5, 2000 Antwerpen, Belgium

[b]University of Antwerp Prinsstraat 13, 2000 Antwerpen, Belgium

Declarations of interest: None

Corresponding author:

Michael Peeters, Zonneweelde 3 2970 Schilde

Email ID: mp@smartbuilding.io

Abstract

The data generated in buildings are used for all types of purposes. The quality of information used in assisting people to escape an emergency situation is of importance. In practice today, none of the data-generating systems that aid in the escape from emergency situations is validated on a regular basis. This study is based on the smart building concept. The rationale behind this concept is to provide information about a building and the usage of that building at each moment in time. An experiment was conducted to measure the impact of different types of information on participants' choice of exit, exit time and distance travelled. Seven identical floors of one building were used with different setups to see if the choice of exit is influenced by the type of information provided at the moment of an alarm. It was found that the information does have a significant impact on the choice of exit, escape speed and distance travelled. Furthermore, it was shown that false information can increase the time it takes to leave the building and the distance travelled, impacting the survival rate. The more imperative information is visualised, the stronger its influence is on the choices made.

Keywords: choice emergency exit; smart building

1. Introduction

The study of building evacuation began at the start of the twentieth century [1–3]. At that time, the main focus was on studying the movement of people in corridors, on stairs and through doors. The measures studied to ensure fire safety in buildings are, according to [4–6], predominantly based on technology. So far, regarding fire alarms, it has been found that those that involve a spoken message or directives for a communication system broadcasting to people are taken most seriously by the participants [7–9]. Fire response performance is an individual's ability to perceive and interpret signs of danger. Decisions are made and carried out according to this ability with the goal of surviving the fire [10]. This definition of fire response performance is process related: it is based on an understanding of the processes relating to evacuation [11–15]. Situations in or around a building upon the occurrence of a fire emergency may be chaotic. They also may not be entirely understood by the first responders. This issue significantly increases the difficulty of on-site decision making. The development of situational awareness might be of great importance in the field of information technology (IT) [16].

Due to developments in the field of IT, increasing information about buildings is being made available, and this can help people to escape hazardous situations. Supporting people with technology when evacuating a building is not new. Watson [17] noted that modern buildings contain considerable digital infrastructure that can serve building occupiers. Watson [17] also concluded that the digitalisation of buildings would go further than merely meeting the IT needs of the occupiers as it can also be used for monitoring, controlling and managing buildings. Tashakkori [18] studied the advantages of having a three-dimensional (3D) indoor and outdoor spatial model that can be used for indoor emergency response facilitation: 'having spatial data at the moment of a disaster would not only help people get out more efficiently, but also help first responders to optimise the intervention times' [18]. Similarly, Tang et al. [19] described how the Internet of Things (IoT) and sensors can be used to indicate danger in real time, notify people about hazardous situations and help them to escape these situations. They also described systems that can indicate the locations of any trapped evacuee. Chen et al. [20] argued that 'casualties in a structural fire are mainly caused by uncertainties about the trend and size of the fire and unfamiliarity with the environment', and described how building information modelling (BIM) can be used in the event of a fire to provide information to firefighters. They also claimed that the system can guide building occupants to safety and minimise casualties. By integrating BIM, fire simulation and IoT technology to create a warning system, they showed that it is possible to visualise danger and monitor the environment. Likewise, Chen and Huang [21] created a system that automatically made routing decisions that could potentially provide responders and evacuees with optimal routes to safety (or away from the hazardous situation). As such, Rüppel and Schatz [22] simulated human behaviour in emergency situations using a gaming approach based on BIM to study the impact of building choices on human behaviour during an evacuation process.

Yenumula et al. [23] noted that the absence of appropriate guidance during an evacuation process poses a threat to evacuees; they therefore promoted the use of a smart signage system and BIM to constantly monitor the building. They claimed that the major concerns were how evacuees respond to the proposed signage system and the 'refresh rate' of the system: 'It would be devastating to watch an exit sign becoming deactivated or turning into a stop mark with flame chasing from the back. Therefore, an intelligent prediction function could be helpful'. Cheng et al. [24] investigated the potential of a BIM-based intelligent fire-prevention and disaster-relief system that integrated 3D spatial and visual information with Bluetooth-based sensor networks, location-aided designs, optimal evacuation/rescue route planning and a real-time mobile application. The system aimed to provide evacuation guidance for evacuees, firefighters and commanders during the early detection/response stages of a fire disaster. They found that 3D visualisation improved the fire safety management process and that being able to monitor disaster areas in real time was an advantage for fire commanders.

All the above-mentioned studies looked at creating systems that process data and have the potential to help people escape hazardous situations. None of this research was experimental, and the authors assumed that people would interpret the data correctly. Some evacuation experiments have been performed where the goal was to research participants' evacuation speed and choice of exit. Specifically, Fu et al. [25] looked at the effect of different signage systems on the exit choice and navigation of the participants. They found that the position of the emergency signs and the behaviour of different groups influenced the choice of emergency exit. Similarly, Nilsson et al. [26] researched the exit choice and how it can be influenced. They conducted their experiment in an office building and a cinema theatre, and they influenced the exit choice by placing flashing green lights around the emergency exit. The results showed that more people chose the door with the green flashing lights. In addition, Chen et al. [27] researched the effect of visibility on evacuation via stairs and found a correlation between evacuation speed and visibility level.

There is a clear gap in the literature regarding the impact of information at the moment of a fire alarm on human behaviour with regards to the choice of emergency exit. While research has focussed on creating new systems and obtaining more and more precise information for people in hazardous situations and first responders, the effects of different information on people's choices made have not yet been studied. Moreover, the impact of false information has not been studied. The present study, therefore, attempts to close this gap by showing the impact of information on exit choice, the importance of information being correct for different levels of visibility and the effect of information on escape time and distance travelled.

In this study, we provided students with different types of information at the moment at which a fire alarm goes off, to help them get to safety. The experiment was set up in such a way that the information could also lead them to more dangerous situations. The difference in speed and distance travelled when given different types of information at the moment of the alarm was measured and tested for statistical significance. The only changing parameters between sets of experiments were the provided information.

In the next section, the method is described and there is a description of the experiment. The results are then presented with a discussion about the interpretation, before ending with the conclusions.

2. Methods

In this study, we considered that data are everything raw/unprocessed that are obtained directly from a measurement (e.g. sensors), while information is processed data, meaning that it has been interpreted in some way. When temperature is measured, the raw data is the Celsius value read out from the thermal sensor. When the Celsius value is printed onto a map in red for values higher than 50°C and in blue when lower than or equal to 50°C, we use the term information. This information is then used by the participants to choose an exit.

2.1. General structure of the experiment

To research the effects of information on the emergency escape process, an experiment was conducted in a former student housing facility the day before refurbishment started. As such, the building was empty, and there were nine identical floors (Figure 1) on which the experiments took place.

Each participant took part in all the different experiments, and each experiment was performed by one participant at a time while they were alone on the floor (other than the observer and the people helping in the experiment). Each of the participants visited a mock-up floor before the experiment started to help them get to know the site. This reduced the learning effect among the different experiments, as the students were able to familiarise themselves with the spatial layout. It was important to avoid the influence of the learning effect to ensure that the results were reliable/trustworthy. To mitigate the learning effect, the setups were organised in such a way that the appearance of incorrect information provided to the students at the moment of the alarm was not predictable.

Each experiment took place on a floor of the building under study. A total of seven floors were used. A different experiment took place on each floor.

To ensure that there were no technical failures, such as mobile phone connection problems, dead batteries and/or lag in information being sent, the information provided at the moment of the alarm was printed on a laminated sheet and given to the participants when the alarm sounded. In reality, this laminated sheet of information is replaced by a technical system (e.g. smartphones or displays) through which the information can be published at the moment of an alarm. Keeping these systems up to date and generating the correct information is a challenge for the management of the building.

2.2. Experiment details

2.2.1. Procedure and floor information

The internal organisation of a typical floor in the building is shown in Figure 1.

Figure 1: Internal organisation of a typical floor in 'Ten Prinsenhove'. The participants could study this floorplan (without the measurements) before the start of the experiment

The procedure followed in this study is as follows:

1. Participants knew:
    a. where room K is, and that this is the starting point of each experiment (Figure 1);
    b. that each floor is exactly the same (Figure 1);
    c. that the distances to A and B are practically equal;
    d. that the alarm going off is represented by the observer tapping them on the shoulder and handing them the information;
    e. that in the case of a real emergency, the fire alarm would ring and the procedures for emergency would be adopted, thereby suspending the study that might be being performed at that time.
2. Participants could study the floorplan as depicted in Figure 1 before the start of the experiment.
3. Participants were given at least 10 minutes to walk around an empty mock-up floor to familiarise themselves with the location.

During the experiment, the participants first studied the floorplan on paper (Step 2), and then walked around an identical floor (Step 3).

Participants were given a briefing before the experiment started. A summary of the brief is provided below:

1. Your only task is to get yourself to safety at A or B (the distances are equal) as fast as possible.
2. You will be given information when the alarm goes off.
3. Fire is represented by  placed in the hallway or room (indicated with a red rectangle in Table 2).

4. There can be more than one site of fire.

After the briefing, the participants were asked to go to the second floor and wait. From the second floor (which was identical to all floors where the experiment took place), participants were instructed to wait, and every three minutes, a new participant could start by going to the third floor, where the series of experiments started. Each participant performed the same series of experiments in the same order. There was no influence of other experiments in any experiment, as the participants could not walk to other floors.

2.2.2. Participants

The participants included 76 students from the AP university college studying integrated safety (IV) (n = 40) or energy management (ENE) (n = 35), except for one participant (n = 1), whose study programme was unknown. The participants ranged from 19 to 28 years old (with the majority being between 19 and 23 years old). In the population, there were six female students. We recognise that the participants are young master’s level students with similar demographic backgrounds. We did not test for demographic differences in terms of educational background, type of household, age or physical impairments. This can be considered a limitation.

This paper presents the results of 66 participants instead of 76 because two did not complete the experiments and 8 were selected to aid in the experiment. Table 1 shows information about the participants of the study.

Table 1: Basic information of the participants

University	Course attended	Number of participants
AP University College	**Integrated safety (IV)**	**40**
	Energy management (ENE)	**35**
	Gender	Number of participants
	Male	70
	Female	6
	Total participants	76

During the experiments, the participants were asked to escape the building (i) without any additional information, (ii) with correct additional information (e.g. the location of the fire and the temperatures of different rooms) and (iii) with incorrect information.

The time taken by each participant to escape, as well as the number of steps they took and whether they changed direction after their initial choice, was measured.

2.2.3. Experiments

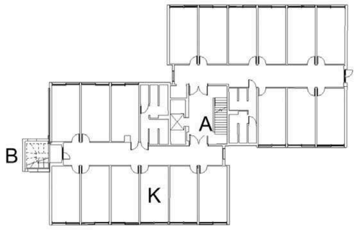
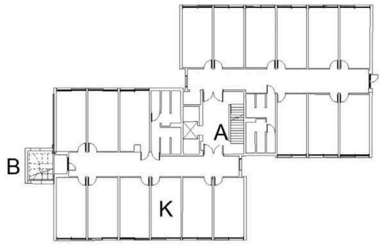
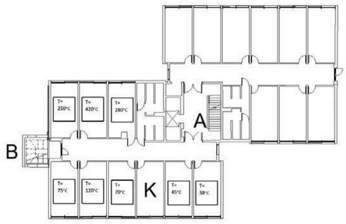
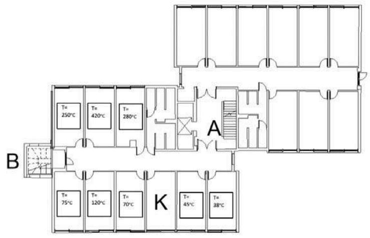
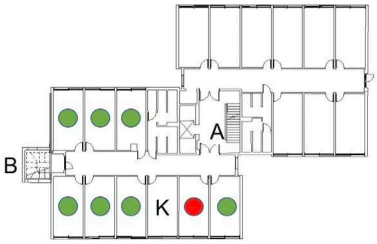
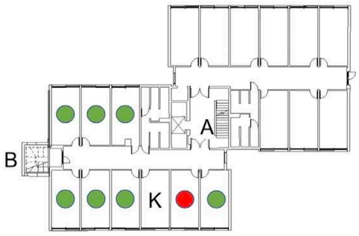
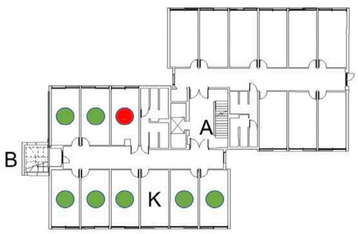
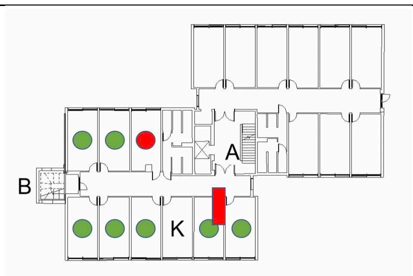
The experiments were grouped into comparison groups, and an experiment could belong to multiple groups. The groups were as follows:

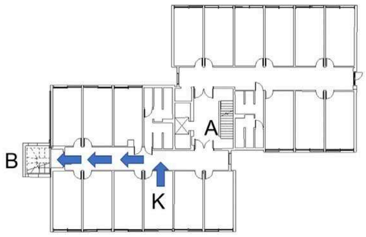
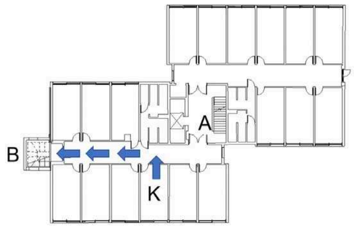
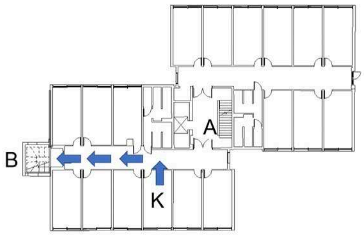
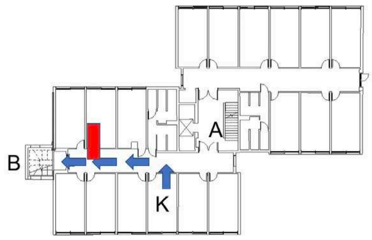
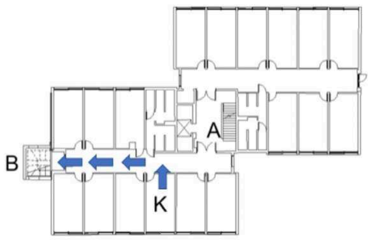
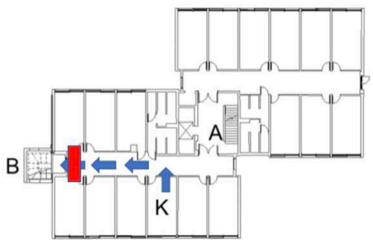
1. Group 1 was experiments in which correct information was given, albeit in different visualisations [experiments 1, 2, 3, 5].

2. Group 2 was experiments in which it was indicated where the smoke detector (green or red dots) was triggered. The information could be false, leading the participant into a possibly more hazardous situation [experiments 2, 6].
3. Group 3 was experiments in which the route towards the exit was indicated by arrows. The information could be false, leading the participant into a possibly more hazardous situation [experiments 3, 4, 7].

The different experiments are shown in Table 2, in which the red and green dots represent the state of the fire detector in a room. Green is all okay, while red is alarm. Both red and green dots occur at once.

Table 2: An overview of the different experiments, indicating the information given and the correct information. The table also indicates the order in which the participants performed the experiments. The red rectangle indicates the site of fire

Group	Experiment name and number of participants	Information given	Correct information	Type of information
1	Experiment 1 n = 66			Static floorplan
1	Experiment 5 n = 66			Temperature indicated in each room.
1/2	Experiment 2 n = 63			Red dot indicates the smoke detector that is triggering the alarm
2	Experiment 6 n = 65			Red dot indicates the smoke detector triggering the alarm. Red rectangle indicates a second fire blocking the obvious escape route.

1/3	Experiment 3 n = 62			Blue arrows show the path to follow
3	Experiment 4 n = 66			Blue arrows show the path to safety. Red rectangle shows the location of a second fire blocking the way.
3	Experiment 7 n = 66 Visibility about 1.5 m			Blue arrows show the path to follow. Due to limited visibility, however, participants only see the fire blocking the pathway when they are within 1.5 m of it.

In Table 2, the results are sorted into comparison groups of experiments. The experiment numbers are organised in the order in which the experiments were conducted, from top to bottom. To cope with the learning effects and in order not to make the logic of the study too obvious, the experiments were not ordered in their logical order.

The red rectangles in experiments 4, 6 and 7 illustrate the site of fire. In experiment 7, the participants wore special goggles (a Misty Mask) that simulated visibility in smoky environments. Visibility was limited to approximately 1.5 m when the participant was standing and 2 m when he or she was crawling. The selected distances complied with the practice of the Misty Mask operator and expert. The order of magnitude was the same as that expressed in [27]. As experiment 7 was performed with limited visibility, several participants crawled during the test.

2.3. Data measurement and analysis

The time taken to reach the exit was measured with a stopwatch with an accuracy of 1/100 of a second. The observer started the clock as soon as they gave the alarm (by tapping on the shoulder of the participant) and handed the participant the information. The number of steps taken by the participants was counted using a manual click counter. The observer was instructed to click each time the participant's left foot hit the ground. The observer also recorded if/when the participant changed direction (choice of exit) during each trial. The trial ended when the participant reached an exit.

Prior to the analysis, data for the continuous dependent variables (i.e. the time taken to reach the exit and the number of steps taken) will be examined for outliers by calculating the standardised values. According to Tabachnick and Fidell [28], standardised values greater than 3.29 in absolute value may be considered outliers. Outlying values should be removed from the data prior to the analysis.

In the first analysis, the IV and ENE students will be compared to determine whether they differed in their choice of exit, changes in direction, time taken and number of steps taken across each of the seven experiments. Specifically, chi-square tests of independence will be conducted to determine whether the IV and ENE students differed in their choice of exit (A versus B) and changes in direction (yes versus no) in each experiment. It is appropriate to conduct a chi-square test of independence when comparing two or more groups on a categorical outcome variable [29]. Separate chi-square tests will be conducted for each experiment and for each dependent variable. A Bonferroni correction may be applied to ensure that the cumulative Type I error rate across the multiple tests does not exceed .05. Distributional assumptions (e.g. normality) do not apply to the chi-square test; however, the expected frequencies in the chi-square contingency table should not be too small. McHugh [29] suggested that the expected frequencies below five should not account for more than 20% of the cells, and there should be no cells with an expected frequency of less than one. To determine whether the IV and ENE students differed in time taken and number of steps, independent sample t-tests will be conducted. It is appropriate to conduct an independent sample t-test when comparing two groups on a continuous outcome variable [30]. Separate t-tests will be conducted for each experiment and for each dependent variable, and a Bonferroni correction should be applied to ensure that the cumulative Type I error rate across the multiple tests does not exceed .05. The tests will be two tailed as the direction of the difference is not important. The assumptions of normality and homogeneity of variance will be assessed for each t-test using

Shapiro-Wilk tests and Levene's tests, respectively. If the assumptions of the t-test are not met, a non-parametric test (i.e. a Mann-Whitney U test) will be conducted instead.

In the second analysis, the experimental conditions will be compared to determine whether the conditions affected the choice of exit, changes in direction, time taken and number of steps taken. Three sets of comparisons will be conducted for each dependent variable. The first set of tests will compare the Group 1 experimental conditions (Experiments 1, 2, 3 and 5), where correct information was provided in different visualisations. The second set will compare the Group 2 experimental conditions (Experiments 2 and 6), where correct or incorrect smoke detector information was provided. The third set of tests will compare the Group 3 experimental conditions (Experiments 3, 4 and 7), where correct or incorrect escape routes were provided. To determine whether the conditions in each set led to differences in choice of exit and changes in direction, McNemar's tests will be conducted. The McNemar's test allows the researcher to determine whether differences exist in a dichotomous outcome between matched pairs of observations. Separate tests will be conducted for each dependent variable, and a Bonferroni correction should be applied to ensure that the cumulative Type I error rate across the multiple tests does not exceed .05. Distributional assumptions (e.g. normality) do not apply to McNemar's test. To determine whether the conditions in each set led to differences in time taken and number of steps, paired t-tests will be conducted. The paired t-test allows its users to determine whether differences exist in a continuous outcome between matched pairs of observations [30]. Separate tests will be conducted for each dependent variable, and a Bonferroni correction should be applied to ensure that the cumulative Type I error rate across the multiple tests does not exceed .05. The tests will be two tailed as the direction of the difference is not important. The assumptions of normality and homogeneity of variance will be assessed for each t-test using Shapiro-Wilk tests and Levene's tests, respectively. If the assumptions of the t-test are not met, a non-parametric test (i.e. a Wilcoxon signed rank test) will be conducted instead.

3. Results and discussion

An outlier analysis was performed, and a limited set of outliers was detected per experiment (max 2 outliers, as statistical tests were performed). These outliers were most probably due to measurement errors, i.e. errors from writing down the numbers or measuring incorrectly.

For further analysis, these outliers were removed from the experiment. The analysis was also performed with the outliers in the dataset, leading to no other conclusions. The experimental results were robust for the outliers. Whether there was a significant difference between the students of the different study programmes (IV and ENE) was checked; in neither the time it took to escape the building, the number of steps taken nor the choice of exit was a significant difference measured between participants of different study programmes. All data were further processed, not distinguishing the two study programmes.

3.1. Influence of information on the choice of exit

Table 3 provides an overview of the choices made by the participants and shows the change of direction, indicating participants' initial tendency to follow the information provided.

Table 3: Results of the choice of exit for the different experiments

Group	Experiment	Exit A	Exit B	Changes direction	More hazardous choice
1	1	60.61%	39.39%		No preference
1/2	2	46.88%	53.13%		Exit A
1/3	3		100%		Exit A
3	4	80.30%	19.70%	54.55%	Exit B
1	5	66.67%	33.33%	5.00%	Exit B
2	6	1.54%	98.48%	44.62%	Exit A
3	7	33.33%	66.66%	65.15%	Exit B

In experiment 1, the participants showed a slight preference to exit the way they came in (Table 3).

In experiments 2 and 6, the fire alarm was indicated by a red dot, and it was assumed that the participants would not go near the fire and would choose the safer route. In practice, however, the two exits were almost equally chosen in experiment 2 (46.88% vs 53.13%; Table 3). This suggests that either the information was not clear or that the participants chose to ignore it. As the information was mostly followed in the other experiments, it is likely that the information in this experiment was not clear. Days after the experiment, some participants (n = 21) were asked about their decision and why they ignored the information. In response, 18 participants said that they did not understand what the red dot represented. Although these participants did not understand what the red dot meant, they still had to make a choice. One of the aims of the paper is to understand the influence of the information. Thus, even if some participants did not understand some information, the influence of the information on the choices made can be correctly analysed.

The fire was represented by a wooden board with flames drawn on it. In experiment 6, the participants discovered the fire when leaving the room and seeing the flames. This experiment showed that the information was almost completely ignored when the danger was visible. In this experiment, a fire blocked the path towards exit A, even though the information indicated that A was the safer exit. Upon seeing the fire, 44.62% of the participants initially headed towards exit A and changed direction towards exit B (Table 3).

Experiment 3 showed that 100% of the participants followed the instructions given by the information (Table 3).

In experiment 4, where the information indicated that participants should go to emergency exit B even though it was blocked by flames, 54.55% changed direction and went towards the exit where there were no flames blocking the way (Table 3).

In experiment 5, the temperatures in the different rooms were given, and two thirds of the participants followed the information given and went towards the least hazardous exit (Table 3).

In experiment 6, the participants saw flames as they left the starting room. This led to 44.62% of participants changing direction and 1.54% trusting the incorrect information and going through the flames (Table 3).

For experiments 3, 4 and 7, the instructions said to go towards exit B, but in experiments 4 and 7, a fire blocked the path. In experiment 4, 19.70% of the participants followed the instructions (Table 3) and went through the flames to arrive at exit B. When asked about their decision (after the experiment took place), all participants that chose to go through the flames said that they assumed it was the safest route; since they did not know how dangerous the other side might have been, they assumed that the information provided knew best.

In experiment 7, which involved limited visibility, 66.66% of the participants followed the information and went towards the fire, changing direction once they encountered the fire. In experiment 7, which had limited visibility, 98.48% reached exit A, with 66.66% initially heading towards exit B before discovering the fire (Table 3). The remaining 1.52% gave up when they discovered the fire and did not reach either exit. No participants went through the fire after discovering it; they chose to look for the other exit, which is in contrast with experiment 4. After questioning the choice made, the participants indicated (14 out of 21 questioned) that they assumed that they were expected to look for another exit when they encountered the fire signs. Also, they were not sure that it was safe to go through the flames. Since they could see the danger in experiment 4, they assumed that it was safe to go through the flames.

The impact of information visualisation on the choice of exit can be discovered by the experiments of group 1. The information provided in experiment 3 was followed by 100% of the participants (Table 3), indicating that this information was well interpreted. In contrast, in experiment 2, almost 50% did not use the information (Table 3). After the experiment, some participants (n = 21) were asked about their decision, of whom 18 said that they did not understand what the red dot represented. In experiment 5, the most dangerous exit (B) was indicated by the room temperature; however, 33% of the participants still chose this exit. When asked why they chose exit B, 16 said that it took too long to figure out what the information meant, so they chose to ignore it.

McNemar's chi-square test was conducted to test the hypothesis that the outcome proportions were equal for the different exit choices within the experiment groups (group 1: experiment 1, 2, 3, 5; group 2: experiments 2, 6; group 3: experiments 3, 4, 7).

For experiment 3, all participants followed the information. Due to the imperative visualisation of the information and the clarity, 100% of the participants chose to follow the information. Table 4 shows the results of exit choice obtained using McNemar's chi-square test.

Table 4: McNemar’s chi-square test on exit choice between experiment groups. ‘Exp.’ is the abbreviation of the ‘experiment’

Group	N	χ^2	*p*	Exit	Exp. 1	Exp. 2	Exp. 4	Exp. 5	Exp. 6	Exp. 7
	62	4.26	.039	A	39	30				
				B	23	32				
1	57	1.14	.285	A	35			39		
				B	22			18		
	55	7.20	.007	A		26		38		
				B		29		17		
2	58	27	< .001	A		28			1	
				B		30			57	
3	62	21.56	< .001	A			49			20
				B			13			42

Experiment 3 is not listed in Table 4 as there is no analysis result if no differentiation can be made between the different results.

For group 1 in Table 4, it can be seen that there is a significant influence of the choice of exit between experiment 1 (plain floorplan) and experiment 2 (indication of the state of the fire detector in the room). Seeing that the only difference between the two experiments is the provided information, it is concluded that the choice of exit was influenced by the information. For experiment 5 (indication of the temperatures in the rooms), the influence of the information provided seems to be missing, leading to similar results in exit choice to those when a plain floorplan was provided (experiment 1). From post-factum ad-hoc questioning of the participants, it is indicated that the information provided in experiment 5 was not clear and was chosen to be ignored. This feedback is supported by the comparison between experiments 2 and 5, where it is clear that the choice of exit was influenced by the provided information of experiment 2 (indication of the fire detector by a green or red dot).

For group 2 (experiments 2 and 6) in Table 4, it is possible to state that the choice of exit was influenced by the presence of a site of fire blocking the path. Among the participants, 44.62% (Table 3) changed direction, and thus were initially misled by the provided information.

For group 3 (arrows showing the way to follow) in Table 4, the difference between experiments 4 and 7 is significant in choice of exit. Experiments 4 and 7 are identical other than the difference of having limited sight in experiment 7. Limiting sight influenced the dependency on information for the participants. As the participants could not see the site of the fire when leaving the room, they assumed that the information was correct. When confronted with the site of fire, they changed direction, losing valuable time by performing more steps.

3.2. Influence of information on escape time and steps

A two-tailed paired sample t-test was conducted to examine whether the mean difference in the time and step variables was significantly different from zero. To obtain valid results, the normality and homogeneity of variance was checked. The normality was checked using a Shapiro-Wilk test and the homogeneity of variance was checked using a Levene's test. If the assumptions were violated, a Wilcoxon signed rank test was also be performed to validate the results of the t-test. The two-tailed Wilcoxon signed rank test is a non-parametric alternative to the paired samples t-test and does not share its distributional assumptions [31]. The results for the Wilcoxon signed rank test are not shown in the tables.

Table 5: Results of the t-tests for two-tailed paired samples for group 1

					Experiment 1		Experiment 2		Experiment 3		Experiment 5	
Group	**Measure**	**N**	**t**	**p**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
1	Time	60	4.76	<.001	12.96	4.09	10.38	2.63				
		55	2.45	.018	12.90	4.04			11.38	2.56		
		61	8.84	< .001	12.97	4.04					8.71	1.99
		55	-1.98	.053			10.40	2.80	11.26	2.56		
		61	5.66	<.001			10.49	2.80			8.76	2.00
		57	6.61	<.001					11.32	2.54	8.74	2.03
1	Steps	61	4.23	<.001	10.49	4.48	7.84	1.42				
		56	2.29	.026	10.98	4.72			9.46	1.48		
		62	3.11	.003	10.65	4.54					8.69	1.96
		55	3.35	.001					9.49	1.48	8.56	1.74
		53	-6.59	< .001			7.77	1.28	9.47	1.51		
		59	-3.72	< .001			7.83	1.44			8.66	1.94
		55	3.35	.001					9.49	1.48	8.56	1.74

Table 6: Results of the t-tests for two-tailed paired samples for groups 2 and 3

					Experiment 2		**Experiment 3**		**Experiment 4**		**Experiment 6**		**Experiment 7**	
Group	**Measure**	**N**	**t**	**p**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
2	Time	57	-4.63	< .001	10.41	2.87					12.50	3.00		
2	Steps	57	-4.75	< .001	7.75	1.42					8.97	1.70		
3	Time	56	0.09	.931			11.37	2.54	11.30	4.62				
		54	-10.86	< .001			11.52	2.46					31.36	12.85
		60	-11.21	< .001					11.17	4.37			31.80	13.42
3	Steps	55	0.38	.707			9.47	1.49	9.27	3.49				
		53	-10.06	<.001			9.55	1.46					18.57	6.19
		60	-9.72	< .001					9.28	3.40			18.88	6.54

From the results in Table 5 and Table 6, it can be concluded that between the experiments in a group, there is a difference in escape time and steps taken. As the only difference between the different experiments within a group is the information provided, it is shown that the information provided impacted the escape time and steps taken. The correctness of and the way in which the information is visualised impacted the initial choice of exit in the experiment.

The only deviation in the above statement is observed for the comparison between experiment 3 and experiment 4 in group 3 (for time and steps). Here, there is no significant difference between the time to escape and the steps taken. This is due to the experimental setup, which was rather small. When the participants left the room, they immediately saw the danger and changed direction. The change of direction was done so fast that for this experiment, there is no significant difference in the measurements. Table 3 shows that in experiment 4, the participants initially followed the information, as 54.55% changed direction. In the experiment, the information provided had an impact on the escape time and steps taken. Given the scale of the floors, these results are considered a best-case impact. If the site of fire would be around a corner, for example, the impact on the escape time and steps taken is expected to be much worse. The result of the experiment in which participants had limited visibility (due to special goggles to simulate sight in smoky conditions) indicate that the participants relied more on the information provided to them compared to the other setups. The impact of the information being wrong was much bigger as it took the participants longer to see the site of the fire and correct their choice of exit.

The authors of [25] and [26] studied the impact of the choices made assuming that the information was correct. The present experiment shows that the choice of exit can indeed be influenced, but that the information quality matters. In the experiment, the participants also followed wrong information that could lead them to more hazardous situations. When other senses are blocked (such as visibility due to smoke), it is seen that, much like in the experiment conducted in [27], the escape time and distance travelled are longer. When provided with wrong information, it takes longer for the person escaping the hazard to correct his/her choice of exit, and as such, the person remains in a hazardous environment for longer.

In practice, it is suggested that system integrity checks, validation tests and robustness tests of the systems used in buildings be carried out, which are practices that are not currently implemented. Note that providing no information other than a static floorplan gives a higher survival rate than any provision of false information. Keeping building data up to date is a real challenge for building managers. However, if data is being used for emergency aid, it is imperative that the information is up to date and correct.

The experiments indicate that not all data sources are suited to aiding a person trying to escape a building. It should be noted that information that is not clear is ignored. Imperative information (i.e. arrows showing the way) was the most influential on the choices made by the participants. It was also with this information representation that the participants were going through the fire, because the information tells them to. Further research can investigate the impact of types of information visualisation on the impact of the choice that is made.

4. Conclusions

The main quantitative findings of the study are summarised as follows.

1. In experiment 1, 60.61% of participants exited the floor through exit A and 39.39% left through exit B. Neither of the two exits was more hazardous than the other.
2. In experiment 2, the two exits were almost equally chosen (46.88% vs 53.13%).
3. Experiment 3 showed that 100% of participants followed the instructions given by the information.
4. In experiment 4, 54.55% of the participants changed direction when the information told them to go to emergency exit B, even though it was blocked by flames, and went towards the exit where there were no flames blocking the way. In this experiment, 19.70% of the participants followed the instructions and went through the flames to arrive at exit B.
5. In experiment 5, 66.67% of the participants followed the information given and went towards the least hazardous exit; 5.00% of the participants changed direction during the experiment.
6. In experiment 6, the fact that the participants saw flames as they left the starting room led to 44.62% changing direction and 1.54% trusting the incorrect information and passing through flames.
7. In experiment 7, which had limited visibility, 98.48% reached exit A, with 66.66% initially heading towards exit B before discovering the fire (Table 3). The remaining 1.52% gave up when they discovered the fire and did not reach either exit. No participants went through the fire after discovering it.

The information provided to the participants at the moment of an alarm influenced the choice they made to find an exit. Once it became apparent that the information might be wrong, the participants often changed their choice and opted for the safer exit. The more imperative and clear the information (i.e. the less room for interpretation by the participants), the more the information was followed. This indicates that not all information and information visualisations are suitable for use as an emergency aid.

To conclude, this type of information can be of importance in our day-to-day lives. We consciously and unconsciously use data for each action we take, and if we are in a crisis, information (derived from some sort of data) is the first thing we need. In an emergency, people need to get to safety as quickly and securely as possible. The purpose of this study was to increase the success of evacuating people safely from a building in case of a fire emergency. When deciding to include information in emergency procedures, it is important to also include these in fire drills. Today, there is no validation of the information that systems generate. This research shows that the information influences people’s behaviour in crises. People involved in the management of buildings (e.g. property managers, owners and asset managers) and policymakers should take the results of this research into account and define how information systems need to be audited and tested on a regular basis to ensure the correctness of their response.

As future work, the use of BIM would contribute to providing information to evacuees. Through data originating from a sensor coupled with the BIM plan, it would be possible to simulate what is going to happen and redirect the people trying to escape. In the case of BIM, keeping the data of the building up to date is a challenge. Making use of the data during emergency situations makes the issue even more challenging. Not providing information is safer than providing false information.

Acknowledgements

None

Funding

Tine Compernolle thanks the Research Foundation – Flanders (FWO) for funding her postdoctoral mandate with grant number 12M7417N.

References

[1] D.J. O'Connor, 'Integrating human behaviour factors into design', *J. Fire Prot. Eng.*, vol. 28, pp. 8–20, 2005, in M. Kobes, I. Helsloot, B. de Vries and J. G. Post, 'Building safety and human behaviour in fire: A literature review', *Fire Safety J.*, Vol. 45, pp. 1–11, 2010. doi: https://doi.org/10.1016/j.firesaf.2009.08.005.

[2] J. L. Bryan, 'A selected historical review of human behavior in fire', *J. Fire Prot. Eng.*, Vol. 16, pp. 4–10, 2002.

[3] D. Tong and D. Canter, 'The decision to evacuate: a study of the motivations which contribute to evacuation in the event of fire', *Fire Safety J.*, Vol. 9, pp. 257–265,

1985. doi: https://doi.org/10.1016/0379-7112(85)90036-0.

[4] H. Frantzich, *A model for performance-based design of escape routes*, 1994.

[5] R. F. Fahy and G. Proulx, 'Toward creating a database on delay times to start evacuation and walking speeds for use in evacuation modelling', in *Second International Symposium on Human Behaviour in Fire*, Boston, 2001, pp. 175–183.

[6] SFPE, *Engineering Guide to Human Behaviour in Fire*, SFPE, 2002.

[7] G. Proulx and J. K. Richardson, 'The human factor: building designer soften forget how important the reactions of the human occupants are when they specify fire and life safety systems', *Can. Consult. Eng.*, Vol. 43, pp. 35–36, 2002.

[8] G. Proulx, 'Why building occupants ignore fire alarms', *Construction Technology Update*, Vol. 42, Ottawa, IRC-NRCC, 2000.

[9] G. Proulx and D. Laroche, ‘Study show slow public recognition of the temporal-three evacuation signal’, *Constr. Innov.*, Vol., pp. 1–6, 2001.

[10] M. Kobes, ‘Zelfredzaamheid bij brand; Kritische factoren voor het veilig vluchten uit gebouwen’, *Boom Juridische uitgevers*, Den Haag, The Netherlands, 2008 [Fire response performance; the critical factors for a safe escape out of buildings].

[11] T. T. Pires, ‘An approach for modelling human cognitive behavior in evacuation models’, *Fire Safety J.*, Vol. 40, pp. 177–189, 2005. doi: https://doi.org/10.1016/j.firesaf.2004.10.004.

[12] D. J. O’Connor, ‘Integrating human behaviour factors into design’, *J. Fire Prot. Eng.*, Vol. 28, pp. 8–20, 2005.

[13] H. Frantzich, *A model for performance-based design of escape routes*, 1994.

[14] J. D. Sime, ‘Crowd psychology and engineering’, *Saf. Sci.*, Vol. 21, pp. 1–14, 1995.

[15] D. A. Purser, ‘Data benefits: fire prevention’, *Fire Eng. J.*, Vol. 21, 2003.

[16] L. Martin and R. Flin, ‘Building fire commander situational awareness from team shared mental models’, *IEE*, London, UK, pp. 1–2, 1997, in N. Li, Z. Yang, A. Ghahramani, B. Becerik-Gerber and L. Soibelma, ‘Situational awareness for supporting building fire emergency response: Information needs, information sources, and implementation requirements’, *Fire Safety J.*, Vol. 63, pp. 17–28, 2014.

[17] A. Watson, ‘Digital buildings – challenges and opportunities’, *Adv. Eng. Informatics*, Vol. 25, pp. 573–581, 2011. doi: https://doi.org/10.1016/j.aei.2011.07.003.

[18] H. Tashakkori, A. Rajabifard and M. Kalantari, 'A new 3D indoor/outdoor spatial model for indoor emergency response facilitation', *Build. Environ.*, Vol. 89, pp. 170–182, 2015. doi: https://doi.org/10.1016/j.buildenv.2015.02.036.

[19] S. Tang, D. R. Shelden, C. M. Eastman, P. Pishdad-Bozorgi and X. Gao, 'A review of building information modeling (BIM) and the internet of things (IoT) devices integration: Present status and future trends', *Autom. Constr.*, Vol. 101, pp. 127–139, 2019. doi: https://doi.org/10.1016/j.autcon.2019.01.020.

[20] X. S. Chen, C. C. Liu and I. C. Wu, 'A BIM-based visualization and warning system for fire rescue', *Adv. Eng. Informatics*, Vol. 37, pp. 42–53, 2018. doi: https://doi.org/10.1016/j.aei.2018.04.015.

[21] A. Y. Chen and T. Huang, 'Toward BIM-enabled decision making for in-building response missions', *IEEE Trans. Intell. Transp. Syst.*, Vol. 16, pp. 2765–2773, 2015. doi: https://doi.org/10.1109/TITS.2015.2422138.

[22] U. Rüppel and K. Schatz, 'Designing a BIM-based serious game for fire safety evacuation simulations', *Adv. Eng. Informatics*, Vol. 25, pp. 600–611, 2011. doi: https://doi.org/10.1016/j.aei.2011.08.001.

[23] K. Yenumula, C. Kolmer, J. Pan and X. Su, 'BIM-controlled signage system for building evacuation', *Procedia Eng.*, Vol. 118, pp. 284–289, 2015. doi: https://doi.org/10.1016/j.proeng.2015.08.428.

[24] M. Y. Cheng, K. C. Chiu, Y. M. Hsieh, I. T. Yang, J. S. Chou and Y. W. Wu, 'BIM integrated smart monitoring technique for building fire prevention and disaster relief', *Autom. Constr.*, Vol. 24 pp. 14–30, 2017. doi: https://doi.org/10.1016/j.autcon.2017.08.027.

[25] L. Fu, S. Cao, W. Song and J. Fang, 'The influence of emergency signage on building evacuation behavior: An experimental study', *Fire Mater.*, Vol. 43, pp. 22–33, 2019. doi: https://doi.org/10.1002/fam.2665.

[26] D. Nilsson, H. Frantzich and W. Saunders, 'Influencing exit choice in the event of a fire evacuation', *Fire Saf. Sci.*, Vol. 9, pp. 341–352, 2008. doi: https://doi.org/10.3801/IAFSS.FSS.9-341.

[27] J. Chen, J. Wang, B. Wang, R. Liu and Q. Wang, 'An experimental study of visibility effect on evacuation speed on stairs', *Fire Saf. J.*, Vol. 96, pp. 189–202, 2018. doi: https://doi.org/10.1016/j.firesaf.2017.11.010.

[28] B. G. Tabachnick and L. S. Fidell, *Using Multivariate Statistics*, sixth ed. Boston, MA, United States: Pearson Education (US), 2013.

[29] M. L. McHugh, 'The Chi-square test of independence', *Biochem. Medica*, pp. 143–149, 2013. doi: https://doi.org/10.11613/bm.2013.018.

[30] A. Field, *Discovering Statistics Using SPSS*, third ed. London: SAGE Publications, 2009.

[31] W. J. Conover and R. L. Iman, 'Rank transformations as a bridge between parametric and nonparametric statistics', *Am. Stat.*, Vol. 35, pp. 124–128, 1981. doi: https://doi.org/10.1080/00031305.1981.10479327.