Graphical tools for helping firefighters in victim rescues. Assessment during a live fire training program.

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ABSTRACT

This study compares three different methods to communicate the features of a building to firefighters, before starting a victim rescue during a live fire training program. Participants in this study did not previously know the hotel used for developing the activities. The effective number of participants was 144, all professional firefighters. One of the exercises in this training program was thoroughly designed not only for training purposes, but also to test different guide versions. The innovative guides were based on two different technologies (simple stapled sheets of paper and digital content displayed on a tablet) and were developed using several graphical tools (conventional pictures, aerial images captured with drone, 3D models, 360º pictures, etc.). With the intention of facilitating firefighters' activity during a victim rescue, results obtained using these tools were compared with a conventional communication method. The assessment methodology applied in this study included the use of an anonym questionnaire, as well as the analysis of the videos captured with action cameras, attached with a harness to the chest of two of the four firefighters in every team, during the training activities. Thanks to these videos, it was possible to compare the time required for rescuing the victim and to observe followed paths, visited rooms and substantial information about the tested tools, including valuable participants' comments. For in emergency situations, the tools described in this paper were preferred to the already existent self-protection plans, usually considered too extensive for fast communication, a matter of special importance in victim rescues.

Keywords: Graphical tools; Rescue of victims; Emergency; Live fire training; Firefighters; Self-protection plans.

1. Introduction

Firefighting is a complex activity with different kinds of physical (Brotherhood et al., 1997; Carlén et al., 2017; Clark et al., 2002; Kilbom, 1980; Lusa et al., 2002; Paley and Tepas, 1994; Paterson et al., 2016; Poplin et al., 2016; Williford et al., 1999) and intellectual (Berges et al., 2018; Gnacinski et al., 2015; Kaikkonen et al., 2017; Kalimo et al., 1980; Wagner and Martin, 2012) requirements, from load movements to interpretation of technical drawings. The time that firefighters need for successfully finishing a rescue is a critical aspect for the health conditions of the rescued victims. For these reasons, methods to optimize times are normally very positive and the use of new or improved tools, as part of these methods, could help.

This study tries to assess the real value of two different new versions of technical documents used to describe the most critical aspects of public buildings and their features. These documents are a key part of the corporate self-protection measures that must be taken by private and public entities in Spain, in order to prevent and control risks and to optimize the response to emergencies. The legal background of corporate self-protection in this country is based on Article 15 of its Constitution (Spain, 1978), which recognizes the right to life and physical integrity, as well as the the EU Charter of Fundamental Rights (European Union, 2012). Particularly, in Spain, the Law on "Civil Protection" (Spain, 1985), in articles 5 and 6, establishes a base and responsibilities in this field, while the Royal Decree 393/2007 (Spain, 2007) approves the "Basic Self-Protection Standards" for those places that could be involved in activities that may originate emergency situations. From the point of view of occupational safety and health, the Spanish Law 31/1995 (Spain, 1995) also promotes the protection of the workers against risks. Thus, for all these reasons, self-protection plans must facilitate the management of control and security in the development of corporate activities (Protección Civil, 2013). These plans must include the analysis and evaluation of risks, the identification of preventive measures and objectives, the resources (both human and material) that the organisation can use to prevent risks and in emergencies, the emergency procedures that would ensure evacuations and the coordination procedures with the public system of Civil Protection. The importance of these plans has been previously described (Sánchez-Palacios et al, 2010) and, according to previous research, they can be applied as technical and educational tools (Castro and Sans 2014). Therefore, it is reasonable that fire departments must have a copy of the self-protection plans, although, according to the opinions of all the firefighters interviewed during this research, these documents are usually too extensive and full of details to be considered useful in an emergency situation, because the intervention times must be as short as possible. This was the reason why, three years ago, the Fire Service of the Province of Zaragoza (Spain) and the University of Zaragoza started collaborating in the development of new formats of the self-protection plans that could be convenient in emergency situations.

Trying to generate a version of the self-protection plans that could be useful in an emergency, a group of firefighters with experts in construction and occupational health and safety specialists started defining new rules of the modified documents as described below.

First, they should be as concise as possible, including only those pieces of information that could be really useful in an emergency.

Second, visual information was considered a key aspect: carefully chosen maps, pictures, 3D models and signage were crucial to communicate as fast and clearly as possible.

And third, the order and clarity of all the information must be always maintained.

According to these principles, shorter documents were generated in order to be used in emergencies, as they were considered really useful by the involved firefighters. They were called “Operative Guides” and one of them is shown in the following video frame (Fig. 1) from a simulated live fire intervention.

Fig. 1. Paper Operative Guide being used in a training session.

The operative guides were printed and stapled to be used in situ by the firefighters. Although they were considered a notable improvement, compared with the much more extensive self-protection plans, the possibility of improving them was considered by using some of the advantages of digital technologies. The main idea was to develop an online repository of digital operative guides that could be accessed with any mobile device used by the firefighters in an emergency intervention. From that point, as digital devices could replace paper documents, additional features could be taken into account, including video, VR, etc. Different options were studied and tested, as described in the following section, and a digital prototype, online-based, was developed to be assessed in this study.

After a long process of collaborative development, which started on 2014, different versions of self-protection plans had been developed, all with positive and negative aspects. This was the reason why this study tried to identify the best option and if some of its aspects could also be improved.

There were different options to assess these versions, but the research team agreed to do it during a live fire training program. Although a questionnaire based qualitative study was possible, the intention was to assess it under realistic conditions, and not only considering firefighters’ opinions. Although the quality of virtual simulations has increased during the last years (Cha et al., 2012; Kolmanič et al., 2013; Xu et al., 2014; Williams-Bell et al., 2015; Li et al., 2017; Buttussi and Chittaro, 2018) thanks to technical innovations, live fire training programs are still considered necessary. In fact, the development of some skills would require much more realism than what virtual reality (VR) systems can simulate nowadays. Thus, fire departments have their training programs which include different kinds of live fire training scenarios (Padgett, 2008; Willi et al., 2016; KOIN 6, 2017; WCPO, 2018). One of these live fire training programs was considered the ideal situation for developing this study, as described in the next section.

2. Method

As the main purpose of this research was to assess and compare the effectiveness of different graphical tools for helping firefighters during a rescue, real training sessions were considered the ideal scenario for developing the tests. Thanks to the collaboration established between the University of Zaragoza (Spain) and the firefighters of the Province of Zaragoza, more than 150 fire professionals participated in this study, as described below.

2.1. Fire training facilities in this study

This live fire training program was developed in an abandoned rural hotel in La Almunia de Doña Godina (Zaragoza, Spain). This training structure is a three-story building, plus basement, with a total of 11 guest rooms and the typical hotel areas (reception, restaurant, kitchen, etc.). This building, with concrete structure, was technically assessed by engineers and firefighters and prepared for the live fire training sessions, after receiving the required permissions.

The importance of paying attention to fires in hotels is evident, as they are strongly associated with high-casualty fires (Lu et al., 2011). When the status of facilities for fire safety in hotels was studied in Spain (Sierra, 2012), a clear statistical co-relation was described between the fire safety conditions of hotels and the requirement to follow reference regulations. According to Campbell (2015), every year, several thousands of structure fires in hotels and motels are attended by fire departments in the USA, with dozens of millions of dollars lost in property damage, more than a hundred civilian injuries and an average of 9 civilian deaths per year, during the period 2009-2013 in that country.

According to the NFPA 1403, no person is able to play the role of a victim inside a live-fire training building (National Fire Protection Association, 2012). In order to replicate the weight, feel and resiliency of the victim, an adult rescue manikin with a weight of 165 lbs (74.8 kg) and 5 feet 5 inches (165.1 cm) height was used to play this role. It was assembled according to its instructions (Simulaids, 2013) and properly protected with clothes, shoes and duct tape, as shown in Fig. 2.

Fig. 2. Rescue training manikin ready for one of the training exercises.

All the participants were equipped with the appropriate personal protective clothing and equipment, according to the UNE-EN 469:2006 (AENOR, 2006), which is the Spanish version of the European standard EN 469:2005 (CEN, 2005), including protective trousers (manufactured by Bristol Uniforms Ltd), firefighter turnout coat (manufactured by Bristol Uniforms Ltd), fire safety boots (manufactured by FAL Calzados de Seguridad, S.A.) and gloves (manufactured by Dragon Gloves), protective hood (manufactured by Protec Solanas, S.L.), firefighting helmet (manufactured by MSA Safety Incorporated), self-contained breathing apparatus (SCBA, manufactured by MSA Safety Incorporated) and personal alert safety system (PASS, manufactured by MSA Safety Incorporated).

Two action cameras (QUMOX SJ4000) were used by each team of four firefighters. Both were attached with a harness to the chest of two firefighters in the team, always including the leader of the group. The purpose of these cameras was not only recording the video of the intervention, but also to store the activity initial and final times, the rescue duration, the followed path, the number of visited rooms and significant information about the tested tools.

Trucks with additional equipment, water and hoses were also available for the teams of firefighters outside of the building, in similar conditions to a real firefighting intervention. Finally, a 10-inch tablet with access to the Internet was available for those firefighters that tested the digital guide to be assessed in this study (Fig. 3).

Fig. 3. Firefighters using a tablet with the digital guide.

2.2. Participants

The course duration was planned for 14 days, with 3 teams of 4 participants each. Out of those 42 ideal teams (i.e. 3 teams each of the 14 days), 3 could not participate due to weather conditions (a snow storm made necessary to postpone one of those days, which was not considered in this study) and 3 more teams had repeating participants (to replace firefighters that could not attend the course), so their results could not be taken into account for this study. With all this, the effective number of teams was 36, with a total of 144 participants (139 males and 5 females) taken into account. All the participants were professional firefighters from Zaragoza, Huesca and Teruel (Spain). Their mean (SD) age was 40.9 (7.42) years, while their mean (SD) experience as professional firefighters was 11.6 (6.93) years.

All the participants received identical training during the course, except in one of the exercises, in which the tools used for transmitting information were different, in order to be assessed. For this purpose, three different types of groups existed:

Type 1: conventional methods were applied, i.e., firefighters only received oral information from the “simulated hotel manager”, a member of the research team who informed the firefighters as explained below, while they visually assessed the emergency situation. Although the existence of self-protection plans could have been considered, this kind of document is not effective during emergency situations, such as the simulated one, as previously explained.

Type 2: in addition to the oral information from the “simulated hotel manager” (identical to type 1 groups), firefighters had (up to 5 minutes) access to the operational guide of the hotel (Fig. 1). This guide had 19 stapled paper sheets, with the relevant information of the hotel for emergency situations.

Type 3: in addition to the oral information from the “simulated hotel manager” (identical to the previously described groups), firefighters had (up to 5 minutes) access to the digital guide of the hotel (Fig. 3). This guide was accessed online with a conventional Web browser, using a 10-inch tablet, and firefighters had access to this guide format for the first time during this course. To introduce these firefighters to the newly presented format of the guide, they received a short training session (of about 5 minutes, just before the beginning of the exercise) given by a member of the research group, prior to starting the exercise in which they applied this tool.

Attitudes of accommodation managers and their intentions to undertake crisis planning have been previously described, obtaining interesting conclusions (Wang and Ritchie, 2012). In this study, the “simulated hotel manager” was always the same member of the research team and the information given was identical for all of the groups, trying to act as a nervous worker (short sentences with limited information) of the burning hotel. The information given to the participants was intentionally restricted, following a short script, in order to always be the same and to force participants to ask or look for the required information by other means. The intention was to accomplish one of the goals of this study, detecting the details of the information required by firefighters in emergency situations. For this reason, the recorded videos were considered crucial and they were thoroughly analysed, paying attention to actions and dialogues.

The distribution of the participants in the groups was randomized and the mean ages (SD) and experience as professional firefighters (SD) is summarized in Table 1.

Table 1
Participants’ mean ages (SD) and experience as professional firefighters (SD).

	Mean age (SD)	Mean experience (SD)
Type 1 (oral information)	41.8 (7.42)	11.4 (6.29)

Type 2 (oral and operational guide)	40.9 (7.97)	12.4 (7.45)
Type 3 (oral and digital guide)	40.0 (6.77)	10.9 (7.03)

All the participants had received prior training, during their previous experience as professional firefighters (on safety, fire behaviour, extinguishers, protective equipment, fire hoses, etc.), so all of them already met the minimum requirements for participating in a live fire training program.

Every training session was coordinated by experienced firefighting instructors and researchers from the University of Zaragoza. Each group of four firefighters had a leader, which was the member with the highest rank *(two ranks were involved, as participants, in this study: firefighter and officer firefighter)*.

2.3. Materials assessed

When a victim rescue in a building on fire starts, the available information about its features is a key aspect for firefighters. This study compares three different methods for communicating this information to the rescue team, in order to assess the effectiveness of each one.

2.3.1. Conventional self-protection plans

As explained in the introduction of this paper, although fire departments have a copy of the self-protection plans, all the firefighters interviewed during this study recognised that they are too extensive (hundreds of pages in most cases) and detailed to be useful in emergency situations.

A small percentage of each self-protection plan can be considered useful in emergency situations, according to the course instructors interviewed during this study. Moreover, these documents are easily out-of-date. In fact, to maintain them always updated, any further modification should be included and printed to generate a new version of the plan, that should be immediately given to the emergency services, and this is not feasible.

For these reasons, the only information that firefighters would receive in this situations would be orally given by the witnesses and/or workers available at their arrival to the emergency site. During the assessed exercises, this information was always given by the same person of the research team, in order to minimize bias.

2.3.2. Operative guides

As detailed in the introduction, the operative guides were developed to have a useful version of the extensive self-protection plans in emergency situations. Their usefulness was based on the clarity of information and conciseness, so they can be available in the firefighting vehicles (being impossible with the extensive self-protection plans), as well as the use of visual information, such as maps, pictures, 3D models, etc.

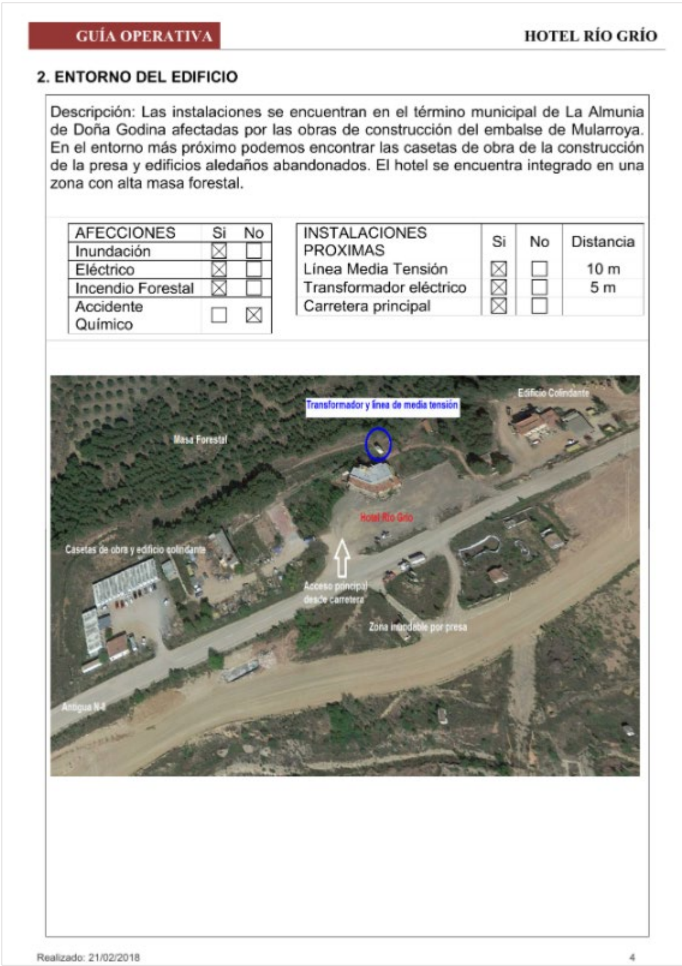
Compared with the self-protection plans, the point of view of the operative guides is quite different. The first ones are more extensively developed by a qualified technician (not being clearly defined by the Spanish law who could develop this role) trying to cover an extensive amount of details, not only related to emergencies, and according to the legal requirements. On the contrary, the operative guides are not legally required, being their structure and contents adapted to what their developers consider fundamental aspects for emergency situations. Due to the novelty of these guides, they are nowadays being developed by a multidisciplinary team of professionals from the Fire Service of the Province of Zaragoza and the University of Zaragoza. Although very summarized, operative guides always include:

· Geographical location of the building, surrounding installations and its environment.

· Main features of the building, paying special attention to fire compartmentation installations, emergency exit routes and firefighting materials available.

· Risk analysis, paying attention to different sources. These risks could be generated by very different causes: building installations (including electrical, gas, fuel, water), surrounding aspects (forests, rivers, roads, industry…), activities developed, etc.

The visual information in these guides is very carefully chosen. Firstly, significant areas of maps and aerial views of the surroundings are included in order to guide rescue teams, especially in difficult access environments, as shown in one of the guide pages below (Fig. 4).


GUÍA OPERATIVA HOTEL RÍO GRÍO

2. ENTORNO DEL EDIFICIO

Descripción: Las instalaciones se encuentran en el término municipal de La Almunia de Doña Godina afectadas por las obras de construcción del embalse de Mularroya. En el entorno más próximo podemos encontrar las casetas de obra de la construcción de la presa y edificios aledaños abandonados. El hotel se encuentra integrado en una zona con alta masa forestal.

AFECCIONES	Si	No
Inundación	☒	☐
Eléctrico	☒	☐
Incendio Forestal	☒	☐
Accidente Químico	☐	☒

INSTALACIONES PROXIMAS	Si	No	Distancia
Línea Media Tensión	☒	☐	10 m
Transformador eléctrico	☒	☐	5 m
Carretera principal	☒	☐	

Realizado: 21/02/2018 4

Fig. 4. Sample page of the operative guide with an aerial view of the building surroundings.

Secondly, pictures of the surroundings, and some outdoor and indoor images of the building to be described are also included.

Thirdly, technical drawings made with computer-aided design (CAD) software display two-dimensionally the details of each floor in the building.

Finally, a 3D model of the building is generated in order to include schematized images (Figs. 5a, 5b) in the guide. Although this 3D model has many advantages, the high amount of resources and time required for its development are important limitations, as explained below.

Figs. 5a, 5b. Front and back 3D views of the building included in the operative guide.

2.3.3. Digital guides

In an effort to improve the paper operative guides and trying to solve some of their restrictions, digital technology was considered to be useful. The digital version of the operative guides made possible to take advantage of most of the positive aspects of the previously developed paper documents, adding the possibility of interaction and online access.

As well as the operative guides, the digital ones include geographical locations, aerial views, technical drawings of the different floors, etc. Thanks to the interaction possibility, hypertext and links were used to easily navigate the guide, like using a conventional browser, while the number of possibilities for the transmission of information was increased. Several of these possibilities could be tested during this study.

Compared with the paper-made operative guides, the most important innovation in the digital ones was the possibility of including 360º images or photospheres (Fig. 6-up), which could be explored by their users, as an evolution of the 3D models previously used. In order to assess the convenience of using this kind of images in the digital guides, the research team generated several jpg files by means of a photographic camera with accelerometer and a tripod.

Fig. 6. A 360º picture of one of the spaces in the building (up) and how it is displayed (down).

These images were integrated in the digital guide to be assessed. For that purpose, they were displayed in the guide (Fig. 6-down) by means of JavaScript code, which made possible to explore (rotating and zooming in and out) the images, as shown in Fig. 7.

Fig. 7. Tablet with an exterior image generated (including metadata symbols) being zoomed.

Over these images, additional information was added. This information was represented as small signs of different kinds. The reduced size of the signs made possible to understand the image easily and also to rotate or zoom it without difficulties. When one of these signs is clicked (tapping with the finger on the screen), additional information is displayed or access to a different place is given. The intention of this simple user interface was to make it very intuitive, so the learning process could be really fast.

All the contents of the digital guides were accessed online (previously uploaded to a server controlled by the research team), although it could be necessary to store them in the tablets taking into account places without good mobile access to the Internet.

2.3.4. Other material

During the preparation of this study, other graphical materials were taken into consideration, although they were not finally used. First of all, carefully filmed videos were captured in and out the building, using different cameras and a drone (Fig. 8) for aerial images. After considering the sizes of the video files, it was impossible to include them in the digital guide, even highly optimizing their quality, being used only the aerial still images. This problem also existed with the video animations generated using the 3D model of the building, due to the same reason.

Fig. 8. Drone capturing aerial video and still images of the building and surroundings.

2.4. Training exercises

All the participants in this study spend a significant percentage of their working time on training and developing skills. For this reason, this study was incorporated in one of the exercises developed, as part of their annual mandatory training program, for the professional firefighters in the Province of Zaragoza.

During this course, several activities had to be completed by all the participants, including an interior fire attack, ventilation, labyrinth orientation or a victim rescue in a building on fire. All the teams performed the same activities, with the only difference of the method for transmitting the information before the victim rescue, which was different for each type of group. This victim rescue was the training exercise used to implement the study. The intensity of the fire was moderate enough, intentionally avoiding extreme temperatures, to ensure that the training objectives were achieved, while the exposure to health and safety risks was reduced. Participants could perform their tasks by walking (with no need to crawl on hands and knees), in two different floors and inspecting up to 11 rooms, so the distances travelled depended on their path to find the victim. Low light conditions and smoke were present during the rescue inside the building, as shown below in the still image from a participant's field of view (Fig. 9) captured with an action camera attached to his chest with an elastic harness. The building was an abandoned rural hotel and an adult rescue training manikin was the simulated victim, as previously detailed.

Fig. 9. Low light and smoke conditions during a victim rescue activity.

Each group had four participants and two of them had a camera attached to their chest. This made possible to measure the time spent by each group in the development of the tasks and to analyse different actions and comments, as explained below. Three different types of groups (one of each type per day) were created, as explained before, in section 2.2.

Not only action cameras were attached to 50% of the participants during the exercises, but also were thermal images used by the firefighters during the victim rescue. Although the analysis of the thermal videos recorded (Fig. 10) was not useful for this study, participants had to use a thermal image camera, as part of a protocol.

Fig. 10. Video frame recorded with a thermal image camera.

2.5. Statistical analysis

The survey results were collected using Microsoft Excel and the data analysis was carried out with Stata/IC, obtaining descriptive statistics. For the five variables analysed (four answers to an anonym questionnaire and time required to find the victim), t tests were performed to compare the results of the teams informed orally with, first, those that used the operational guide and, second, with those that used the digital guide. Statistical significance was considered at $p < 0.05$.

3. Results

The obtained results come from three different sources of information. Firstly, four questions were included in the anonym questionnaire that the participants answered to assess the global formative session (not only the live fire exercise, which this study was focused on, but also the rest of activities) when it finished. Secondly, the time required from the beginning of the exercise to different crucial moments (when the leader of the group decides to get into the building, when the participants find the victim, etc.), obtained from the recorded videos. Finally, the movements of the participants and their comments, recorded in the videos, were carefully evaluated, trying to find how they used the tools, their sincere comments and opinions, difficulties, etc.

3.1. Anonym questionnaire

The first question included in the anonym questionnaire was: "Mark from 1 (very easy) to 5 (very difficult) the difficulty of finding the victim". This question assesses the participant perception of the difficulty level during the victim rescue, as shown in Table 2. The questions answered by the participants of the three different groups were identical, trying to compare in this case the spatial view of the participants in each group and if this could be related to the tool used by them.

Table 2.
Results of question about difficulty of finding victim.

	Mean value (SD)
Type 1 (oral information)	2.9 (0.85)
Type 2 (oral and operational guide)	2.4 (0.83)
Type 3 (oral and digital guide)	2.5 (1.01)
All types (1, 2 and 3)	2.6 (0.91)

The second question included in the anonym questionnaire was: "Was the interior layout of the building similar to what you expected thanks to the previously received information? (1 = very different; 5 = very similar)". This question tries to assess the quality of the descriptive information about the building that the participants received before entering the building, as shown in Table 3.

Table 3
Results of question about expected interior layout.

	Mean value (SD)
Type 1 (oral information)	3.2 (1.18)
Type 2 (oral and operational guide)	4.4 (0.80)
Type 3 (oral and digital guide)	4.5 (0.92)
All types (1, 2 and 3)	4.1 (1.12)

The third question included in the anonym questionnaire was: "Mark from 1 (not useful at all) to 5 (very useful) the information obtained before starting the rescue". This question takes into account the information received in general, not only spatial, and its results are shown in Table 4.

Table 4
Results of question about usefulness of obtained information.

	Mean value (SD)
Type 1 (oral information)	2.9 (1.32)
Type 2 (oral and operational guide)	4.2 (0.83)
Type 3 (oral and digital guide)	4.3 (0.87)
All types (1, 2 and 3)	3.8 (1.20)

The fourth question included in the anonym questionnaire was: "General assessment of the training day: 1 (not useful at all) to 5 (very useful)". This was the final question and, although it is very generic, it gives an idea about the positive level of perception of the training day, as displayed in Table 5. The intention of taking into account this general aspect was to evaluate if the participants were perceiving more or less useful the training day when a new tool was used.

Table 5
Results of generic question about the training day.

	Mean value (SD)
Type 1 (oral information)	3.9 (1.03)
Type 2 (oral and operational guide)	4.1 (0.96)
Type 3 (oral and digital guide)	4.4 (0.76)
All types (1, 2 and 3)	4.1 (0.94)

3.2. Time required

The amounts of time spent from the beginning of the exercise to get into the building, to find the victim, etc. were obtained, after finishing the training days, from the analysis of the videos recorded with the action cameras.

Two amounts of time were considered important in this study: the one required for oral communication with the "simulated hotel manager" and, just after it, the period required to find the victim.

The time spent for oral communication was always very short, as the information given must be limited, according to the rules defined for the exercise, for all the teams of participants. For this reason, it could be observed that the mean values were very similar for the three types of groups, with a mean for all these groups of 20 s and small variations in the means of each type of group of only 2 to 4 s.

About the periods required for finding the victim, the mean values of each type of groups are shown in Fig 11. Comparing the highest value (8 min 14 s for type 1 or oral information) with the lowest one (7 min 24 s for type 3 or digital guide), it can be noticed a difference of almost one minute, which can be considered crucial in victim rescues.

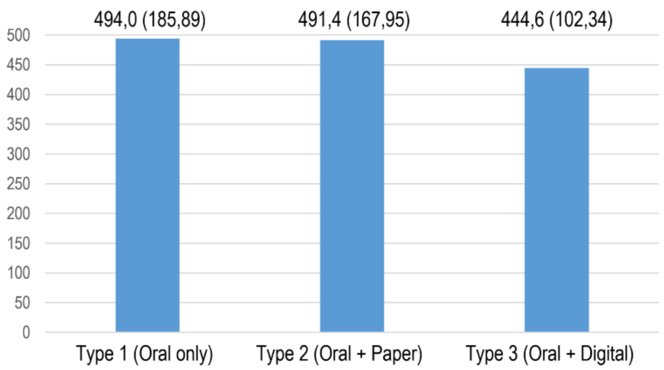


Fig. 11. Mean values (SD) of time in seconds required to find the victim by each group type.

3.3. Captured videos

The information collected from the analysis of the recorded videos added some interesting details about the performance of the firefighters who attended this course. This will make possible to review some protocols in the near future thanks to this study, after detecting incorrect firefighting procedures in some exercises, such as extinguishing fire before evacuating the victim (increasing the amount of water steam, mixing gases…).

An exhaustive analysis of these videos, paying attention to their audio, made possible to identify questions made by participants, giving interesting information in relation to each type of group. It was particularly relevant that in the 58,33% of the type 1 groups made questions related to the spatial location of the victim, while this percentage was 38,46% for type 2 and 18,18% for type 3.

Some comments made by different participants after forgetting that this information was being collected were very interesting. A clear example was the answer given by one of the group leaders to the instructor who coordinated his exercise, using the digital guide:

Instructor: "How was it, *Name*?"

Participant: "Very well… With the guide… [Takes a breath] The guide is really useful…"

Instructor: "Did you find the information useful?"

Participant: "Yes, yes, yes [Moving head up and down]."

This opinion was considered particularly relevant due to the sincere expressions observed in the video and the tone of the speech. Moreover, this could also be confirmed by the feedback given by the instructors of the training sessions during personal interviews.

Some comments gave the possibility to improve the guides. For example, a group of participants asked about the scale factor of the technical drawings in the digital guide. This made the research team consider the possibility of including distances in these drawings between key points to help firefighters in the estimation of the required lengths of hoses.

One more interesting result was observed in the way that the participants of types 2 and 3 used the guides to share information. The possibility of pointing on important positions of the drawings in the guides simplified the communication process, e.g. to plan the intervention. The special feature offered by the digital guides of previsualizing the interior of different building areas, thanks to the 360º images, was particularly highlighted by instructors and participants of type 3 groups.

4. Discussion

According to Hamp et al. (2014), during victim rescues, to quickly localize them and to manage the exchange of information efficiently between the responders placed in the field and those in the emergency operation centre are key challenges. These aspects have been taken into account in different studies, with similar goals. Among others, thermo-vision systems have been considered for rescues in toxic, flammable and explosive environments (Găman, 2014); the detection of cellular phones and the use of a ground-penetrating radar have been presented as search technologies to find unconscious victims (Hamp et al., 2014); other technologies, such as Bluetooth and Wi-Fi, have also been used to develop a disaster rescue platform (Han and Han, 2018). This section discusses the results obtained with two different graphical tools for helping fire services in the rescue of victims, although they could also be used by other emergency services, if knowing the features of a building is required before entering.

According to the questionnaire answers, finding the victim was easier for those teams who used the graphical information included in both types of guides (paper and digital). In a Likert scale where 5 was "very difficult" and 1 was "very easy", teams without guides marked with 2.9 this level of difficulty, while those with operational (paper) and digital guides marked it slightly better, according to Table 2. Comparing the results from the first type of groups (oral information) and the second one (oral and operational guide), the t test clearly revealed statistical significance of the reduction in the perceived difficulty of finding the victim ($p<0.01$), whereas there is not enough evidence comparing the first type with the third one (oral and digital guide). This fact could be related to the similar results and the intentionally limited time (up to 5 minutes) to know the new tool (digital guides were presented for the first time, while operational ones were previously known by participants). For this reason, comparing times is considered crucial in this study. It can be observed that this exercise was not found extremely difficult by the participants of any type of team, probably due to the controlled conditions of this kind of training activities, although the use of graphical tools can be observed as an improvement.

In the case of the expected interior layout, the difference between teams with and without graphical tools is much clearer, with 24% and 26% increments in the values of the expectations for the teams with operational guides and digital guides, respectively, according to Table 3. This can also be connected to the information obtained from the analysis of the questions recorded in the videos in relation to the spatial location of the victim. Most of the teams without guides expressed spatial doubts in the victim location, while only 18.18% of those using the digital guide made questions of this kind. Statistical significance was found ($p<0.001$ in both cases).

Similar differences could be observed when the usefulness of the obtained information was compared. In this case, the usefulness values increased a 26% and a 28% for the teams with operational guides and digital guides, respectively, according to Table 4, compared with those that only received oral information. Again, statistical significance could be noticed ($p<0.001$ in both cases).

Paying attention to the general assessment of the training day is also interesting, observing a very positive result, according to Table 5, with a mean value of all the groups over 4 points in the 1-5 Likert scale. Each training day had the same structure and the firefighters participated only one day. All the teams attended a general theoretic introduction and three practical exercises, being only one of them different for each type of group (due to the different ways to transmit information, as previously described). Even with this small difference the general assessment had significant differences among the three groups. In general, the opinion of the participants at the end of the training day was very positive, with the best values in the group that used the digital guide. In this case, statistical significance is only found comparing the first type (oral) with the third one (oral + digital guide), being $p<0.01$, whereas there is not enough evidence comparing the first type with the second one (oral and operational guide). Using this new tool could be stimulating and, according to the opinions registered, it was considered useful by the participants who used it in the training.

As explained in the previous section, the amount of time required for the oral communication was similar for the three types of teams. On the contrary, comparing the mean values of the time required to find the victim, it decreased using the guides, especially with the digital one, needing almost one minute less when using digital guides (Fig. 11) with a clear decrease of the standard deviation from 186 s to 102 s. As in the previous case, statistical significance can only be found in the results comparing the first type (oral) with the third one (oral + digital guide), being $p<0.01$, whereas there is not enough evidence comparing the first type with the second one (oral and operational guide).

Comparing the required time for producing an operational guide and a digital one is also interesting. Most stages are similar in both processes, but 3D modelling the building can be considered a time consuming process. As mentioned in section 2.3.2, although the 3D models in the operative guides are a powerful graphical tool, the high amount of resources and time required for their development are important limitations. On the contrary, taking 360º pictures with nowadays technology is fast and simple and, although they are not useful in paper format, the possibility of manipulating them in digital format was considered intuitive and useful to preview unknown places. Compared with the 360º pictures, the views of the 3D model are much more schematic, which could be positive in some cases, but participants in this study revealed that the interactive pictures gave them a considerably clearer idea of what to expect before knowing the interior of a building or its surroundings. For example, it is possible to have an idea of specific details of furniture or installations, that could have been omitted in the 3D models.

The novelty of the digital guides makes them require some improvements and considerations. For example, although they should be always available online, the possibility of needing them offline in emergency situations must also be considered for evident reasons, such as issues with telecommunications or server problems. Thus, an offline version of these documents, being periodically updated, must be considered for further improvements.

One more important aspect to be considered in further development of digital guides is the security related to any information system based on online content. Controlling the access to the available information, replicating the content or protecting data would be some of the aspects to cautiously consider. In this sense, part of the content in public buildings or industries should not be shown in the 360º pictures, e.g. faces of hospital patients or residents, fragments of industrial processes or machinery… A solution for these cases would be easy and efficient, merely blurring or totally hiding the areas to protect in the pictures.

Finally, an advantage of the developed digital guides is the possibility of using a smartphone to have access to their online contents. Although this possibility could be useful in many cases, for best conditions not only is the software important, but also the hardware should be optimal for emergency situations, taking into account its durability, screen brightness, battery life, etc.

5. Conclusions

This study gives an idea of how important the good perception of an emergency situation is, before starting to solve it. Understanding the details of the building and surroundings in which a disaster is occurring, even before arriving, can save time and, thanks to it, lives and material goods.

It could be observed that using graphical tools, such as technical drawings, 3D models or 360º pictures, improves the process of information transmission, being particularly useful under stress situations in which oral communication could be limited or even blocked. Images can help explaining and understanding a victim location, facilitating spatial perception to the rescue team before entering an unknown building in risk situations.

These communication improvements also benefit the information transmission among team members. Digital guides were particularly appreciated by participants of this study, highlighting their interaction possibilities. Zooming a picture to understand a key detail or virtually exploring a room, thanks to the possibilities of 360º pictures, were two aspects especially valued. Beyond this, possibility of having access to metadata from the embedded icons on critical areas of the images was also found advantageous.

The fundamental consequence of the previously detailed aspects was the improvements of time spent to find a victim in an unknown building under risk conditions. Although a live fire training exercise was assessed, so risk was always controlled, the low light, high temperature and smoke were real factors during all the sessions, helping to simulate real conditions.

After concluding that digital guides were useful, further development will be necessary for real-life emergencies, such as their development for major buildings and additional assessment out of a training environment.

Although it was not specifically tested, improvements like these could also be considered useful in complex and long interventions with different teams participating, needing fast coordination and information transmission, e.g. when a team of firefighters is relieved by another one or teams from different squads must collaborate. In fact, these tools could also be adapted to become useful for other professionals, such as policemen.

Finally, this kind of tools could be very useful for reporting firefighting activity or a rescue evolution. Elaborating technical reports could be much easier and more efficient with the possibility of including relevant pieces of information generated with the assessed graphical tools.

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