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Occupants' Perspectives of the Use of Smartphones during Fire Evacuation from High-Rise Residential Buildings

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Abstract: Over the past few years there has been a significant change in fire safety design and management. As the possibility of safe escape is the most crucial aspect of a building's fire safety features, the understanding of human behaviour under fire conditions is important for a successful evacuation. Previous research studies have developed models, prototypes, and serious games that help engineers/architects to design or firefighters to improve design so that the building facilitates a smooth evacuation process. Although these studies have looked into human behaviour, perceptions of important stakeholders (such as occupants, structural engineers, fire engineers, facility managers) are still not understood. These perceptions are important for the appropriate application of technology for evacuation. The broader research effort, of which this paper is part, stems from the premise that bespoke evacuation instructions can be sent directly to evacuees' smartphones. Information from a BIM model with the aid of sensors can be used to customise these evacuation instructions. The prospect of information being delivered to occupants during a fire emergency is still at its premature phase and more research is needed. Twenty-three interviews were conducted with occupants who currently live in high-rise residential buildings in Egypt and the United Kingdom to understand their views of using smartphones to assist during fire evacuations. The sampling strategy targeted occupants who currently live in high-rise residential buildings but have not necessarily experienced a fire evacuation. The research clearly shows the importance of smartphones during evacuation and the role they can play in assisting occupants to find the fastest and safest egress route. The interview findings will assist in future research to develop an evacuation framework system that could be implemented for high-rise residential buildings.

Keywords: fire safety; high-rise residential buildings; evacuation simulation; human behaviour

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1. Introduction

The main goal of fire safety is to provide a safe environment for occupants in a building or near a building in case of a fire emergency [1]. Its second goal is to provide firefighters with as much safety as possible during the fire emergency. The third goal of fire safety is to provide a safe and effective environment for occupants during the day-to-day use of the building. Fire safety is still, and will continue to be, one of the main topics discussed when designing high-rise buildings; this is mainly due to the number of occupants in the building, which makes it difficult for all occupants to evacuate at the same time. Some occupants may be unaware of a fire situation and not all occupants have the same knowledge, experience, and physical ability to deal with a fire situation.

High-rise residential buildings count as a high-risk type of building [2]. The high population density and diverse levels of mobility found in high-rise buildings have a

significant potential for increasing injuries or fatalities during fire emergency evacuations. A large number of occupants might not be able to evacuate the building due to chaos and crowdedness at exit routes. As occupants tend to evacuate the building through stairwells, there is a risk that impaired mobility would hinder successful evacuation. This could therefore cause a state of panic among occupants and consequently hamper firefighting and rescue operations. In addition, vertical shafts in high-rise buildings, such as a stairwells or elevator shafts, allow the spread of smoke [2].

Despite having exit signs in almost all buildings, previous research [3,4] shows that occupants will tend to evacuate the building through a familiar route or will use the same route by which they entered the building. This is suboptimal for fire evacuation, leading to increased evacuation times and occupants' prolonged exposure to fire emergency conditions. Previous research [4] also reports that wayfinding depends on the geometry (layout) of buildings and seems to be largely unaffected by escape route signs [4]. Besides familiarity with the building, the choice of a suitable exit depends on a number of factors such as the availability of exits and layout complexity. In addition, it is important for occupants to react quickly, preferably within the first three or four minutes [5]. Moreover, occupants tend to assume that the exit sign with the pictogram of a running man is all that is important for a successful evacuation. This can be the case for simple structures, but for high-rise residential buildings or complex structures, the exit signs will not be enough as they often do not give enough direction to the safest and shortest path.

It is important to clearly understand the definition of wayfinding and what factors might affect occupants in choosing certain egress routes. An earlier definition [3] stated that wayfinding refers to the planning and decision making that allows one to reach a destination that is not in the immediate sensory field and includes such tasks as choosing efficient routes, scheduling, and interpreting verbal route directions.

Human behaviour during fire emergencies is hard to predict, as humans tend to behave differently depending on a large number of factors. Human behaviour in fire emergencies is defined as the study of human response, including people's awareness, beliefs, attitude, motivations, decision making, and coping strategies, during exposure to fire and other similar emergencies in buildings, structures, and/or transportation systems [6]. In addition, human behaviour can be defined as the actions people take in a particular situation, their intentions for action, and the considerations before any action is carried out [7]. Following the 9/11 terrorist attacks, which resulted in the death of more than 2000 people in the United States [6], the understanding of human behaviour under fire situations has changed. However, recent fire disasters, such as the Grenfell Tower disaster in London, present a bleak reminder that, despite the advancements in fire safety, there is still some room to learn from these occurrences and it remains necessary to reflect upon the adequacy of fire safety preparedness [8].

The behaviour of occupants in high-rise residential buildings is different compared with in other buildings. The complexity of the egress routes means that the effects of occupants being asleep, cooking, or not dressed can have unforeseeable effects on egress time in high-rise buildings. Due to the variety of domestic actions occupants are undertaking, they are often not ready to evacuate. Occupant behaviour would vary depending on three major elements, namely the characteristics of the occupants, the building, and the fire [9].

A number of evacuation factors and activities experienced during the pre-evacuation stage have been identified in previous research [10]. The most important activity described was occupants investigating the origin of the fire. In this stage, people tend to gather information to determine the level of hazard and whether it is a false alarm. The second activity was occupants starting to evacuate after a clue is identified. Due to the lack of knowledge occupants have about the spread of fire and smoke, they tend to evacuate after the fire alarm goes off. The other activities identified were fighting the fire and looking for family, friends, or other occupants sleeping. In addition to these findings, Proulx [9] indicates that obtaining warning information from other occupants appears to be a better indication of a fire emergency rather than relying on the smell of burning or seeing smoke.

As fire and smoke spread rapidly during a fire in a building, the evacuation process must be carried out as quickly as possible. The parameters that affect the time and effectiveness of emergency evacuation in high-rise buildings have been studied [11]. The authors considered several evacuation scenarios, taking into account situational awareness related to the availability of staircases and emergency exits. The impact of the number of storeys, the width of escape routes, and the location and number of exits were assessed. Risk was simulated with a view to improving evacuation procedures. Evacuation times were estimated with realistic smoke and fire exposure. It is worth noting that making the inhabitants aware of the emergency and informing them about the available rescue options shortened the evacuation time by up to 24%.

Researchers [12] reviewed the available literature on people's behaviour during evacuation in high-rise buildings. These were the behaviours of both individuals and the crowd. Virtual Reality Technology was used in evacuation experiments to test its effect on group behaviour in tall buildings. The necessity was indicated for further quantitative studies of behaviour during evacuation, the auxiliary function of the elevator, and the influence of group relations on evacuation, especially in the context of the individual physical characteristics of people and problems with movement or fatigue.

Identifying the behaviour of individual people during a fire accident in connection with their perception of risk was studied by Mousavi and Kariminia [13]. The authors highlighted the need to raise the awareness of the rescued persons about the possibility of escaping from the threat. Such options include appropriate marking and quick provision of information on emergency exits and emergency procedures. The role of proper training was also emphasised—for both individuals and groups—as was the importance of information about the location and availability of fire extinguishers.

Fire brigades and rescue teams often use the tactic of keeping victims at the point of danger. Two opposing points of view on this tactic are presented in [14]. In the described research, firefighters' and survivors' direct reports and practical experiences were analysed. The conclusions indicate that the tactic of staying in place is outdated and may cause catastrophic errors in assessing the situation and the effectiveness of a rescue operation. Hence, the more significant role was highlighted of the rapid two-way delivery of information. On the one hand, the access of emergency services to the video monitoring system is important, especially infrared cameras, and the use of artificial intelligence algorithms can automate the detection and prediction of incidents. On the other hand, quick and unambiguous messages from rescue teams can be directed at the rescued. Modern smartphones offer this option.

High-rise residential buildings can be inhabited by large numbers of families and people who are unable to communicate directly with each other. Contemporary human relations and mutual isolation make this condition even worse. Therefore, informing occupants about threats and the current rescue action requires other communication tools. These tools need to be able to connect with the occupants immediately and should be able to connect with many people simultaneously, even if they are located in other parts of the building. Modern smartphones offer such possibilities [14]. Thanks to smartphones, it is possible to connect instantly with many people in different locations of a building at risk of fire. The universal possession of mobile phones allows direct access to information to virtually all building occupants. As a result, the occupant has fast and reliable access to the necessary data and information needed to decide his/her reaction. Instant access to such information is crucial during emergencies, especially when firefighting equipment and tools might not function as expected or even be available such as in the case of developing countries [15].

Such fire disaster preparedness, which entails appropriate planning, earmarking resources, and simulation of disaster response exercises, is pivotal in effective disaster mitigation, especially during evacuations [15,16]. The overall goal during evacuation is to save the lives of the building's occupants [15]. The factors influencing evacuation have been highlighted in the literature to include: the speed of the occupants, the number of

occupants, the evacuation route, the evacuation travel distance, and the density of the occupants [15,17]. It has been reported that awareness about fire preparedness is crucial for building occupants, and that poor and inadequate awareness about preparedness has contributed to many fire disasters [15,18]. Therefore, when occupants are aware, they know what to do in order to avert a fire disaster; they identify risks in the building and immediately avoid them [15]. Nonetheless, none of the existing studies explored the use of the smartphone as a preparedness tool to support fire evacuation in high-rise buildings.

Based on the analysis of research to date, it is clear that fire evacuation from high-rise buildings is an active research area, which has still not been unequivocally resolved. Human behaviour in such situations is complex and not always understandable. Therefore, providing occupants with information via smartphones is a potentially important opportunity to shape the behaviour of evacuees. Realising the potential of this approach requires further research into the perceptions of evacuees. Research on these issues is still important and needed.

This study aims to explore and understand evacuees' perception of the use of smartphones during fire evacuation from high-rise residential buildings. In order to realise this ultimate goal, the study focuses on three specific objectives: (1) to explore the likelihood of smartphone use during evacuation; (2) to identify effective modes of communicating information to evacuees; and (3) to understand other helpful uses of smartphones for other purposes during evacuation. These objectives are discussed in the remaining sections of this paper, which are organised as follows: the second section presents the research methodology; the third section discusses the research results and key findings; and the final section summarises the conclusions.

2. Research Methodology

Interviews

Interviews can be deeper data collection methods; they help gather reliable and valid data that can address research questions and objectives [19]. Interviews can be defined as a face-to-face interpersonal situation in which the interviewer asks a number of designed questions to either collect or validate research data [19,20]. In addition, any person-to-person interaction, either face-to-face or otherwise, between two or more individuals with a specific purpose in mind can be called an interview [21]. Interviews are appropriate for addressing research questions where the subjective perception or opinion of human stakeholders is more important than "objective truths". The interview would solicit the interviewee's opinions, past experiences, or even their insights, explanations, and meanings related to a certain situation.

As stated previously, little research has been published on fire accidents and evacuation in Egypt. Only one paper [18] has discussed the challenges of occupants' behaviour during fire evacuation of high-rise residential buildings in Egypt. An important element of this research is to choose the most appropriate research methods/techniques for data collection that will address the research questions. The research limitations also played a role in deciding the data collection methods chosen. The aim of this research is to collect actual perceptions as well as insights of occupants on the use of smartphones for fire evacuation from high-rise residential buildings. In addition, there were no previous literature or data collected on human behaviour under fire emergencies for high-rise residential buildings in the Middle East. It was challenging to find occupants who had experience of fire evacuation from high-rise residential buildings. Through social media and through word of mouth, five individuals agreed to be interviewed. The various posts in social media had a total of 4183 views. The posts were shared a number of times by other professionals and friends.

Interviewees were invited to be part of a 15–20-min semi-structured interview that consisted of 11 questions. Based on the research aim, it was crucial to develop interview questions that investigated occupants' usage of smartphones and their opinion of the use of smartphone to aid them during evacuation. The main justification when developing the questions was to understand how occupants will use their smartphones during evacuation,

how would they receive information, and what should the information contain. In addition, it was important to understand occupants' opinions on signalling issues.

Furthermore, research notes the difficulty of collecting data from a whole population because of cost and time limitation [22]. Moreover, because of resource limitations, data collection is usually restricted to local areas. In addition, Kumar [21] explains that when selecting the sample type the researcher should achieve two key aims of sampling: the first is to avoid bias in the selection of the sample and the second is the attainment of the maximum precision for given resources. Therefore, the philosophy of sampling in qualitative research is to reach a point where the researcher believes he/she achieved data saturation. Collecting data about human behaviour during fire is challenging, especially in the region of the Middle East where little research has been conducted. It was suggested that "snowball sampling" should be used when data is difficult to access [23]. The snowball sampling should be used when the population is difficult to reach or hidden [23].

At the end of each interview for this research, the interviewee was asked to nominate other occupants who might be willing to be interviewed. This process was very successful and resulted in 23 interviews with occupants who lived in high-rise residential buildings. After conducting 23 interviews, it was felt that saturation had been reached and additional interview data would not add value.

Definitive criteria for high-rise residential buildings can vary depending on minimum building storeys and building height. In the UK, for example, the National Fire Chief Council defines high rise buildings as those having a height of 18 m or more, or 7 storeys or more [24], as shown in Table 1. The authors could not find a published document on the definition of high-rise buildings in Egypt. However, four discussions took place with firefighters and fire engineers in Egypt to define high rise buildings. All four discussions showed that a building is considered high rise if it is 21 m or more in height.

Table 1. Comparison of High-Rise Building Definitions.

Country	High-Rise Building Criteria	Type
UK	≥18 m or ≥storeys	Definitive criteria
Egypt	≥21 m	Commonly agreed upon

This paper presents the key findings from interviews that were conducted with occupants of high-rise residential buildings. There were two sets of interviews. The first set of interviews targeted occupants who currently live in high-rise residential buildings in Egypt, while the second set focused on those in the United Kingdom. A total of 23 interviews were conducted, 17 with Egyptian occupants and 6 with United Kingdom occupants, who all currently live in high-rise residential buildings but who have not necessarily experienced a fire evacuation before, as illustrated in Figure 1. All 17 Egyptian interviewees were based in Cairo, while the 6 UK interviewees were based in different cities outside the capital. This was due to the limited number of UK high-rise residential building occupants who were willing to participate in the research. Interviewees were invited to be part of a 15–20 min semi-structured interview that consisted of 11 questions, as shown in Table 2 (Appendix A). The findings of the interviews were then used to develop scenarios for evacuation modelling and aid with the development of the egress system developed.

Table 2. Semi-Structured Interview Questions.

Q. No.	Description
1	Do you have a smartphone? If yes, how often do you use your smartphone?
2	If you are asked to evacuate the building, will you make sure you are carrying your smartphone? How important to you is it to carry a smartphone during evacuation? Please explain your answer.

Table 2. *Cont.*

Q. No.	Description
3	Are you aware of signalling problems that could happen during evacuation? Please explain your answer.
4	Would you consider using your phone as a source of information during evacuation (if yes, how)?
5	Does it matter to you if information sent to you during an emergency is graphical or textual? Which one of both options would you prefer and why?
6	Do you think the smartphone screen is too small to receive any graphical or written information during evacuation? Why have you chosen such an answer?
7	How do you think mobile technology could help you make decisions during evacuation?
8	Let us assume that a message would be sent to your smartphone during evacuation, what do you think should be included in the message?
9	Other than using your phone to call friends, family, etc., during the emergency would you consider using your smartphone for other purposes?
10	Do you think you could use the smartphone to locate other family members within the building? If yes, how do you think this could be possible?
11	Do you have any other comments on the usage of the smartphone during fire evacuation from high-rise residential buildings?

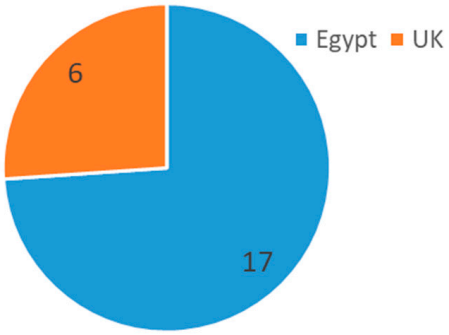

Figure 1. Distribution of interviewees by country.

3. Results and Discussion

3.1. Smartphones and Mobile Signals

The first question explored whether occupants were holding smartphones at the time of the interview. All interviewees stated that they always carry a smartphone (as shown in Figure 2) and that it is very important for them as it contains work-related and other essential private information. From the responses to this interview question, it is safe to assume that smartphones can be used as a tool during a fire emergency since all interviewees owned/were carrying/reported generally carrying a smartphone. Question 2 investigated the importance of carrying the smartphone during evacuation. All interviewees stated that they would be holding their smartphones during evacuation, as shown in Figure 3. One interviewee stated, "smartphones are an easy way to communicate with people" and another interviewee stated, "it has private and personal information that I would feel more comfortable carrying with me". Three interviewees expressed that even if their smartphone is far from them within their apartment they would look for it before starting the evacuation process. Nine interviewees explained that the importance of holding a smartphone during evacuation is based on the amount of information that could be received either from other building occupants who have already evacuated the building, from firefighters, or from other family members.

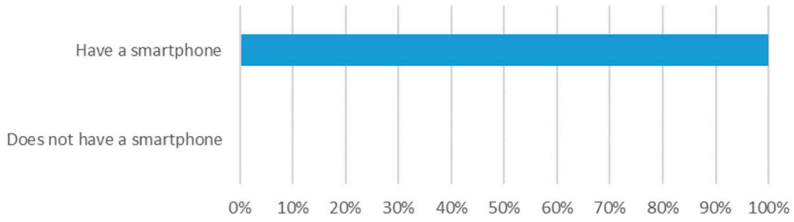

Figure 2. Responses to smartphone ownership question.

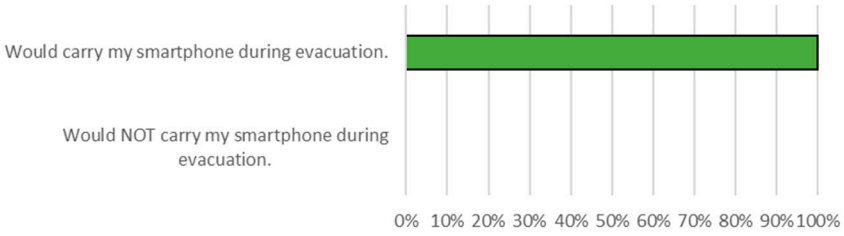

Figure 3. Responses to the question about carrying a smartphone during evacuation.

All interviewees believed that holding the smartphone during evacuation would not just allow them to communicate with others but would also allow them to feel safer, since they can call for help at any point. The terms "very important", "information", "communication" repeatedly occurred in all the 17 interviews conducted with occupants who currently live in high-rise residential buildings in Egypt. Two interviewees stated that technology plays an important role in their daily life and, since the smartphone is with them all the time, it seemed sensible to use it during a fire emergency. Seven other interviewees explained the importance of holding the smartphone during evacuation to seek help and call the fire services if they had not already been called.

Question 3 of the interview solicited occupants' opinions about the possibility of signal problems that could affect the smartphone during evacuation. It is clear from the responses that interviewees believed that fire or smoke would not affect the signal of their smartphone. One interviewee stated that "there are many places we go to and we find that there is no smartphone signal, but we still carry the smartphone, so I will still be willing to carry the smartphone during evacuation and take the risk". It is worth noting that the word "risk" was used five times in interviewees' responses to this question, however it was clear that occupants are still willing to carry their smartphones during evacuation. As all interviewees expressed that fire and smoke would not affect smartphone signals in high-rise residential buildings, there were concerns about the use of smartphones through emergency routes. One interviewee explained: "I believe that there might be signalling problems during the emergency exit routes as they are usually safe and I think the signal will be affected by the construction materials especially concrete". "Building material" occurred in five interviewees' responses.

The responses to Question 3 clearly raise the issue of weak signals in lifts, underground parking, stairs, and in some areas of the building. Smartphone signals in the apartments as expressed by interviewees are much stronger compared with other parts of the building such as floor corridors. Although interviewees expressed concerns over signalling problems in some parts of the building, all interviewees pointed out that the smartphone usually functions properly even with a weak signal and they can still receive or make calls. Two interviewees stated that if a system is to be developed for the smartphone to be used during an emergency, it is important that such a system uses the mobile telephone network and does not depend on the home broadband. This is because the home broadband might be affected by the fire or smoke in the building. Three interviewees stated that smartphone technology is improving very rapidly and their signals are getting stronger, especially in

concrete buildings. One interviewee explained "the risk of not having signal is very small compared to higher chance of having good signal, and I am still willing to take the risk".

3.2. Smartphones for Evacuation

Question 4 explored whether occupants would consider using their smartphone for information during evacuation. All interviewee responses were positive, as they all agreed that they would use it as a source of information. The first and most important reason was to gather information from neighbours or other family members within the building. It was clear that information gathered would allow occupants to evacuate the building much faster. This is by knowing which evacuation route to use and the less crowded area in the building. Interviewees believed that information would make them feel safer. Information such as the shortest route to take was very important to interviewees as they clearly stated that the purpose of gathering information is to make sure they are aware of the fire situation in the building and to aid them in finding the most suitable egress route based on their location. Other interviewees explained that other than making and receiving calls to either provide or gather information, there is a WhatsApp group that they have as building tenants, which is also used for communication. The use of the WhatsApp group chat to gather information was raised by eight interviewees, either for communications from occupants who have already evacuated or who are still in the building. Moreover, the word "information" occurred 48 times in all interviewee responses, which clearly highlights the importance of using smartphones to gather or send information. Other interviewees focused on information about the location of the fire and confirmation if the fire services had already been informed. Other information could be exchanged through the use of text messages. Interviewees believed that this might be quicker than voice calls as crowdedness and noise would make voice conversations difficult. All interviewees agreed that information gathered would allow them to avoid floors with high traffic, slow speed, and, more importantly, floors that have fire or smoke.

In addition to what actions they need to take, four interviewees explained that they do not have the knowledge to deal with fire evacuation so they would use their smartphone to call fire services or building security. It is clear from the results that all interviewees would consider using their smartphone during evacuation either by making or receiving calls to/from relatives and neighbours, sending or receiving text messages, and communicating with others on WhatsApp chat. However, two interviewees explained that, although they would use their smartphones during evacuation, this use would be concentrated in the first minutes after detecting the fire. However, other interviewees believed that it could take a couple of minutes to gather information and that is why the use of smartphones would still result in a faster evacuation as they will have more information on the fire situation and what actions they need to take.

3.3. Textual vs. Graphical Instructions on Smartphones

In Question 5, interviewees were asked whether they prefer receiving information on their smartphones using graphical or textual media and why. Interviewees' responses varied between text messages, graphical information, or a mix between both options. Interviewees who preferred text explained that a text would be easier to understand and follow, while graphical information could be confusing and delay evacuation. As all interviewees stated that they are familiar with the building in which they are currently living, a text message would give clear instructions and they would not need a map to follow. Interviewees also stated that, although graphics have the advantage of precisely displaying the route, some displays would require training of the occupants and there is a risk that smartphones would not receive all the relevant information, which could prevent the generation of an accurate graphical display.

Four interviewees stated that during a fire emergency "evacuation time" is a very important factor that plays a role in their decisions; having a short message that contains all relevant information is important for a faster evacuation. The text message could include

information that the graphical information would not provide. This could be the location of the fire, emergency contact number, alternative routes, and the time occupants have to evacuate the building. Other interviewees explained that they are familiar with the text messaging functionality of their smartphone as they use it on a daily basis and it would be the quickest way to convey information. One interviewee stated, "I prefer texts because I think visuals or graphics can sometimes be misconstrued, people see things and understand something differently than what they are intended to understand". It is clear from the interviewees' responses that the text was the easier medium to understand, especially during a fire emergency. This was also supported by two interviewees who stated that they cannot trust how the graphics would be presented and whether the graphics would function the way they should.

Moreover, it was stated if a graphical option is used then it needs to show occupants a live view of the route they are taking. However, two interviewees were not sure if the smartphone would be able to send and receive weighty graphical information, especially with signalling challenges that could arise from the building material. One interviewee explained that the text message would suit them better as they would not need to wear their spectacles to read a text as they would need to when deciphering a graphical display. In addition, that interviewee explained that graphics can be complicated and it would be very difficult to keep holding the smartphone while evacuating to get updated information. One interviewee stated that a text would be the preferred option as not all occupants might have the latest smartphone and those with older smartphone models having reduced graphics capabilities would still be able to receive text messages.

Interviewees above the age of 60 preferred the text message option as they stated they were not completely familiar with all the smartphone technology. One interviewee stated that a graphical display would be more usable for occupants with visual impairment.

On the other hand, eight interviewees stated that they prefer the graphical option. Two out of the eight interviewees explained that it would be easier to understand graphics and follow directions than reading a text message. The same two interviewees stated that a text message would be acceptable if it is short.

Interviewees who preferred the graphics option believed that the text would have limited information, while looking at the building floorplan can be easier to follow. However, three of the eight explained that information received by text could not be clearly communicated in graphics, such as an indication of family members in the building, alternative routes, and what actions they need to take to evacuate the building. Time was a concern expressed by all eight interviewees that understanding and following instructions by text message would take longer than graphics. Four of the eight interviewees believed that their smartphone had the required graphics' capability. They believed that graphics would provide more accurate results, since they provide live coverage and present information in 3D.

The text font could be easily adjusted. One interviewee stated that they would prefer graphics, because they believe they would show the exact fire location in the building and therefore occupants can head in the opposite direction. The interviewee added that the graphics need to be simple; the display does not necessarily need to show the whole building or the locations of other evacuees. It would only need to show the location of the fire and the route that occupants need to take. Another interviewee agreed with this and stated that graphics will require less time to understand and follow. While a text needs time to read and follow instructions, a graphical display can simply show the optimum evacuation route. One of the eight interviewees stated, "As I work with graphics on a daily basis, I prefer graphics as it is easier for me to understand".

3.4. Smartphone Screen Size

Following Question 5 and understanding which option occupants prefer between graphical or textual information, Question 6 solicited each interviewee's opinion about the size of the screen and whether the screen size is acceptable to receive graphical or

textual information. It was clear that there is consensus amongst all interviewees that smartphone screens are an acceptable size. Text or graphics could be adjusted to suit the user's preferences. One interviewee stated, "I send and receive text messages every day and never felt the screen size is small". It is noteworthy that one interviewee stated that for graphics purposes the screen will be small as they will have to zoom in and out to see the egress routes they are taking if the display shows the whole building.

3.5. Message Content and Trust

Question 7 explored the interviewees' views of how smartphone technology could help them make a decision during evacuation. As soon as the fire has been detected, interviewees explained that they would start gathering information. Smartphones would allow occupants to identify the most suitable egress route and update their route in real time as information is received about the badly changing fire situation. Six interviewees stated that smartphones would allow them to change their decision as they will trust the evacuation system. Part of the decision making would be based on information such as power cuts and lighting. It was repeatedly stated that the information gathered needs to be accurate and needs to give precise instructions. The decision-making process as expressed by nine interviewees was to investigate the fire, gather belongings, and start evacuating based on information received.

The decision process will also depend on instructions that occupants will need to follow. One interviewee explained that to rely on a system or a smartphone while making a decision during evacuation, the system would need to provide relevant and reliable information continuously from the fire detection stage until successful evacuation of the building. The main factor interviewees identified that would aid them in making the correct decision using their smartphones is to trust the system that is sending the information. One interviewee stated that they would evacuate the building through the nearest exit. However, the instructions sent to occupants by their smartphone could allow occupants to make a different decision. For example, occupants may be instructed to stay in their apartments, use lifts, or use different egress routes than originally planned. Based on interviewees' answers, it is clear that the occupants first need to trust the system before they could follow instructions. The quality of information received by occupants and the speed at which they receive that information would allow a faster evacuation process. All interviewees agreed that their smartphone would enable them to make better evacuation decisions as it would convey more reliable information.

Question 8 investigated interviewees' opinions about what an emergency message should contain when sent to them during an emergency. Interviewees clearly explained that the location of the fire was the most important factor they wanted to be included in the message, once the fire has been detected and confirmed. One interviewee stated, "the nature of the situation needs to be known". Eleven interviewees explained that the message should only be sent if the fire has been confirmed. The second most important factor was to know what is the safest and shortest escape route to take, based on their location. Although the safest route and shortest route to take might not be the closest to the occupant's location, interviewees explained that their trust in the egress system will motivate them to follow instructions. In addition, the interviewees stated that they wanted to know whether they could use the lift. Four interviewees stated that the message should confirm whether they should stay in the apartment and wait for help or evacuate immediately.

Interviewees wanted to know whether they should be evacuating via the ground floor, heading towards the top floors, or staying away from the fire and waiting for help to arrive. A number to call in case occupants were stuck was also stated by interviewees, as they explained it should be included at the end of the text message. The text message should contain what assembly point occupants should meet at. Two interviewees mentioned that the message needs to be short but needs to contain enough information to allow them to evacuate safely. One interviewee also stated that they wanted confirmation whether their family members within the building have already evacuated. From the responses,

it was clear that occupants wanted to know the location of the fire, which egress to take, and roughly the estimated time available for escape. Four interviewees added to this by stating they wanted a clear set of instructions from the detection of the fire until evacuating the building. Some of these instructions could be: evacuate immediately without taking any belongings, use egress emergency stairs instead of main stairs, fire is located on the fourth floor, please wait in your apartment until help arrives, use the second lift to evacuate the building.

Interviewees believed that receiving a set of instructions might reduce pressure and allow the evacuation process to be easier. It is worth noting that three interviewees expressed concerns about the time they have to use the egress route that was recommended in the message. As the fire situation in the building could change within seconds, it is important that the message contains a rough estimate of the time occupants have to evacuate the building before it is unsafe. Interviewees who live on higher floors, compared with interviewees living on the first couple or middle floors, wanted to know if the lift could be used when evacuating the building. The responses are understandable, as the evacuation time will be longer for occupants living on higher floors. Having an alternative option to evacuate was also a key requirement raised by all interviewees. They called it a "Plan B". One interviewee stated that they would expect a second message following the first message within a couple of minutes explaining what actions needed to be taken following the evacuation. For example, "meeting at assembly point", "move your car", "stay as far as possible from the building". Additional information suggested by interviewees was to know whether firefighters are on the way or in the building. Three interviewees stated that that they also wanted to know whether they should be heading to another floor and waiting for help there.

It is clear from the responses that the location of the fire, options to evacuate and alternative options, duration of the time before the route is unsafe to be used, and clear instructions what to do were the main information interviewees believed the message should contain. Although the message should be short, it is required to have enough detailed instructions for faster evacuation. It is worth noting that one interviewee stated that they wanted to know the time when the fire had been detected, for example, the message could include a "fire has been detected on the 7th floor at 14:27". The interviewee believed that knowing the precise fire detection time would reduce stress levels as it would enable the evacuees to estimate the time they have to evacuate the building.

3.6. Other Uses for Smartphone in Fire Emergency

In Question 9 it was important for the researcher to understand whether occupants/interviewees will consider using their smartphone for any purposes during the fire emergency other than contacting family and friends. A large proportion of interviewees indicated that they would not have time to use their smartphone to contact anyone else during the evacuation other than friends and family. Firstly, because they believe they do not have time and, secondly, checking on family members was more important to them than any other matter during the emergency. However, it is worth noting that two interviewees stated that occupants in general could use their smartphone to record what is happening or take photos for future reference. It was clear from the responses that interviewees' priorities will be to use their smartphone to gather information and to receive or make calls. One interviewee stated that they will use their smartphone to locate other family members within the building.

Three other interviewees stated that they would call emergency services if they had not been called and to make sure they are on their way to evacuate the building. Moreover, one interviewee explained that they would use their smartphone to check social media quickly to see if any useful information regarding the situation has been posted. However, the interviewees also expressed concerns about time. It was clear that the smartphone will be used to receive or make calls, in addition to gathering information and possibly locating other family members. The word "time" occurred in all interviewee responses, which

clearly indicates that time was the most important factor that affected the usage of the smartphone. Interviewees explained that making sure family and neighbours evacuated the building is very important, as well as calling fire emergency services.

3.7. Locating Friends and Family Using Smartphones

The last two questions of the interview explored interviewees' opinions about the possibility to locate other family members within the building and investigate their opinion on the usage of smartphone during evacuation. The responses show that all interviewees believed that, yes, they would like the ability to locate other family members within the building. However, it was stated that in order for the system to work as intended, all building occupants needed to be trained on that system. Locating occupants as stated by the interviewees would be important for family members and also for firefighters/fire services to know who has or has not left the building. Another interviewee stated that technology is advancing on a daily basis and locating others within the building could be developed. The same interviewee gave examples of simple measures for locating others: using CCTV or inferring the presence of occupants from switched-on lights or running air conditioning. Interviewees believed indoor mapping could be developed to locate others within the building.

This would reduce panic as it will make occupants know whether family members have evacuated the building or are still inside. Although interviewees stated that, yes, it is possible to locate family members within the building, they are not sure how the system or application could be developed. Concerns were expressed by four interviewees about how exactly locating family members is possible, for example, their floor or even their location within the floor. They assumed the location will just identify whether their family members are in the building or have evacuated. On the other hand, other interviewees believed that the system or the application could actually locate their family members' or neighbours' exact location within the building. The system or the location option will be activated as soon as the occupants or the visitors enter the building. Although interviewees agreed that by locating others within the building will reduce evacuation delay, they acknowledged that the system needs to contain all phone numbers of occupants and visitors whilst being connected to the system that would identify exactly their location within the building.

Two interviewees explained that since they have family within the same building, they will actually ignore the emergency evacuation message in order to help their family members. By locating family members, they would be able to provide assistance much faster. Two other interviewees explained that they are already using a similar application to locate each other within their family, but it knows a street location and not their exact location within the building. The same interviewees explained that the system or the application needs to contain locations of all the family members within the building.

However, occupants would have to grant access by the building management team to their location within the building. One interviewee added to this by stating that there is an option called "live location" which they use within their family. They stated a similar system could be developed that would aid occupants during the evacuation. Although all interviewees agreed that such an option is possible as stated previously, none of the interviewees were sure if the location could be detailed enough to show the exact location within the floor. However, they believed that if such a system is developed, it will be very beneficial for the evacuation process, would reduce stress and panic, and speed up evacuation.

3.8. General Proposed System Feedback

The interviewees' comments on the usage of smartphone during evacuation were very positive. All interviewees agreed that developing an evacuation emergency system that sends messages to occupants during evacuation would be very useful. However, five interviewees raised concerns that occupants during evacuation tend not to concentrate on what actions they are taking due to stress and panic. The proposed egress system should

not be web-based because of the risk of network problems, but might be driven by a nearby control room on a local area network. Different occupants had different understanding and knowledge of fire evacuation, therefore training/induction would help the evacuation process. Another four interviewees stated that smartphone technology is advancing very rapidly, and since they carry smartphones everywhere, then it needs to play a key role during the evacuation. One of the interviewees stated "smartphone is an item that one cannot stay without for many people. So if you know everyone is carrying the device, you can also use it to also assist with the fire evacuation for high rise residential building would be great".

Moreover, one interviewee explained that this evacuation system should only be used for buildings above 20 floors, as they believed any buildings less than 20 floors could be easily evacuated without such a system. The same interviewee explained that in order for this system to work, smartphones need to attract their owner's attention even when the owner was far from the smartphone, for example, by using bright lights or a loud alarm sound. This would ensure that occupants have received their unique text message and are in the process of gathering information and following instructions. One interviewee stated that just as smoke detectors and heat detectors set off the fire alarm, similarly signals from such sensors can trigger the delivery of alerts to the smartphone. In addition, one interviewee added that they have a similar system installed in their car and smartphone. The car is parked between 11 pm and 8 am in the building garage. Hence, if the car moves between these times, then the phone beeps. Therefore, the interviewee explained that a similar system could be created for fire emergencies. However, they added that the smartphone would need to keep beeping in case of fire to make sure the message is received by the occupants even if they are sleeping.

It was added that the building evacuation plan should be on every occupant's smartphone, even if the system is not working. Interview results show that developing an evacuation egress system is promising and will have many advantages during fire evacuation. However, it was stated by six interviewees that training is required for all building occupants and the system needs to be tested in a number of fire drills before it gets implemented fully in high-rise residential buildings. One interviewee added that when they enter their bank, they get a welcome message on their phone, their queue number, and the approximate waiting time. A similar concept could be adopted for smartphones and high-rise residential buildings. Although buildings have a number of evacuation routes and an evacuation plan, it can still be difficult to decide which is the suitable route to take. Therefore, developing a system that could aid during evacuation will be beneficial for occupants. The responses showed that interviewees believed that when new tenants move into the building, they will need to be given an induction of the fire safety plan in the building and how to use the evacuation system developed to evacuate in case of a fire emergency.

One interviewee stated that "the system could not just be used for high-rise residential buildings but it could be used for other building such as hotels", where occupants are not familiar with the evacuation plan and egress routes. Another interviewee agreed and stated that evacuating from high-rise residential buildings will continue to be a challenge. Therefore, smartphones should play a major role in the evacuation process. Overall, there were positive responses on the use of smartphones during evacuation. Concerns were raised regarding occupants being able to use the system and follow instructions. In order for the system to work successfully, all occupants must be trained. Once the system is functioning properly and occupants are trained it also needs to provide accurate detailed instructions swiftly in case of a fire emergency to result in a faster evacuation.

4. Conclusions

The findings of this research clearly highlight the important information required during evacuation, occupants' opinions about the use of smartphones during evacuation, and the preference between graphical or textual information. Occupants did not perceive

an unreasonably high risk of poor smartphone signals in a fire emergency; this augurs well for the adoption of a system which delivers evacuation instructions to smartphones. It was also important during the interviews to understand how information received during the fire could affect occupants' decision making. From the interviews, it can be seen that all interviewees believed that a smartphone is an important tool to have to communicate with others. Interviewees would feel safer when they had their smartphone with them during evacuation, as they could call for help at any point. It was also clear that occupants will make sure they are holding their smartphone during evacuation. The smartphone will not just allow occupants to call relatives but will also be the source of information during evacuation.

Smartphones would be useful in leading evacuees to the best route to expedite evacuation. Having established that evacuees would always strive to keep their smartphone in their possession, and therefore a system which delivered evacuation instructions to smartphones was viable, the research turned to the question of textual versus graphical formats for these instructions. A majority of the interviews preferred text instructions, although a significant proportion of interviewees acknowledged the value of graphical instructions or a combination of graphical and textual. Instructions superimposed on a floorplan, creating an indoor mapping system, seems workable. Screen size does not appear to be an issue. Locating friends and family within the building would be a useful function.

It was clear from the research findings that smartphones could play a big role during the evacuation of occupants from high-rise residential buildings. They would provide accurate information regarding the fire situation within the building and provide evacuation routes for occupants to follow, possibly optimised based on the fire situation. Smartphones would aid occupants in finding the safest and shortest route to evacuation. The interview findings show that emergency text messages should be short but should contain accurate and useful information. A number of information items also should be included in the message. The location of the fire is the most important information occupants felt should be included, in addition to having two preferred evacuation options. The routes provided to occupants will depend on the traffic flow on the main stairs, emergency, and queues at corridors. Further research is required with high-rise residential building occupants who previously experienced fire emergency evacuation to compare the results with the current research findings. The findings will then form the backbone of developing an intelligent egress system framework.

Limitation of this research must be acknowledged. The number of interviewees is arguably small. However, as interviewees were non-probabilistically purposely recruited, it can be argued that the 23 interviewees were an adequate representation of the general population of high-rise building occupants. The precise details of their high-rise building residence were deemed to be unnecessary, as long as they clearly lived in a building that could be definitively classified as high rise. Similarly, the limited number of interviewees meant that an analysis of the demographics of the interviewees would not bear any statistical power. However, gender, age, and other demographics can have an impact on fire egress perceptions and behaviours, and therefore merit future research. The technical feasibility (e.g., locating friends and family within the building) and ethics (e.g., communicating locations of friends and family) of the smartphone use suggested by these findings will of course require further research. The direct perceptions reported here are crucial for developing an intelligent egress system framework.

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Appendix A Interview

Interview Questions

1. Do you have a smartphone? If yes how often do you use your smartphone?
2. If you are asked to evacuate the building, will you make sure your carrying your smartphone? How important to you is it to carry a smartphone during evacuation? Please explain your answer
3. Are you aware of signalling problem that could happen during evacuation? Please explain your answer
4. Would you consider using your phone as a source of information during evacuation (If yes, how?)
5. Does it matter to you if information sent to you during an emergency is graphical or textual? Which one of both options would you prefer and why?
6. Do you think the smartphone screen is too small to receive any graphical or written information during evacuation? Why have you chosen such answer?
7. How do you think mobile technology could help you make decisions during evacuation?
8. Let's assume that a message would be sent to your smartphone during evacuation, what do you think should be included in the message?
9. Other than using your phone to call friends, family, etc, during the emergency would you consider using your smartphone for other purposes?
10. Do you think you could use the smartphone to locate other family members within the building? If Yes how do you think this could be possible?
11. Do you have any other comments on the usage of smartphone during fire evacuation from high rise residential buildings?

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