Human Factors investigation of the behavioural response to cues of a fire emergency

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Abstract

Safety is a significant priority in the contemporary building environment and a focus for many organisations and businesses. Studies have been conducted to review different factors regarding human behaviour during fire evacuation and to utilize the findings to model improved egress procedures and to train occupants on how to evacuate safely. However, much is still unknown about the processes of perceiving and responding to an emergency when cues from different information sources conflict. For example, when a fire evacuation warning has been issued, but the conditions in the area appear to be fine, some of the building occupants may have uncertainty about the correct action to take.

There are several cues to an emergency, and some of these may not lead to optimum behaviour. For example, prior research has shown that, in cases where there has been a prevalence of nuisance alarms such as false alarms, occupants may not take action when a real fire alarm is sounded (Proulx, 2007). Moreover, cues to an emergency are often ambiguous and may not be immediately perceived as a threat.

This research was conducted to understand the human responses to cues of an emergency in greater detail. It was based on the Protective Action Decision Model (PADM) (Lindell & Perry, 2012), which outlines the research framework conducted within this PhD. PADM provides a formal model of human behaviour during an emergency. Still, it should be expanded into a more comprehensive method of predicting how people behave in a fire or an evacuation (Kuligowski, 2013). The PADM model identifies several stages in the process of emergency detection and response. The first stage defines several factors that influence awareness of a fire scenario; environmental and social contexts, information sources, warning messages, channel access, and receiver characteristics. This PhD conducted a series of experimental studies to identify the influence of some of these factors on user response to fire alarm cues. The research also compared the use of different research methods, specifically, scenario talk through and virtual reality (VR) simulation, to evaluate user behaviour in response to a fire alarm.

Four studies have been conducted: the first extended the talk-through method previously used by Lawson et al. (2013) by adding the influence of social cues to the fire scenario. The second study presented the same fire scenario and influence of social cues as study 1, using VR. The pattern of results was consistent with previous literature in that passive behaviour of others resulted in longer evacuation times for the participants. Thus, these methods can reveal the influence of social behaviour on predicting human responses to an emergency. Study three extended the VR scenario to include other factors from stage one of the PADM model. These factors include the source of information during an emergency, the content of the information, and the recipient's characteristics. Therefore, the source of information, level of details, and information channels were all identified as significant in emergencies such as fire evacuations. Finally, the fourth study was conducted to understand the effects of social cues (passive or active conflict) on an authority figure or siren in the evacuation process. Again, three groups were identified and exposed to three different messages in a virtual environment. Results showed that an authority figure in an active conflict situation showed a significant reduction in the evacuation times. Thus, this thesis will show that understanding behavioural response to fire emergency cues has potential value in predicting human behaviour in a fire emergency.

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Table of contents

Abstract i

Acknowledgements iii

List of figures viii

List of tables xii

1 Chapter 1. Introduction 2

1.1 Chapter overview 2

1.2 Background 2

1.3 Aims & objectives 6

1.4 Thesis overview 7

2 Chapter 2. Literature review: Human behaviour during fire emergencies 10

2.1 Chapter overview 10

2.2 Human behaviour in fires 10

2.3 Elements in fire evacuation 11

2.4 Evacuation behaviour 11

2.5 A phase of fire & their influence on human behaviour 20

2.6 Risk perception 21

2.7 Protective action decision model (PADM) 22

2.7.1 Protective Action Decision-making: Risk Identification 24

2.7.2 Protective Action Decision-making: Protective Action Search 24

2.7.3 Protective Action Decision-making: Information needs assessment 24

2.7.4 Protective Action Decision-making: Communication Action Implementation 24

2.8 Stages of PADM 25

2.8.1 Environmental Cues 25

2.8.2 Social Cues 25

2.8.3 Information Sources 25

2.8.4 Channel access 28

2.8.5 Warning messages 30

2.8.6 Characteristics of receiver 31

2.9 Understanding crowd behaviour 32

2.10 Influence of social behaviour 34

2.11 Methods for predicting human behaviour 37

2.11.1 Models of human behaviour in fire ... 37
2.11.2 Talk-through approach as a method for identifying the influence of social behaviour on an emergency ... 41
2.11.3 Virtual environments in fire safety as a method for identifying the influence of social behaviour on an emergency ... 43
2.12 Chapter summary ... 52
3 Chapter 3. General approach ... 55
3.1 Chapter overview ... 55
3.2 The first stage of PADM as a suggested model ... 55
3.3 Talk- through approach ... 55
3.4 Virtual environments ... 56
3.5 Experimental studies ... 58
3.5.1 Study1: Predicting Social Influence in a Fire with the Talk-Through Approach ... 58
3.5.2 Study 2: The Influence of Social Behavior in Fire Evacuation in Virtual Environment 58
3.5.3 Study 3: Investigation of Influence the Relative Influence of Information Sources/ Message content and Receiver Characteristics on Behavior during Emergencies (Fire) in a Virtual Environment ... 59
3.5.4 Study 4: Investigation of the Effect of Information Source (Authority figure and Siren) in the Presence of Two Social Conditions (passive and Active conflict) on Behavior during Emergencies (Fire) in a Virtual Environment. ... 59
3.6 Chapter summary ... 60
4 Chapter 4. VR development ... 62
4.1 Chapter overview ... 62
4.1.1 Unity game engine ... 63
4.1.2 Animations ... 73
5 Chapter 5. Study 1: Predicting social influence in a fire with the talk-through approach 85
5.1 Chapter Overview ... 85
5.2 Introduction ... 85
5.3 Method ... 88
5.3.1 Participants ... 88
5.3.2 Study design ... 88
5.3.3 Procedure ... 88
5.4 Results ... 90
5.4.1 Perceived evacuation time ... 90
5.4.2 Time to leave the computer room ... 90

5.4.3 Influence of the behaviour of others 93
5.4.4 Frequency of acts 94
5.4.5 Sequence of acts 97
5.5 Discussion 99
5.6 Chapter summary 101
6 Chapter 6. Study 2: The Influence of social behaviour during a fire evacuation in a virtual environment 103
6.1 Chapter Overview 103
6.2 Introduction 103
6.3 Method 106
6.3.1 Participants 106
6.3.2 Study design 106
6.3.3 Materials 107
6.3.4 Procedure 109
6.4 Results 112
6.4.1 Time to evacuate 112
6.4.2 Influential of the behaviour of other 115
6.4.3 Frequency of acts 116
6.4.4 Sequence of acts 117
6.5 Discussion 119
6.6 Chapter summary 121
7 Chapter 7. Study3: Investigation of the relative influence of information sources/ message content and receiver characteristics on behaviour during a fire emergency in a virtual environment 123
7.1 Chapter Overview 123
7.2 Introduction 123
7.3 Method 125
7.3.1 Participants 126
7.3.2 Study aim 126
7.3.3 Study design 126
7.3.4 Materials 127
7.3.5 Procedure 132
7.4 Results 134
7.5 Discussion 144
7.6 Chapter summary 146

8 Chapter 8. Study 4: Investigation of the effect of information source on (virtual) fire evacuation behaviour in the presence of two social conditions (passive and active-conflict) 149

8.1 Chapter Overview ... 149

8.2 Introduction ... 149

8.3 Method ... 151

8.3.1 Participants ... 151

8.3.2 Study design ... 152

8.3.3 Materials ... 152

8.3.4 Procedure ... 153

8.4 Results ... 156

8.5 Discussion ... 162

8.6 Chapter summary ... 163

9 Chapter 9. General discussion chapter ... 165

9.1 Chapter Overview ... 165

9.2 Summary of Findings ... 165

9.3 Discussion of Findings ... 168

9.4 Contribution to knowledge ... 170

9.5 Future work ... 171

9.6 Limitations of Research ... 171

9.7 Conclusion ... 172

10 References ... 174

11 Appendix A: Study1 ... 183

12 Appendix B: Study2 ... 190

13 Appendix C: VR source code snapshots ... 197

14 Appendix D: Study3 ... 202

15 Appendix E: Study4 ... 212

16 Appendix I: Posters, Presentation ... 221

List of figures

Figure 1 Overview of the studies conducted for this thesis, mapped to the first phase of the Protective Action Decision 7

Figure 2 The Framework of the Protective action decision (Lindell & Perry, 2012) 23

Figure 3 Design stages of the VR experience (based on Hale and Stanney, 2014) 63

Figure 4 Unity game engine 64

Figure 5 Smoke which the Particle System generates 64

Figure 6 shows the settings of the smoke particles created by the unity particles system, and it shows the amount of smoke it will produce and how long the smokes particles take to disappears 65

Figure 7 The smoke image used to produce smoke particles 66

Figure 8 Script that controls the smoke in the VR experience 67

Figure 9 Shows a fundamental physics that's unity provide 68

Figure 10 Shows collider attached to players 69

Figure 11 AI player with collider (the green shape) 71

Figure 12 Colliders attached to doors and walls 71

Figure 13 Rigid body settings for AI Players 73

Figure 14 Player bones characters shown from Maximo 74

Figure 15 Shows animation stats for player 75

Figure 16 shows animation settings 75

Figure 17 Red nodes un-walkable area, where white nodes show the area which player allowed to move 77

Figure 18 First method used by AI to Request the path. the second method used the path was processed and then keep the result of the path 78

Figure 19 Main A* method: used to find the path to the target. If a path were found, it would call the Done Processing method. if the target or AI are on a node that cannot be walked, it will not find the path 79

Figure 20 A* the path was founded go through the path and create a vector 3 points of the path for the AI to be able to reach the target 80

Figure 21 Simplifying the path by reducing the points on to the target 81

Figure 22 Function used to start pathfinding from AI current positon to the target position 82
Figure 23 Function used to tell the AI Player to start moving after finding the path to a target 83
Figure 24 Study1 Mapped to the protective action decision model 85
Figure 25 Plan view of the physical building layout used in study 1 88
Figure 26 Average time for participants to move out of the main office in each condition 91
Figure 27 Average time for participants to move out of the building in each condition 92
Figure 28 Median scores- a rate of influence 94
Figure 29Total frequency of acts in control, active, and passive conditions 96
Figure 30 Decomposition diagram: control condition 98
Figure 31 Decomposition diagram: active conflict condition 98
Figure 32 Decomposition diagram: passive condition 99
Figure 33 Study 2 Mapped to the protective action decision model 103
Figure 34 The Vive head-mounted 107
Figure 35 The fire evacuation office. The numbers indicate key areas relevant to the study Participants would start in (1). In the active conflict condition, co-inhabitants would move to (2). There is a choice of exit routes (3) & (4) 108
Figure 36 Screenshots of the office building 108
Figure 37 Screenshots of the experimental conditions. In the Passive condition VAs (virtual agents) ignore the smoke detector 110
Figure 38 Screenshots of the experimental conditions. In the Active conflict condition, Vas (virtual agents) is moving to the meeting room 110
Figure 39 Screenshots of the control condition, in which participants are alone in the virtual environments 111
Figure 40 Average time for participants to move their avatar out of the main office in each condition 112
Figure 41 Average time for participants to move their avatar out of the building in each condition. 114
Figure 42 Boxplot of participant ratings of the influence of other avatar behaviour on their response to the fire alarm 115
Figure 43 Total scores for actions in all conditions 116

Figure 44 Decomposition diagram: control condition 118

Figure 45 Decomposition diagram: active conflict condition 118

Figure 46 Decomposition diagram: passive condition 119

Figure 47 Mapped to the protective action decision model 123

Figure 48 The Screenshots of the office building 128

Figure 49 Screenshots of the top scene 128

Figure 50 Screenshots of the scene for the stranger were giving instructions (scenario 1) 129

Figure 51Screenshots of the scene for the stranger were giving instructions (scenario 2) 129

Figure 52 Screenshots of the scene for the instructions via siren (scenario 1) 130

Figure 53 Screenshots of the scene for instructions via siren (scenario 2) 130

Figure 54 Screenshots of the scene for the authority figure giving instructions (scenario 1) . 131

Figure 55 Screenshots of the scene for the authority figure giving instructions (scenario 2) . 131

Figure 56 Average time for participants to move their avatar out of the time to leave the building in each condition in high details massage 136

Figure 57 Average time for participants to move their avatar out of the time to leave the building in each condition in no details massage 136

Figure 58 Average time for participants to move their avatar out of the main office in each condition in high and low details massage 137

Figure 59 Influence for participants to move their avatar out of the building in each condition in high details massage 140

Figure 60 Influence for participants to move their avatar out of the building in each condition in no details massage 140

Figure 61 Boxplot of participant ratings of the influence of information sources in great details massage 141

Figure 62 Boxplot of participant ratings of the influence of information sources in no details massage 142

Figure 63 Boxplot of participant ratings of the influence of level of warning 143

Figure 64 Boxplot of participant ratings of the influence of level of warning 143

Figure 65 Boxplot of participant ratings of the influence of level of warning 144

Figure 66 Study 4 mapped to the Protective Action Decision Model (Lindell & Perry, 2012) ... 149

Figure 67 Screenshots of the top scene 153

Figure 68 Screenshots of the scene for the authority figure giving instructions to the participant (off-camera) showing the other AI agents (Scenarios A & B) 155

Figure 69Screenshots of the scene for the siren giving instructions to the participant with AI Agents (Scenarios C and D) 155

Figure 70 Average time for participants to move their avatar out of the building in each condition 157

Figure 71 Average time for participants to move their avatar out of the building 157

Figure 72 Average time for participants to move their avatar out of the building 158

Figure 73 Average time for participants to move their avatar out of the building 158

Figure 74 Chart bar of participant ratings of the influence of information sources on participant's decision to evacuate from the building 159

Figure 75 Boxplot of participant ratings of the influence of information sources on your decision to evacuate from the building 160

Figure 76 Chart bar of participant ratings of the influence of other avatars on the decision to evacuate from the building 161

Figure 77 Boxplot of participant ratings of the influence of other avatars on the decision to evacuate from the building 161

Figure 78 Overview of the studies and results conducted for this thesis, mapped to the first phase of the Protective Action Decision 166

List of tables

Table 1 Meantime for participants to move their avatar from their desk to safety, recorded at two evacuation points: outside of the main office and outside of the building 90

Table 2 Analysis of variance for time to leave the main office... 91

Table 3 Analysis of variance for time to leave the building.. 92

Table 4 Frequency of acts in control, active, and passive conditions 96

Table 5 Mean time for participants to move their avatar from their desk to safety, recorded at two evacuation points: outside of the computer room and outside of the building......... 112

Table 6 Analysis of variance for time to leave the main office... 113

Table 7 Analysis of variance for time to leave the building... 114

Table *8* Frequency of acts in control, active, and passive conditions 117

Table 9 Comparison of talk through results and VE results 121

Table 10 The Scenarios for the Experiment 132

Table 11 Meantime for participants to move their avatar from their desk to safety, recorded . 134

Table 12 Tests of Within-Subjects Contrasts of warning message level of detail on time to leave the building 135

Table 13 Mean influence for participants to move their avatar from their desk to safety, recorded 138

Table 14 Tests of Within-Subjects Contrasts of warning message level of detail on influence to leave the building 139

Table 15 The scenarios for the experiment. Participants were assigned to one of the four scenarios.. 154

Table 16 Meantime for participants to move their avatar from their desk to safety, recorded . 156

Table 17 Tests of Between-Subjects Effects time to evacuate from the building...................... 156

Chapter 1

1 Chapter 1. Introduction

1.1 Chapter overview

This chapter contains an overview of the introduction to this thesis. First, the aim of the research, to evaluate the perception of cues to an emergency as they inform the decision-making process. Then, an outline of the studies and investigations is presented, noting the questions that this thesis aimed to address and using the overview of the studies conducted for this thesis, mapped to the first phase of the Protective Action Decision.

1.2 Background

Emergencies in buildings pose a significant threat to occupants of buildings and thus could lead to substantial loss of life and property (Johansson & Petersson, 2013). Regarding their frequency, fire and rescue incident statistics in England (2019) provide information on incidents attended by fire and rescue services in England each year. The adventures attended to by Fire Rescue Services (FRS) during the year are categorized into three groups or types: non-fire attended incidents, fire incidents, and false fire incidents. The data for 2019 show an overall number of 578,113 fire incidents, of which 41% were fire false alarm incidents, 28% fire-related incidents, and 30% non-fire incidents. (Home Office Statistical Bulletin, 2020). These figures demonstrate that fire incidents remain relatively common in recent years. While technological interventions, such as alarms and building materials can improve fire safety, human behaviour has a significant impact on the outcome of an emergency (Home Office Statistical Bulletin, 2020). It is therefore essential to study and understand the process of response and decision-making to avoid tragic accidents.

In most cases, casualties result from people who are unable to evacuate themselves from the premises in which the fire is located due to intoxication or other forms of injury (Johansson & Petersson, 2013). To reduce such occurrences, fire safety engineers often use calculation techniques to understand and predict the safety that a particular building offers to the tenants. However, these calculations cannot currently provide accurate predictions of how these people will respond during emergencies.

Humans react differently in a fire emergency. This has attracted scientific interest in studying human behaviour in a fire to determine methods of improving fire evacuation processes, developing ancillary technologies, and enhancing evacuation training (Johansson & Petersson, 2013). As a result, evacuation models simulating human evacuation from a building have been developed (Kuligowski, 2008), and these focus primarily on determining the time required to evacuate buildings on fire. However, more research is needed on the impact of diverse human behaviour on the efficacy of evacuation strategies and processes. This is likely due to the paucity of data available regarding human behavioural factors, thus contributing to the relative inaccuracy of existing evacuation models (Kuligowski, 2008).

Furthermore, the interplay between human psychology and applied solutions rooted in engineering must be considered to achieve a successful evacuation (Kuligowski, 2008). Kuligowski (2008) points out that many traditional methods of modelling evacuation fail to integrate human behaviour fully. These evacuation models, which do consider engineering and physical calculations to determine whether or not a building is safe enough to be evacuated in a timely fashion in the case of a fire, do not effectively incorporate potential human behaviour during an evacuation. Specifically, Kuligowski (2008) explains that a wide variety of human factors can impact how well people evacuate from a building. These include social elements, which can influence the degree to which human beings are willing to evacuate and how quickly and orderly the evacuation is. Kuligowski’s central point is that to gain a more solid understanding of how human beings will evacuate from a given building, as is the ultimate intention of the developed models, human factors must be integrated into evacuation models. To do this most effectively, Kuligowski insists that those researching fire evacuation and creating evacuation models must first develop a comprehensive theory of human behaviour during evacuations due to fires. Proulx (2001) had previously made similar claims, indicating that those studying human behaviour during the case of a fire on an intellectual level, and even those who discuss the matter practically, often fail to acknowledge the way that human beings behave during a fire. Taking into account these human factors can represent the difference between life and death. At the very least, they significantly affect how quickly and effectively people evacuate from a building with a blaring fire alarm.

In brief, studies have determined that the decisions of building occupants upon discovery of a fire may not lead to an optimal evacuation. In other words, their behaviour is likely to have a negative impact on evacuation times and the safety of the occupants, either individually or as a collective group. For this reason, it is crucial to predict these decisions so that they can be incorporated into evacuation models and cause occupant evacuations to become more timely and controlled. For example, Johansson and Petersson (2013) have found that when building occupants must leave a building in the event of a fire, and the building shows no apparent structural damage, occupants tend to leave via the pathway used for entry. This choice may be made regardless of whether other exit routes are closer or safer. Another behaviour evident in emergency situations is that of "swarming" or "running". This irrational behaviour has been explained as the loss of ability, in high alert states that result from danger, to choose a course of action and instead to follow others in the desire to escape the situation. This occurs especially when high volumes of people need to move at high speed to escape (Johansson & Petersson, 2013).

Interestingly, recent research into human behaviour in fire emergencies has revealed that actions are likely aftereffects of social and dynamic frameworks instead of relying on chance (Johansson & Petersson, 2013). Assessments of clearings during disillusionments and building fire has shown that before individuals act, they see specific prompts, decode the situation and the danger implied by those signs, and then make decisions about their actions based on these interpretations. Thus, to develop a competent predictive behavioural model, we must better understand this cue perception and decision-making process. To build such a model, the numerous factors that affect decision making must be defined; challenging tasks for two specific reasons. To begin with, there are both rapidly changing and indirect variables that make behaviour challenging to predict accurately. To be more precise, while the perception stage of fire by building occupants results in a specific and limited number of behavioural choices, the interpretation, dynamic and action stage evidence a tremendous number of options, which makes it challenging to create linkages between these stages. For example, inhabitants have a vast number of interpretations that can be made as to the condition of the fire and the risk associated with it.

As stated in the evacuation process, the method that evacuees choose by which to leave the building is based on social, behavioural systems and various other cues to an emergency, causing such behaviour to be challenging to model. Therefore, it is crucial to understand that every system begins with signals and information from the physical and social conditions. These signals must be perceived and then deciphered before a decision is made. During an evacuation, individuals engage in this process whilst also taking physical action. The consequent segments of the process must be understood and categorized to develop improved evacuation techniques. By observing the factors that seem to impact each phase in the social system, experts can thus begin to develop a lead model, Protective Action Decision Model (PADM), for evacuation in the case of a fire within a structure.

Given the lack of understanding around perception, interpretation and response-making of human behaviour in emergencies, this thesis focuses on essential influencing elements such as social influence, environmental cues, information sources, warning level, and receiver characteristics (gender) in relation to participants' behaviour in a fire emergency. The work was framed using the Protective Action Decision Model (PADM), of cues, ecological and social settings to emergencies, pre-decision processes, perception and action decision making and behavioural response (Lindell & Perry, 2012). In particular, the research conducted for this PhD sought to develop an understanding of how environmental cues, information sources, social cues, and receiver characteristics can affect perception and decision making in response to a building fire scenario. Given the ethical and safety considerations of studying behaviour in actual emergencies, the work relied heavily on hypothetical and simulated emergencies, using the talk-through approach and VR experimental studies.

1.3 Aims & objectives

The primary aim of this research was to evaluate the perception of cues to an emergency as they inform the decision-making process. Elements to be considered included: smoke, social factors, and personal characteristics, for example, gender.

The work was based on the following objectives:

1. To develop a previously studied talk-through approach (Lawson et al. 2013) to include the influence of social factors.
2. To compare the use of self-report scenario-based methods with scenario presentation using virtual reality (VR) simulation. This objective was set to validate the use of VR simulation as a suitable method to predict user response to a building fire scenario.
3. To identify the impact of information sources and warnings massages on human behaviour during fire emergencies.
4. To design and build a simulation in VR to present fire scenarios to study participants and observe their behavioural responses.
5. To conduct a series of experiments to systematically evaluate the influence of specific factors defined in the first stage of the Protective Action Decision Model (PADM) (Lindell & Perry, 2012) on participant behavioural response. The studies which were conducted to satisfy this objective are presented in Chapters 5, 6, 7 and 8.

1.4 Thesis overview

This section presents a general outline of the studies and investigations and a description of each contributing study. To address the research objectives, a series of experimental studies was conducted exploring the influence of different factors on participant response to a fire scenario. The factors were mapped to the PADM model and posed as research questions related to different combinations of cues, information source and receiver characteristics, as illustrated in Figure 1. To overcome the danger and ethical challenges associated with conducting research in real building fires, the research work relied on pseudo-simulation methods. One of the research objectives was to compare results obtained using different methods – specifically the traditional talk-through approach with virtual reality simulation. Both methods were used to address research question 1 (RQ1: How do social and environmental cues influence human response to a fire scenario?). Having established the suitability of VR simulation as a method for the prediction of human response to a fire scenario, the virtual environment was then used to examine the influence of different factors to answer RQ2 and RQ3.

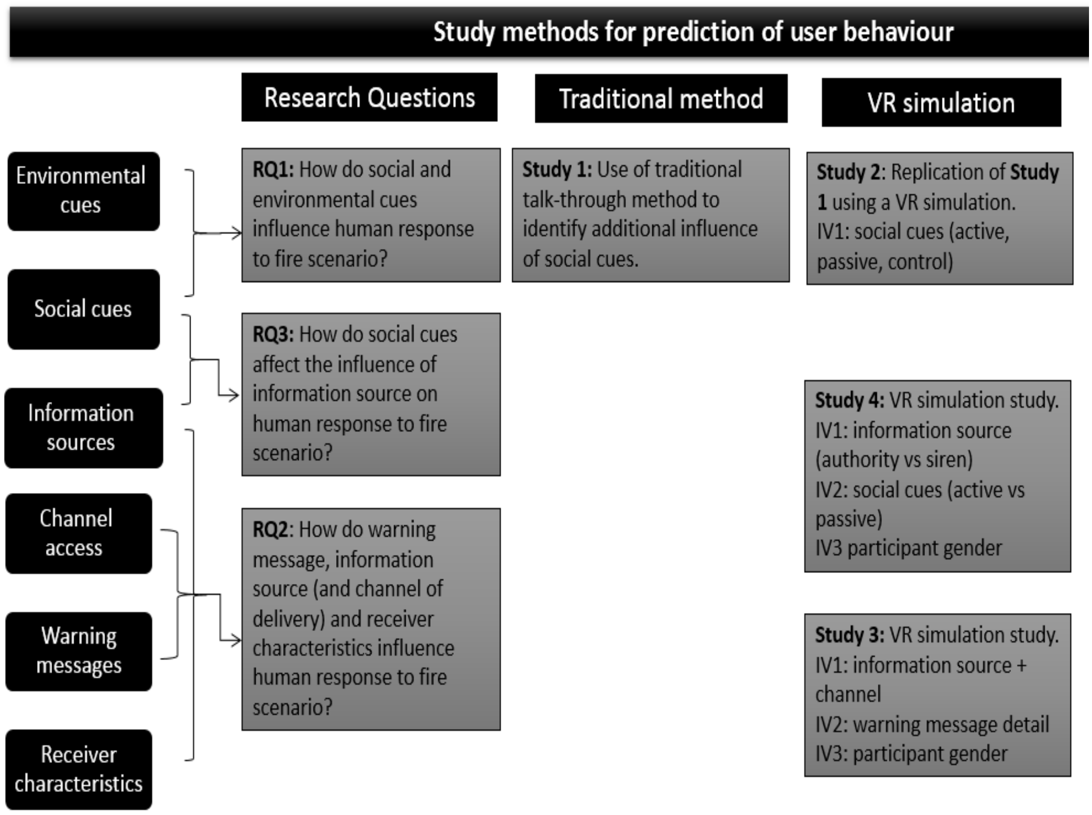

Figure 1 Overview of the studies conducted for this thesis, mapped to the first phase of the Protective Action Decision

Chapter 1, presents the rationale for the research. The aims and objectives of the research are described, together with the specific research questions addressed in the experimental studies. An overview of the experimental studies is mapped to the first phase of the Protective Action Decision.

Chapter 2, provides an in-depth review of literature on the various aspects of human behaviour in a fire and how an understanding of such behaviour can improve evacuation techniques. It presents an overview of the importance of human behaviour in fire and other emergency situations, the state of current research on risk perception when people are in distress and the influence of social behaviour on evacuation in a fire.

Chapter 3, presents the general approach to the research describing different methods used for the prediction of human behaviour in response to fire situations. A more detailed overview of the experimental studies is presented.

Chapter 4, details the design and development of the virtual environment scenarios used in the experimental studies.

Chapter 5, provides a detailed description of study 1 in which the talk-through method was used to assess the influence of social and environmental cues on participant response to a described fire scenario.

Chapter 6, provides a detailed description of study 2 which replicates study 1 using a virtual reality simulation in place of the described scenario.

Chapter 7, provides a detailed description of study 3 which aims to study the effects other factors may have on human behaviour, including the source of information during an emergency, the content of the information, and the recipient's characteristics. This studed also used a virtual reality simulation .

Chapter 8, provides a detailed description of study 4 which was conducted to investigate the effect of the two most effective cues to an evacuation, but in the presence of social cues.

Chapter 9, presents a discussion of the research findings, with acknowledgement of the limitations of the research and conclusions for further work.

Chapter 2

2 Chapter 2. Literature review: Human behaviour during fire emergencies

2.1 Chapter overview

This chapter contains an overview of the literature on human behaviour during a fire emergency. In particular, it presents an overview of the importance of human behaviour in fire and other emergency situations, the state of current research on risk perception when people are in distress and the influence of social behaviour on evacuation in a fire. The chapter concludes that researching fire evacuation and creating more detailed models could help further develop an understanding of human behaviour during the evacuation from building fires.

2.2 Human behaviour in fires

Research into human behaviour in fire has changed over time to better understand responses to emergencies, with technology playing an important role. For example, computer simulation has improved response and safety strategies (Shields & Proulx, 2000). Many of the changes can be attributed to the development of performance-based fire safety regulations and codes, which aim to validate the performance of a building in a fire scenario, rather than prescriptive building codes, which mandate door widths and other such prescriptive structural requirements. Performance-based assessment has also been made more effective by computer simulations (Shields & Proulx, 2000). In essence, the advent of computer simulations for evacuation in case of fire offers future hope concerning fire safety. Future research is now pointing towards developing more performance-based approaches and ensuring improved fire safety in residential houses. To do this, performance models must incorporate accurate representations of human behaviour. However, actions for occupants in buildings and regards to fire are complex (Shields & Proulx, 2000). Amongst other factors, they involve the occupants’ environmental and spatial interactions. These are a result of an individual's psychological, physiological and sociological domains. It is important to note that while new technology offers essential tools to ensure fire safety, more work is required to understand human behavioural characteristics fully.

2.3 Elements in fire evacuation

Proulx (2001) breaks down the complete suite of elements involved in fire evacuation into three categories: the occupants' characteristics, the building's characteristics, and the fire's characteristics. She also mentions that too much attention is often paid to the building and fire characteristics, and too little is paid to the occupants' features. Proulx (2001) also suggests that too little attention is paid to the interplay of all traits together. However, some attention is paid to the interaction between the characteristics of the building and the characteristics of the fire. In terms of the first of these categories, the occupants' characteristics can be affected by knowledge and experience, including their familiarity with the building, whether they have past fire experiences, and fire safety training or other relevant training. The building characteristics include aspects such as whether it is used for residential, commercial or industrial purposes. The architecture of the building also plays a crucial role, such as the number of floors and the emergency exit routes, amongst others. Another key influence is the activities in the building, such as if the people in the building are working or sleeping. Another point to note is that, in modern times, almost every building has fire precautions and fire safety systems that are meant to facilitate safety during fire incidents (Hofinger et al., 2014). In terms of the last category, the characteristics of the fire include visual cues such as frames and smoke, olfactory cues such as a burning smell, or other cues such as objects falling and increased heat.

2.4 Evacuation behaviour

Evacuation strategies are also dependent on the fact that people have different information processing capacities, which occur during extreme events such as fires. Therefore, analysis of human behaviour during fire emergencies can be utilized in developing better fire evacuation and management strategies to minimize threats to human life during a fire. Several studies have been conducted since the late 1900s, which seek to determine the correlation in findings and build upon the best fire reaction practices (Bryan, 1999). In a study by (Galea et al., 2011), the key objective was to identify the environmental, structural, individual, and organisational factors significantly associated with the 2001 World Trade Centre emergency outcomes. The length of time required to initiate an evacuation, the subsequent duration of time to evacuate the World Trade Centre's two towers fully, and any potential injuries sustained in the process were found to be significant factors. Another key finding of the research was that delays to evacuation were due, in part, to the inability of building occupants to identify the fire's location.

Regarding the initiation of the evacuation, factors such as impairments, disabilities, and injuries sustained during the emergency incident played a role. In addition, structural (building) conditions also extended the length of evacuation, such as the height of the building, and a lack of leadership during the evacuation did not help. By identifying and understanding these aspects, the researchers highlighted that improving strategies for emergencies in high-rise building design, emergency regulations, codes, and emergency evacuation procedures reduce the risk of harm to the occupants.

There is then a need to understand how different cues to an emergency correlate with time pressure and stress during an evacuation process to influence people's decision making (Ozel, 2001). As explained, people will react differently during a fire emergency due to differences in decision-making and perception of danger. This has been demonstrated through the theory of differentiation and consolidation that considers decision making as an active process where an individual weighs up different options before settling on one (Ozel, 2001). According to Ozel (2001), time pressure and stress have been found to be critical factors during emergency egress. More specifically, in stressful situations, one tends to weigh different threat levels and then take the course of action perceived as causing the least harm. The thought process starts from a stage of conflicted inertia after learning about the threat, then escalates to an un-conflicted decision, the defensive avoidance of more danger, and eventually, hypervigilance, whereby the individual might decide on extreme reactions that are directly aimed at avoiding the fire. This explains why a victim might decide to take the stairs rather than lift during an evacuation process, even though a lift would be faster (Ozel, 2001). This implies that they fear the lift might jam on the way down and expose them to increased threats. The same person might take the stairs from the 8th floor and, upon reaching the 2nd floor, decide to jump off a balcony – this would demonstrate that they perceive the threat on the lower floors to be higher than the risk of injuring themselves from the jump (Ozel, 2001).

Lessons learned and personal stories from real fire evacuation scenarios can determine best practise in evacuation situations. Evacuation behaviours have also been determined to depend on factors such as standards of fire safety provisions in the buildings and the occupant population, which resonates with the competition for available evacuation resources (Purser & Bensilum, 2001). It also depends on the distribution of occupants within the building, whereby scarcely distributed populations are more straightforward to evacuate than densely populated structures. In cases of fewer people being in the vicinity, such as inside a house, the response is usually speedy and efficient. On the other hand, in public places, the rescue is complicated by aspects such as multitudes of people moving in a uniform direction due to crowd mentality (Purser & Bensilum, 2001). Thus, designing buildings to facilitate smooth evacuation is an approach that is being pursued as architects work collaboratively with psychiatrists to determine the best models. Other factors, such as the activities in the building during the fire, play an integral role. These activities include occupants being asleep or in a mall with several populated events taking place concurrently. Further analysis has been conducted to gain a deeper understanding of evacuation patterns in high-rise buildings due to the prevalence of such buildings in major cities (Purser & Bensilum, 2001).

A seminal example of this is a case study on the 9/11 twin tower disaster in the High Rise Evacuation Evaluation Database showing the collective approach to determining the best evacuation approaches (McConnell et al., 2009). In terms of recognition of imminent danger, most of the participants detailed diverse perceptions. Some indicated that they heard loud bangs; others saw debris falling. Still, others saw the planes heading for the building, whereas a final group saw fire and smoke. These reports were also found to correlate with the respective positioning of the participants in the building: those in the upper half mainly were part of the group that saw the plane heading for the building, and those in the middle and lower sections of the buildings mostly heard the bang and saw debris falling. Findings were published regarding how they reacted. More than 50% of the participants responded by inquiring about what was happening, and only 11% responded by immediately evacuating. More than 30% made an initial response of collecting their belongings in readiness for a (McConnell et al., 2009). This shows significant differences in perceived risk and indicates that recognition is an integral aspect that influences reactions. The 11% of participants that resolved to an initial response from an evacuation all said they saw the planes and heard the impact. In their minds, they knew danger was upon them. On the other hand, the remainder first inquired about what was happening before evacuating, increasing personal risk.

Following the evacuation attempts, different factors came into play. This influenced the development of the High Rise Evacuation Evaluation Database (HEED) to analyse various factors and utilize them in determining the best approach to evacuating such buildings. One paper focused on the methodologies used to collect the information from some of the survivors to determine how different factors affected the evacuation (Marselle, 2007). Among the key factors was cue recognition and response; many participants did not recognize cues as early as possible and were thus slow to respond. Training management and organisational structure were also determined to be crucial factors. Some of the survivors had previous evacuation training and experience in the same building during a prior incident in 1993. These were among the survivors due to their smooth evacuation process. Choosing and locating an exit was also a key consideration, and the thought process utilized to decide on the evacuation process was an integral part of the study (Marselle, 2007).

In another related study, merger flows and deference behaviours were studied to determine how people coordinated and complemented each other's evacuation processes. The findings of the federal investigation after the attack on the WTC in September 2001 are particularly revealing. The analysis primarily focused on the evacuation and the approaches used by the survivors. The factors that were taken into consideration included the evacuation initiation delay times. This depended on factors such as the recognition of cues and the type of signals that were perceived. In line with the conclusion of the previously cited study, Averill et al. (2012) reported that those who witnessed the planes heading for the building and saw the actual impact were the first to react with an unconditional evacuation resolve. Others who heard loud bangs and saw smoke and debris waited to question what was happening and thus lost more time before evacuating. The same study by Averill et al. (2012) determined that another aspect of the evacuation that affected its success was the normalized stairwell evacuation time. It was determined that after the electrical failure of all the elevators, most of the evacuation time was the time spent in the stairwells. This analysis identified the factors and social processes that influenced the normalized stairwell evacuation time per flight of stairs for the people who evacuated WTC 1 on September 11, 2001. The report's primary recommendations included suggestions that egress systems should be designed to maximize the remoteness of egress components (i.e., stairs, elevators, and exits) without negatively impacting the average travel distance. It was also suggested that they should maintain their functional integrity and survivability under foreseeable building-specific or large-scale emergencies. Final recommendations included systems being consistent with consistent layouts, standard signage, and guidance so that systems become intuitive and evident to building occupants during evacuations.

High-rise buildings became a primary concern in terms of evacuation following the WTC 9/11 disaster, and thus the UK also conducted an analysis of evacuation processes in such buildings (Galea et al., 2011). Among the critical components studied were the stoppages involved in the evacuation process and the factors that influenced these stoppages. The study found that 124 people in the North Tower (87% of the sample) said they had stopped at least once during their descent. It was found that 40% of stoppages were due to congestion, while 8% of stoppages were for resting due to fatigue. Among the personal factors that came into play here included being overweight or having medical conditions. Another issue investigated was stair travel speeds. The analysis determined that the travel speed data for 30 occupants indicated that they were moving down the stairs at an adjusted stair speed of 0.31m/s. The study also determined that occupants with stair speeds less than the average rate encountered high congestion levels for at least 50% of their journeys. The study thus concluded that the lower than expected stair speeds appeared to be affected predominately by high levels of congestion experienced on the stairs for significant periods. Interestingly, BMI and fitness were not predictors of stair travel speed; however, this is likely due to the high levels of congestion encountered.

The utilization of computer modelling resulted in a series of essential findings relevant not only to the particular circumstances of 9/11 but to high-rise buildings in general, and identification of areas in human factors and evacuation modelling technology requiring further research and development. An evacuation analysis was utilised to determine the factors that impacted the initiation and time for an evacuation amid the attack. Demographics were a significant factor here as it was determined that a majority of 60% of the participants were male, with an average age of 44 years ranging from 25 to 75 years (Gershon et al., 2011).

The safety of personnel and customers in any situation is a top priority for any organisation. The responsibility of the organisation towards its employees and customers is mandated within the law. Samochine et al. (2005) analyse simulated evacuation scenarios in different contexts looking at the response of employees in five different retail stores in Wales and Northern Ireland. While completing the analysis, the theory of occupancy is introduced, which states that reaction depends upon the location and the familiarity with which a particular person has. Different scenarios were studied to assess the variation in response, with each differing in degree of attachment and responsibility to the customer.

In all five scenarios, four elements were tabulated: staff pre-movement time, staff response to the alarm, staff impact on customer's behaviour, and staff travel speed. Staff pre-movement speed was slowest in situations where there was direct interaction with the customer. Under staff response to the alarm, a 'wait and seek information' response was the most common response in all scenarios. However, those in direct contact with the customer scored higher than others, which staff actions were seen to have an important influence on customers' behaviour. A detailed analysis of the video tapes determined that staff impact on customer's behaviour indicates that 79.5% of staff observed had a direct influence on customers. It was evident that positive responses from staff directly influenced faster responses from customers and vice versa. Regarding travel speed, staff moved faster than customers and men were faster than women generally. Across the board, it was noted that increased activity indicated a realization of the emergent situation. In conclusion, it was noted that training and preparedness of the staff in fire drills and evacuation directly affected the outcome of an emergency situation.

Considering other building types, Huo et al. (2014) look at the factors that could complicate pedestrians' evacuation in underground buildings. These factors include the structure of the building, the characteristics of pedestrian movement, and the seriousness of emergency events. The evacuation time incorporates these three phases; the cue validation phase, decision-making phase, and movement phase. The cue validation and decision-making phases can be defined as pre-movement time, and the actual movement phase can be defined as movement time. The total evacuation time includes both the pre-movement and movement time. Other factors considered while calculating the time include the number of exits and the width of each exit. The overall evacuation efficiency of exits presents an area on the flow of people by recording each individual per second. The number of evacuees in each exit also plays a role in the flow of people; therefore, obstacles from nearby emergency exits should be removed, and the clustering places for evacuees should be far away from the emergency exits.

Individuals behave differently in the event of fire; therefore, this study focuses on the pre-movement time, exit choice during the evacuation process, and the influences of staff behaviours on the evacuation process. The behaviours of the pedestrians were also studied. From analyzing the questionnaires used in collecting information, the researchers found out that in the event of a fire and the fire alarm goes off, about 41% of the participants chose to run towards the exits, about 26% called the police and another 25% decided to alert others. Regarding exit choice, 63% of participants choose the nearest exit, and only 14% of participants might choose the most familiar. However, most of the participants in the research were familiar with the building; therefore, the results might be different with people unfamiliar with the building. In addition, other studies suggest that people are likely to choose what they are most familiar with rather than choosing a closer route (Proulx, 2001; Heliövaara et al., 2012; Johansson & Petersson, 2013).

By the same token, Kallianiotis & Kaliampakos (2016) evaluate several underground spaces regarding their evacuation effectiveness and compares them to similar above-ground spaces with a similar type of occupancy, whether residential building, business setting industrial, or even storage. The evaluation of underground spaces is determined based on the factors that affect evacuation effectiveness which include evacuation time and social effect. In addition, these determining factors on the evacuation effectiveness are influenced by three evacuation parameters included in standards and regulations: evacuation distance, travel in a dead-end, and angle between exit doors. From the analysis, surface structures scored more highly to evacuation procedures than underground surfaces. Underground surfaces highlighted show structures that do not frequent people for most days of the week compared to surface structures which seemed to frequent people daily. However, underground surfaces should score high on structure evacuation effectiveness to improve their desirability and profile, which is rather low than surface structures. From the data given in the text, the results revealed by underground surfaces were quite more satisfactory compared to those from surface structures, even though it is difficult to alter the design of underground surfaces to incorporate more exits. This means that the exits are placed correctly, and also, the design of the interior space does not leave areas in dead ends or far away from the closest exit.

Considering another application area, evacuation in urban residential communities in emergencies is a critical issue, as timely evacuation of individuals can prevent the occurrence of extensive damage, injuries, or even loss of life (Kuligowski, 2008). On the other hand, in untimely evacuations during emergencies, more people are likely to get injured; for example, a stampede occurred in Shanghai Bund on 31 December 2014, which resulted in 36 people dying and 49 people injure (Chu et al., 2019). To reduce these adverse effects in evacuations, emergency management is important.

Unlike in business settings, evacuations in residential areas are cumbersome because the people tend to slow as they have created some emotional connection to their dwellings and have some valuable possessions they feel they want to protect. Under evacuation mode, residential buildings are mostly occupied by different households, whereby each household holds a family. It is therefore difficult for residents to run alone without their family members. Walking speed is also a determinant that is classified according to the age and gender group to simplify the task of walking speed setting. Older individuals are slower in walking and women are slower than men. The spatial distribution is subject to the design and structure of the building. The distribution of people in the buildings as well as in the household can only be acquired by other data sources, such as demographic data and reasonable estimation methods of the population in buildings. After acquiring the spatial data, the dynamic process of residents' evacuation can be duplicated or even documented.

Therefore, the behavioural characteristics of people have a direct impact on the evacuation process. To accurately simulate the evacuation process and predict the evacuation time in communities, it is necessary to analyze residents' behavioural characteristics during emergencies (Chu et al., 2019). Chu et al. (2019) posit four behavioural characteristics of residents: evacuation mode, walking speed, spatial distribution, and physical trait, which could complicate the evacuation process and increase the evacuation time.

Each of the above focused on either evacuating individuals from buildings in the event of emergencies from the surroundings of residential areas, while others attempted to analyze evacuation effectiveness in different building types. One of the major similarities identified in all these above is that there are factors that affect the evacuation activity in a building. Some of these factors include the number of exits, the nature of job/business, the flow of people, delays/pre-movement times, slow occupant groups, and the behaviour of the individuals, and route choice of the occupants.

The other similarity is that all the above focus on calculating the evacuation time with average performance rankings on different structures relying on evacuation time and the number of individuals evacuated as a major factor. The evacuation time occurs in different phases, which include the cue validation phase, decision-making phase, and movement phase. They highlight that evacuation effectiveness in most buildings is influenced by three parameters included in standards and regulations: evacuation distance, evacuation in a dead-end, and angle between exit doors.

One of the differences between the building types is the differing physical characteristics of the residents in the building and those of the building itself. For example, in residential buildings, evacuation mode, as well as pedestrian static space, are major factors. At the same time, in underground surfaces, the number of exits and the width of the exits are major factors. In as much as creating better evacuation paths, increasing the number of exits, increasing the width of the exits, and reducing dead-end paths is important in emergency management, and each building type has standard requirements in the design. For example, the number of exits in a school setting could be more and with a larger width than those of a business/office type of setting.

2.5 A phase of fire & their influence on human behaviour

During a building fire, different phases can influence human behaviour. These phases are as follows: perception of the fire, its interpretation, decision-making on this basis, and finally, implementation of a decision (Kuligowski, 2009). In the interpretation phase, the resident attempts to interpret the information provided by the signals that are perceived during the perception phase, and during the interpretation phase, occupants explain or define the situation and the risks to themselves to others (Kuligowski, 2009). The third phase of the behavioural process, decision making, involves occupants make decisions about what to do next based on their interpretations of situations and risks (Kuligowski, 2009). Finally, in phase 4 of the behavioural process, occupants may take action they decided upon at the decision-making stage. To get a complete version of the theory behind each phase in this process (Kuligowski, 2009).

An alternative classification would be that evacuating occupants during a fire emergency comprises two periods: the pre-evacuation and the actual evacuation period (Kinateder et al., 2014). Pre-evacuation behaviour would typically including seeking more information, talking to colleagues, finishing tasks, or gathering belongings (Canter et al.,1978). Risk perception influences when occupants leave a building on fire; risk perception is formed when the initial fire cues are interpreted or confirmed. This often marks the transition from pre-evacuation to evacuation behaviour (Kinateder et al., 2014). The evacuation behaviour is thus when the occupant begins a series of actions to evacuate the building.

In the event of a fire in a building, how one responds and the time is taken to do so determines the efficiency of response. Thus, in the event of a fire in a building, the time necessary and available for occupants to successfully evacuate to safety – also referred to as the Available Self Egress Time (ASET) – typically depends on the particular time of fire detection and the onset of hazardous conditions in the building. The concept of ASET is usually incorporated into building designs. In this case, if a building is considered safe, the ASET time for the threatened spaces in the building should be longer than the time required for the building occupants to evacuate the areas successfully. This required time is referred to as Required Self Egress Time, abbreviated as RSET. Thus, a building is safe during the time of a fire incident if the ASET is greater than the RSET (Cooper & Stroup, 1982). However, human factors play a critical role in the RSET and its prediction. These are described in further detail in the following section.

2.6 Risk perception

As indicated by its name, "risk perception" concerns risk and perception, with the former denoting the hazard, threat, and consequences of an event and the latter defining the organisation, identification, and interpretation of information to understand the environment (Kinateder et al., 2014). During a building fire evacuation, risk perception is influenced by the evacuees' understanding of the evacuation process, the perceived level of threat, and the building design. In this regard, understanding risk perception and its importance in the evacuation decision-making process contributeo the development of accurate evacuation models and, ultimately, improvements in building safety (Kinateder et al., 2014). Risk perception is modulated by several situational, social, and organisational factors that may be dynamic or static in nature but nonetheless interact with each other. These include the number of fire cues and floor levels, information credibility and information processing, the occupants' genders and ages, and perhaps most crucially, their previous experience of evacuation (Kinateder et al., 2014). Other variables that affect risk perception are the emotional states of the occupants, their hazard knowledge, certain cognitive biases, and the individual and group behaviour of occupants in the building that is influenced by such factors as gender, the experience of fire events, and social status. Emotional states, such as state anxiety, correlate with arousal and increase perceived risk (Kinateder et al., 2014). Hazard knowledge refers to the knowledge that any person has related to specific types of hazards associated with an incident, including the consequences of the hazard and appropriate responses, and cognitive biases refer to systematic distortions in human information processing and decision-making (Kinateder et al., 2014). These factors have been shown to increase perceived risk, although these effects are complex and still not fully understood (Kinateder et al., 2014).

To further explore this concept of behavioural responses to an emergency, people's reactions during a fire are informed by their behavioural characteristics and their thought processes – or the manner in which they make their decisions (Kuligowski, 2009). In a fire incident, people work on cues and react differently to them. These cues include factors such as smelling smoke, hearing other people talk about the emergency and their actions to ensure escape, and advanced visual aspects such as seeing flames (Kuligowski, 2009). The reactions to these cues depend on individual attributes: some will want to go closer and see how they can help potential victims and contain the fire; others will have an intuitive reaction of fleeing in the perception that the fire might cause them harm.

2.7 Protective action decision model (PADM)

Studies on human behaviour have shown that people do indeed make rational decisions when faced or are in disaster situations. Based on this, a primary model, the Protective Action Decision Model (PADM), is used to explain how people make decisions when faced with a fire emergency situation.

The first stage of the Protective Action Decision Model (PADM) contributes to the understanding of emergency response (see Figure 2 below for a visual representation of the model) as it relates to the occupants' interactions with fire signals, people, or buildings in the case of a fire outbreak and, consequently, their decision-making process, which affects their responses. The protective action decision-making process involves a reflection process in which an individual assesses the emergency through the information available regarding threats posed by the hazard. The reflection process also involves assessing alternative protective actions as well as social stakeholders. This aspect influences the behavioural response chosen by the individual. This demonstrates that, in emergencies, panic rarely occurs and that the behavioural response is based on rational decision making influenced by the aspects mentioned above. Indeed, studies on disaster response indicate that inappropriate emergency response is mostly due to inadequate information rather than defective cognitive processing of the persons facing an emergency (Lindell & Perry, 2012).

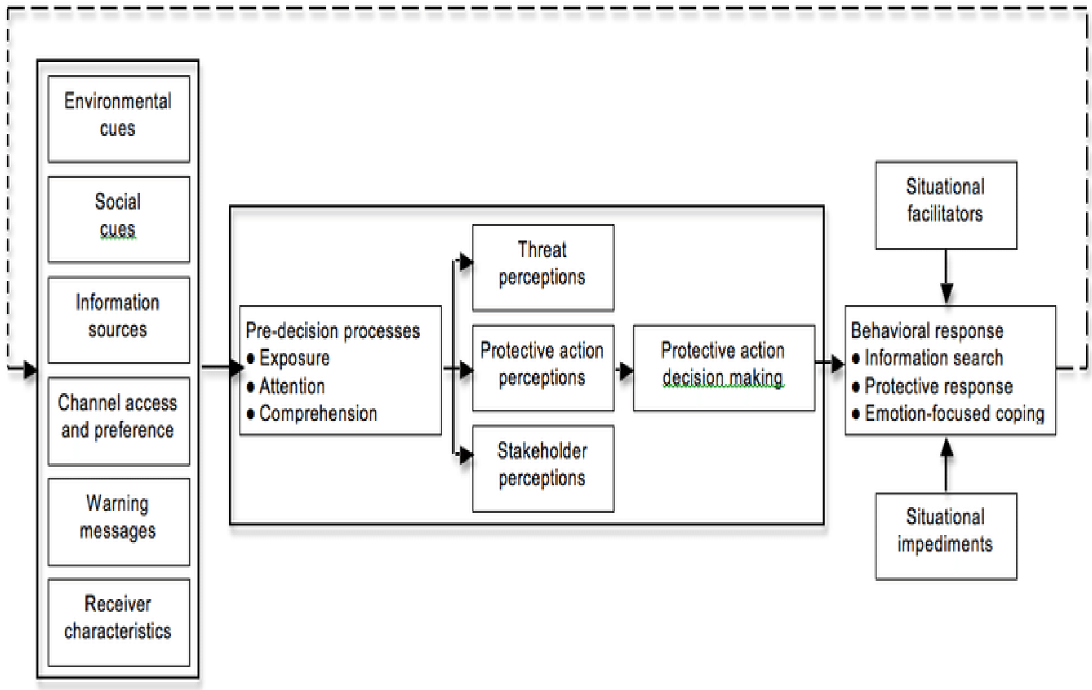

Figure 2 The Framework of the Protective action decision (Lindell & Perry, 2012)

The protection action decision-making process involves a reflection process in which an individual assess the hazard or disaster through the information available regarding threats posed by the hazard. The reflection process also involves assessing alternative protective actions as well as social stakeholders. These aspects influence the behavioural response chosen by the individual. This clearly demonstrates that panic rarely occurs in disaster and hazard situations and that the behavioural response is based on rational decision-making influenced by the above-mentioned aspects. Indeed, studies on disaster response indicate that inappropriate disaster responses are majorly due to inadequate information rather than defective cognitive processing on the part of the persons facing the disaster (Lindell & Perry, 2012). Indeed response to a disaster depends or varies based on warning belief, receiver characteristics, content, sender characteristics, and warning source (Dash & Gladwin, 2007; Mileti et al., 1975).

2.7.1 Protective Action Decision-making: Risk Identification

According to research, the protection decision-making process begins when individuals recognise and decide that the environmental conditions are abnormal and thus risky. However, in most cases, individuals rarely do this even when the evidence suggests otherwise. Responses often are quick or increase as the threat belief increases in different hazard situations (Lindell & Perry, 2012).

2.7.2 Protective Action Decision-making: Protective Action Search

According to Lindell & Perry (2012), this aspect of protective action decision making involves remembering or subsequent retrieving of one or more appropriate protection actions from memory. It also involves obtaining protective action information from others. Protection action search may also be based on; individual personal knowledge of the disaster or hazard, disaster warning, vicarious experience, observing social cues, and hazard awareness programs. However, according to Mileti & Sorensen (1987), many warning messages adopted or sent to persons facing hazards or disasters contain inadequate guidance.

2.7.3 Protective Action Decision-making: Information needs assessment

According to Lindell & Perry (2012), information needs assessment as part of the protective action decision making occurs when the information needs regarding a particular hazard are not met and if there is time to address the problem. In this regard, if the information needs have not been sufficiently meeting, it is important to undertake this process. In this case, the necessary information may include risk severity, logistical support for the respective protective actions, risk certainty as well as risk immediacy. Logistical support thus may include evacuation routes and modes of transportation (Lindell & Perry, 2012).

2.7.4 Protective Action Decision-making: Communication Action Implementation

In times of hazards, it’s important to ensure people at risk get the necessary information on time. Thus, after the information has been sourced, it’s imperative to have it reach people immediately. To achieve this, the appropriate communication channel should be adopted (Lindell & Perry, 2012). The information being sought by people and the channel depend on the location and the threat.

2.8 Stages of PADM

PADM is based on several approaches and stages. The various stages defined in the action model include the social and environmental contexts, situational impediments and facilitators, and psychological processes. The first stage, the ecological and social settings, is defined through an examination of environmental cues, information sources, and social cues, such as warning messages and channel access and receiver characteristics (Lindell & Perry, 2012). These will be explored in the following sections. Together, these form the PADM model of human behaviour during an emergency such as a fire in a building. Due to its perceived validity, PADM has been adopted as an existing model of human behaviour in fire situations. However, it should be noted that Kuligowski (2013) strongly argues that it is currently insufficient as a model. He suggests that it should be used more robustly in explaining human behaviour in fire and that it should be expanded and developed further to ensure it is more comprehensive at predicting how people will behave in a fire or an evacuation.

2.8.1 Environmental Cues

Environmental cues are considered to be visual, olfactory, or audible signals that indicate the onset of a risk. The absence of environmental cues, or knowledge of environmental cues, even in the existence of warnings, may hinder people from taking appropriate action (Aguirre, 1988). See section2.32.3 for more details.

2.8.2 Social Cues

Social cues come from notifications of others' behaviour (Lindell & Perry, 2012). For example, if neighbours are watched evacuating, this information may be useful to an observer and can signal that evacuation is the suitable response to risk. See section 2.10 for more details.

2.8.3 Information Sources

In considering the response to and prediction of emergencies, the flow of information following the occurrence or imminent occurrence of an emergency must be considered to ensure good evacuation timing and efficiency and provide individuals with enough information for them to allow them to make more informed decisions to develop a protective action plan. As a first step in the response process, information must be passed to residents in an accurate, concise and timely fashion. Information sources in such situations can include authorities in that particular area, peers or fellow residents, and the media. Aside from official sources, it has been suggested that “informal notification plays an important role in the warning dissemination in most emergencies” (Sorensen, 2000). These sources are important factors in the warning process and ensure that the receiver has access to information that can ensure effective decision making when it comes to evacuation or positive response action to disasters (Sorensen & Mileti, 1988). Moreover, Proulx (1988) argues that an adequate method of inducing a reaction in a fire and reducing stress is to provide precise information. This helps the accurate interpretation of the situation, enhances decision-making and problem-solving, and decreases stress. In short, to ensure an efficient evacuation, it is clear that precise information about the situation, a fire’s location, and what is expected from users should be transmitted to the public by a source in which people have confidence.

Considering other influences on response strategies, a fire alarm is among the primary alert systems used to communicate the threat of fire. This is a cue that most people react to differently, which causes it to be challenging for safety engineers to determine the best approach to use for primary alert systems based on human behavioural characteristics (Proulx, 2007). In Proulx’s (2007) study, it was concluded that how people respond to a fire alarm depends on several factors. One of the critical factors is the type of building where the alarm is activated. In most cases, a fire alarm activated at home will lead to a speedy response by the occupants. In comparison, the response in a building is slower, and in some instances, occupants may completely ignore the signal and pursue their normal activities. In large commercial sectors such as an airport, a cinema, or a shopping mall, the activation of a fire alarm without any additional cue may not trigger any particular response from occupants visiting these premises. This lack of response has been suggested but to the role and responsibility (or lack thereof) occupants perceive they have in such venues. As visitors, occupants tend to continue their normal activities if other visitors are also not paying attention to the alarm. There is also the prevalence of nuisance alarms, such as false alarms, test alarms, and fire drills, which are determinants in occupants not taking action when a real fire alarm is sounded (Proulx, 2007). This is likely related to the number of such alarms that an individual has experienced. In sum, the findings point to the need for more follow-up cues to complement a fire alarm and prompt evacuation.

In situations in which fire emergencies are spread over a wide area, the heightened need to manage fire evacuations in a better or more effective approach has been informed by the reliance of most households on information sources, the factors that affect their decisions to evacuate, the timing of their evacuation decisions and the amount of time it takes actually to prepare to evacuate (Lindell & Prater, 2005). In a similar vein, risk area residents rely more on some external sources of information than others, yet respective evacuation decisions are mostly informed or rely mostly on their peers as well as with local authorities. Therefore, a source such as local news media may be important for information dissemination purposes but has little impact on the evacuation decision by risk area residents. Thus, a few minutes with a friend can positively affect a household’s evacuation decision faster than hours of watching the same information on television or listening to a radio broadcast (Lindell & Prater, 2005).

To ensure effective risk information or communication, disaster management planning must include an understanding that effective disaster management translates into minimization of the hazard’s impact. This can be achieved through effective communication of risk information in a timely manner as well as in a form that all stakeholders can comprehend with ease. In brief, the vulnerability or potential impact precipitated by natural hazards can be reduced significantly, or their impact is mitigated successfully through extensive and up-to-date hazard education as well as effective warnings (Clerveaux et al., 2008). These two basic requirements are the premise upon which any disaster management plan or model should be constructed. To help in this regard, a hazard map can be provided, which typically informs, educates, and identifies vulnerable or at-risk populations, and for this reason, the various scenarios that result from this can be depicted in two-dimensional formats. In addition, the hazard map provides an easily accessible and impactful information source that communicates the need to take sufficient measures that lead to personal protection and reduction of property damage (Clerveaux et al., 2008).

In conclusion, a wide range of devices, platforms, avenues, and mediums can be used to communicate risk information to different populations and to diverse or mixed cultural backgrounds. Consequently, the onus is on disaster managers to select the most effective communication tool that can prompt immediate evacuation from a vulnerable area in the face of imminent or even perceived threat. The tsunami model, for instance, is a type of digital disaster manual that disaster managers can utilize for assessing the effectiveness of the disaster management strategies currently in place (Clerveaux et al., 2008). In relation to PADM, information sources are important because they are used in the model to determine the best course of action during an evacuation. The sources are hugely important components in the notification method and assure that beneficiaries receive information that can ensure safety.

2.8.4 Channel access

The second and connected consideration in information flow is channel access, which determines the efficiency and effectiveness of a message. Channels in emergency response include print and electronic media such as newspapers, magazines, television and radio (Lindell & Perry, 2012). Other channels include sirens and face-to-face communication (Sorensen, 2000). It is vital to note, though, that a good channel should ensure that the information or message is not distorted, is accurate, and is concise enough to ensure reliability and easy access, as a reliable information channel impacts the receivers' ability to conduct a risk assessment and respond positively. These different channels have comparative advantages and disadvantages. Generally, it has been found that individual preference of channel is largely decided by access and availability (Lindell & Perry, 2012), but in terms of making decisions to evacuate, peers have the greatest influence. The use of sirens has actually been ineffective due to individuals' inabilityo misinterpret the siren message (Sorensen, 2000).

For years, social scientists have studied human responses to emergency warnings, focusing mostly on people being evacuated from hazardous places to other locations in an attempt to explain why some people hear and respond to a warning and evacuate immediately while others do not. The general observations are that variations exist between the receptions of a warning, the time spent to decide on evacuating, the assembly of resources, and the time spent on the actual act of evacuating (Sorensen, 1991). Available data indicate a logistical distribution trajectory between warning reception and departure times or evacuation mobilization times. Various factors affect warning receipt, with the channel of disseminating emergency information having a clear effect on enhancing or boosting warning receipt, which makes the mass media the most effective or the primary source of receiving or hearing such warnings. While electronic media may be initially effective, newspapers eventually become the most important source of information for events that are slow to unfold (Sorensen, 1991). Of course, this conclusion was offered nearly 30 years ago, and since social media and digital news outlets have largely superseded print newspapers as the news source of choice for most, further investigation is needed in this regard.

Other factors that affect warning receipt include proximity to the potential impact site, voluntary association membership, general community involvement, frequent kinship system interactions, and close relationships with relatives. Age, socioeconomic status, parenthood, gender, and cultural elements are also concomitant factors that enhance the likelihood of hearing a warning. Knowledge about the disaster agent, fatalism, prior disaster experience and a physiological ability of a warning receiver are equally important factors. Finally, perceived threat and constraints andocial structure and social context, such as a separated family during the evacuation, can all affect the mobilization time and time of warning receipt (Sorensen, 1991).

Whilst there are a number of channels, these are distinct and different from each other. Thus, their effectiveness in terms of precision, message distortion rate, message access and penetration, and receiver coverage and reach also differ. Indeed, the different channels have both advantages and disadvantages. A fast channel, for instance, might not provide detailed information. For the information channel to be effective, it should be able to factor in the various languages used by the residents. Thus, broadcasting in the English language in a predominantly Spanish speaking community might not be effective. In terms of information channels, news media are the most effective as they provide on-time and detailed warning messages to a large base. However, when it comes to decisions to evacuate, peers have greater influence. However, the use of sirens might not be effective due to the inability of individuals to interpret the siren message. Finally, the use of route alert in information dissemination is limited due to the number of personnel required for it to be effective (Lindell & Perry, 2012)

Data concerning fires, the effects, and the various evacuation and rescue strategies utilized are also key in human behaviour research. Proper data storage practices avoid distortion and loss of data, and those primarily utilized media data (print and electronic) in the form of papers, magazines, TV and radio (Lindell & Perry, 2012). Other channels merge alerts and close correspondence (Sorensen, 2000). It is fundamental to note, at any rate, that a normal channel ought to guarantee that the data or message is not destroyed, is definite, and is sufficiently short of guaranteeing quality and direct access.

2.8.5 Warning messages

General emergency information, and warnings and protection from future emergencies, are two separate types of risk communication, with the former disseminated in non-emergency situations to increase hazard awareness and emergency preparedness. The warning component is situation-specific dissemination after a threat has been detected, the disaster is imminent, and protective action recommendations are dispersed. Thus, conveying warnings depends on the warning system in place. Most buildings have fire alarm systems installed, and in situations in which a hazard threatens a while region, a public address system is often used to guide the evacuation process. Lack of an efficient warning system leads to a challenging evacuation strategy due to limited correspondence and coordination of the processes.

Clearly, warning messages must be communicated in a timely manner to be effective. To achieve this, the appropriate communication channel should be adopted (Lindell & Perry, 2012). The information being sought by people and the channel depend on the location and the threat. According to Lindell and Perry (2012), information needs must be assessed as part of the protective action decision making. In this regard, the necessary information may include risk severity, logistical support for the respective protective actions, risk certainty, and risk immediacy. Logistical support thus may include evacuation routes and modes of transportation (Lindell & Perry, 2012). In addition, research by Dash and Gladwin (2007) sought to establish the variables impacting a decision to evacuate and concluded that a warning should be developed in such a way that the receivers are able to discern the risk posed and make an informed decision based on it (Dash & Gladwin, 2007).

Warnings, particularly those associated with the impact or adverse effects of a natural hazard, such as a tornado, hurricane or flash flood, are essentially a social process comprising the evaluation, dissemination, and response elements. Evaluation entails the process that takes place from the moment an environmental hazard has been detected to the point where some measures are employed to communicate the message of a probable adverse impact of the natural agent to the endangered community (Mileti, 1975). Communicating or conveying such information is what constitutes dissemination, while the third basic element of response is the behaviour of the recipients to the warning. Evacuation success then depends on the warning content, communication mode, situational context, and warning belief. Warning belief by itself is a function of warning content, communication mode, perceived warning certainty, and warning confirmation. In terms of the latter of these, warning confirmation has been deemed a function of warning context, communication mode, situational context and warning certainty (Mileti, 1975). Mileti (1975), in analysing data to further the general understanding of the social process through which people evacuate in response to short-term warnings of natural hazards, found the nature of the evacuation to be complex social progress. It is clear, though, from his research, that confirmation, belief, and response to hazard warnings differ in exogenous variables as well as in the number of warnings received.

2.8.6 Characteristics of receiver

Characteristics of receiver contain physical (e.g., strength), psychomotor (e.g., vision and hearing), and cognitive (e.g. primary and secondary languages as well as their mental models/schemas) abilities as well as their economic (money and vehicles) and social (friends, relatives, neighbours, and co-workers) resources" (Lindell & Perry, 2012). In his explanation of receiver characteristics, White contains a socioeconomic dimension, including race, income, and age; a decision-maker dimension, including the ability to process and understand information, and is broadly psychological in nature; and an environmental dimension, including knowledge of magnitude, frequency, duration and location of a hazard (Dash & Gladwin, 2007).

2.9 Understanding crowd behaviour

Leading on from the social cues factor of the PADM model section 2.7, non-adaptive crowd behaviour can arise in an emergency. During an emergency, non-adaptive crowd behaviour can occur, including stampedes, crushing, or even trampling. From a sociological perspective, human behaviour is an external manifestation of internal psychology, which nevertheless is affected by other concomitant factors such as information dissemination constraints that, in retrospect, affect instant decision-making, thus increasing panic.

Several studies have been conducted on the interpretation of fire situations and how the data can be analysed to determine better and more advanced methods of modelling the correct and most effective reaction and evacuation techniques (Kuligowski, 2009), all of which will be explained in detail in the sub-sections that follow. One fundamental conclusion from these studies is that an understanding of the various underlying factors that influence the decisions made during a fire incident is a reflection of the differences in human perceptions and decision-making. As a brief example, researchers have studied the effect of random utilization of fire drill experiments on diverse platforms with random participants to observe their reactions and then conduct interviews to understand why people react distinctly (Kuligowski, 2009). Thus, human factors are critical for every evacuation process.

As soon as a fire has been confirmed in a building, the occupants either have to rely on themselves or wait to be rescued by those in their vicinity, since in some instances, the assistance of firefighters and treatment by paramedics can only be offered after this stage. During this initial phase, human behaviour or the conduct of the occupants is based on their perception of the fire situation, their intention to act accordingly, and other attendant considerations, thus defining what is known as evacuation behaviour (Kobes et al., 2010). While safe escape depends on a building's fire safety features, which include fire prevention tools and the ability to restrict, contain the spread of fire and smoke or extinguish the fire, there are several human factors that determine the outcome of an emergency.

Evacuation behaviours (EV) vary because they constitute the direct expressions of intrinsic psychology (He et al., 2013). In this regard, Pan et al.'s

(2006) study focused on safe egress as a critical design issue identified by facility planners, managers, and inspectors. There are now advanced computational tools utilized for the simulation and design of emergency evacuation. However, Pan et al. (2006) determined that these tools rely heavily on assumptions about individual human and social behaviours, mostly inconsistent with human reactions during the heat of the moment. Understanding the collective dynamics involved in crowd movements during emergencies is key to limiting the risks of deadly crowd disasters. However, collective dynamics in regards to crowd behaviour under stressful emergencies has remained a problematic subject area due to the finding that behaviour under emergency conditions tends to be self-serving (Moussaïd et al., 2016). Empirical research from various case studies has underscored the prominent dynamics influencing crowd behaviour involved during an emergency, such as feelings of collective social identity in a crowd (Moussaïd et al., 2016). Generally speaking, collective dynamics that occur during extreme or stressful emergency evacuation are least understood in crowd behaviour, yet they are also essential for crowd safety.

Some studies suggest that risk perception is a contagious aspect. This may imply that anxiety can spread from one occupant to the other during a stressful evacuation or that a collective underestimation of the risk can lead to critical evacuation delays (Moussaïd et al., 2016). Another essential factor influencing crowd behaviour is if there is a resourceful person who can offer leadership within a crowd. Evacuation research has determined that crowd and group phenomena are crucial aspects that can influence the success of an evacuation effort. If there is a resourceful person who can offer leadership within a crowd at such a time, the situation is easier to manage than when everyone is applying themselves in a different way, which leads to confusion (Mawson, 2005; Hofinger et al., 2014).

2.10 Influence of social behaviour

Leading on from the social cues factor of the PADM model section 2.7, human behaviour can be predicted from an individual's intentions, which therefore determines his or her attitude towards the preceding expression, perceived norms concerning the behaviour, as well as the perceptions of control in regards to the behaviour. These three constructs underlie the corresponding behaviour and control, normative and behavioural beliefs,eeing that the core and processes that precipitate all social behaviours of human beings are practically the same and can be defined as a small set of constructs (Azjen, 1980).

In an emergency, the people involved have an impact based on their experiences; some are spectators, whereas others do all they can to assist in the situation. Fischer et al. (2006) study look further into the bystander effect and analyses the impact that bystanders have on an emergency's outcomes and found that the proximity of on-looker decreases, helping conduct in a crisis (spectator impact). This exploration was, for the most part, focused on settings of non-risky, peaceful emergencies. The researchers theorized that spectator impact does not happen in increasingly perilous circumstances because they develop more quickly and are perceived as crisis. Thus, the more significant risk associated with helping others in this situation dissuades action in this regard.

Numerous authors (see (Kinateder & Warren , 2016); (Kinateder et al., 2014); (Nilsson & Johansson, 2009); (Shields & Boyce, 2000); (Latane & Darley, 1968) have shown that social interaction and cues play a significant role in a fire evacuation. People use social cues like they use fire alarms to determine whether or not they should evacuate. Sometimes, social cues are far more critical than alarms in steering the decision to evacuate (or not) (Nilsson & Johansson, 2009). However, several challenges are associated with studying human social behaviour in response to a fire evacuation, outlined in the behavioural research methods 2.11.

Several studies on social behaviour in fire evacuation have explicitly focused on how people react to fire alarms when they are in the presence of others—namely, manipulating others' reactions to the fire alarm and studying how this reaction affects the participant's responses. For example, Latane and Darley (1968) confirmed a social influence associated with fire behaviour. This was revealed through their smoke-filled room study, for which a participant would wait in a room which slowly filled with smoke. In the first scenario, the individual would be alone. In the second scenario, the individual was with two other confederates, who would purposefully disregard the smoke and remain in the room, responding to the part naïve. In the third scenario, there were three naïve subjects, none of whom had been primed to react in any particular way. The results of this study showed that 75% of the people who were alone indicated that there was smoke. However, only 38% of the people who were naive participants did so. An even lower percentage, 10%, of participants with non-responding confederates reported smoke. These results reflected that passive behaviour exhibited by individuals around smoke leads to a decreased chance of actual evacuation behaviour. Finally, Kinateder et al. (2014) showed that social influence could affect evacuation behaviour. This was revealed through the smoke-filled room study using a virtual tunnel fire to examine. In this study, 40 participants were tested on how conflicting social information may affect evacuation in four social influence conditions:

- Control which participants were alone.
- No conflict condition, in which the virtual agent moved towards the exit.
- The actual conflict condition is in which the virtual agent moved towards the opposite direction of the exit.
- The passive conflict condition in which the virtual agent remained.

In conflict conditions, participants were less likely to move to an emergency exit than in the no-conflict state. Compared to all other terms, participants in the passive conflict condition moved the most extended distances and showed significant pre movement and movement time's delays. Through this test, Kinateder et al. (2014) confirmed that social influence affects evacuation behaviour, precisely the passive response of others. Kinateder and Warren (2016) conducted a similar test that indicates that the same behaviour occurs at the sound of a fire alarm. One hundred fifty participants were tested on how they would react to a fire alarm condition, one of three states, conducted in both real and virtual environments. In control, condition participants implemented a perceptual matching task alone. In the passive bystander condition, they performed the same duty with a primed colleague to ignore the alarm. In the third condition, the colleague left when the alarm sounded.

Generally, participants who evacuated in the active bystander condition were more than in the control condition, less in the passive bystander condition than the control condition. The pattern of results was similar across real and virtual environments, although the response to the alarm was reduced, and the negative influence of bystanders was weakened.

Social influence has also been shown in emergencies based on the distance between people and on the clarity presented by the alarm. Nilsson and Johansson (2009) studied how people interacted with each other when it came to the unannounced evacuation of cinemas. Results indicated that the amount of social influence was dependent on the distance between the people. These two were inversely correlated in that social influences increases the closer people are together. Social behaviours, such as looking for others' actions and copying others, were higher in the presence of ambiguous cues to the emergency. Further strength to the influence of social factors on behaviour in an emergency was given by Shields and Boyce (2000). They showed through an unannounced fire evacuation at a department store that many occupants readily recognized that their decision to evaluate was based on the action of others.

During an emergency evacuation, the evacuees take different directions and choose diverse ways of evacuating based on their decision-making. Factors such as physical fitness, disability and breathing problems are among the factors that influence an evacuee's choice of heading to safety. A study by Heliövaara et al. (2012) examined behaviour in an evacuation with two possible exits, with one exit nearer than the other. The members were requested to leave through the exits as quickly as could be allowed. The particular geometry was picked because it forced participants to make a nontrivial choice on which exit to utilize. In contrast, the quickest exit choice is evident for a dominant part of members in numerous other geometries. The key research question was as follows: Are individuals likely to select the fastest route out? How does the beginning situation in the group identify with the chose exit? How do the directions to act egotistically or to coordinate influence the result of clearings? Typically, a large number of outcomes may rely upon a particular clearing situation and geometry. The results of the investigation increased understanding of human departure conduct. In brief, clearing times, exit utilization, and the impact of the initial situation on leave determination can likewise hinder the evacuation's effectiveness. To be more specific, it was determined that when acting agreeably, the individuals beginning made their way slowly to the more distant exit, and the ones starting from the left chose the closest exit. The total departure times were substantially quicker when the members acted solely and attempted to limit their personal departure times than when they tried to coordinate. This contradicts some past investigations; however, the distinction can be clarified by the diverse motivating force frameworks utilized in the tests.

In a fire emergency, occupants who become hysterical and react randomly affect the behaviour of everyone else around the area. This makes it hard even for those trained in safe evacuation to effectively evacuate or contain the situation due to the panic levels involved. The typical response to various threats and disasters is often not to flee but to seek the proximity of familiar persons and places; moreover, separation from attachment figures is a greater stressor than physical danger. Such observations can be explained by an alternative "social attachment" model that recognizes the fundamentally gregarious nature of human beings and the primacy of attachments (Heliövaara et al., 2012).

2.11 Methods for predicting human behaviour

2.11.1 Models of human behaviour in fire

Evacuation models are computational tools used to estimate the time taken to evacuate a building. As noted previously, computer modelling has revolutionized evacuation modelling. However, the programs being utilized are, at times, not effective because they lack the conceptual model of human behaviour during an evacuation process (Kuligowski & Gwynne, 2010). Thus, a gap exists between the integration of human behavioural characteristics and computerized evacuation techniques. Among known behavioural characteristics is that people tend to follow the familiar when they decide to evacuate. They tend to all head towards the same doors, elevators or staircases with which they are accustomed. This increases the risks of a stampede, leading to chaotic evacuation and injury from the fire (Kuligowski & Gwynne, 2010). Developing a method of modelling such natural reactions to evacuation in a computer program is among the critical challenges fire safety engineers attempt to overcome. Studies have determined that the development of a predictive model based on actual simulation of evacuation events takes into consideration all the factors that influence human behaviour at the time. Thus, if it becomes possible to accurately model human behaviour during fire incidents, this will significantly affect how conceptual frameworks can be developed and implemented according to specific scenarios with different variables such as demographics. This is important since children, for instance, react differently from adults in an emergency (Kuligowski & Gwynne, 2010). There is thus a need to provide standardized guidance for future data collection efforts in the field of evacuation from building fires.

Analysis of current evacuation models has determined that most of the models do not simulate occupant behaviour as required. There is a need to improve the process of developing fire safety conceptual models built upon data and theory embedded in evacuation models to predict occupant actions. In the currently utilized theoretical models, occupant actions are a result of the simulation's developing conditions, which are then determinants of the decision-making process (Kuligowski & Gwynne, 2010). There are many benefits to the development of a comprehensive conceptual model for the field of human behaviour in building fires. For instance, a theoretical model in computer evacuation tools will enable a comprehensive model that can predict occupant behaviour in a building fire and require the user to provide only the initial input for the scenario, allowing more widespread and rapid data collection.

The focus is now on the development of predictive models based on actual simulations of evacuation events and that consider all the factors that influence human behaviour at the time. These will be based on understanding the various underlying factors that influence the decisions made during a fire incident and reflect the differences in human perceptions and decision-making (Kuligowski & Gwynne, 2010). There is also the indication in existing research that research-based fire management techniques will be integral components of future architecture and fire safety systems development geared towards upholding public safety. There is such a conceptual model highlighting human behaviour during the fire that has been designed by Kuligowski (2013) to help understand how humans respond. In the theoretical model, a path for response is suggested through a diagram approach model. The actions defined in the diagram establish relationships and activities performed by people during fire emergencies. For instance, it proposes the probability of a particular action preceding or succeeding another during a fire incidence. In Kuligowski (2013) study, crucial aspects that offer an essential understanding of human behaviour in domestic fire cases and hospital and occupancy fires are presented. These include recognition of an event involving fire, the location of the building's occupants, their ongoing behaviour, and the subsequent sequence of actions and perception of the said situation by occupants. However, the researcher noted a need for further studies to help establish a comprehensive behaviour model.

The emergent norm theory (ENT) stipulates that non-regular behaviour is typical during a normative crisis, whereby people react collectively to underlying factors. In necessary research by Aguirre et al. (1990), this theory was utilized to analyse the reaction to an explosion at the World Trade Center on February 26, 1993. ENT is primarily centred on people's perception and interpretation of events and the reaction processes inherent in instances of collective behaviour. In its support, the study determined that the transformation of people's understanding of their environment's relative safety as determined by the crisis is an essential determinant of their collective behaviour. Moreover, engaging in training as a precautionary effort has been determined to improve collective action in instances of fire evacuations. The theory also points out that social relationships, whether emergent or enduring, are not only useful in differentiating collective behaviour from institutionalized behaviour but even amongst individuals. This implies that if people in a building are familiar with each other, the evacuation process is made more accessible, as they can subconsciously discern who to follow depending on how well they are aware of each other's strengths. The theory also finds that social relationships of the affected people in a fire incident often work against the espousal and adoption of norms supporting individual and competitive flight behaviour and the adoption of cooperative behaviour that delays their exiting the building. People who know others well tend to concern themselves with their fates. In other words, crowds of known people inhibit individualistic solutions in favour of a shared norm.

A comparative study of human behaviour in the case of an emergency has been conducted on the aviation and rail industries to determine whether the knowledge base in regards to human behaviour offers a better understanding of how humans behave in the case of an emergency. This study has noted that understanding how human beings behave in situations where they are faced with or perceive danger is significant. Based on this, several models have been developed (Stedmon et al., 2017). However, these models have not advanced any theory concerning human behaviour in the case of emergencies. Thus, it is essential to develop advanced, more robust, and efficient policies to handle emergencies. The models that explain human behaviour in distress is the panic model, bounded rationality model, the social attachments and affiliation models, and the self-categorization and emergent norm models.

Most models focus mainly on predicting and calculating the evacuation movement of the occupants. In other words, how long the occupants take to move from their original position to a place of safety. However, the models ignore the prediction of behaviour that occupants usually perform before and, subsequently, during the evacuation process, and that can impact their safety through delays (Kuligowski, 2008). Such conduct may include fighting the fire by themselves, helping others to escape, and seeking information. Rather than predicting simulated occupants' behaviour in a particular building, most models make assumptions regarding occupant behaviour. If the premises are incorrect, this concept can negatively influence the ability to effectively evacuate and address incidences of fire emergencies (Kuligowski, 2008). The solution to these problems is developing a comprehensive model that is robust and validated in regards to human behaviour during the evacuation in case of fire in a building.

Another critical focus of existing research has been on aggregating the essential aspects and developments over time in regards to behavioural theories attached to human behaviour during evacuations and then incorporating human behaviour in evacuation modelling (Kuligowski & Gwynne, 2010). The subsequent expansion of the use of computer models in evacuation models has been made possible by increased computer capabilities as well as the reduced monetary cost. These new models are based on occupant movements and behaviour data. However, the models cannot effectively and accurately simulate human behaviour during the fire. Based on this, a recommendation for a comprehensive evacuation model incorporating human behaviour in fire is required. This is based on the gaps in existing models. Improvements in these models will effectively ensure increased safety during an evacuation in case of fire.

Though there are currently theories used to understand human behaviour during a fire used in simulation models for evacuation, there is a need for a conceptual model. The behavioural approaches have been obtained from data on how people behave and what they do during fire incidences. Without that conceptual model, most of the simulated models will be partially ineffective. Hence, they will lead to poor judgment, which can affect performance during evacuation processes (Kuligowski & Gwynne, 2010). In this regard, sociological theories on human behaviour can help establish a comprehensive evaluation model. Based on this fact, the most crucial step is developing an evacuation model that factors humans' behavioural aspects during a fire. Incorporating such factors will ensure accuracy, increased safety, and reduce injuries during the evacuation. It will also provide training and education of responders as well as occupants of buildings (Kuligowski & Gwynne, 2010).

2.11.2 Talk-through approach as a method for identifying the influence of social behaviour on an emergency

Due to the persistent difficulties encountered when researching human conduct in emergencies, various methodologies have been developed in an attempt to combat them. As with VR experiments, there are other ways to predict human behaviour during fire evacuation without placing participants in real situations, thus avoiding any danger (Lawson, 2011). One such approach is the talk-through approach, in which participants explain how they would respond to an emergency based on a description of the situation (Lawson et al., 2013). This combines the talk-through method (Kirwan & Ainsworth, 1992) with sequential analysis, which is used to study behaviour resulting from events as they unfold over time (Bakeman & Gottman, 1986). Importantly, when a participant is undertaking a task using this approach, it is usually necessary for them to self-commentate to avoid distortions or to forget bits of the information collected. However, what is worth noting is that it is not possible to internalize all mental processes and then verbalize them. In other words, it becomes challenging to focus on one’s behaviour when one is trying to verbalize. Verbal protocols are also used, which are widely used in carefully monitored laboratory settings when carrying out complex experiments. This specific application runs concurrently with what is being processed to avoid losing the data and are coded verbally (Kirwan & Ainsworth, 1992).

The technique is comprised of four main stages: preparation, recording, verbal, and supplementation. In the preparation stage, the respondent must be encouraged to make a continuous commentary. The aim of doing so is to minimize the likelihood of the respondent rationalizing their thoughts. When recording the verbal information, every utterance must be recorded at every protocol session. An extraneous vocabulary reduction is carried out to ensure that words that do not add meaning to the text are removed. A comments column is recommended to show how the protocol is progressively transcribed. As it is almost inevitable that words and phrases will be repeated and used to describe the same thing, an analyst should be careful with the wording so that ambiguities in the text are minimised. In practice, verbal protocols aid in accessing mental processes. The challenge is usually in managing to match the verbalization without distorting it (Kirwan & Ainsworth, 1992).

2.11.2.1 Benefits and drawbacks of the talk-through approach

One of the pros of this approach is that participants' behaviour can be captured without placing them in any real danger. The second reason is that overall, this approach has proved to be fairly reliable and valid in predicting how humans respond. The one key deficiency with this approach is that it has, until now, lacked the inclusion of social factors, which are important factors steering the outcome of an evacuation (Lawson, 2011; Nilsson & Johansson, 2009). The talk through approach also helps improve the interpretation of fire situations and how this can be analysed in the future to determine better and more advanced ways of modelling the right and the most effective reaction and evacuation techniques. Finally, the talk through approach is also practical because it enables a comparative analysis of human behaviour in the case of emergency fires. In this case, talking with occupants enables researchers to determine the different individual attributes and address them effectively.

2.11.3 Virtual environments in fire safety as a method for identifying the influence of social behaviour on an emergency

Virtual environments are gaining increasing popularity as a research method in the area of human behaviour in fire scenarios. These are termed virtual reality (VR) experiments. VR experiments are controlled, systematic investigations that usually involve participants who are immersed in computer-generated virtual environments. An essential component of a VR experiment is a virtual environment (VE), which can be defined as a digital space where the movement of the participant is tracked and where the environment is generated and displayed to the senses of the participant concerning his or her actions (Fox et al., 2009).

The development of fire evacuation models based on engineering information and calculations can be beneficial in understanding how people may act in a building during a fire. However, regardless of the amount of data that can be obtained from such traditional models and the degree to which these models can accurately reflect real-world human behaviour in fire is limited. Many of these limitations deal with the cost and the safety of those who might be involved (Gately, 2002). These limitations have been identified by both those who are responsible for the development of these traditional models as well as those who are interested in developing newer, more flexible and realistic models. Beyond directly criticizing the limitations of older models, there have been some severe efforts poured into developing new ways to consider and study human behaviour during a fire. Technology has undoubtedly spurred on this attempt to create better ways to study human behaviour in fire. Specifically, the development of virtual environments for studying the phenomenon has been highly prevalent within the past two decades.

In recent years, there has been an increased emphasis on the application of simulations to determine and understand human behaviour under heightened tension during evacuation processes. For instance, Pan et al. (2007) focused on using computational instruments for the re-enactment and structure of crises to determine how accurate the data was compared to real-world scenarios. They found that, because of the shortage of human and social conduct information, these computational devices depend on presumptions that have been discovered as conflicting or unreasonable. Their paper displays a multi-specialist-based structure for re-enacting human and social conduct during crisis departure. A prototype framework has been created, which can exhibit some new practices, for example, focused, lining, and grouping practices.

Human behaviour experiments are usually categorized into laboratory and field experiments. The field experiments are typically performed in a real-world setting, for instance, a real building or a tunnel. However, while such field experiments have high ecological validity, they are challenging to implement with a high level of reliability. This is owing to the difficulties involved in achieving high levels of experimental control (Nilsson et al., 2005). Laboratory experiments are either performed in physical environments or include the prediction of behavioural responses to hypothetical situations. The latter of these is termed behavioural response experiments (Nilsson et al., 2005). Virtual reality is consistently gaining popularity as a tool for studying human behaviour during an emergency by simulating emergencies. In fact, it has been suggested that it is more effective to conduct emergency management by using IVR due to its capability to model human behaviour with a high degree of fidelity.

2.11.3.1 Immersive virtual environments (IVET)

A seminal study by Bailenson et al. (2008) focused on the effectiveness of Immersive Virtual Environments (IVET) in determining human reactions and using this data to determine the best approach of developing evacuation techniques. IVET can be defined as used IVET as a methodological instrument that can be utilized to analyse human conduct over an assortment of spaces. Utilizing IVET, analysts can structure three-dimensional, computerized, virtual people bearing photographic, morphological, and conduct similar to real people. In the past few years, analysts have started to utilize IVET to investigate standard mental procedures, including relational separation. Generally speaking, these investigations show that using IVET bolsters the possibility that individuals collaborate with virtual others as social creatures to the degree that the virtual others show reasonable nonverbal conduct (e.g., familiar eye stare, squinting, lip development when talking). In addition, an individual can enter a virtual world and connect with a virtual specialist who looks like their real-world counterpart. Self-portrayals can take outside structures dependent on different kinds of innovation; for example, perfect representations, photos, voice chronicles, videotapes, and verbal portrayals. In Bailenson et al. (2008) study, they used a VRS. The investigation showed that individuals associate with VR in a predictable manner close to real-world situations when a VRS is used. The study exhibited orderly contrasts between members collaborating with VRSs and members associating with VROs to such an extent that members in the previous condition demonstrated more unusual engaging reactions. This shows that IVET is a useful tool for determining behavioural patterns and developing bespoke structures towards preventing casualties in an evacuation.

Another study conducted by Bode et al. (2015) investigated the changes in the occurrence of helping behaviour in an evacuation scenario that used a VE simulation of an evacuation from a building to study the effect of varying the cost to an individual of assisting on the propensity of that individual to help. The findings indicated that in a new situation wherein the evaluation of the risks associated with higher costs was difficult to assess, the increasing costs reduced the tendency to help. Both younger and male participants were found more likely to help in these situations than older and female participants. This indicates that a somewhat related study by Duarte et al. (2014) aimed at emulating a disaster situation that required evacuation to determine how people respond to signs during high-pressure situations and when they feel threatened. The study utilized an IVET to examine how dynamic features in signage affect behavioural compliance during a work-related task where people are calm and calculated, followed by an emergency egress. The pool of participants selected was introduced to virtual reality technology, where they were first exposed to performing a work-related task followed by an emergency egress. Throughout the test, compliance with un-cued and cued safety signs was assessed before a fire incident involving escape with exit signs. Although dynamic presentation produced the highest compliance, the difference between dynamic and static presentation was only statistically significant for un-cued signs. Un-cued signs, both static and dynamic, were effective in changing behaviour compared to instances where there were no signs. The key challenge was to determine whether people can observe signs while attending to other tasks, such as working on a regular job or when escaping disaster.

The findings were that during regular work, the participants were not aware of egress related signs, with some not noticing them. However, during the emergency, participants were eager to know where they were going, looking for doorways and hallways to escape. During the test, the cued signs showed no static versus dynamic differences. This implies that compliance was quite high across conditions, so there is some inclination to giving a ceiling-effects explanation for these non-significant differences. It seems that situational demands may be the root cause of behaviour during an emergency egress, and the IVE was useful in providing effective behavioural outcomes among the participants. Another study by Zou et al. (2016) was based on the understanding that evacuee behaviours during emergencies are largely determined by the efficiency in which the evacuees conduct themselves and also affects the evacuation time, which is a vital aspect of ensuring safe evacuation.

A study by Andrée et al. (2016) sought to determine the effectiveness of various evacuation routes in a high-rise building and thus settled on the development of an IVET. The VR model was created in the Unity3D game engine. Unity3D was developed to create computer games but has been successfully used in previous evacuation experiments. One benefit of using this engine is that it is possible to insert a 3D drawing from another program into Unity. In this study, both Auto desk Maya and Unity3D were used to create a building in the VR model with 35 floors. It was determined that waiting times, the intensity of the fire, and the evacuation elevator design were critical factors that influenced the decision of the study participants as to whether to use the evacuation elevator. Lifts were installed with a green light to show the safety of using the elevator in one experiment and no green light in the control experiment. It was found that the majority of the participants chose to take the evacuation elevator that had a safety greenlight as compared to the one that did not have a greenlight. It was inferred that evacuation elevators should have communication systems that ensure evacuees that it is safe to use the elevator amidst the disaster because the safety of the lift is one of the evacuee's primary concerns.

A study by Liu et al. (2014) focused on the utilization of different tools towards improving emergency evacuations, specifically addressing the capacity to integrate BIM, immersive games, online games, and socio-psychology and physics models to solicit and collect real human behaviours in different emergency scenarios. The data collected was then utilized to complete the human behaviour library and make it available for future emergency evacuation simulations. This is an important step in the use of VR as a methodological tool to conduct research into ways in which fire safety protocols can be improved. In developing this library, the researchers found that an imperative factor in fire evacuation is the rate of fire growth and the amount of heat it emits. This impacts evacuation behaviour because of the increased risk factors, such as intense smoke, that can lead to suffocation. The research also discusses the psychological approach to fire and fire safety, the current strategies that have been determined to be more effective in fire safety evacuation, and how they are being integrated into building designs to address fire risks consistently. These findings contribute to the development of mechanisms in evacuation research and planning techniques that can be effectively simulated. Interestingly, the study also found that it was easier to obtain reliable results from a simulation of a residential home than having participants engage with a high-rise building simulation due to the increased familiarity they had with the former, indicating that perhaps actual simulations of IVR evacuation should match the representation of structures with which participants are intimately familiar.

A further study by Meng et al. (2014) utilized VR technology to investigate way-finding behaviour and response in a fire emergency by comparing it with behaviour under a typical way-finding condition. The comparison results between the two defined groups showed that the treatment group participants had significantly higher physiological stress and psychological stress. Thus, the results showed that the first objective of the study, designing a virtual fire environment with relatively high fidelity between that of typical way-finding environment/fire drill and that of real fire scenarios, was accomplished. Furthermore, by adding multi-sensory stimuli in an ideal way-finding environment, the virtual fire environment provided a more stressful way-finding environment. The study also analysed the interpretation of fire situations by different people and how this can be analysed in the future to determine better and more advanced ways of modelling the most appropriate and effective reaction and evacuation techniques. The study stipulates that research-based fire management techniques are an integral element of future architecture and fire safety systems development that is geared towards ensuring public safety. Indeed, through their findings, fire engineers are effectively developing improved systems that can prevent fire, predict the spread of the fire, and guide a fire evacuation through the integration of such with computer programs. In short, the constant development of fire evacuation and management techniques has led to the development of innovative designs, significant cost savings, and more safety.

Virtual simulations are constantly evolving and improving as an assessment method in the zone of human lead in fire circumstances. Human behaviour during emergencies has thus been studied through the application of various models that simulate emergencies and trying to model human behaviour through social models. With the development of virtual reality technology, researchers can simulate emergencies and consequently use the same technology to gather real-time data regarding human reactions. Despite their importance in evacuation studies, the behaviours of individual evacuees have to date not received the attention they deserve, as evidenced by the absence of a computable and verifiable behavioural model. It should also be noted that it is challenging to ensure that VR experiments meet ecological validity so that the decisions and actions made by the experiment subjects are what they would make in reality. Due to the increased adoption of VR based studies, this experiment was focused on determining effective ways of achieving ecological validity, examining the feasibility of using a combination of subjective and objective measures, including an emotion scale and a physiological indicator, to assess the emotional responses of subjects in IVET-based evacuation experiments. Two VR based experiments were created for the study, both simulating a fire incident but having different realism characteristics and levels to determine how differences in structures and resources influence human behaviour during an evacuation. The results of this assessment reveal that the social impact on the decision to clear was maximized in the virtual condition. The beneficial effect of onlookers was comparative between scenarios, but the negative effect was less pronounced in VE. The relative similarity in results between scenarios adds weight to the argument that virtual simulations can be applied successfully to such research.

2.11.3.2 Benefits and drawbacks of VR research

Kinateder (2014) thoroughly investigates the strengths, weaknesses, threats, and opportunities of employing virtual reality environments for studying human behaviour in fire. The article commences by pointing out the increasing popularity of applying virtual realities in investigating human behaviour in fire, thereby justifying the importance of further investigating the strengths, weaknesses, threats, and opportunities associated with using this technology for the stated purpose. The significant advantage of employing virtual reality technology in terms of investigating human behaviour in a fire is that the technology is highly controllable. This means that nearly all of the variables within the environment are under the control of the experimenter. This is extremely important because, in most real-world experimental scenarios, this is not the case. Another essential strength associated with employing virtual reality in studying human behaviour in fire is that it is straightforward to replicate. This is important for verifying the validity of any results that may be produced from a given experiment. When an environment is challenging to replicate, it is nearly impossible to test the validity of the results that correspond to the research associated with the environment. Again, this is the case with real-world scenarios. Finally, using virtual reality technology to study human behaviour in fire is also advantageous because it allows the safe study of occupant behaviour (Kinateder et al., 2014). In other words, it does not require that anyone is involved in a dangerous situation.

While many strengths directly correspond to employing virtual reality to study human behaviour in fire, there are also some apparent weaknesses. The first glaring weakness is that it entails a lower degree of topological validity when compared to field research (Kinateder et al., 2014). Simply put, because it is not a real environment, its topological validity is, by definition, less than real-world cases. In addition to this, there are some technical limitations, which are simply related to the current weakness of the technology. This boils down to the fact that such virtual realities are often imperfect reflections of reality. The opportunities associated with using virtual reality in studying human behaviour in fire range drastically. However, they all boil down to one thing, the promised advancements in technology (Kinateder et al., 2014). As technology advances, virtual reality in general increases in realism and versatility, and correspondingly, the use of virtual reality in studying human behaviour in fire advances. As virtual reality can be better fashioned and purposed to study human behaviour in fire, all of the strengths mentioned above will be underscored, and all of the weaknesses discussed above will be diminished. This means that the general trend of the increased usage of virtual reality in study human behaviour in fire is certain to continue.

The main threat to virtual reality as a means of studying human behaviour in a fire has concerns how it is criticized by those who believe that it is not an effective way to obtain information about the subject matter. However, this threat is relatively tenuous. Even those who do not think that it is the best way to study human behaviour in fire recognize that it can provide useful information. They acknowledge that it has some clear benefits lacking in other methods such as a fire drill. Building evacuations are a vital research area investigated using these types of experiments. Before detailing the results of VR experiments in any detail, it should first be noted that in prior research conducted on validating the applicability of VR in experimental research about emergency management situations. Cosma (2014), Kobes et al. (2010), and Smith and Ericson (2009) point out that a good correlation has been found between the results of experiments based on virtual versus real-life tests. Moreover, while fewer studies have been conducted using VR technologies, there are some key research papers that should be highlighted. For instance, Kinateder and Warren (2016) conducted a one trial experiment using VR technology to study evacuation behaviours. They acknowledged VR as a promising tool that enables the study of evacuation behaviours in a safe and experimentally controlled simulation or otherwise potentially dangerous situations. They also pointed out that validation studies comparing evacuation behaviour in real and virtual environments are rare and an area that should be further studied. Their study compared the evacuation decisions in response to a fire alarm in matched physical and virtual environments. The study involved the testing of 150 participants in one of three conditions. The fire alarm went off in the control condition, and the participants had to perform a mock perceptual matching task. The participants performed the task with an associate who ignored the fire alarm in the passive bystander condition. In the active bystander condition, the associate left the room when the fire alarm went off. Half of the participants experienced the scenario in a lab environment, with the other half in a VE with a virtual bystander present on the HMD. The active bystander group was more likely to evacuate than the control group, and the passive one was less likely to leave than the control group. This social influence trend was observed in both real and virtual environments. The results of the study revealed that the social influence on the decision to evacuate was reduced in the virtual environment; however, the positive impact of the bystanders was commensurate with each other in both groups. The negative influence was weaker in VE. The results supported the use of VR as a research tool or method to study evacuation behaviour in emergency building fire scenarios due to the degree to which the findings in real and virtual environments matched. However, the effect sizes were likely to be smaller in VR than in physical conditions. This is perhaps due to the virtual nature of the experiment, which may cause participants to feel that they are in an unreal environment and thus act differently than if they were in a real-world scenario.

Another emergency scenario studied using VR is in road tunnels. It has been determined that human behaviour is one of the significant factors determining the outcome. Mühlberger et al. (2015) examined the effect of information and instruction on drivers' behaviour in such a situation and also the utility of the virtual environments in the simulation of such emergencies. They assessed the tunnel safety awareness of the general public using an online questionnaire, and tunnel safety behaviour was evaluated in a VR experiment. This required 44 participants to complete three drives through a virtual road tunnel where they were confronted with a traffic jam, no event and an accident scenario. The participants were randomly assigned to a control group (with no intervention), an informed group who had read a safety brochure before entering the VR tunnel, or an informed group that read the prospectus before entering the tunnel and also received instructional assistance during the emergencies. The better-informed participants showed better safety behaviour than the control group. Their findings indicated there was a problem in the behaviour of the control group and that safety knowledge information encouraged better safety behaviour. On the same theme, Kinateder et al. (2013) investigated the effects of data with or without additional VR training on self-evacuation using a simulated emergency in a road tunnel. Forty-three participants were randomly assigned to three groups with increasing preventive training. The control group only filled in the questionnaire. The first experimental group additionally read an information brochure on tunnel safety, while the second experimental group received additional behavioural training in a VR tunnel scenario. A week later, the actual VR experiment was carried out in which the participants were confronted with heavy smoke and a two-vehicle collision. Unsurprisingly, the informed and the behaviourally trained participants were able to self-evacuate more effectively, highlighting the necessity of providing appropriate awareness training to individuals.

A study more directly applicable to this present research was conducted in a fire emergency scenario in a tunnel assessed the effect of conflicting information from the emergency signboards and installations on the decision-making and behaviour of the evacuees during such emergencies (Kinateder et al., 2013). They examined whether and in what manner conflicting social information was likely to affect evacuation decisions and behaviours. To test this, 40 participants were placed in a VR smoke-filled tunnel with an emergency exit visible to one section of the participants. Four social influence conditions were applied, and the control condition required the participants to be alone in the tunnel. In the three experimental conditions, a Virtual Agent (VA) was present. In the no-conflict state, the VA moved to the emergency exit, and in the conflict condition, the VA moved away from the emergency exit. In the passive condition, the agent stayed in a passive mode. The findings showed that the participants were less likely to move to exit in conflict conditions as compared to the no-conflict ones. Also, the passive behaviour of others was found to inhibit the participant's actions towards safe evacuation. This lends credence to the idea that her mentality plays a role in evacuations and that the actions of peers are a very strong influence on such actions.

In another similar case study, Ronchi et al. (2015) analysed the evacuation travel paths of participants in VR tunnel fire experiments. They compared the travel paths between experimental groups and reference paths. The results showed that the shortest distance to arrive at a possible escape point might be an oversimplification of the evacuation path. These results can be compared with a study by Sime (1985) on the direction of the escape of people from a fire in a big room containing an entrance and emergency fire exits in opposite corners. The results suggested that in a situation of probable entrapment, people would try to move towards familiar people and places. The choice of location and exit was found to be mediated and affected by person and place affiliations, despite some importance given to proximity to exit. This adds even more weight to the effect of the action of peers and confirms the conclusions previously cited that occupants of structures would attempt to leave via the place they entered.

2.12 Chapter summary

This chapter looks at the various aspects of human behaviour in a fire and how an understanding of such behaviour can improve evacuation techniques.

Successful fire evacuation is a process that relies on various factors. The majority of studies on the subject have focused on how building design influences fire evacuation and have concluded that it plays an indispensable role in how and why people evacuate. It has also been shown to contribute to the speed and success of evacuation. However, there are a number of challenges associated with studying human behaviour in response to a fire evacuation, which is outlined in the following description of the main behavioural research methods.

It has been determined that failure to understand or know the fundamentals of preferred courses of action during a fire leads to increased building fire fatalities. Current studies are pointing towards the progression of more execution based approaches and ensuring improved fire training. To do this, execution models must join exact depictions of human behaviour. Regardless, exercises for occupants in structures and concerning fire are bewildering. They incorporate the occupant's environmental and spatial participation. These are an eventual outcome of an individual's psychological, physiological and sociological zones.

Chapter 3

3 Chapter 3. General approach

3.1 Chapter overview

This chapter presents a description of the approach taken to this research. It explains that the research was based on the PADM framework (Lindell & Perry, 2012), and relied upon two methods, the Talk-through approach and Virtual Environments, to investigate the human perception of cues to an emergency and the influence of other building occupants. An outline of the studies and investigations is presented as an overview of this research enquiry, with noting the questions that this thesis aimed to address.

3.2 The first stage of PADM as a suggested model

PADM was adopted as a framework for studying human perception/action in a fire emergency. The primary proposition of PADM is that cues from the environment received by an individual can interrupt the individual's normal activities. Once these cues are interpreted and depending on how the cues are understood, the model predicts that people will either seek additional information, proceed to protect people or property, engage in action to reduce physiological stress or resume whatever activity they were engaging in before they received the cues (Figure 1, Lindell and Perry, 2012). Despite the currency of PADM as a model of human behaviour in fire, Kuligowski (2013) strongly argues that it is insufficient for predicting behaviour and that it should be expanded and developed to be more comprehensive. Thus, while PADM framed the research conducted for this PhD, the work also aimed to inform the development of the PADM model.

3.3 Talk- through approach

There are many ways to predict human behaviour during fire evacuation without placing participants in real situations, thus avoiding any danger (Lawson, 2011). One such approach is the talk-through approach, in which participants explain how they would respond to an emergency based on a description of the situation (Lawson et al., 2013). This combines the talk-through method (Kirwan & Ainsworth, 1992) with sequential analysis, used to study behaviour resulting from events as they develop over time (Bakeman & Gottman, 1986).

One of the advantages of this approach is that participants' behaviour can be captured without placing them in any real danger. The second reason is that overall, this approach has proved to be fairly reliable and valid in predicting how humans respond (Lawson et al., 2013). The one key deficiency with this approach is that it has, until now, lacked the inclusion of social factors, which are important factors steering the outcome of an evacuation (Lawson, 2011; Nilsson & Johansson, 2009). Finally, the talk through approach is also practical because it enables a comparative analysis of human behaviour in the case of emergency fires by presenting participants with different starting scenarios and capturing the differing responses of the participants.

In general, the literature reported in section 2.10 has shown that social interaction plays a very important role in fire evacuation and indicates that the lack of consideration of social factors in previous studies using the talk-through approach limits the accuracy of the predictions arising from these studies. People use social cues much in the same way that they use fire alarms in determining whether or not they should evacuate. In fact, sometimes social cues are even more important in influencing the decision that people decide to make about whether or not to evacuate. The fact that social cues and social interactions play such a tremendous role in the rate of evacuation and whether or not people decide to evacuate is important because it means that acknowledging this in the design of buildings, training and emergency response procedures is essential to facilitate the safe evacuation of buildings. Therefore, the first study in this PhD research adopted the talk-through approach as applied in previous studies reported in the literature, with the addition of an important first step to study its ability to predict human behaviour in fire under the influence of social conditions.

3.4 Virtual environments

Over the years, virtual reality (VR) has been increasingly adopted in experimental psychology. It has advantages in the sense it allows for subsequent implementation of dangerous and complex scenarios with experimental control in the safety of the laboratory environment (Ericson, 2007). Furthermore, virtual reality is cost-effective compared to observations and field control (Bode et al., 2015). Furthermore, VR studies are easy to replicate (Kinateder et al., 2014). Numerous studies have utilized VR. For example, Meng et al. (2014) demonstrated that participants who evacuated from a simulated fire in a virtual library demonstrated actions that were likely to indicate impulsive behaviour or panic (Meng et al., 2014).

Thus, VR offers the possibility of gaining new insights into human behaviour in emergency situations which is a normal situation that would be difficult to explore. However, the effectiveness and subsequent usefulness of virtual reality rely mostly on the external validity of the simulation. Imperatively, external validity can be assumed if participants show the same cognitive, emotional, behavioural and psychophysiological reactions in both the real world and virtual reality. To establish this, numerous studies have been conducted to obtain evidence for the validity of VR, as outlined in section 2.11.2.1.

In scientific studies focusing on behavioural characteristics, replication is a vital factor that can be achieved in VE. This replicability is critical for accurate assessments of behaviour (Walsha, 2018). The capacity to replicate suggests the emphasis of an examination using comparable techniques with different individuals and experimenters. Studies ought to be imitated to test their reliability, authenticity, generalizability. Genuine assessments, especially field and relevant investigations, offer data to only a single unequivocal event and are VERY challenging to copy (Walsha, 2018). Natural authenticity suggests the degree to which the techniques for an examination address a real circumstance that is being broken down. VR offers a similar degree of natural authenticity as traditional lab experiments, and depending on the research focus, one system or the other may be more dynamically suitable. For example, certain features of a fire emergency, for instance, the visual diversion of flares, may be imitated with higher control in VR anyway various functions. In another example, contact may be dynamically irksome yet not difficult to emulate in VR and therefore imply the use of both virtual and real elements (Walsha, 2018).

Conducting a fire evacuation is vital, and thus there has been a lot of research to determine the core factors that affect the evacuation process. The psychology of the evacuees is an integral factor in ensuring an efficient evacuation process which implies an increased emphasis on studying human behaviour in a fire incident. Real-time drills were conducted that involved the simulation of a fire, which was found to expose participants to danger during the experiments.

3.5 Experimental studies

3.5.1 Study1: Predicting Social Influence in a Fire with the Talk-Through Approach

In this experiment, participants were given a narration of the situation and asked to map out their anticipated response. Safety is one reason for such an approach, avoiding a situation where people are put in real danger even though in a controlled situation. This approach was also adopted as its validity for predicting bheaviour has been demonstrated in previous research (Lawson et al., 2013).

The experiment conditions were that three different scenarios were presented: **active, passive, and control,** which describe the behaviour of the other (hypothetical) building occupants. In all situations, the **evacuation time** was recorded. In addition, there was one independent variable (**response mode of others**) with three levels. In the active condition, the participants were asked to think of how occupants of other buildings move in the opposite direction of the exit. In the passive condition, occupants remained in their original positions, while in a controlled condition, the participant was alone.

Fifteen participants were recruited, with five in each of the three different groups; each presented the action room. The intention was to find how fast they would leave the room and, eventually, the building.

3.5.2 Study 2: The Influence of Social Behavior in Fire Evacuation in Virtual Environment

In this study, there was an effort to apply technology in the experiment by replicating the actions in study 1 in virtual reality. The environment's virtual reality simulator replaced the description of the conditions which were presented in written form in study 1. Like study 1, the sequence of acts, frequency of acts, time, and social behaviour influence were measured.

Unlike study 1, study 2 had 45 participants making the sample bigger. Several hypotheses were tested using a virtual office building and a VR system with an HTC Vive. Participants were allowed time to familiarize themselves with the simulator equipment and showed the ability to move in any direction. There was one independent variable (**response mode of others**), with three levels; **active conflict**

condition, **passive condition**, and a **control condition**, in virtual agents behaved in a manner which was broadly similar to that described for study 1.

3.5.3 Study 3: Investigation of Influence the Relative Influence of Information Sources/ Message content and Receiver Characteristics on Behavior during Emergencies (Fire) in a Virtual Environment

While studies 1 and 2 looks at the social influences on behaviour during emergencies, this experiment aims to study the effects other factors on human behaviour during an emergency, including: the source of information during an emergency; the content of the information; and the recipient's characteristics. In an emergency situation, the warnings as messages have varying degrees of success depending on the message; the channel used the receiver's perception of the message and ability to assess the risk being communicated correctly. Emergency messages, therefore, need to be timely, with the right information, and precise.

Three groups were set up in the experiment while being exposed to a virtual environment. **The first group** was exposed to a virtual environment where a virtual agent dressed formally shouted a detailed message and another scenario with less detailed information. **The second group** saw a virtual agent dressed informally and did as the first agent. **The last group** was exposed to sirens with detailed versus non-detailed information. Several hypotheses were laid out with a total of sixty participants. **Three independent variables** were examined in the study:

- **IV1:** information source(channel) had three levels: authority figure (visual and auditory); stranger (visual and auditory); siren (auditory-only)
- **IV2:** level of detail of warning message had two levels: detailed and not detailed
- **IV3:** receiver characteristics (participant gender) had two levels: male and female

3.5.4 Study 4: Investigation of the Effect of Information Source (Authority figure and Siren) in the Presence of Two Social Conditions (passive and Active conflict) on Behavior during Emergencies (Fire) in a Virtual Environment.

Studies 1, 2, and 3 were suggestive of the idea of using cues as signals in the evacuation process during emergencies. This study's effort is to understand the effects of social cues (passive or active conflict) on authority or siren in the evacuation process. Again, **three groups** were identified and exposed to three different messages in a virtual environment. **The first** was exposed to a virtual agent informal clothing, presenting both detailed and non-detailed information. **The second** was presented as a stranger in informal clothing with both detailed and non-detailed messaging. **The third** was presented a siren warning with both detailed and non-detailed messaging. Again, the environment was virtual, and the participants were allowed time to familiarize themselves with the virtual system, which was the VR system and HTC Vive.

A between-group experimental research design was used with several hypotheses outlined. This experiment had 80 participants, but the experiment had to be cut short due to the Coronavirus pandemic to only 64 participants. There were two levels of each IV as follows:

IV1: information source: authority figure or siren

IV2: social behaviour of virtual agents: active or passive

IV3: gender: male or female (with a deficit in female representation due to the Coronavirus pandemic).

3.6 Chapter summary

The chapter outlined the methodological approach taken within the research conducted for this PhD. The key aim of the research was to predict people’s behaviours in hypothetical and simulated emergency situations with talk-through and VR experimental studies. Mainly, the issue surrounding elements of human behaviour such as social influence, environmental cues, information sources, warning level, and receiver characteristics (gender) in relation to participants’ behaviour in a fire emergency is investigated. It also has prepared the reader to follow the research progress as it investigated the behavioural response to cues of a fire emergency. Finally, the outline of the studies has been presented using the overview of the studies and results conducted for this thesis, mapped to the first phase of the Protective Action Decision.

Chapter 4

4 Chapter 4. VR development

4.1 Chapter overview

This chapter contains an overview of the development of the virtual reality technologies used in the study. To commence, it was necessary to identify a software tool to develop the virtual world. After searching the available tools such as 3DS Max, Blender, Unreal Engine, and Unity game engine, it was decided to employ the Unity game engine. Compared to other development environments, Unity3D supports many platforms and is a powerful tool for developing 3D game applications. Furthermore, unity is developing very quickly and has a strong community and many resources and services.

The process of designing the virtual environment is outlined in Figure 3, based on Hale and Stanney, 2014. To develop the VR for this research, the tools that were used were:

- Unity engine: used to construct the VR experience.
- Maximo: used to add animations to a player.
- A* algorithm: pathfinding algorithm.

These are described in the following sections.

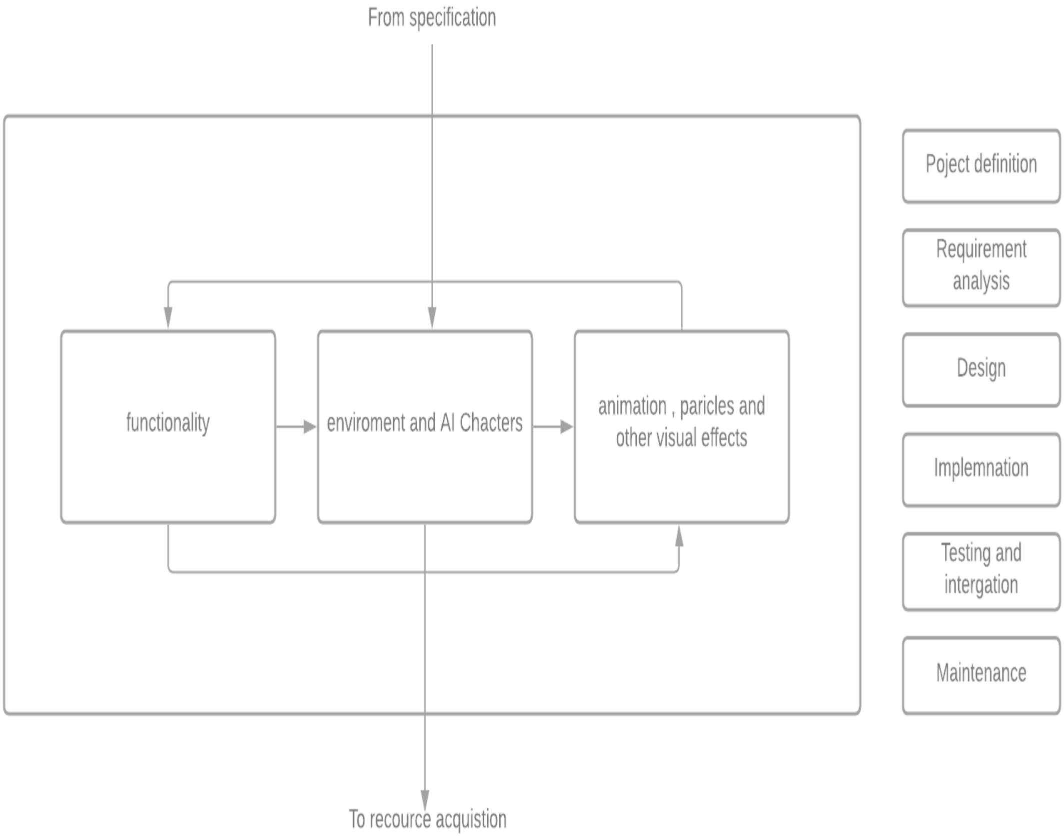

Figure 3 Design stages of the VR experience (based on Hale and Stanney, 2014)

4.1.1 Unity game engine

Unity affords users the ability to experience worlds in both 2D and 3D. Furthermore, the Unity game engine offers a primary scripting Appliation Programming Interface (API) in C#. Unity can provide a plethora of the most germane built-in features that make a game work as a game engine. These include elements like physics, 3D rendering, and collision detection. Unity will render the designed VR world. Moreover, it will handle all the physics, graphics, animations, and other relevant factors. Figure 4 shows the Unity game engine interface. A top bar on your right at the top of the screen contains the usual system status bar and on the left is the menu bar when you run any program.

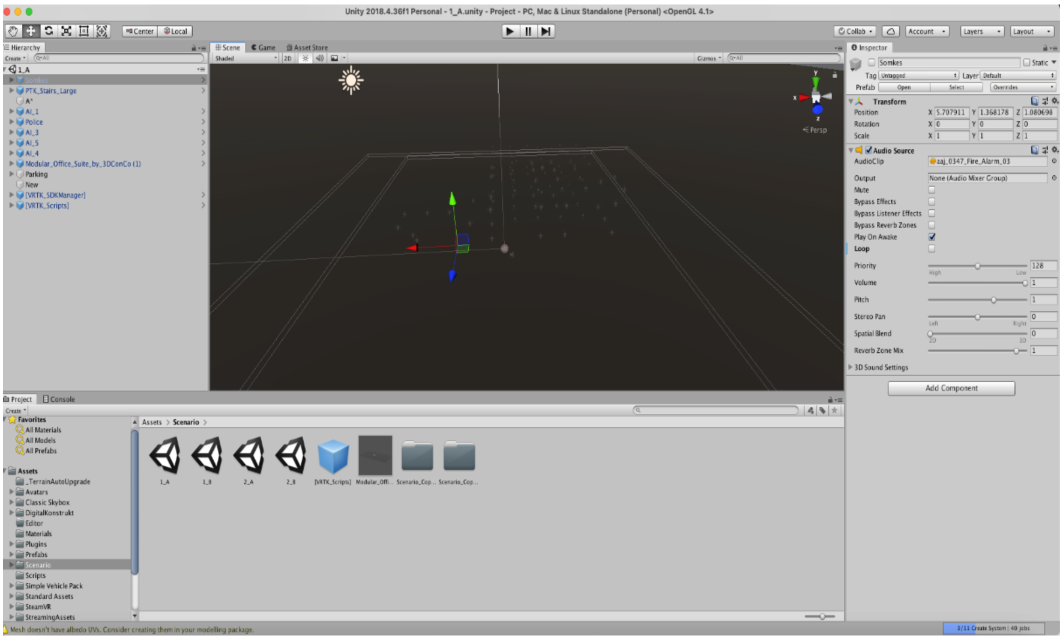

Figure 4 Unity game engine

4.1.1.1 Particle system

Unity features a robust Particle System that can effectively simulate moving liquids, smoke, clouds, flames, magic spells, and a whole slew of other effects. In this virtual reality experience, it was necessary to use smoke to simulate the conflagration inside the building and give the user the feeling of fire inside the building. Figure 5 shows the smoke which Particle System generates.

Figure 5 Smoke which the Particle System generates

The smoke will start after 10 seconds from starting the VR experience. A script was created that controlled when to start or end the smoke particles from being generated. This script also commenced playing a sound that indicated the evacuation process. The specific sound (e.g. alarm or message), or absence of a sound, was based on the scenario. With a script attached to a particle system, one can have more control of the behaviour of the particles. Figure 6 depicts the settings of the smoke particles created by the unity particles system, and it shows the amount of smoke it will produce and how long the smoke particles take to disappear.

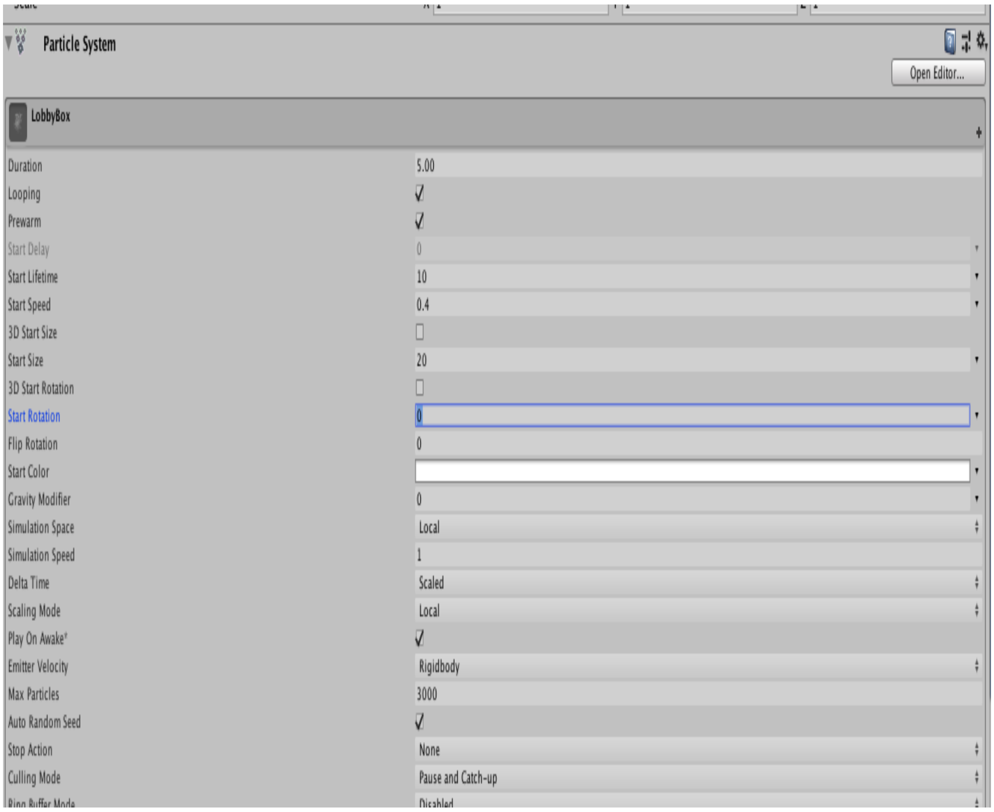

Figure 6 shows the settings of the smoke particles created by the unity particles system, and it shows the amount of smoke it will produce and how long the smokes particles take to disappears

As mentioned before, Unity particle's system provides powerful features. It allows one to customize how the particles are generated, move, and the lifetime of each particle generated. For example, in figure 6, 5 seconds were specified for the particle duration, meaning Unity would generate new smoke particles every 5 seconds. In addition, it the value of looping was set to "true" to inform the Unity particle system that it was wanted the particles to be generated automatically.

Here is a description of the main settings of the particles system

- **Duration**: If looping isn't checked, this determines how long the Particle will play. **Looping**: Determines if the Particle loops or plays only once.
- **Pre-warm**: Only used when looping is enabled. The Particle System will act if it's already completed an entire cycle on start-up.
- **Start Speed**: The initial speed of the particles. The greater the speed of the particles, the more spread out they will be.

Start Lifetime: The initial lifetime in seconds for the particles. The particle is destroyed after this elapsed time.

Following the configuration of the settings of particle systems, one needs to attach them to a Game Object (A game Object in Unity is any component that can exist on the game scene) and optionally attach a script that will have more control of the particles and the Game Object. Figure 7 depicts the image used by the Unity particles system to produce the smoke particles. The image must be transparent, and the shade field must be set as specified in the image.

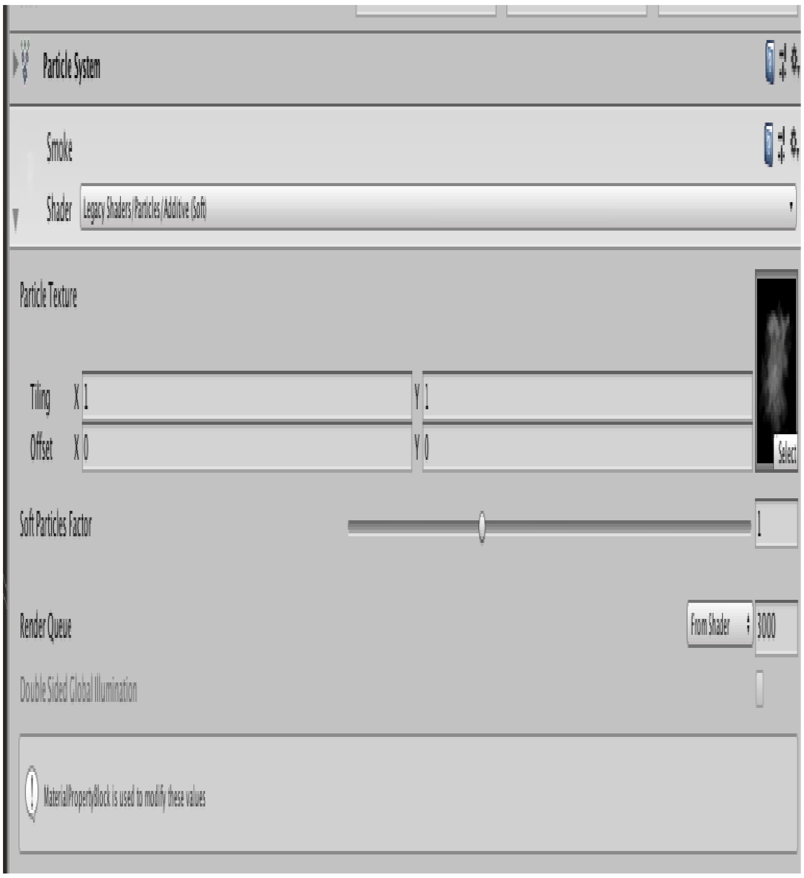

Figure 7 The smoke image used to produce smoke particles

A transparent image and shade setting made the smoke particles look more realistic. It is recommended to use smaller and lower quality images to avoid any impact on performance. Figure 8 shows the script that controls the smoke in the VR experience, which is a script that is used to start the smoke particles.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class StartSomke : MonoBehaviour {
	public GameObject Smoke;

	public AudioSource FireAlert;

	public bool IsDir = false;

	public AudioClip Dir;
	public AudioClip Alert;

	public GameObject Signs;
	public GameObject Ligths;


	public bool IsLigths = false;

	// Use this for initialization
	void Start () {
		if (IsLigths) {
			Signs.SetActive (false);
			Ligths.SetActive (true);
			FireAlert.enabled = false;
		} else {
			FireAlert.enabled = true;
			if (IsDir) {
				if ( Dir != null) {
				FireAlert.clip = Dir;
				}
			} else {
				FireAlert.clip = Alert;
			}

			Signs.SetActive (true);
			Ligths.SetActive (false);

		}



		StartCoroutine (Wait());
	}

	// Update is called once per frame
	void Update () {

	}

	IEnumerator Wait(){
		yield return new WaitForSeconds (8);
		print ("starting smoke !!! ");
		Smoke.SetActive (true);

	}
}
```

Figure 8 Script that controls the smoke in the VR experience

4.1.1.2 Physics

Unity engines provide tremendously powerful tools and techniques to represent real physical properties. For example, the built-in Physics Engine manages physics in Unity. Namely, the built-in Physics Engine in Unity handles the physics for Game Object interactions and the various effects like gravity, acceleration, collisions, etc. Figure 9 depicts the quintessential physics that Unity imparts.

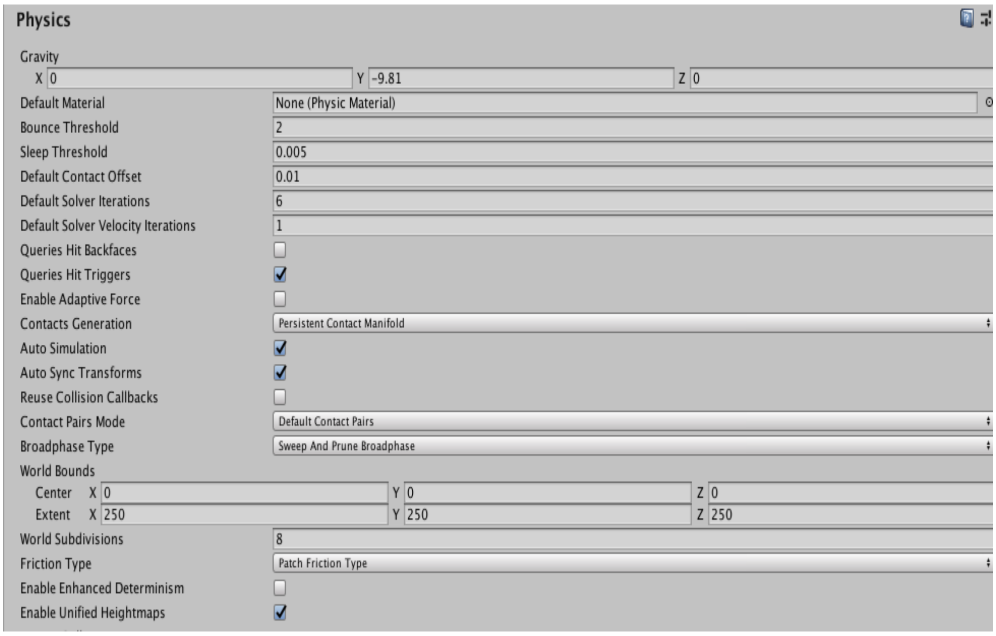

Figure 9 Shows a fundamental physics that's unity provide

Two of the essential physics tools that Unity provides are **Collider** and **Rigid body**. **Here is a description of the main settings of the particles system.**

- **Gravity:** one can customize the gravity factor and change the axis this gravity has an impact on. For this experience, the gravity factor was not edited.
- **Bounce Threshold:** If two colliding objects have a relative velocity below this value, they do not bounce off each other. This value also reduces jitter, so it is not recommended to set it to a low value.
- **Default Contact Offset**: Establish and summarily define the collision detection system's distance to generate collision contacts. The value must be positive, and if set too close to zero, it can cause a jitter. This is set to 0.01 by default. Colliders only generate collision contacts if their distance is less than the sum of their contact offset values.

- **Collider:** Collider components define the shape of a Game Object (the player in the game or any 3d or 2d object). A collider, invisible, does not need to be the same shape as the Game Object's mesh for physical collisions.

4.1.1.2.1 Collider

Unity physics system can detect when collisions occur and initiate an action's function. For example, a collider was used to automatically open doors when AI characters or the player collider interacted with a door collider to detect when one collider enters the space without creating a collision. A collider configured as a Trigger (using the *is Trigger* property) does not behave like a solid object and shall simply allow other colliders to pass through.

When a collider enters its space, a trigger will call the On Trigger Enter function on the trigger object's script to make a collider behave like a solid object. It was needed to set the Trigger property to false and add a rigid body that gives a Game Object mass and other physical properties. A rigid body provides a character with a mass, the ability to move with specified velocity and speed, and resist gravity power.

Collider helps to avoid characters moving to throw walls, offices or other obstacles. With colliders, characters will have a body to which all laws of physics apply. Figure 8 shows collider attached to players. Figure 10 shows collider attached to players.

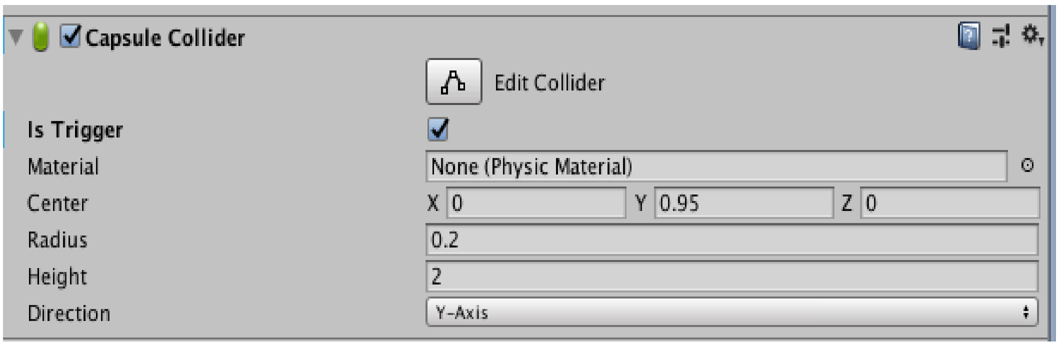

Figure 10 Shows collider attached to players

Here is a description of the capsule collider properties settings of the particles system:

- **Is Trigger:** If enabled, this Collider is used for triggering events and is ignored by the physics engine.
- **Material:** Reference to the Physic Material that determines how this Collider interacts with others.
- **Centre:** The position of the Collider in the object's local space.
- **Radius:** The radius of the Collider's local width.
- **Height:** The total height of the Collider.
- **Direction:** The axis of the capsule's lengthwise orientation in the object's local space.

To control how a Game Object behaves when it collides with other Game Objects with a collider component, one needs to attach a script to the game object and then handle the collision events when they happen. You can attach each of these colliders to your Game Object. For example, figures 11 & 12 depict a collider set to be the trigger to false to detect when AI characters interact with the collider. Then the door shall open and then when the Characters leave the collider area, the door will be closed.

These are the primitive collider types in Unity:

- **Box Collider:** the primitive shape of a cube
- **Sphere Collider:** the primitive shape of a sphere
- **Capsule Collider:** the primitive shape of a capsule
- **Wheel Collider:** specifically for creating cars or other moving vehicles

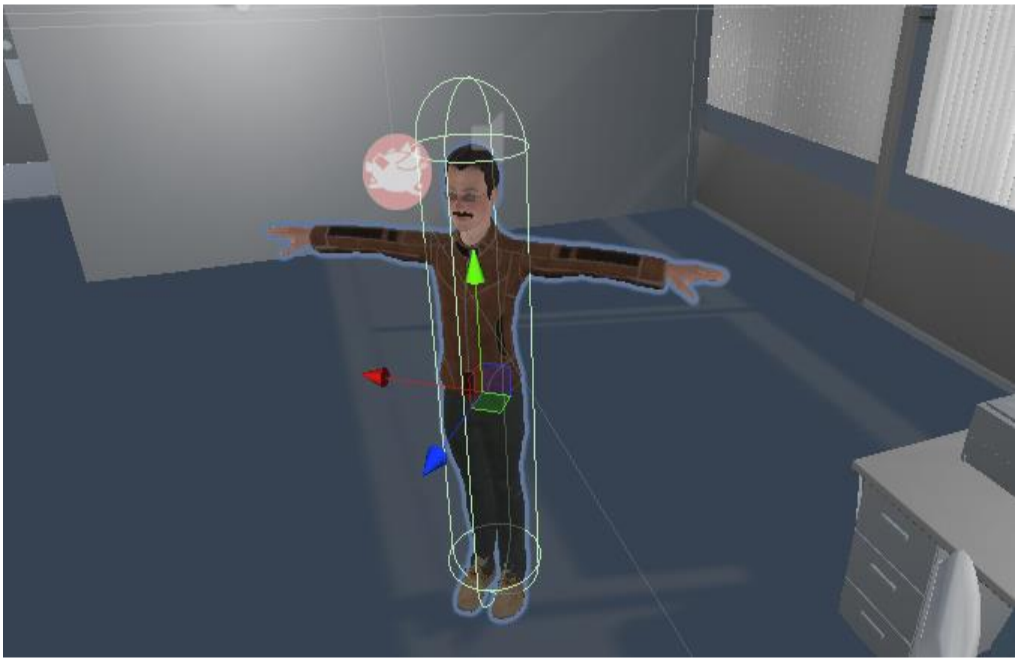

Figure 11 AI player with collider (the green shape)

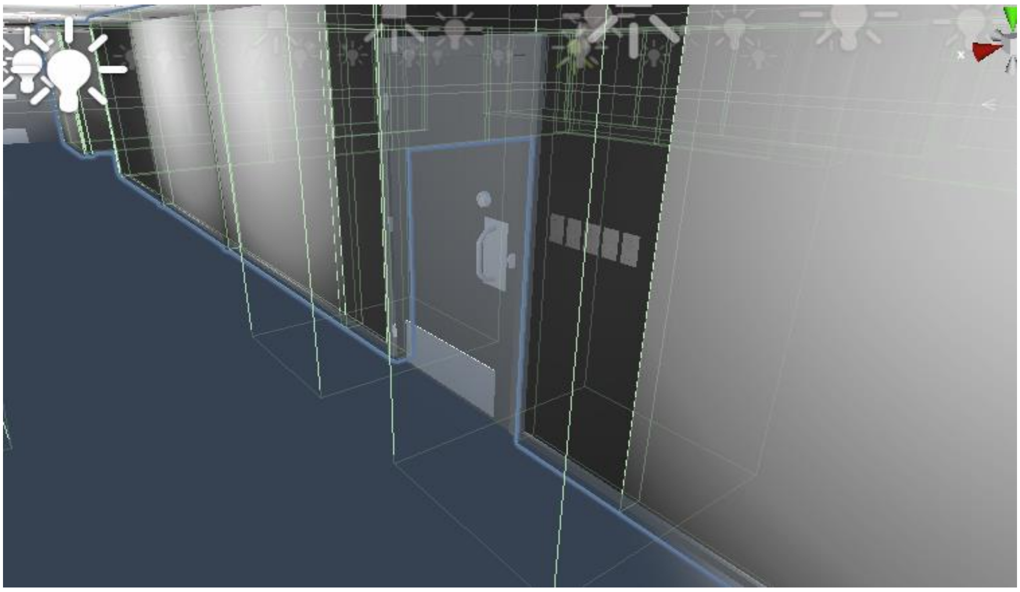

Figure 12 Colliders attached to doors and walls

4.1.1.2.1.1 Types of a collider in Unity

4.1.1.2.1.1.1 Compound colliders

Compound colliders approximate the shape of a Game Object while keeping a low processor overhead. Compound Colliders are combinations of primitive Colliders, collectively acting as a single rigid body. They come in handy when you have a model that would be too complex or costly in terms of performance and want to simulate the collision of the shape in an optimal way using simple approximations. To create a Compound Collider, create child objects of your colliding object, then add a Collider component to each child object. This allows one to position, rotate, and scale each Collider easily and independently of one another. You can build your compound collider out of several primitive colliders and/or convex mesh colliders.

4.1.1.2.1.1.2 Mesh colliders

There are some cases, however, where even compound colliders are not accurate enough. In 3D, one can use mesh colliders to match the shape of the Game Object’s mesh exactly. These colliders are much more processor-intensive than primitive types, so use them sparingly to maintain good performance. Also, a mesh collider cannot collide with another mesh collider (i.e., nothing happens when they make contact).

4.1.1.2.2 Rigid body

Rigid bodies allow your Game Objects to act under the control of the physics engine. This opens the gateway to behaviours such as realistic collisions. Manipulating Game Objects by adding forces to a rigid body creates a very different feel and look than adjusting the Transform Component directly. Generally, one shouldn’t manipulate the rigid body and the Transform of the same Game Object - only one or the other. Rigid bodies must be explicitly added to your Game Object before they will be affected by the physics engine. Figure 13 depicts rigid body settings For AI Players.

- **Mass:** The mass of the object (in kilograms by default).

- **Drag:** How much air resistance affects the object when moving from forces. 0 means no air resistance, and infinity makes the object stop moving immediately.

- **Angular Drag:** How much air resistance affects the object when rotating from torque. For example, 0 means no air resistance. Note that one cannot make the object stop rotating just by setting its Angular Drag to infinity.

- **Use Gravity:** If enabled, the object is affected by gravity.

- **Is Kinematic:** If enabled, the object shall not be driven by the physics engine and can only be manipulated by its Transform.

- **Freeze Position:** Stops the Rigid body moving in the world X, Y and Z axes selectively.

- **Freeze Rotation:** Stops the Rigid body rotating around the local X, Y and Z axes selectively.

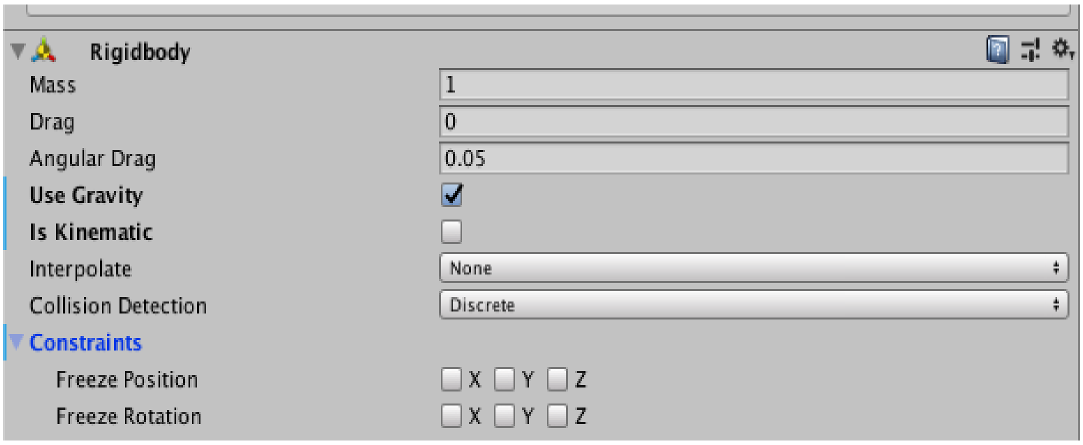

Figure 13 Rigid body settings for AI Players

4.1.2 Animations

Unity's animation system provides ample possibilities for animating Game Objects. It was used animation to animate players, door opening and closing, chairs and other game objects that need to be animated. To animate players, it was first required to attach bonds to each character. To be able to do that, it was used, Maximo. Maximo is a powerful online tool that helps us to animate 3d objects. Figure 14 player bones characters shown from Maximo.

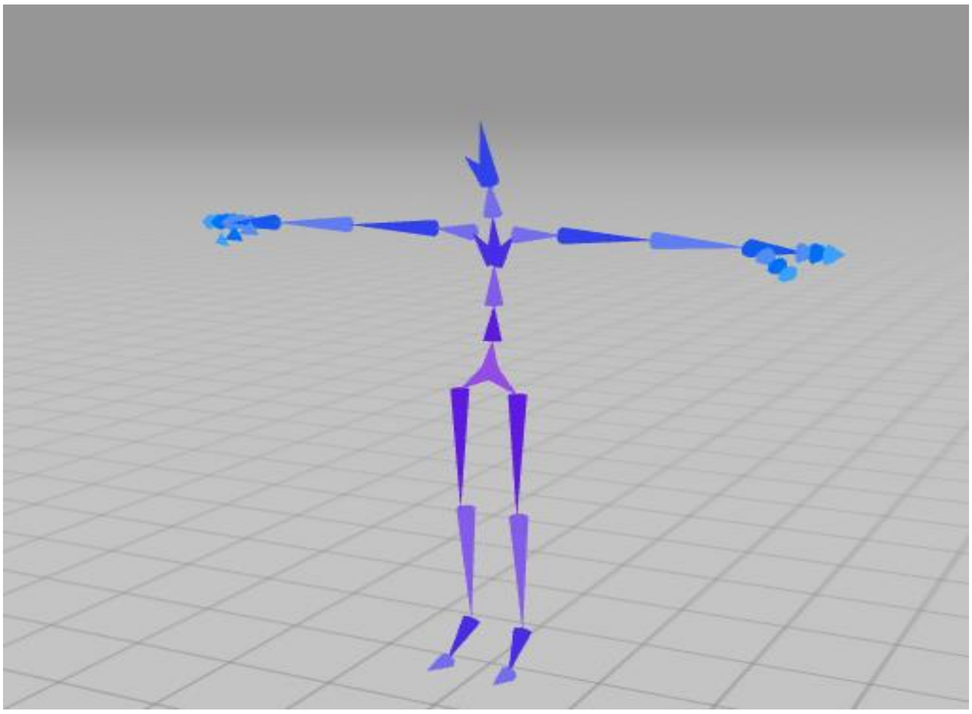

Figure 14 Player bones characters shown from Maximo

After applying bones and animations from Maximo, it is necessary to define states to trigger each animation. To do that, the Unity Animator System was used, which will control switching between animation stats. Figure 15 shows animation stats for players, and Figure 16 shows animation settings.

- **Motion:** is the animation that will be played when the status of the player is set to (sit)
- **Speed:** the speed rate at which animation will play
- **Transitions:** shows the next state linked to current stats, which means when this animation is finished, and the Unity animation received a flag from a script that controls the animation, it will start playing the following animation.

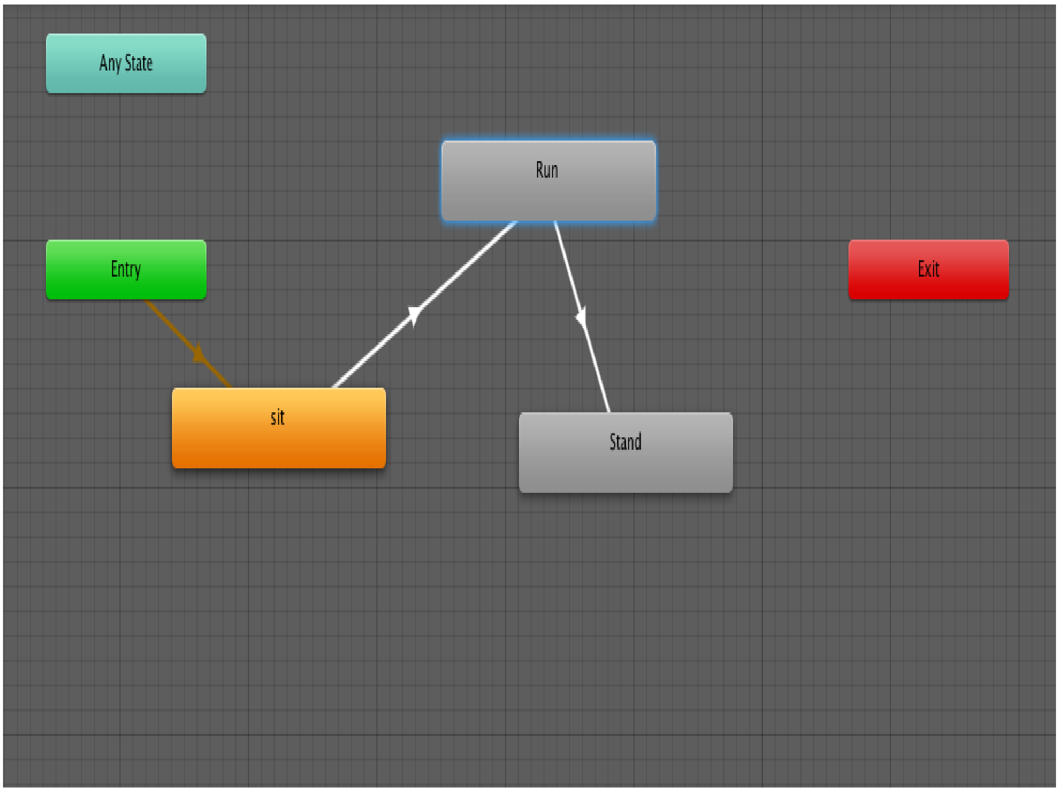

Figure 15 Shows animation stats for player

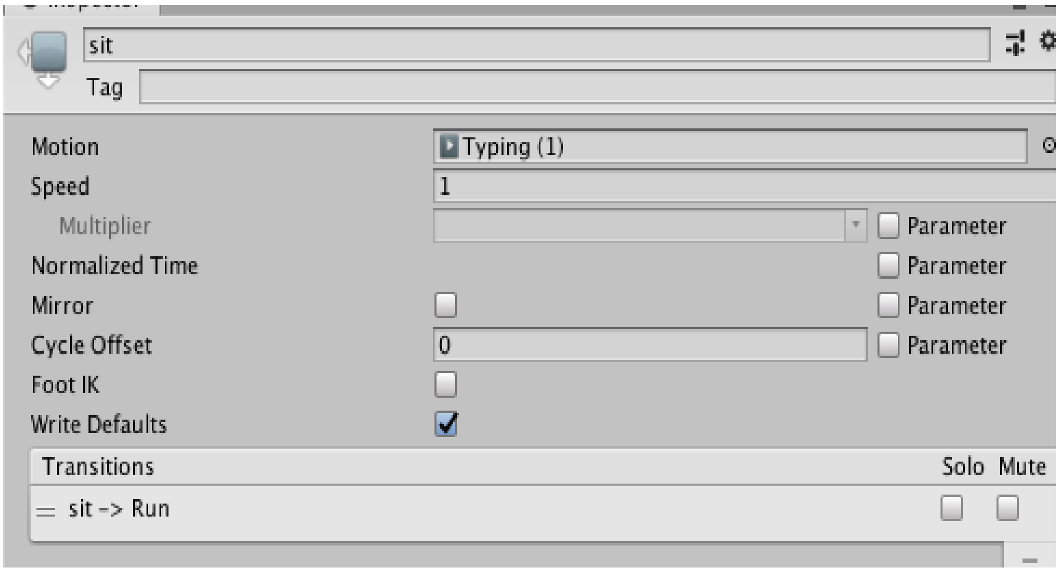

Figure 16 shows animation settings

4.1.2.1 Path Finding

Path Finding has been one of the oldest and most prevalent applications in computer programming. One could virtually find the most optimal path from a source to a destination by adding costs representing time, money etc. There are many paths finding algorithms, for example, Dijkstra's algorithm, Any-angle path planning, D* algorithm and A* algorithm.

4.1.2.2 A* Algorithm

In this VR simulation, the robust and well-known A* algorithm was used. A * algorithm is a searching algorithm that searches for the shortest path between the *initial and the final state.* It is used in various applications, such as *maps*. For example, the A* algorithm calculates the shortest distance between the source (initial state) and the destination (final state) in maps.

4.1.2.2.1 Parameters of A* algorithm

A* algorithm has three parameters:

- **g:** The cost of moving from the initial cell to the current cell. It is the sum of all the cells that have been visited since leaving the first cell.
- **h:** The heuristic value is the estimated cost of moving from the current cell to the last cell. The actual cost cannot be calculated until the last cell is reached. Hence, h is the estimated cost. It was must make sure that there is never an overestimation of the cost.
- **f:** It is the sum of g and h. So, **f = g + h**

The way that the algorithm makes its decisions is by taking the f-value into account. The algorithm selects the smallest f-valued cell and moves to that cell. This process continues until the algorithm reaches its goal cell. To make the A* algorithm avoid obstacles, it was used colliders and tags and give each object in a game a collider a tag and defined two tags: un Tagged and un-walkable. Where objects with a collider and a tag are Un walkable, A* algorithm shall ignore when it tries to find a path. Figure 17 red nodes show an un-walkable area, where white nodes show the area in which players are allowed to move.

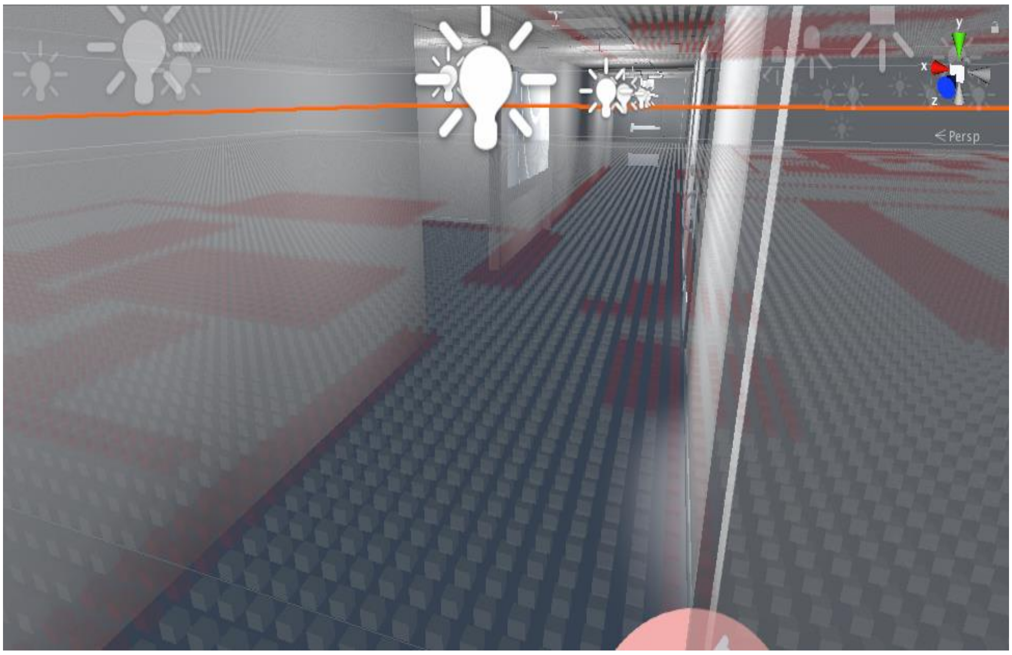

Figure 17 Red nodes un-walkable area, where white nodes show the area which player allowed to move

Figure 17 shows a visual presentation of the nodes that the A* algorithm has generated. The red nodes indicate an unwalkable area, and the white node indicates areas where AI characters can walk. When the A* algorithm generates a path for a character, it will avoid all red nodes (unwalkable). These unwalkable areas are hidden colliders that have is triggered set to true and has a flag unwalkable set to true. To give a more realistic path and allow characters to move more realistically. These colliders were located in places to make charters avoid colliding with nearby obstacles or objects.

As one can see in the office on the left, I have placed many of these colliders in the middle of the room where the offices and chairs are placed, so when the algorithm starts calculating the shortest possible path, it will avoid going over the offices or chairs. Figure 18 shows the first method used by AI to Request the path. The second method used the path was processed and then keep the result of the path.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System;
public class PathFinding : MonoBehaviour {
	Grid grid ;

	void Awake (){

		grid = GetComponent<Grid> ();

	}

	public void FindPath(PathRequest requst , Action<PathResult> callback) {
		// Find Path To target

		Vector3[] WayToTarget = new Vector3[0]; // save the path to target
		bool pathSuccess = false;

		Node startNode = grid.NodeFromWorldPoint (requst.start); // current AI posstion
		Node TargetNode = grid.NodeFromWorldPoint (requst.end); // current Target
Posstion

		if (startNode.walkable || TargetNode.walkable) {

			Tree<Node> Open = new Tree<Node> (grid.MaxSize);
			HashSet<Node> Colsed = new HashSet<Node> ();
			Open.Add (startNode);

			while (Open.Count > 0) {
				Node cuurentNode = Open.RemoveItem ();

				Colsed.Add (cuurentNode);

				if (cuurentNode == TargetNode) {
					pathSuccess = true;

					break;
				}

				foreach (Node neighbour in grid.GetNeighbours(cuurentNode)) {
					if (!neighbour.walkable || Colsed.Contains (neighbour))
{

						continue;
					}

					int CostToNeigbour = cuurentNode.Gcost + GetDistance
(cuurentNode, neighbour);

					if (CostToNeigbour < neighbour.Gcost || !Open.Contains
(neighbour)) {

						neighbour.Gcost = CostToNeigbour;
						neighbour.Hcost = GetDistance (neighbour,
TargetNode);

						neighbour.Parent = cuurentNode;

						if (!Open.Contains (neighbour)) {
							Open.Add (neighbour);

						}else
							Open.UpdateItem (neighbour);
					}


				}



			}
		}
```

Figure 18 First method used by AI to Request the path. the second method used the path was processed and then keep the result of the path

Figure 18 shows a script attached to AI characters when the characters start the evacuation of the building. They first request a path to a destination point; the destination for each charter was predefined. When the path is ready and can be used by the charter, the A* algorithm will call the Done Processing function, which returns a list of nodes the characters should walk through to get to the destination. Figure 19 shows the Main A* method: used to find the path to the target. If a path was found, it would call the Done Processing method. If the target or AI are on a node that cannot be walked, it will not find the path.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;

public class AI : MonoBehaviour {

        private Transform Target; // the posstion were the AI will walk to

        public Transform targetUpStaris; // the posstion were the AI will walk to
        public Transform targetDownStaris; // the posstion were the AI will walk to
        public GameObject Mychair; // the chair were the AI sit in the office room
        public float speed = 1.0f; // speed of the AI
        Vector3[] Path; // the path to target
        Vector3 AI_2_standPosstion; // the path to target
        int tagetIndex; // used in loop
        public Animator myAnimation; // to contral Animation
        public bool IsUpsatris = true;
        private bool StartRuning = false;
        // Use this for initialization
        public Rigidbody rb ;
        void Start () {
                AI_2_standPosstion = new Vector3 (0.5102216f, 3.4f, -12.342f);
                //target = targetUpStaris;
         rb = GetComponent<Rigidbody>();
                transform.parent = Mychair.transform; // sit the chair as AI parent
                if (GameObject.Find ("New").GetComponent<MangePaths> ().IsEscape) { // Start Find path
                        StartCoroutine (FindPath ());
                }
        }

        IEnumerator FindPath(){
                // wait for 12 seconds then start find path
                if (IsUpsatris){
                        yield return new WaitForSeconds (15.0f);
                        if (transform.name == "Al_2" && SceneManager.GetActiveScene().name == "4" ) {
                                gameObject.GetComponent<AudioSource> ().enabled = true;
                                Mychair.GetComponent<Animation> ().enabled = true;

                                        while (Mychair.GetComponent<Animation> ().isPlaying) { // wait
unitl chair Animation finshed
                                                yield return null;

                                        }
```

Figure 19 Main A* method: used to find the path to the target. If a path were found, it would call the Done Processing method. if the target or AI are on a node that cannot be walked, it will not find the path

Figure 19 shows the main A* algorithm responsible for finding a valid path from a start node to Target Node, where the start Node is the character's position before the pathfinding process. The function will loop throw the grid to check if the node is walkable or not. If the current node were walkable, it will compare the cost of moving to that node compared to its neighbour nodes and then decide if it should use the current node if the path is returned to the characters that requested the path. While, Figure 20 shows that A* the path was found that when the path is finally found from a start point to the endpoint, A* will translate that path to a Vector3 point which is a coordinate in XYZ, so the characters can understand the path and can navigate to the destination. Through the path and creating a vector, 3 points of the path for the AI to reach the target.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Node : ITreeItem<Node> {

	public bool walkable; // Indicate if this node walkable or not
	public Vector3 worldposstion; // posstion of th node in the game
	public int x; // index of the node in nodes array
	public int y; // index of the node in nodes array
	public int Gcost; // the cost of the path from the start node
	public int Hcost; //  estimates the cost of the cheapest path
	public Node Parent; // parent of this node " the past node "
	int treeIndex;
	public int Fcost { // cost to the target
		get{
			return Gcost + Hcost;
		}
	}
	public int TreeIndex {
		get{
			return treeIndex;
		}
		set{

			treeIndex = value;
		}
	}

	public Node(bool Walkable , Vector3 WorldPosstion,int x, int y){
		this.walkable = Walkable;
		this.worldposstion = WorldPosstion;
		this.x = x;
		this.y = y;
	}
```

Figure 20 A* the path was founded go through the path and create a vector 3 points of the path for the AI to be able to reach the target

Figure 21 shows a script that simplifies the path by reducing the points onto the target, which will help smooth the AI movements.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Node : ITreeItem<Node> {

        public bool walkable; // Indicate if this node walkable or not
        public Vector3 worldposstion; // posstion of th node in the game
        public int x; // index of the node in nodes array
        public int y; // index of the node in nodes array
        public int Gcost; // the cost of the path from the start node
        public int Hcost; //  estimates the cost of the cheapest path
        public Node Parent; // parent of this node " the past node "
        int treeIndex;
        public int Fcost { // cost to the target
                get{
                        return Gcost + Hcost;
                }
        }

        public int TreeIndex {
                get{
                        return treeIndex;
                }
                set{

                        treeIndex = value;
                }
        }



        public Node(bool Walkable , Vector3 WorldPosstion,int x, int y){
                this.walkable = Walkable;
                this.worldposstion = WorldPosstion;
                this.x = x;
                this.y = y;
        }



        public int CompareTo(Node nodeToComare){
                int compare = Fcost.CompareTo (nodeToComare.Fcost);
                if (compare == 0)
                        compare = Hcost.CompareTo (nodeToComare.Hcost);


                return -compare;

        }

}
```

Figure 21 Simplifying the path by reducing the points on to the target

4.1.2.3 Characters' movements

AI characters will have a starting point, the position at the start of the experiment, and an endpoint in which each character has a different endpoint. A* Algorithm will be responsible for providing the shortest path from the starting and endpoint for each AI Character. A* will calculate the shortest path then inform the character whenever the path is ready. It will tell the character exactly where to go, avoiding any obstacle in the way. When the characters have a valid path to the destination, the animation of characters will be changed from idle to standing then running, and it will stay running until the characters reach their destination. Figure 22 shows the function used to start pathfinding from AI current position to the target position.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class Grid : MonoBehaviour {

        public LayerMask unwalkable; // indicate the nodes were its forbiden for the AI
        public Vector2 gridWorldSize; // the size of the grid
        public float nodeRadius; // size of the node
        Node[,] grid; // tree "Array" of nodes
        float nodeDiameter;
        int grideSizeX,grideSizeY; // x , y of the grid [,]


        public int MaxSize{
                get{
                        return grideSizeX * grideSizeY;
                }
        }
        // Use this for initialization
        void Awake () {

                nodeDiameter = nodeRadius * 2;
                grideSizeX = Mathf.RoundToInt (gridWorldSize.x / nodeDiameter);
                grideSizeY = Mathf.RoundToInt (gridWorldSize.y / nodeDiameter);
                CreateGrid (); // build the grid
        }

        public Node NodeFromWorldPoint(Vector3 posstion){

                float percentX = (posstion.x + gridWorldSize.x / 2) / gridWorldSize.x;
                float percentY = (posstion.z + gridWorldSize.y / 2) / gridWorldSize.y;
                percentX = Mathf.Clamp01 (percentX);
                percentY = Mathf.Clamp01 (percentY);
                int x = Mathf.RoundToInt ((grideSizeX - 1) * percentX);
                int y = Mathf.RoundToInt ((grideSizeY - 1) * percentY);

                return grid [x, y];

        }
```

Figure 22 Function used to start pathfinding from AI current positon to the target position

After the smoke starts to show after the conflagration Alarm fires, the characters will call the Find Path function, which will call the A* algorithm to find the path. A* algorithm will require each character to provide its current position and a destination where the character is going. When a path is found and ready to be used by the character, the character's animation will be changed to running state by triggering the required flag and then call follow Path function, which will loop throw the list of points that the A* algorithm created. Figure 23 shows the function used to tell the AI Player to start moving after finding the path to the target.

```
/*
this Script will handle many AI asking to Find Path to a Target each Requst will be proccessed in
different thread to keep performance



*/

using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System;
using System.Threading;
public class MangePaths : MonoBehaviour {

        Queue<PathResult> Results = new Queue<PathResult> (); // Keep the Result "Path to Target
in this queue to avoid threads unwanted Behaviour "
        public bool IsEscape = true; // indcate whether AI Will run From the Smoke
        PathFinding pathfinding;

        void Awake () {
                //ins = this;
                Application.targetFrameRate = 60;
                pathfinding = GetComponent<PathFinding> ();
        }


        void Update () {
                // in Update will proccess all Path Requsets if any

                if (Results.Count > 0) {
                        int count = Results.Count;

                        lock (Results) { // protected from other threads

                                for(int i = 0 ; i < count ; i++){
                                        PathResult result = Results.Dequeue ();
                                        result.callback (result.path, result.success);
                                }

                        }


                }


        }
```

Figure 23 Function used to tell the AI Player to start moving after finding the path to a target

Chapter 5

5 Chapter 5. Study 1: Predicting social influence in a fire with the talk-through approach

5.1 Chapter Overview

This chapter presents a study using the talk-through approach for predicting human behaviour in emergencies (Lawson et al., 2013). In particular, this work builds on prior research by investigating the use of the talk-through approach for predicting behaviour under conditions of social influence.

5.2 Introduction

Figure 24 Study1 Mapped to the protective action decision model

As outlined in the literature review of sections 2.102.102.11human behaviour experiments are usually categorized into laboratory and field experiments. However, there are other ways to predict human behaviour during fire evacuation without placing participants in real situations, thus avoiding any danger, as Lawson (2011) reported. One such approach is the talk-through approach, in which participants explain how they would respond to an emergency based on a description of the situation (Lawson et al., 2013). This present study adopts this approach for several reasons. As described by Lawson et al. (2013), the first is that participants' behaviour can be captured without placing them in any real danger. The second reason is that, overall, this approach has proved to be fairly valid in predicting how humans respond (Lawson 2011; 2013). However, one key deficiency with this approach that requires further investigation is that it has, until now, lacked the inclusion of social factors, which are essential factors steering the outcome of an evacuation (Lawson, 2011; Nilsson & Johansson, 2009). Therefore, the focus of this first study was to test the talk-through method's ability to identify valid social behaviour in an emergency situation. The present study adopted the social conditions used in a previous study of social factors during an evacuation, albeit a virtual reality (VR) experiment (Kinateder et al., 2014). In both Kinateder et al. (2014) and the study presented in this chapter, there were three conditions: active conflict, passive, and control conditions. In the active conflict condition, hypothetical other building occupants moved towards the opposite direction from the exit; in the passive condition, hypothetical others remained as they were at the start of the emergency. In the control condition, the participants were alone. Thus, the three conditions present the opportunity to study the influence of divergent social influences on an evacuee.

Canter et al.'s (1978) study of human behaviour in real fires used frequencies and sequences of acts to explore differences in behaviour in different evacuation scenarios. Canter et al. (1978) also used sequential analysis (Bakeman and Gottman, 1986) to study the patterns of behaviour as they evolved over time. Analysis of the sequence of actions taken by each participant was used to generate transition probability diagrams. Decomposition diagrams were then created to represent the sequences of a list of acts defined in rows and columns and the frequency of the acts. This established the transition matrix. This matrix shows the likelihood of each defined act giving rise to another act. This provides information or numerical descriptions of fire for subsequent statistical analysis. Further, the transitional matrix provides analysis on established acts that are more likely to follow or precede each other. This makes it possible to define a sequence or pattern in which particular equivalence groups occur. In this case, the greater the intricacy of a particular behaviour, the greater the number of acts in the subsequent group. This aspect leads to the establishment of decomposition diagrams in which act equivalence classes are defined as circles. From the diagram, dashed circles establish or show acts which subsequently occur with lower frequency. They are thus included to provide the reader with an idea of behavioural relationships.

Furthermore, in the matrix, the relationship between acts or their sequences is indicated through the use of arrows. In the diagram, an act can be repeated. Such a repeated act is usually an act that follows itself. Next to arrows established in the matrix, the numbers between two acts define the strength of the relationship or association between the two defined acts. In this case, the higher the number between the two, the higher or stronger the association or relationship. This shows that there is more likelihood of the occurrence of one-act will be followed by the other. For instance, if every time an individual encounters fire, they leave the said area immediately, there would be a higher number. Thus the matrix is important as it often summarizes complex series of events in a visual way. Thus it's possible to test any likelihood of an act.

A similar approach was adopted in the research presented in this chapter. Several authors (Averill, 2012; Johansson & Petersson, 2013; Zou et al., 2016) have studied evacuation time, given its impact on safety outcomes, and again the hypothetical time to leave was studied in this work. Finally, subjective ratings were used to understand the influence on various cues to evacuation, to understand participant's experiences in the different conditions. Participants were asked to estimate two measures of evacuation time; (I) how long they thought it would take them to leave the #computer room, and (ii) how long they thought it would take them to leave the building.

This study addressed the following research question:

RQ: How do social and environmental cues influence human response to fire scenario?

The hypotheses of this study were:

$H1$: Reported time to leave the room will be different between all conditions (active conflict, passive, and control).

$H2$: Reported time to leave the building will be different between all conditions (active conflict, passive, and control).

$H3$: Subjective rating of influence of the behaviour of other people will be different between all conditions (active conflict, passive, and control).

5.3 Method

5.3.1 Participants

A total of 15 (student and staff) participants (8 male, seven female; mean age = 30.53, SD = 9.03) at the University of Nottingham were allocated a 20 min appointment each. Each participant was asked to sign a consent form that emphasised that they could withdraw from the study at any point if they felt distressed.

5.3.2 Study design

The experiment was conducted in a between-group design as it was considered that, having completed an evacuation in one condition, participants may be “primed” for an evacuation in other conditions, thus influencing the outcomes.

5.3.3 Procedure

The experimenter led the participants to a small private meeting room in the (physical) research lab. The experimenter firstly requested that the participants met the established criteria by having them sign consent. The experimenter then informed the participants to make it known if they feel distressed at any time during the experiment. Participants were shown in figure 25 a plan view of the physical building layout used. They were individually presented with one of three hypothetical conditions related to an emergency situation:

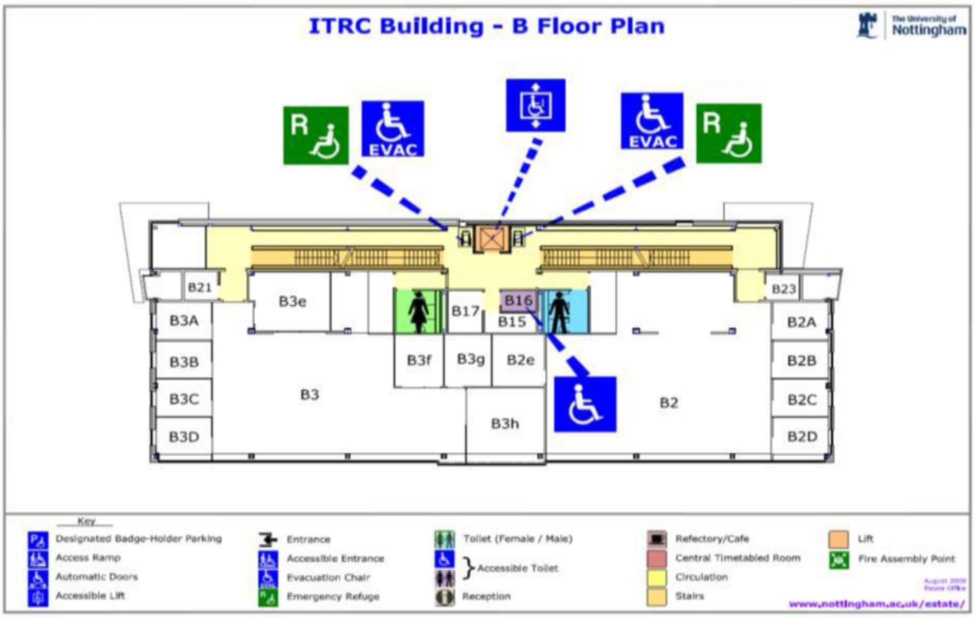

Figure 25 Plan view of the physical building layout used in study 1

1. Control group, in which the participants were told they were alone. This group was included in order to have an understanding of how people would normally react when they imagine that a room begins to fill with smoke if there is no social influence.

2. Active conflict, in which participants were told they saw others moving in the opposite direction of the emergency exit. This condition will provide an important test about how social behaviour affects decisions about fire evacuation, and it pits that the force social element of surrounding individuals reacting to a room-filling with smoke.

3. Passive, in which participants were told the other building occupants remained in place. This condition also provides an important test about how social behaviour affects decisions.

In all conditions, participants were asked what they would do and were questioned about where they would be likely to conduct each of their actions. Additionally, they were asked to report an approximation of the (hypothetical) time they would take to leave the research computer room and the building. After the hypothetical description of their behaviours, they were asked for subjective ratings of the (hypothetical) influence of the behaviour of other people in each of the conditions using a rating scale where 1 = Not at all Influential and 5 = very influential. The participant was asked hypothetically to give as detailed an account as possible of everything that had happened from the time they heard the alarm. The participant transcript was analysed, and the number of occurrences of each action type was noted.

5.4 Results

5.4.1 Perceived evacuation time

In this study, participants were presented with a hypothetical scenario related to an emergency situation. Then, they were asked to estimate two measures of evacuation time:

(i) Time to leave the computer room, measured as the time elapsed from awareness of the fire alarm until they had passed through the exit door of the room.

(ii) Time to leave the building, measured as the time elapsed from awareness of the fire alarm until they had passed through the exit door of the building.

5.4.2 Time to leave the computer room

The hypothetical time to leave the computer room and building are shown in table 1 and figures 26 and 27. The ANOVA test results are shown in tables 2 and 3. The descriptive statistics show the effects of three conditions: active conflict, passive, and control conditions on time to evacuate. For time to leave the computer room, Passive condition took the longest. For time to leave the building, active condition took the longest. Statistical analyses of these results are presented below.

Study condition	**Time (seconds) to leave the computer room**				**Time (seconds) to leave the building**			
	N	Mean	SD	Std. error	N	Mean	SD	Std. error
Control condition	5	13.00	2.79	1.23	5	25.00	6.12	2.74
Active condition	5	8.00	2.79	1.23	5	61.00	17.56	7.81
Passive condition	5	44.00	10.84	4.85	5	54.00	10.25	4.58
Total	15	21.67	17.59	4.54	15	46.67	19.70	5.09

Table 1 Meantime for participants to move their avatar from their desk to safety, recorded at two evacuation points: outside of the main office and outside of the building

5.4.2.1 Time to leave the main office

A one-way between-subjects ANOVA and table 2 identified a significant effect of condition on time to leave the main office [F (2, 12) = 43.06, p<0.001]. Figure 26 shows a graph of the meantime taken for the participants to leave the main office for each of the three study conditions.

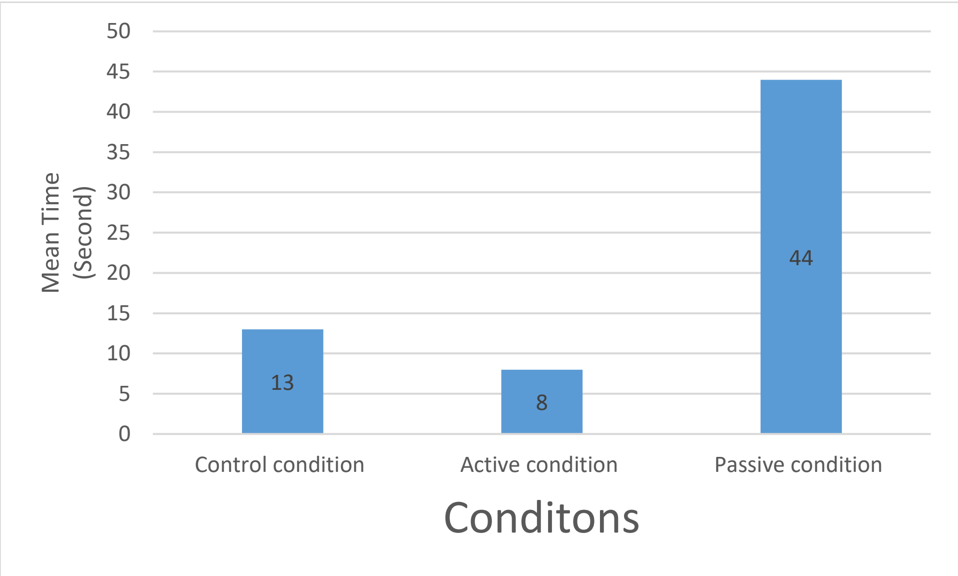

Figure 26 Average time for participants to move out of the main office in each condition

		Sum of Squares	df	Mean Square	F	Sig.
How long do you think it would take to leave the main office	Between Groups	3803.333	2	1901.667	43.057	.000
	Within Groups	530.000	12	44.167		
	Total	4333.333	14			

Table 2 Analysis of variance for time to leave the main office

Post hoc pairwise comparisons using the Bonferroni test identified a significant difference in main office evacuation time between the active conflict condition and the passive condition (mean difference = -36.00 seconds, p<0.001); evacuation time was faster in the active condition (*M* = 8.00 seconds; SD = 2.74

seconds) than the passive condition (*M* = 44.00; SD = 10.84 seconds). There was also a significant difference in mean scores between the control condition and the passive condition (mean difference = -31.00, P<0.001); evacuation time was faster in the control condition (*M* = 13.00 seconds; SD = 2.74 seconds) than the passive condition (*M* = 44.00 seconds; SD = 10.84 seconds). There was no difference in main office evacuation time between the control condition and the active conflict condition (mean difference = 31.00, p=0.77).

5.4.2.2 Time to leave the building

A one-way between-Ss ANOVA and table 3 identified a significant effect of study condition on time to leave the building [F (2,12) = 12.21, p<0.001]. Figure 27 shows a graph of the mean reported time taken for the participants to leave the building after the fire alarm was raised.

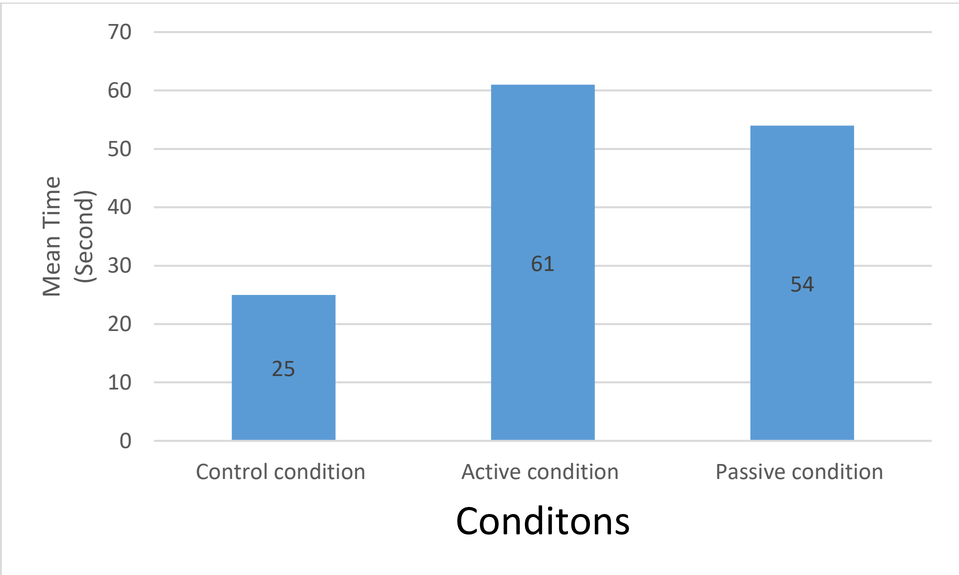

Figure 27 Average time for participants to move out of the building in each condition

		Sum of Squares	df	Mean Square	F	Sig.
How long do you think it would take to leave the building	Between Groups	3643.333	2	1821.667	12.212	.001
	Within Groups	1790.000	12	149.167		
	Total	5433.333	14			

Table 3 Analysis of variance for time to leave the building

Post hoc pairwise comparisons using the Bonferroni test identified significant differences in building evacuation time between all of the study conditions. Building evacuation time was faster in the control condition (*M* = 25.00 seconds; SD = 6.16 seconds) than the active condition (*M* = 61.00; SD = 17.50 seconds); mean difference = 36.00 seconds, $p<.002$. Building evacuation time was also faster in the control condition (*M* = 25.00 seconds; SD = 6.12 seconds) than the passive condition (*M* = 54.00 seconds; SD = 10.25 seconds); mean difference = 29.00, $p<.008$. Building evacuation time was faster in the passive condition (*M* = 54.00 seconds; SD = 10.625 seconds) than the active condition (*M* = 61.00; SD = 17.50 seconds); mean difference = 7.00 seconds, $p<0.008$.

5.4.3 Influence of the behaviour of others

At the end of the experiment, participants in the active conflict and passive behaviour conditions were asked to rate how much they considered that the behaviour of the others influenced their hypothetical response to the fire alarm. Scores were given using a 5-point ordinal rating scale in which a higher score represents a higher perceived level of influence. A Mann-Whitney U test identified a significant difference in rating scores between the two conditions [$U = 0.00$, $p<0.008$], with a higher level of influence reported in the passive condition (Median = 4.6; range = 4-5) than the active condition (Median = 2.6; range = 2-3). Figure 28 shows a bar chart of scores obtained.

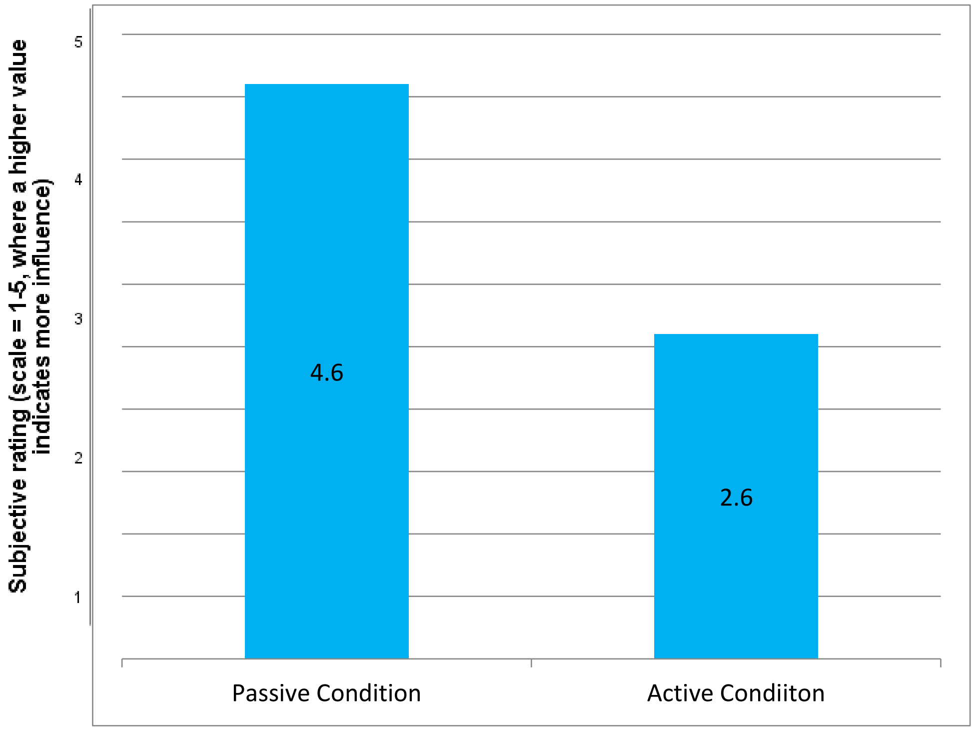

Figure 28 Median scores- a rate of influence

5.4.4 Frequency of acts

The frequencies of the acts reported in this study were coded into action types based on those originally reported by Canter et al. (1978). These are listed in table 5. It was anticipated that a two-way chi-square test would be applied to determine whether the pattern of actions differed between the study conditions. However, as many of the action types recorded a frequency value of less than 5, statistics tests could not be run. Instead, a descriptive analysis of the pattern of reported actions was applied.

During fire scenarios, action responses differ between individuals based on a number of aspects. In this study, participants were presented with a hypothetical fire scenario and asked to describe how they would respond to this situation. The acts mentioned by participants are listed, and a frequency count of references to each act for each study condition is shown in table 4. From the results, patterns can be seen in the responses given in each study condition. During pre-event action, the frequency of response in the three conditions among participants is the same. In this case, the participants are not exposed to the emergency. However, one action people in fire situations often do is to seek information about the incident. In this s study, it is evident that participants in the active conflict condition are more likely to seek information compared to those in the passive conflict condition and control condition in that order. Hence people are more likely to seek critical life-saving information in an active conflict fire situation.

Further, when an alarm is sounded indicating a warning, it was noted that participants in the passive condition are more likely to warn others compared to those in the active condition. This may be attributed to the participant's state of mind at the time of the incident. For example, people in an active fire condition may prioritize their safety first hence the difference.

In the active conflict, condition participants were more likely to feel concerned about others compared to those in the passive and control condition in that order. Further, regarding moving to an area of safety upon recognizing the fire alarm warning, most participants in the active fire situation are likely to move to an area of minimal risk. This information demonstrates how the severity of the condition influences safety decision making and thus the importance of fire disaster preparedness. Another key action that can determine safety is waiting for a person during a fire incident. From the study, a higher likelihood of waiting for a person was reported in the passive condition (frequency = 5), compared to the active condition (frequency = 3) and control condition (frequency = 0). This also indicates the state of mind and safety concern for self during a fire incident. In a passive condition, an individual's personal safety concern is not at peak, and thus they may wait for another person. When it comes to taking action of fighting the fire, people in active fire incidents or conditions are least likely to take fire-fighting action indicating (frequency = 1). There is also high frequency in regards to the action of ensuring accessibility in the three conditions. Phoning for assistance is another reported in both active and control conditions (frequency = 2), with a lower likelihood in the passive condition (frequency = 1). From the study, the differences can be attributed to participants' preparedness and knowledge in regards to fire emergency response, states of mind and safety concerns. These differences indicate that persons in active conditions are more likely to make or prioritize personal safety concerns first and make the appropriate decision regarding their safety.

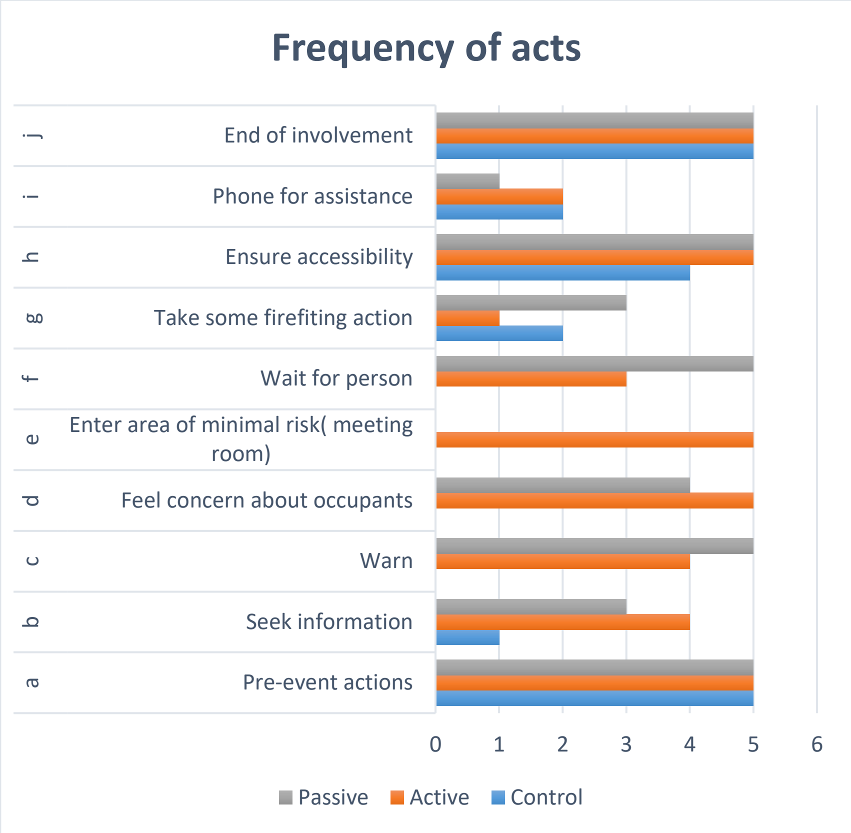

Figure 29Total frequency of acts in control, active, and passive conditions

Code	Actions	Control	Active	Passive
A	Pre-event actions	5	5	5
B	Seek information	1	4	3
C	Warn	0	4	5
D	Feel concern about occupants	0	5	4
E	Enter area of minimal risk(meeting room)	0	5	0
F	Wait for person	0	3	5
G	Take some firefighting action	2	1	3
H	Ensure accessibility	4	5	5
I	Phone for assistance	2	2	1
J	End of involvement	5	5	5

Table 4 Frequency of acts in control, active, and passive conditions

5.4.5 Sequence of acts

Transitional probabilities and sequential analysis, which are used to study behaviour resulting from events, were calculated to investigate the transitions between acts, using the process described in Bakeman and Gottman (1986). Observational analysis of participant behaviour in the talk-through method reported a list and frequency count of actions taken in each study condition. Analysis of the sequence of actions taken by each participant was used to generate transition probability diagrams. Decomposition diagrams were then created to represent the sequence of acts data. This is done by creating a matrix showing the frequency of each act as listed in table 4, followed by those in the rows.

Further, “Transitional probabilities is simply one kind of conditional probability. It is distinguished from other conditional probability in that the target and given events occur at different times. ” (Bakeman and Gottman,1986). Figures 30, 31, and 32 present decomposition diagrams for each study condition, respectively. It can be seen that transitional probabilities are the frequency for a particular cell divided by the frequency for that row. Each letter stands for an event, and arrows stand for transitions between the nodes. The variability of the actions which follow the encountering hypothetically of an emergency was explained by participants in all conditions. It can be seen from figures 30, 31, and 32 that the active conflict condition diagram generates a variability response sequence and more complex shape of behaviour than the control and passive conditions. This variability may be due to the influence of social behaviour. The main differences exist in the behaviour following investigation and are affected by co-workers. While both active conflict and passive conditions tended to be affected by co-workers, the active conflict condition was likely to lead to delayed evacuation. The response of active conflict conditions may be delayed by interaction with co-workers. Participants in both active conflict and passive conditions were likely to investigate the source of the smoke.

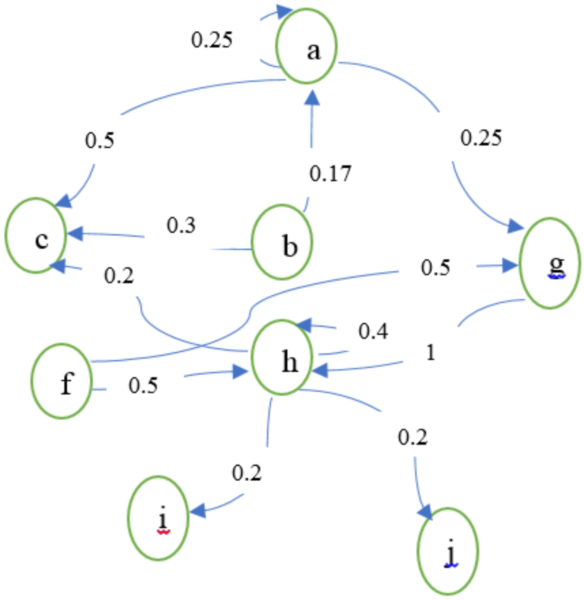

Figure 30 Decomposition diagram: control condition

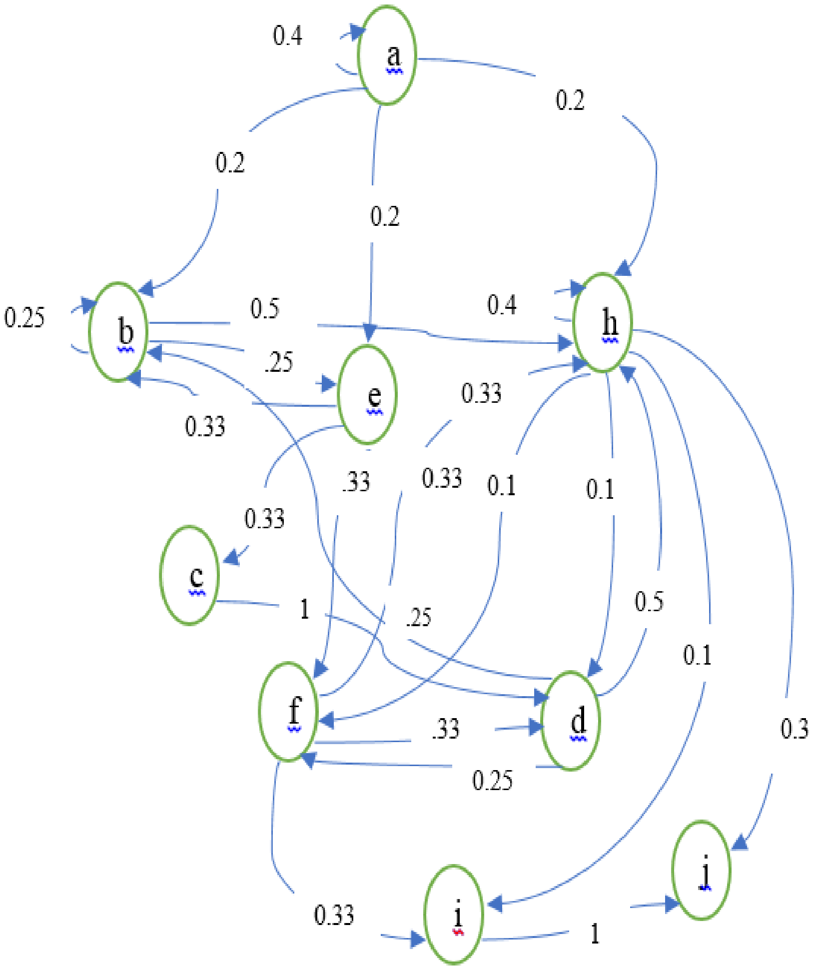

Figure 31 Decomposition diagram: active conflict condition

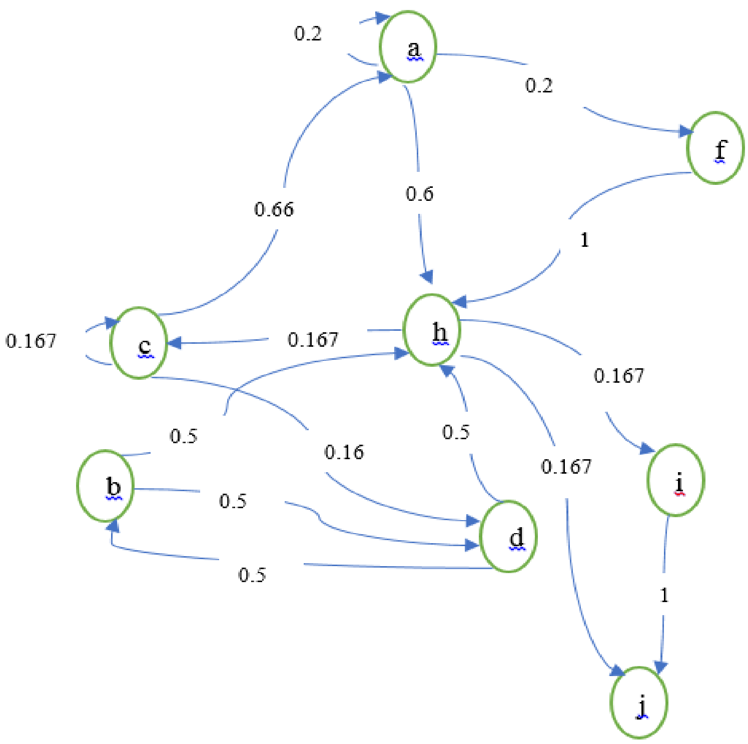

Figure 32 Decomposition diagram: passive condition

5.5 Discussion

This study sought to establish or predict human behaviour in a fire situation and during evacuation. While human behaviour experiments can be conducted in the field or experiments in the lab, such studies involving physical exposure could be dangerous for the participants, especially in real-life fire situations. Thus, the study adopted the talk-through approach to understanding behaviour. The talk through approach involves having people explain their actions and behaviours in a situation where there is fire. Thus it is possible to predict human behaviour during fire evacuation using this approach since the participant's behaviour can be captured without necessarily having to put their lives in danger. Further, the method has previously proved effective, valid and reliable in predicting how individuals or humans respond (Lawson, 2011; Lawson et al., 2013). This approach, however, has been criticized for lack of or failure to include or factor social factors. These factors are very important as they subsequently influence the outcome of an evacuation (Kinateder et al., 2014).

To undertake the study, the participants were placed into three conditions: active conflict, passive and control. The active conflict condition presented a hypothetical situation in which other building participants moved towards the opposite direction of the emergency fire exit. In the passive condition, the other (hypothetical) building occupants remained as they were before the emergency fire situation. In the control condition, the participants were alone, which sought to establish how people would normally react if there were no social influences in a fire situation or smoke as a result of the fire.

From the study, a number of results were observed. For the main office, the passive behaviour of hypothetical other occupants led to the longest evacuation time. This result is consistent with Latane and Darley (1968), who concluded that passive behaviour exhibited by individuals who are around smoke leads to a decreased chance of effective evacuation behaviour. Interestingly, when it came to leaving the building, participants in the active conflict condition reported the longest hypothetical evacuation time. This is likely to reflect the social influences, in that the other building occupants walked towards a meeting room rather than evacuating. Thus, we see a pattern of results whereby passive behaviour of others leads to the longest delays to leave the room, but the movement of others to a room within the building led to the longest delays to evacuate the building. These results are generally in agreement with Kinateder et al. (2014), who confirmed that social influence affects evacuation behaviour.

Further, the study sought to establish how the influence of others during emergency fire situation influence behaviour. In this case, the passive condition has a greater influence on individuals compared to the active condition. Moreover, frequencies of action such as waiting for others and fighting fire were reported and were consistent with actions reported in previous studies (Kuligowski, 2008) Nonetheless; passive condition participants seemed to have higher frequencies in most of these actions. Thus the study provides a better understanding, not human behaviour, given the existing conditions. From the study, it can be established that the talk-through approach is effective for studying the influence of social behaviour in fire. Although the approach holds the benefits of safety for the participants and indications of validity, a need for a realism scenario was identified for future experiments.

5.6 Chapter summary

This study confirmed that the talk-through approach could reveal the influence of social behaviour on evacuees during a (hypothetical) emergency. It also showed that the pattern of results was consistent with those found in previous research.

Chapter 6

6 Chapter 6. Study 2: The Influence of social behaviour during a fire evacuation in a virtual environment

6.1 Chapter Overview

This chapter presents research into the use of virtual environments to predict human behaviour in emergencies during social influence conditions. The study replicated the experimental conditions used in study 1. Still, it replaced the written condition description with a VR simulation model representing an office environment similar to that used in study 1.

6.2 Introduction

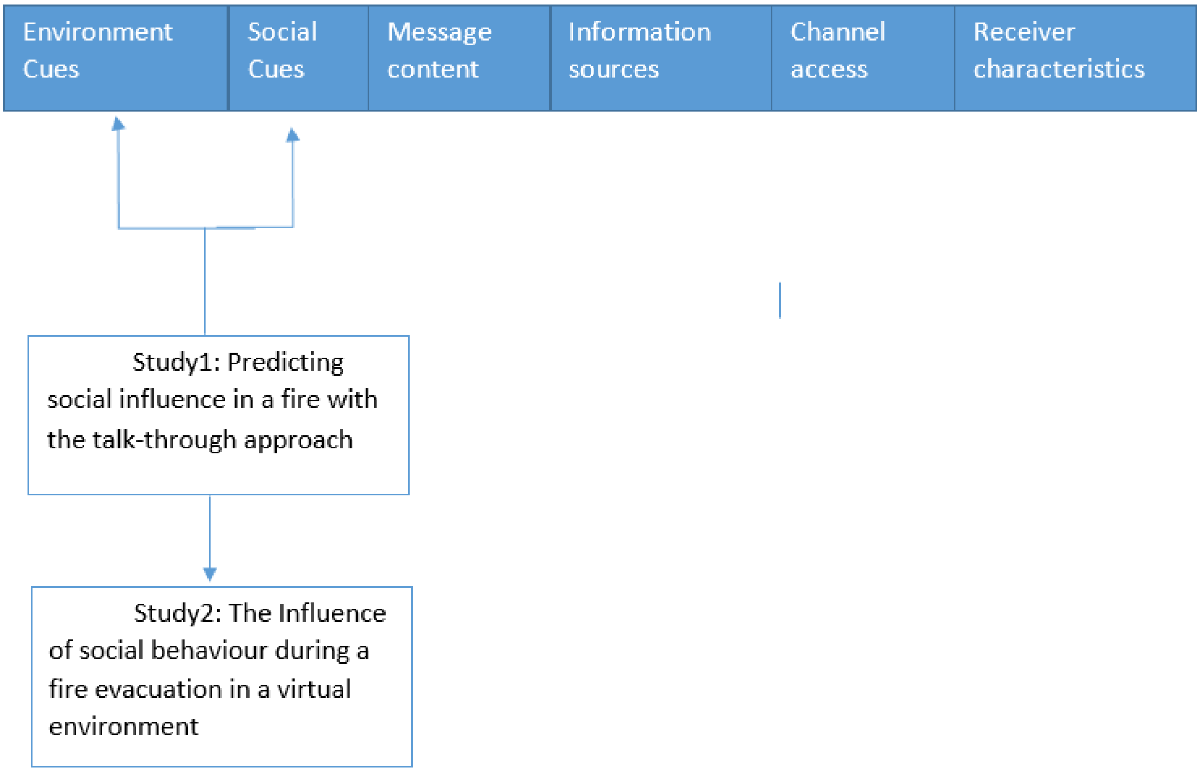

Figure 33 Study 2 Mapped to the protective action decision model

Study 1 demonstrated that the talk-through method is an effective method for generating predictions of user behaviour in fire evacuation conditions and could be used to understand the effect of social influences on user decision making. This factor (social influence) was chosen from the Protective Action Decision Model (PADM) (Figure 33, (Lindell & Perry, 2012)) introduced in2.7 2.7.

However, Virtual reality is consistently gaining popularity as a tool for studying human behaviour during an emergency by simulating emergencies (Nilsson et al., 2005). One significant advantage that comes from employing virtual reality technology for investigating human behaviour in a fire is that experience is highly controllable (Kinateder et al., 2014). This means that nearly all of the variables within the environment are under the control of the experimenter. This is important because, in most real-world experimental scenarios, this is not the case. For example, during a fire evacuation study, it would be difficult to ensure that a participant witnessed the exact same behaviours from the same building occupants at the same time in their evacuation. Another important strength with employing virtual reality in studying human behaviour in fire is the fact that it is replicable. This is important for verifying the validity of any results that may be produced from a given experiment. When an environment is challenging to replicate, it is nearly impossible to test the validity of the results that correspond to the research associated with the environment. Again, this is the case with real-world scenarios. Finally, using virtual reality technology to study human behaviour in fire is also advantageous because it allows the safe study of occupant behaviour (Kinateder et al., 2014).

Kinateder et al. (2014) previously demonstrated that social influence affects evacuation behaviour. This was revealed using a virtual tunnel fire to examine. In this study, 40 participants were tested on how conflicting social information may affect evacuation in four social influence conditions in a simulated fire scenario: (1) control, a condition in which participants were alone, (2) no conflict condition, in which the virtual agent moved towards the exit, (3) the active conflict condition in which the virtual agent moved in the `opposite direction' of the exit, and (4) the passive conflict condition, in which the virtual agent showed no response to the fire scenario. The results found that participants were less likely to move to the emergency exit in the conflict conditions compared to the no-conflict condition. Compared to all other conditions, participants in the passive conflict condition moved the longest distances and displayed significant delays in pre-movement and movement times.

As technology advances, virtual reality in general advances and correspondingly, the use of virtual reality in studying human behaviour in fire advances. More recently, virtual reality can be better fashioned and purposed to study human behaviour in fire. For example, virtual reality has proven to be very useful in helping to determine how people already in a building behave in a fire (Gamberini et al., 2003; Kobes, 2010; Xu et al., 2014; Kinatederet al., 2014).

The study presented in this chapter was conducted to see if the patterns of the results seen in the talk-through study (Chapter 5) could be replicated in a virtual environment (VE), and therefore reveal the ability of VEs to identify patterns of socially influenced behaviour. The study replicated the experimental conditions used in study 1 but replaced the written scenario descriptions with a VR simulation model representing an office environment similar to that used in study 1. The research again investigated the active conflict condition, in which the others move towards the opposite direction from the exit (meeting room); the passive condition, in which the others remained; and the control condition, in which participants were alone in the virtual environment. In addition, the study focused on sequences of acts, frequency of acts, time to delay and, based on virtual situations, measured the effect of social influences on behaviour in the event of a fire.

This study addressed the following research question:

RQ: How do social and environmental cues influence human response to fire scenario?

Analysis focused on the following performance measures and observations:

- Does the behavioural response of others in the virtual environment affect participant evacuation time (measured as the time taken to leave the room and time to leave the building)?
- Do participants consider that the behavioural response of others in the virtual environment influences their own response to a fire alarm?
- What actions do participants make in response to a fire alarm?
- Are these actions influenced by the behavioural response of others in the virtual environment

6.3 Method

6.3.1 Participants

Forty-five participants (29 male, 16 female; mean age = 30.53, SD = 9.03) were recruited from staff, and research students at the University of Nottingham were allocated a 30 min appointment each. Each participant was asked to sign a consent form that emphasised that they could withdraw from the study at any point if they felt distressed.

6.3.2 Study design

This research aimed to investigate the influence of the behaviour of others (represented by virtual agents in a virtual environment simulation) on participant response to a fire evacuation scenario. The experimental study applied a between-group research design, with 15 participants randomly assigned to each experimental condition. There was one independent variable (response mode of others), with three levels; **active conflict condition**, in which the virtual agents moved towards the opposite direction from the exit of the meeting room in response to the fire alarm, **passive condition**, in which the virtual agents remained seated at their desks and displayed no reaction to the fire alarm, and a **Control condition**, in which no virtual agents were present and the participant was alone in the Virtual Environment. The dependent variables were:

- Time to leave the main office, measured as the time elapsed from immediately after the fire alarm/ information they have had been given until the participant had moved their avatar to the door of the main office.
- Time to leave the building, measured as the time elapsed from immediately after the fire alarm/ information had been given until the participant had moved their avatar to the outside of the building using either the main exit or one of the emergency exits.
- Subjective rating of the influence of virtual agent behaviour on participant decides to leave the room, measured using a 5 point scale, where five = high-level influence indicates more significant influence where 5 indicates greater influence.

The experimental hypotheses tested were:

$H1$: Time to leave the main office is different between all conditions (control condition, active conflict condition, and passive condition).

$H2$: Time to leave the building is different between all conditions (control condition, active conflict condition, and passive condition).

$H3$: Subjective rating of the influence of the behaviour of other people is different between all conditions (active conflict condition and passive condition).

6.3.3 Materials

6.3.3.1 VR system

The VR system used the VR system & the HTC Vive (Figure 34). For this study, the researcher built an office environment in Unity. For source code, refer to appendix B. This study used the office environment built by the researcher.

Figure 34 The Vive head-mounted

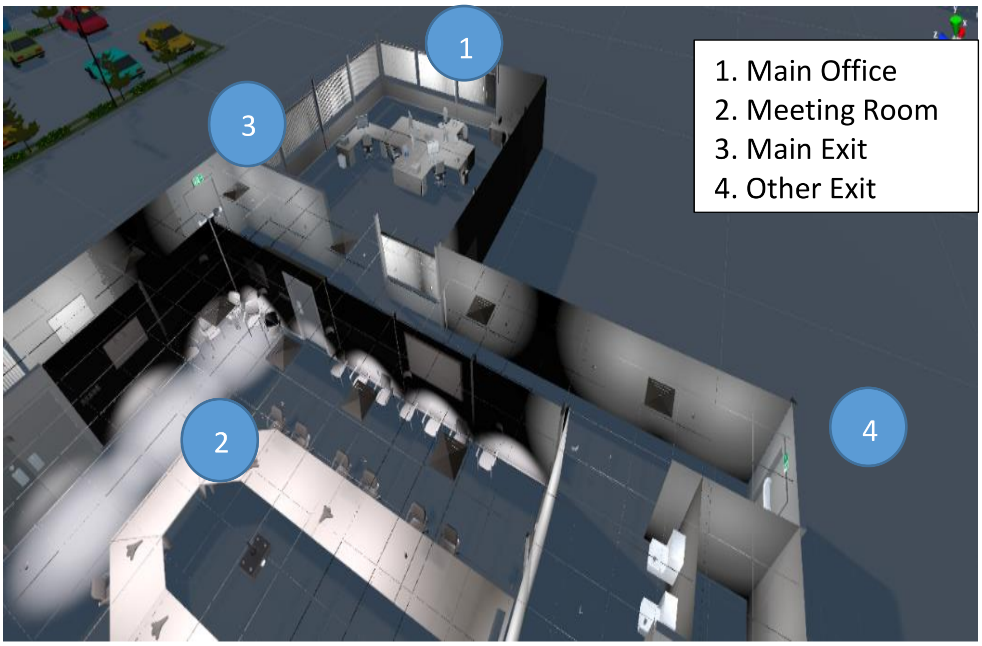

Figure 35 The fire evacuation office. The numbers indicate key areas relevant to the study Participants would start in (1). In the active conflict condition, co-inhabitants would move to (2). There is a choice of exit routes (3) & (4)

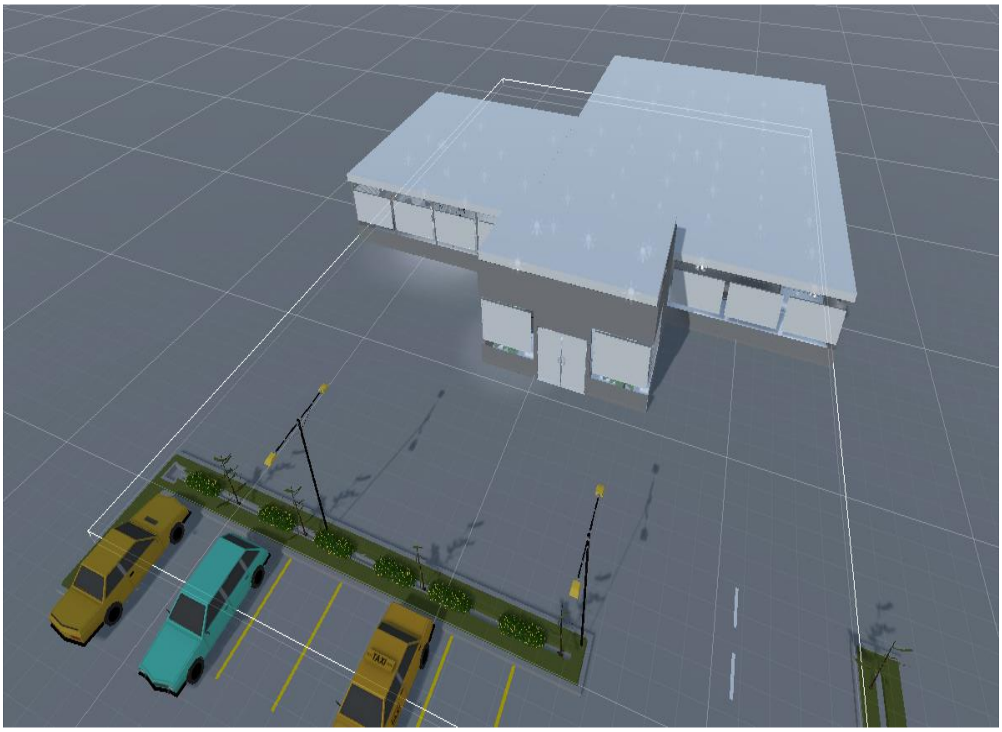

Figure 36 Screenshots of the office building

6.3.3.2 Pre-test

The experimenter led the participants to a private meeting room in the Human Factors Group room (B3e); then, participants received information about the study, then were asked to read the information sheet & fill the consent form and the pre-test questionnaires. See Appendix B.

6.3.4 Procedure

The experimenter led the participants to a private meeting room in the real world (the same as that used in Study 1). The experimenter firstly confirmed that the participants met the established criteria by having them sign consent. The experimenter then explained the risk of simulator sickness and had participants complete the short simulator checklist such that participants were aware of any potential symptoms. Finally, the researcher explained which procedures would be followed if simulator sickness arose during the study.

The experimenter allowed the participants to use the simulator before starting the evacuation, and they were able to navigate in any direction for around 5 minutes. They were then instructed to wait in the office (in the VR simulation in the main office), as shown in figure 37. After 2 minutes, an alarm sounded begun to fill the office. If present, the other virtual agents acted as follows: In the active conflict condition, the agents moved toward the meeting room (no. 2 in Figure 38). In the passive condition, the agents ignored the smoke detector. In the control condition, the workplace was empty, and no agents were present. If the participant moved to the exit door of the building (Parking area), the trial was ended. After performing the task, questionnaires in appendix B .were given to the participant to complete.

Figure 37 Screenshots of the experimental conditions. In the Passive condition VAs (virtual agents) ignore the smoke detector

Figure 38 Screenshots of the experimental conditions. In the Active conflict condition, Vas (virtual agents) is moving to the meeting room

Figure 39 Screenshots of the control condition, in which participants are alone in the virtual environments

6.4 Results

6.4.1 Time to evacuate

Descriptive statistics of the time taken for participants to evacuate their avatar from the main office and from the building in each study condition are shown in table 5. The mean scores indicate a different pattern of results in each condition, with the fastest evacuation times in the control condition but different outcomes for the experimental conditions for each time measure. Statistical analyses of these results are presented below.

Study condition	Time (seconds) to leave the main office				Time (seconds) to leave the building			
	N	Mean	SD	Std. error	N	Mean	SD	Std. error
Control condition	15	18.93	2.43	.62	15	33.33	5.18	1.33
Active condition	15	13.8	2.83	.73	15	85.73	21.3	5.5
Passive condition	15	45.87	10.21	2.6	15	64.4	10.65	2.74
Total	45	26.2	15.48	2.3	45	61.15	25.73	3.83

Table 5 Mean time for participants to move their avatar from their desk to safety, recorded at two evacuation points: outside of the computer room and outside of the building

6.4.1.1 Time to leave the main office

A one-way between-Ss ANOVA identified in table 6 shows a significant effect of study condition on time to leave the main office [F (2,42) = 112.93, p<0.001]. Figure 40 shows a graph of the meantime taken for the participants to move their avatar out of the main office after the fire alarm was raised.

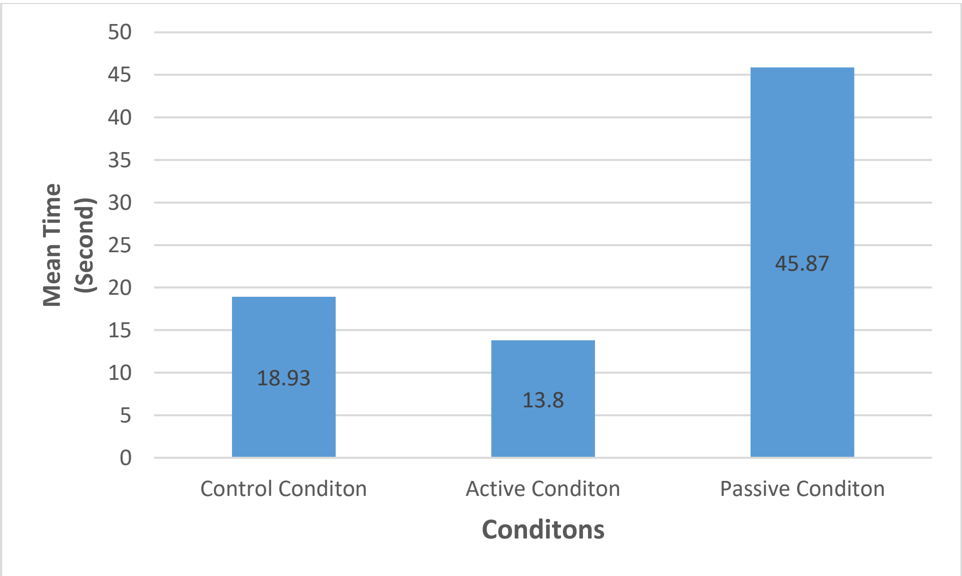

Figure 40 Average time for participants to move their avatar out of the main office in each condition

		Sum of Squares	df	Mean Square	F	Sig.
How long do you it would take your avatar to leave the main office	Between Groups	8900.133	2	4450.067	112.928	.000
	Within Groups	1655.067	42	39.406		
	Total	10555.200	44			

Table 6 Analysis of variance for time to leave the main office

Post hoc pairwise comparisons using the Bonferroni test identified a significant difference in main office evacuation time between the active conflict condition and the passive condition (mean difference = 32.07 seconds, $p<0.001$); evacuation time was faster in the active condition (*M* = 13.8; SD = 2.83 seconds) than the passive condition (*M* = 45.87; SD = 10.21 seconds). There was also a significant difference in mean scores between the control condition and the passive condition (mean difference = -26.93, $P<0.001$); evacuation time was faster in the control condition (*M* = 18.93; SD = 2.43 seconds) than the passive condition (*M* = 45.87; SD = 10.21 seconds). There was no difference in main office evacuation time between the control condition and the active conflict condition (mean difference = 5.13, $p=0.91$).

6.4.1.2 Time to leave the building

A one-way between-Ss ANOVA identified in table 7 shows a significant effect of study condition on time to leave the building [$F(2, 42) = 52.6$, $p<0.001$]. Figure 41 shows a graph of the meantime taken for the participants to move their avatar out of the building after the fire alarm was raised.

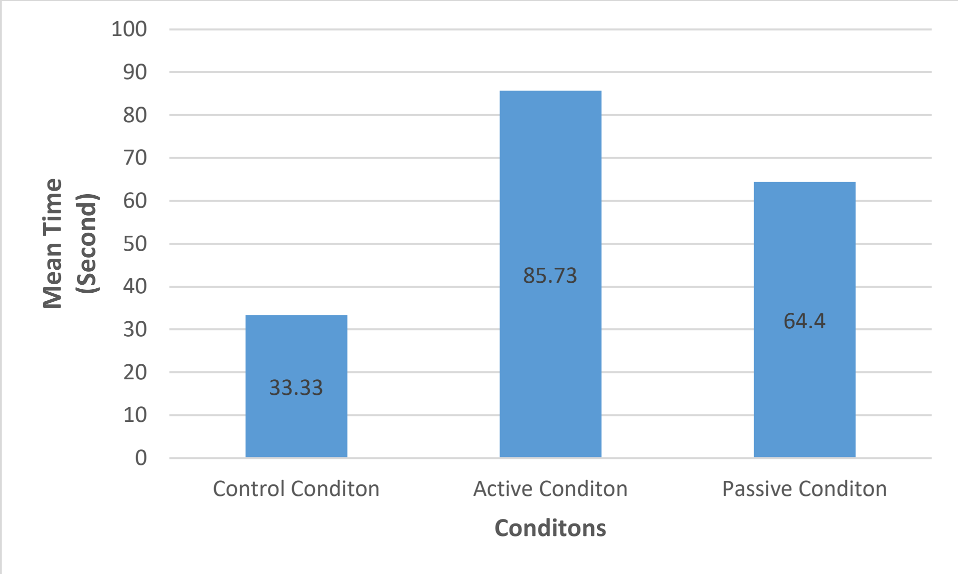

Figure 41 Average time for participants to move their avatar out of the building in each condition.

		Sum of Squares	df	Mean Square	F	Sig.
How long do you think it would take to leave the building	Between Groups	20830.044	2	10415.022	52.602	.000
	Within Groups	8315.867	42	197.997		
	Total	29145.911	44			

Table 7 Analysis of variance for time to leave the building

Post hoc pairwise comparisons using the Bonferroni test identified significant differences in building evacuation time between all of the study conditions. Building evacuation time was faster in the control condition (*M* = 33.33; SD = 5.18) than the active condition (*M* = 85.73; SD = 21.3 seconds); mean difference = 52.4, p<.001. Building evacuation time was also faster in the control condition (*M* = 33.33; SD = 5.18) than the passive condition (*M* = 64.4; SD = 10.65 seconds); mean difference = 31.07, p<.001. Building evacuation time was faster in the passive condition (*M* = 64.4; SD = 10.65 seconds) than the active condition (*M* = 85.73; SD = 21.3 seconds); mean difference = 21.33, p<0.001.

6.4.2 Influential of the behaviour of other

At the end of the experiment, participants in the active conflict and passive behaviour conditions were asked to rate how much they considered that their response to the fire alarm was influenced by the behaviour of the other avatars in the virtual environment. Scores were given using a 5-point ordinal rating scale in which a higher score represents a higher perceived level of influence. A Mann-Whitney U test identified a significant difference in rating scores between the two conditions [U = 13.5, $p<0.001$], with a higher level of influence reported in the passive condition (Median = 4; range = 3-5) than the active condition (Median = 3; range = 2-4). Figure 42 shows a boxplot of scores obtained.

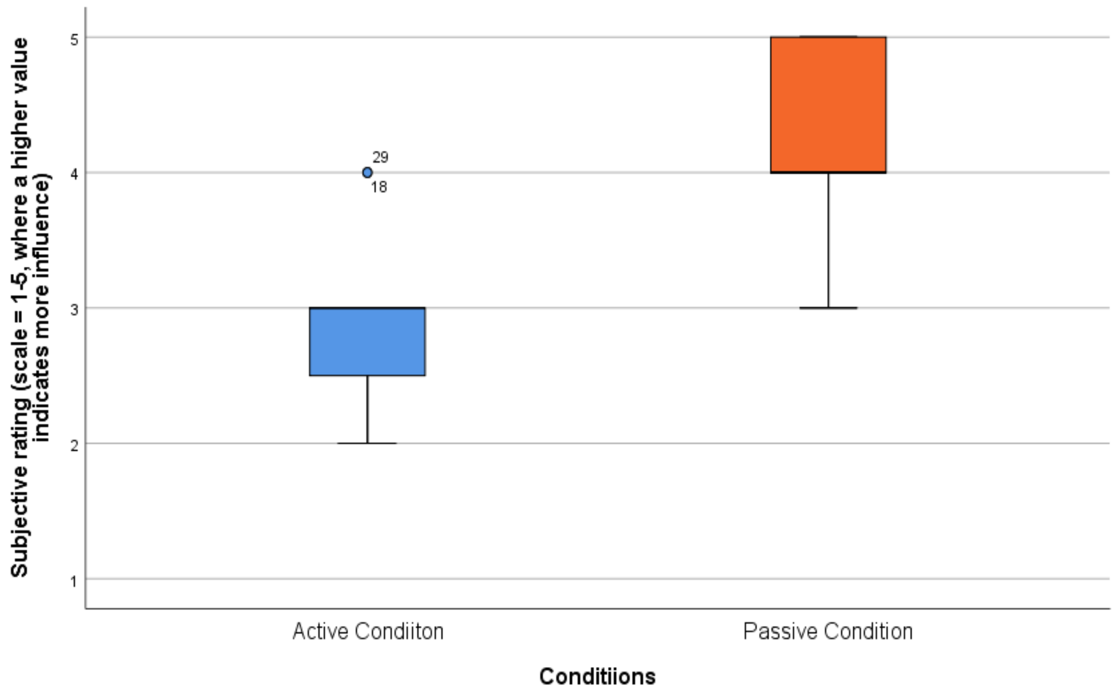

Figure 42 Boxplot of participant ratings of the influence of other avatar behaviour on their response to the fire alarm

6.4.3 Frequency of acts

As per the process described in section 5.4.4, the frequencies of the acts reported in this study were the number of action types identified, based on the taxonomy presented by Canter et al., 1978. These are listed in table 8 and show the frequency of acts observed by participants in each study condition. It can be seen that in the study, many participants in the passive condition were more likely to wait for a person (frequency = 14) than the active condition (frequency = 5) or control condition (frequency = 0). In the passive condition, an individual's personal safety concern is not at peak, and thus they may wait for another person. There is also high frequency in regards to the action of ensuring accessibility in the three conditions. From the study, the differences can be attributed to participants' preparedness and knowledge in regards to fire emergency response, states of mind and safety concerns. These differences indicate that participants in the active and passive conditions were more likely to make or prioritize personal safety concerns first and make the right decision regarding their safety.

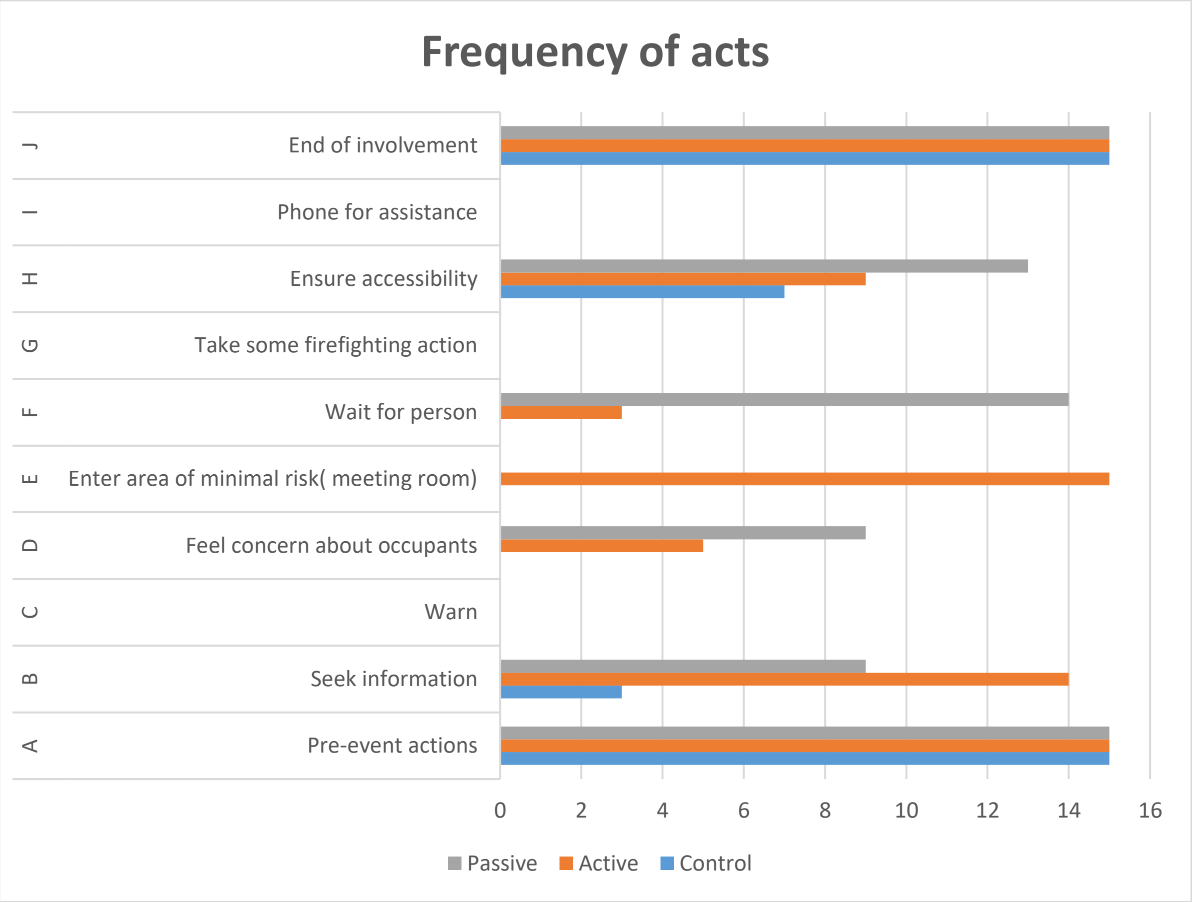

Figure 43 Total scores for actions in all conditions

Code	Actions	Control	Active	Passive
A	Pre-event actions	15	15	15
B	Seek information	3	14	9
C	Warn	0	0	0
D	Feel concern about occupants	0	5	9
E	Enter area of minimal risk(meeting room)	0	15	0
F	Wait for person	0	3	14
G	Take some firefighting action	0	0	0
H	Ensure accessibility	7	9	13
I	Phone for assistance	0	0	0
J	End of involvement	15	15	15

Table *8* Frequency of acts in control, active, and passive conditions

6.4.4 Sequence of acts

As per the process described in section 5.4.5, a matrix was entered with the frequency of each act shown in table 8, followed by those in the rows. Figures 44, 45, and 46 present decomposition diagrams for each of the study conditions in which transitional probabilities is the frequency for a particular cell divided by the frequency for that row. Each letter stands for an event, and arrows stand for transitions between the nodes. The variability of the actions which follow the encountering hypothetically of an emergency was explained by participants in all conditions. It can be seen from Figures 44, 45, and 46 that the active conflict condition diagram of the variability response sequence displays a more complex shape of behaviour than the control and passive conditions. This variability was likely due to the influence of social behaviour.

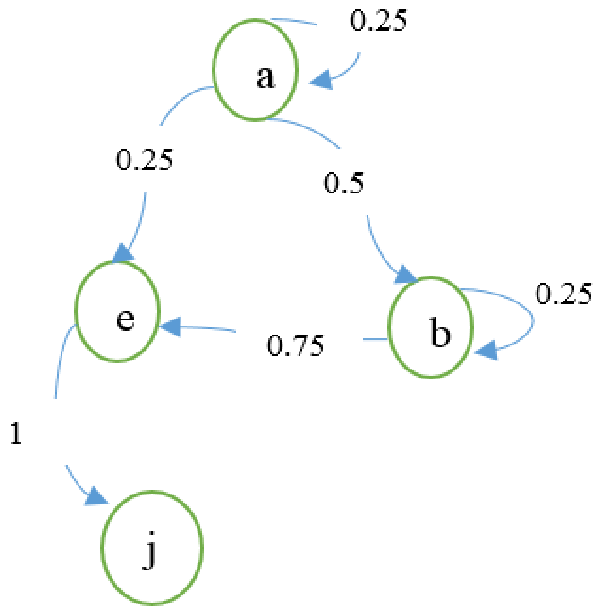

Figure 44 Decomposition diagram: control condition

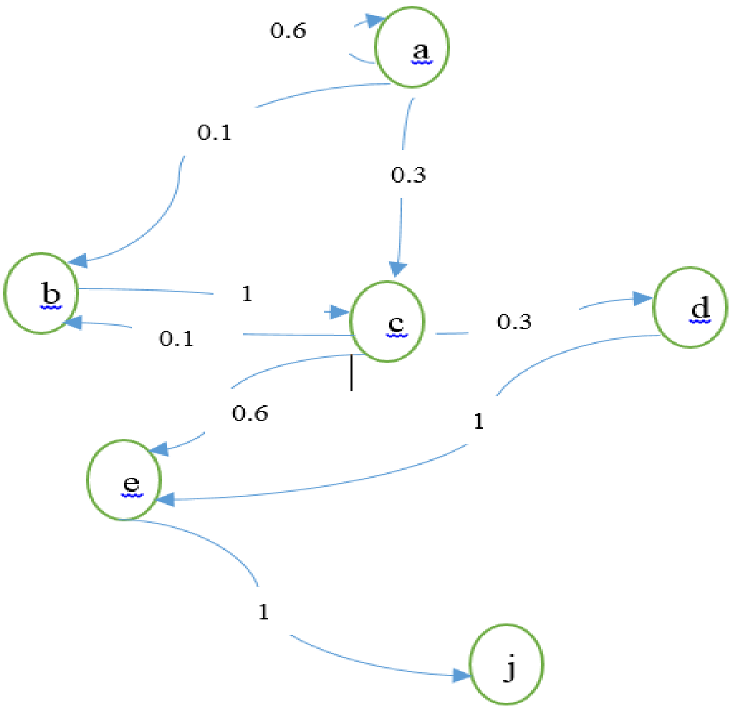

Figure 45 Decomposition diagram: active conflict condition

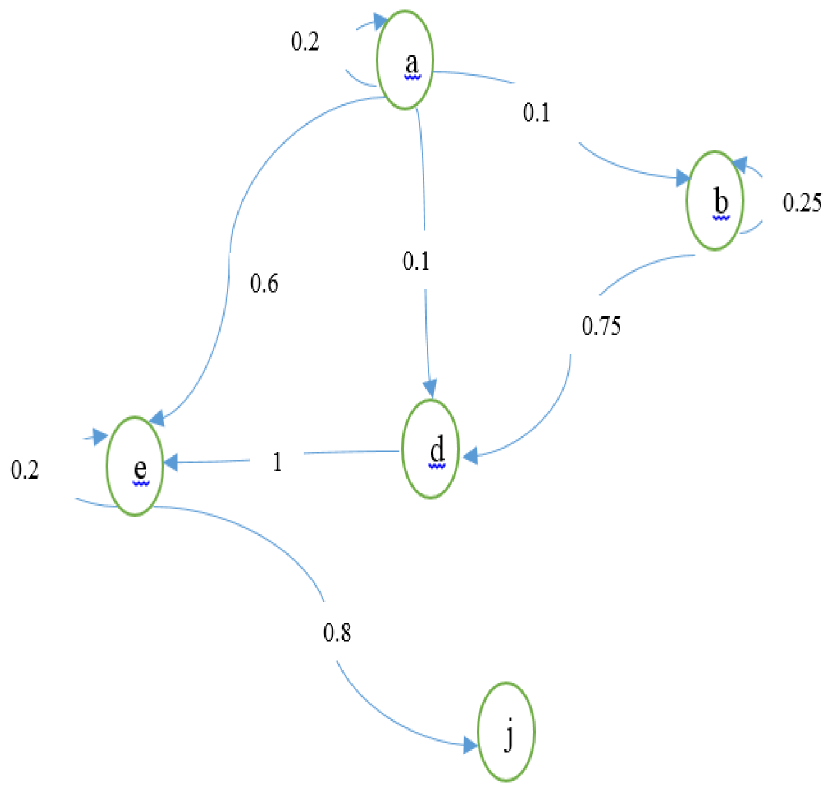

Figure 46 Decomposition diagram: passive condition

6.5 Discussion

The study of fire evacuation and, consequently, the influence of social behaviour has been advanced over the years through the use of simulation and virtual reality. This model has in recent years proved effective compared to other approaches as it adopts the use of technology informs of virtual reality to predict human behaviour during an emergency fire evacuation. This model use of virtual reality has already been employed to predict and understand how people in a building will behave in the event of a fire.

Thus, the model was used to show whether the result of human behaviour in emergency tire situations and influence of social factors defined through the talk-through consisted of such an environment was simulated through virtual reality. Thus, this study replicated the same condition adopted in the previous study, which used the talk-through approach. However, the passive, control and active condition defined in the first study were replaced with simulations of the office environment and office space similar to the one adopted in the previous study. The simulation or virtual reality model focused on the frequency of acts, sequence of acts and time to delay based on virtual situations. It also measured the effect of social influences on behaviour in the subsequent event of a fire.

From the study, it was interesting to establish that similar results were obtained in the VR study as those obtained in the previous study using the talk-through approach. For instance, the study showed that active condition was highest when it came to leaving the building, with passive condition brought the highest when it came to leaving the main office. Further, as expected and as hypothesized, different building evacuation times were observed between the study conditions. Additionally, the study established that participants in the passive condition took more time to leave the building compared to participants or individuals in the active or control conditions. This is consistent with Latane and Darley (1968), who found that passive behaviour exhibited by individuals who are around smoke leads to a decreased chance of effective evacuation behaviour.

Further, in regards to the influence of the behaviour of others, the study showed that both active and passive conditions had an influence on the behaviour of participants to evacuate. This finding is similar to previous research; for example, Kinateder et al. (2014) confirmed that social influence affects evacuation behaviour. Thus, from the study and by comparing the findings of the Chapter 5 study adopting the use of the talk-through approach, it can be established that both have similar results. This indicates that both methods (talk-through and VR simulation) are appropriate for research into human behaviour in a hypothetical/simulated fires situation.

Despite the comparability of results for evacuation times, the frequency of acts did not demonstrate a major difference between all conditions in the virtual environment. Therefore, in this example, table 8 highlighted that behaviour in virtual environments was more variable than using the talk-through method and has the capacity to increase evacuation times in emergency situations.

Measure	Talk-through (Chapter 5)	VE (Chapter 6)
Time to leave the main office	Fastest: Active conflict condition Middle: Control condition Slowest: Passive condition	Fastest: Active conflict condition Middle: Control condition Slowest: Passive condition
Time to leave the building	Fastest: Control condition Middle: Passive condition Slowest: Active conflict condition	Fastest: Control condition Middle: Passive condition Slowest: Active conflict condition
Frequency of acts	It seems that differences indicate that persons in active condition are more likely to make or prioritize personal safety concerns first and to make the right decision in regards to their safety	It seems that differences indicate that persons in active and passive conditions are more likely to make or prioritize personal safety concerns first and to make the right decision in regards to their safety
Sequence of acts	Most complex: Active conflict condition Least complex: Control condition	Most complex: Active conflict condition Least complex: Control condition

Table 9 Comparison of talk through results and VE results

6.6 Chapter summary

In this study, a virtual reality simulator was used to recreate the three conditions (passive, active conflict and control) used in Study 1. Like study 1, dependent variables included: sequence of acts, frequency of acts, time (to leave the main office /building), and influence of social behaviour were measured. In both active and passive situations, the behaviour of others seemed to influence the behaviour of the participants. The results show that passive behaviour of others leads to a slower evacuation process, thus both confirming the results of Study 1 and confirming findings from prior literature that social behaviour does affect the evacuation process. The social influence on the passive condition is more pronounced than in the active situation. Virtual environments created a higher variance compared to talk through experiments, which indicated that they increased evacuation times in such conflict situations.

Overall this study demonstrated that virtual environments are a useful method for studying the influence of social behaviour on evacuees. It has also begun to develop a more nuanced understanding of the actual behavioural response to different social influences. However, social influence is just one of the cues in the Lindell and Perry (2012) PADM model; the following chapters seek to augment Study 2 through the study of other cues to an emergency.

Chapter 7

7 Chapter 7. Study3: Investigation of the relative influence of information sources/ message content and receiver characteristics on behaviour during a fire emergency in a virtual environment

7.1 Chapter Overview

This chapter presents research into the use of virtual environments for predicting human behaviour in emergencies. This third study extends by investigating the relative influence of information sources, message content and receiver characteristics on behaviour during a fire emergency.

7.2 Introduction

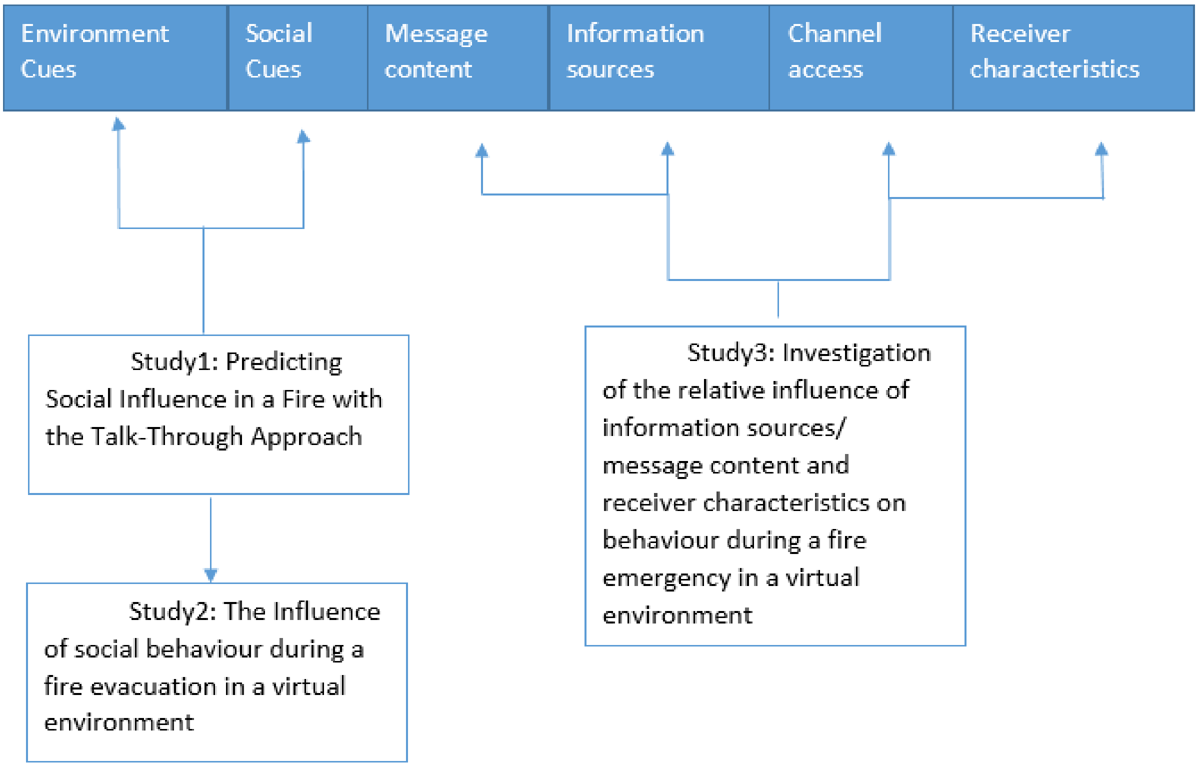

Figure 47 Mapped to the protective action decision model

The third research extends the study by investigating the relative influence of information sources, message content and receiver characteristics on behaviour during a fire emergency in a Virtual Environment. While the first two studies reported in chapters 5 & 6 considered the effect of social influence on human behaviour, study 3 aimed to explore other cues taken from the PADM model. The previous literature on human behaviour in fire (Proulx, 2001; Kuligowski, 2008) indicates the potentially vital role of information source, level of warning, and receiver characteristics in emergency situations that entail evacuation. The successful transition of a message is influenced by: the information (i.e. the content of the message), the channel by which it's conveyed, and people's perception and assessment of risks (Yang et al., 2013). If participants receive information in time and the information is detailed and precise, they factor that information into subsequent decisions on the protective action to be taken. More effective transition of information positively affects the decision making of building occupants in an evacuation. Channels in emergency response include, for example, sirens and face-to-face communication (Sorensen, 2000). It is important to note, though, that a good channel should ensure that the information or message is not distorted, is accurate, and is concise enough to ensure reliability and easy access, as a reliable information channel impacts the receivers' ability and willingness to understand and assess the risk and respond positively. Thus, a few minutes with a friend can positively affect a household's evacuation decision faster than hours of watching the same information on television or listening to a radio broadcast (Lindell & Prater, 2005). In other words, the vulnerability or potential impact precipitated by an emergency can be reduced significantly, or their impact can be mitigated through effective warnings (Clerveaux et al., 2008). However, while the previous literature has shown the importance and influence of message content and channel on emergency behaviour, the relative strength of these influences has not been investigated. This is important, as understanding the contribution of these cues to an emergency could inform the focus and allocation of effort in developing safe emergency preparedness equipment and processes.

Therefore, the aim of study 3 was to investigate the relative influence of information source, message content and receiver characteristics on participant response to a fire alarm in a virtual reality simulation. Thus, this study builds on the study of the influence of social cues explored in studies 1 & 2 to study the influence of the remaining factors listed in stage 1 of the Protective Action Decision Model (PADM), as shown in Figure 47.

This study addressed the following research question:

RQ: How do warning message, information source (and channel of delivery) and receiver characteristics influence human response to fire scenario?

The hypotheses examined in this study were:

H1: There was a difference in evacuation times as a consequence of different information sources.

H2: There was a difference in evacuation times as a consequence of receiver characteristics (gender).

H3: There was a difference in evacuation times as a consequence of the level of detail in the warning message.

H4: There was a difference in influence ratings as a consequence of different information sources.

H5: There was a difference in influence ratings as a consequence of receiver characteristics (gender).

H6: There was a difference in influence ratings as a consequence of the level of detail in the warning message.

7.3 Method

The study made use of the same virtual environment that had been used in study 2 with added (very detailed message/message without detail) as a level of warning. An authority figure, stranger, and siren as an information Sources Manipulation of the variables of interest was achieved using different clothing on virtual avatars and different levels of detail in the auditory warning messages presented. Thus in the VR scenario, the fire alarm warning was delivered by one of the following representing the **study condition**:

- A virtual agent in formal clothing (to imply an authority figure) who shouted the alarm warning using one of two levels of warning: very detailed message/message without detail. This was the **authority figure condition**.

- A virtual agent in informal clothing (to represent a “stranger”) who again shouted the alarm using one of two levels of warning: very detailed message/message without detail. This was the **stranger condition**.
- No visual cue; the fire alarm was given by an audible siren which presented one of two levels of warning: very detailed message/message without detail. This was the **siren condition**.

7.3.1 Participants

A total of 60 participants (30 male, 30 female; mean age = 27.24, SD = 7.12) were recruited among students and staff at the University of Nottingham to take part in a 45 minutes simulator experiment using poster requests for participation.

7.3.2 Study aim

To investigate the relative influence of information source, message content and receiver characteristics on behaviour during emergencies (fire) in a Virtual Environment.

7.3.3 Study design

Three independent variables were examined in the study:

- IV1: information source(channel) had three levels: authority figure (visual and auditory); stranger (visual and auditory); siren (auditory-only)
- IV2: level of detail of warning message had two levels: detailed and not detailed
- IV3: receiver characteristics (participant gender) had two levels: male and female

A between-subjects experimental design was applied for the variables of information source and receiver characteristics, and a within-subjects design was applied for the variable level of detail. Thus, a 3x2x2 mixed ANOVA was applied for analysis of the study results. As in the previous study, the dependent variables were:

- Time to leave the building, measured as the time elapsed from immediately after the fire alarm/ information had been given until the participant had moved their avatar to the outside of the building using either the main exit or one of the emergency exits.
- Subjective rating of the influence of virtual agent behaviour on participant decides to leave the room, measured using a 5 point scale, where five = high-level influence indicates greater influence where 5 indicates greater influence.
- Subjective rating of the influence of level of detail in the warning message on participant decides to leave the room, measured using a 5 point scale, where 5 = high-level influence indicates greater influence where 5 indicates greater influence.

7.3.4 Materials

7.3.4.1 Pre-test

The experimenter led the participants to a private meeting room in the Human Factors Group room (B3e) then participants received information about the study, then were asked to read the information sheet & fill the consent form and the pre-test questionnaires to gather demographics and pre-screen for simulator sickness (Appendix D).

7.3.4.2 VR system

The VR system used the VR system & the HTC Vive. The same VR system, including the HTC Vive, as used in Study 2 (Figure 13) was used again for Study 3.

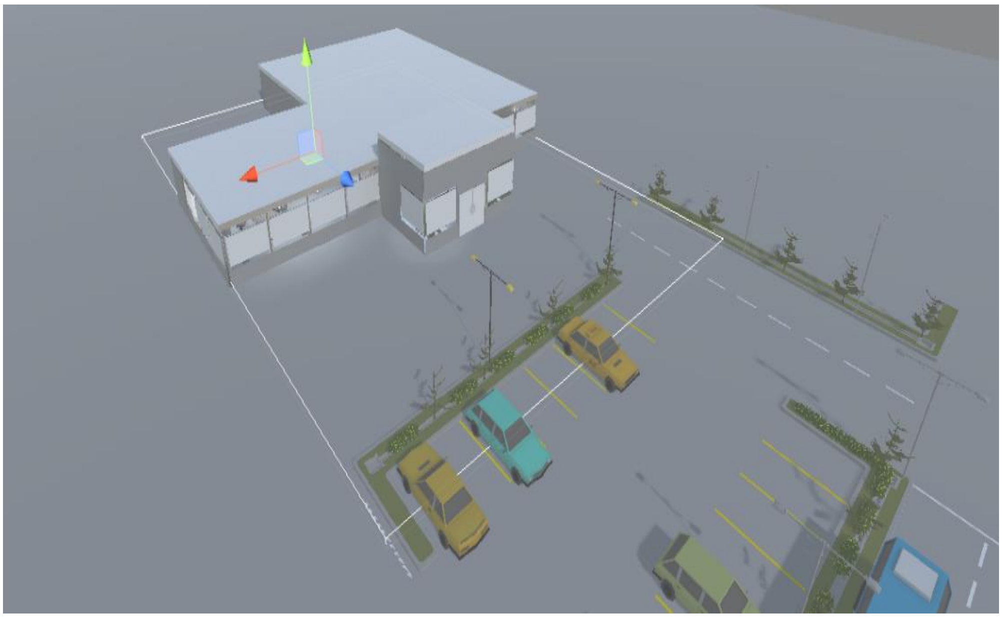

Figure 48 The Screenshots of the office building

7.3.4.3 Virtual environments

The VE was in a building office. The participants were individually presented in an emergency scenario for studying human behaviour. The VE consisted of three conditions, as shown in the figures below. In all conditions, participants were alone in the virtual environment before the emergency warning was received. They were told to play the game solitaire on a PC in the virtual world.

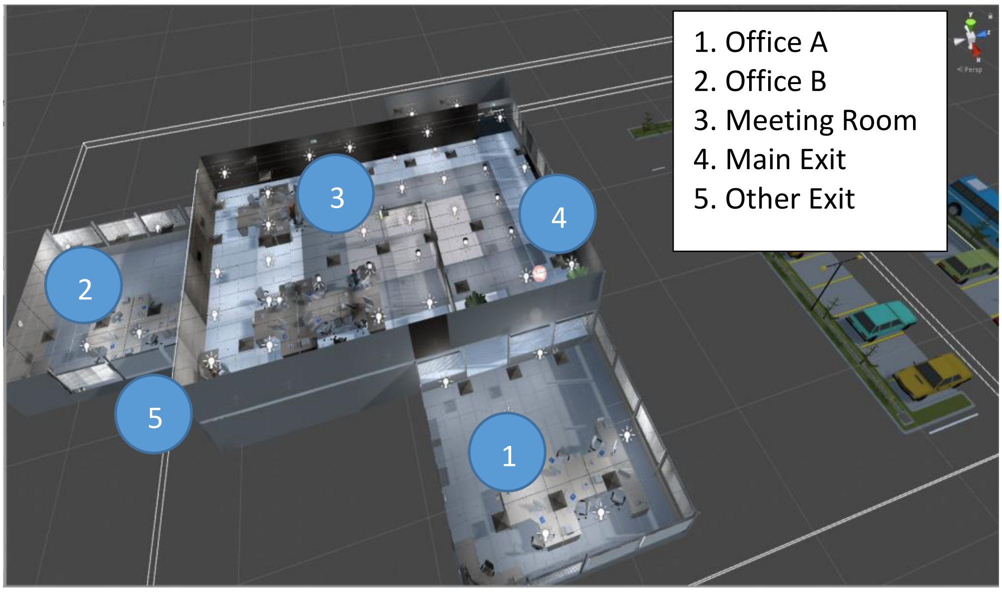

Figure 49 Screenshots of the top scene

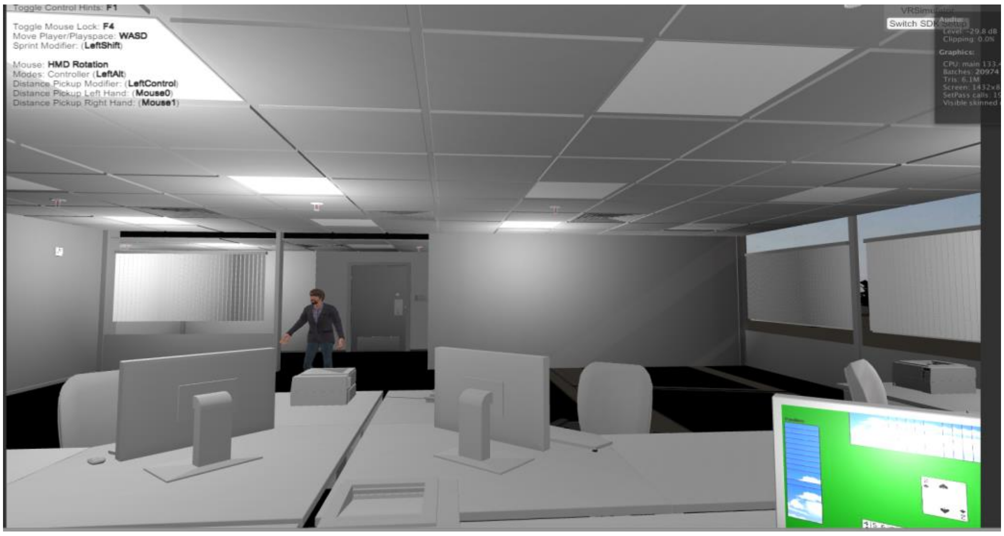

Figure 50 Screenshots of the scene for the stranger were giving instructions (scenario 1)

Figure 51Screenshots of the scene for the stranger were giving instructions (scenario 2)

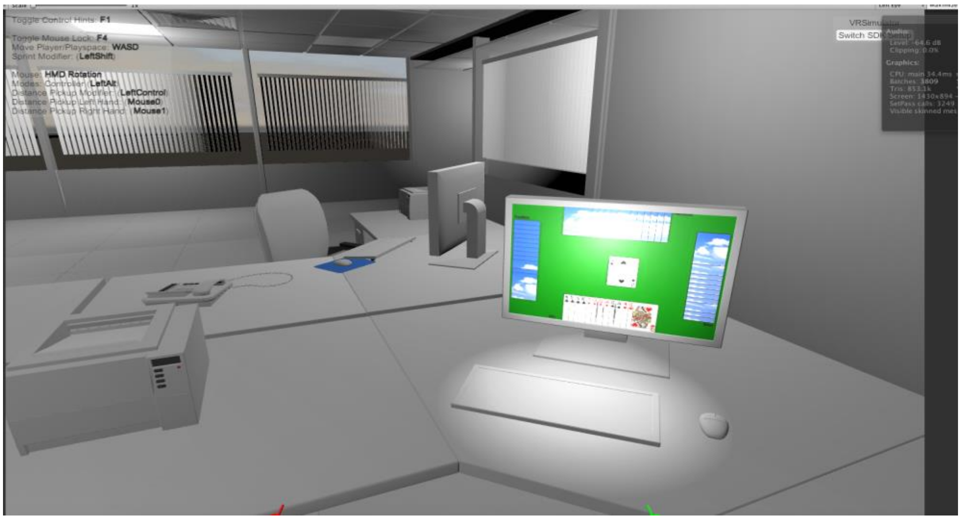

Figure 52 Screenshots of the scene for the instructions via siren (scenario 1)

Figure 53 Screenshots of the scene for instructions via siren (scenario 2)

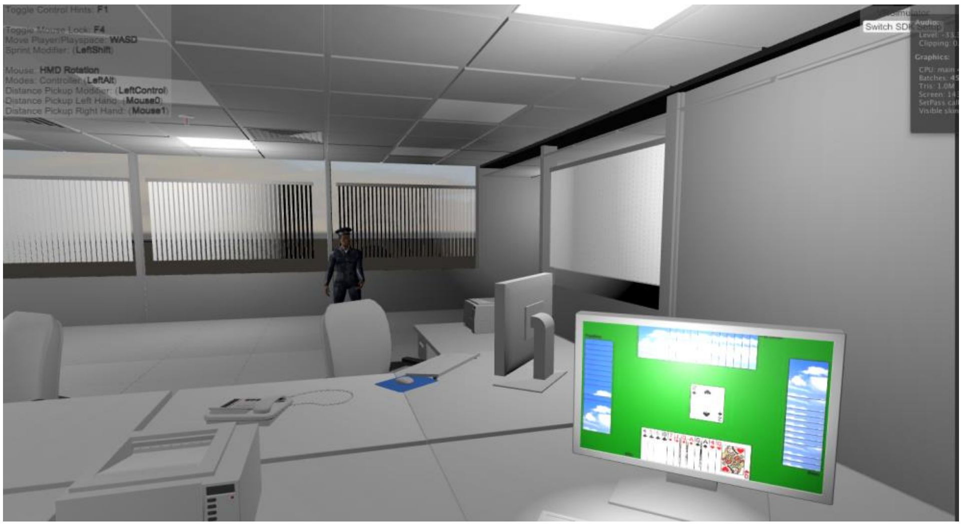

Figure 54 Screenshots of the scene for the authority figure giving instructions (scenario 1)

Figure 55 Screenshots of the scene for the authority figure giving instructions (scenario 2)

7.3.5 Procedure

The experiments were conducted as a mixed-group study. The participants performed the task in VE. Each participant engaged in two scenarios, both with the same information source, but in one scenario, they received a very detailed message; in the other, they received a message without detail. The experimenter allowed the participants to use the simulator before starting and checked that they were able to navigate in any direction. Then, they were presented with the fire emergency scenario individually in two rooms (A and B) which are in different locations. An overview of the experimental conditions is shown in Table 10 **The Scenarios for the Experiment** below.

Fire evacuation scenario	Level of warning (within-subjects)	Receiver characteristics (Gender) (between subjects)	Information Sources /Channel access (between subjects)
A	very detailed message/message without detail	M/F	An authority figure
B	very detailed message/message without detail	M/F	A stranger
C	very detailed message/message without detail	M/F	A siren

Table 10 The Scenarios for the Experiment

The two messages were as follows:

Very detailed message: “a fire has been reported on the ground floor of the building; you must leave the building now to avoid contact with the fire heat and smoke, go now to the lobby and then leaves the building.”

Message without detail: “evacuate the building now; it's on fire, go to the closest emergency exit and then leaves the building.”

One group saw a virtual agent in formal clothing who shouted with two levels of detail. In the “stranger” condition, participants saw a virtual agent in an informal dress who again shouted with two levels of warning: a very detailed message and a message without detail. The third group was the siren condition, which again received both levels of detail message through an audible warning channel.

The participants performed two scenarios: very detailed message/message without detail with different rooms assigned using counterbalancing. The interaction was video recorded (using Ultimate Replay software) to obtain the evacuation time. After each task was performed, the questionnaires in Appendix D 14were given to each participant to understand the influence of information received on their decision to evacuate.

7.4 Results

Descriptive statistics of the time taken for participants to evacuate their avatar from the building in each study condition are shown in table 11. The mean scores indicate a different pattern of results in each condition, with the fastest evacuation times in the authority figure but different outcomes for the experimental conditions for each time measure. Statistical analyses of these results are presented below.

Level of warning	Gender	Conditions	Mean	Std. Deviation	N
High detailed message Time	Male	Authority Figure	22.5000	2.41523	10
	Male	Stranger	32.9000	4.01248	10
	Male	Siren	27.7000	3.49762	10
		Total	27.7000	5.40849	30
	Female	Authority Figure	17.9000	1.85293	10
	Female	Stranger	28.4000	3.62706	10
	Female	Siren	18.5000	2.17307	10
		Total	21.6000	5.53110	30
		Authority Figure	20.2000	3.15561	20
		Stranger	30.6500	4.38028	20
	Total	Siren	23.1000	5.50502	20
		Total	24.6500	6.23502	60
No detailed message Time	Male	Authority Figure	27.0000	3.16228	10
	Male	Stranger	38.5000	7.26101	10
	Male	Siren	41.2000	6.79542	10
		Total	35.5667	8.54474	30
	Female	Authority Figure	20.9000	1.91195	10
	Female	Stranger	35.5000	3.86580	10
	Female	Siren	31.1000	3.31495	10
		Total	29.1667	6.91866	30
		Authority Figure	23.9500	4.03243	20
		Stranger	37.0000	5.86695	20
	Total	Siren	36.1500	7.34327	20
		Total	32.3667	8.35640	60

Table 11 Meantime for participants to move their avatar from their desk to safety, recorded

A 3-way mixed-model ANOVA was performed on the data with message detail as a repeated measures variable and participant gender and information source/channel of delivery as independent samples variables. Table 12 shows the ANOVA output table for within-subjects contrasts on warning message level of detail on time to leave the building. Identified a significant effect of warning message level of detail on time to leave the building [F (1, 54) = 136.958, p<0.000]. There was also a significant interaction between level of detail and conditions [F (2, 54) = 17.651, p<0.000], and level of detail and gender [F (1, 54) = 0.052 p<0.001], and level of detail, gender, and conditions [F (2, 54) = 0.483 p<0.001] on time to leave the building.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Message detail	1786.408	1	1786.408	136.958	.000
Message detail * Gender	.675	1	.675	.052	.001
Message detail * Conditions	460.467	2	230.233	17.651	.000
Message detail * Gender * Conditions	12.600	2	6.300	.483	.001
Error(Message detail)	704.350	54	13.044		

Table 12 Tests of Within-Subjects Contrasts of warning message level of detail on time to leave the building

The interaction plots are illustrated in figure 56, and 57 which shows the meantime (seconds) taken for participants to move their avatar out of the building in each of the study conditions for each level of detail in the alarm warning message and gender. It can be seen that the mean scores indicate a different pattern of results in each condition, with the fastest evacuation times in the Authority Figure condition in both males and females, in high & no details massage but different outcomes for the experimental conditions for each time measure.

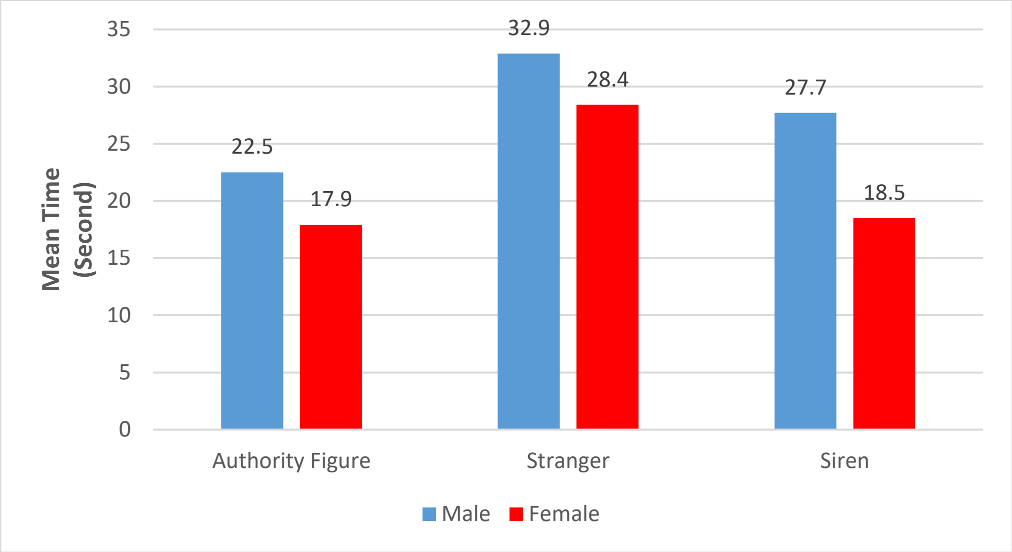

Figure 56 Average time for participants to move their avatar out of the time to leave the building in each condition in high details massage

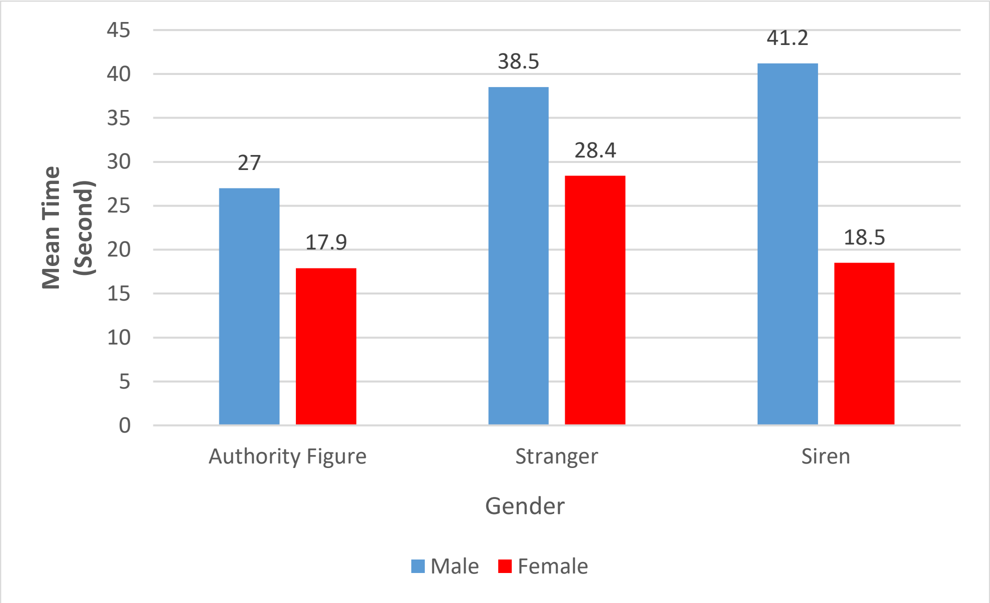

Figure 57 Average time for participants to move their avatar out of the* time to leave the building *in each condition in* no *details massage

The interaction is illustrated in Figure 58, which shows the mean time (seconds) taken for participants to move their avatar out of the main office in each of the study conditions for each level of detail in the alarm warning message.

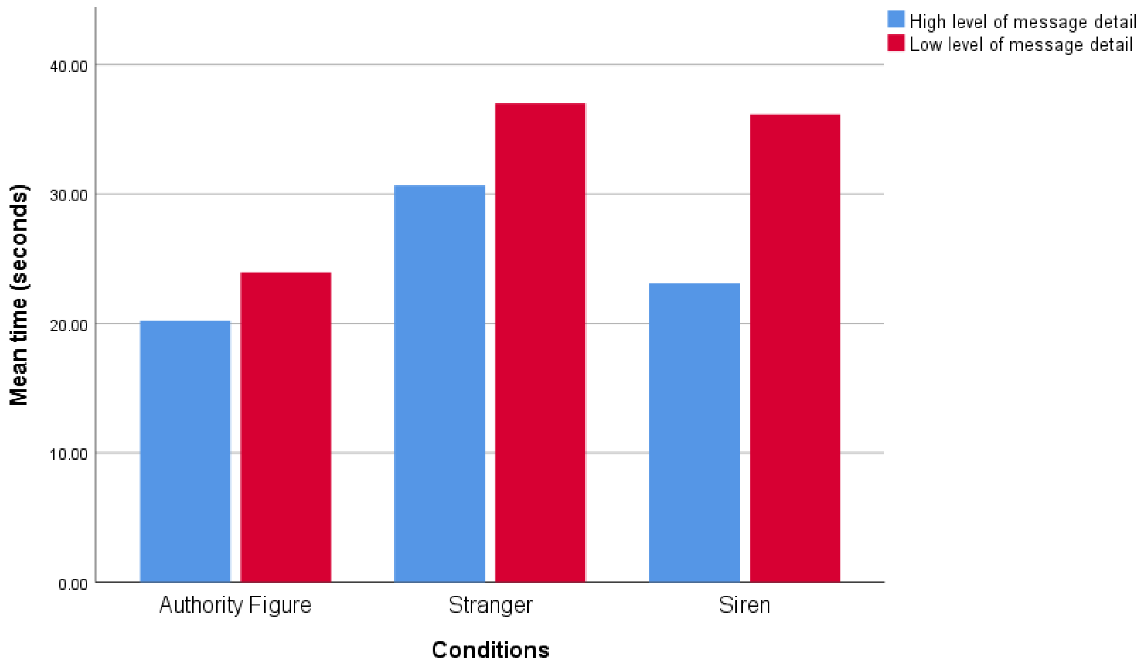

Figure 58 Average time for participants to move their avatar out of the main office in each condition in high and low details massage

Descriptive statistics of the influence on participants when evacuating their avatar from the building in each study condition are shown in table 13. The mean scores indicate a different pattern of results in each condition, with more influence on behaviour in the authority figure condition but different outcomes for the experimental conditions for each influence measure. Statistical analyses of these results are presented below.

Descriptive Statistics					
	Gender	Conditions	Mean	Std. Deviation	N
High detailed message	Male	Authority Figure	4.2000	.63246	10
		Stranger	3.4000	.51640	10
		Siren	3.8000	.63246	10
		Total	3.8000	.66436	30
	Female	Authority Figure	4.6000	.69921	10
		Stranger	3.8000	.42164	10
		Siren	4.5000	.52705	10
		Total	4.3000	.65126	30
	Total	Authority Figure	4.4000	.68056	20
		Stranger	3.6000	.50262	20
		Siren	4.1500	.67082	20
		Total	4.0500	.69927	60
No detailed message	Male	Authority Figure	3.4000	.51640	10
		Stranger	2.7000	.82327	10
		Siren	1.9000	.73786	10
		Total	2.6667	.92227	30
	Female	Authority Figure	4.6000	.51640	10
		Stranger	3.7000	.48305	10
		Siren	2.3000	.67495	10
		Total	3.5333	1.10589	30
	Total	Authority Figure	4.0000	.79472	20
		Stranger	3.2000	.83351	20
		Siren	2.1000	.71818	20
		Total	3.1000	1.10008	60

Table 13 Mean influence for participants to move their avatar from their desk to safety, recorded

A mixed-model ANOVA at table 14 identified a significant effect of warning message level of detail on influence to leave the building [$F(1, 54) = 83.308$, $p<0.000$]. There was also a significant interaction between level of detail and conditions on influence to leave the building [$F(2, 54) = 27.923$, $p<0.000$].

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Message detail	27.075	1	27.075	83.308	.000
Message detail * Gender	1.008	1	1.008	3.103	.084
Message detail * Conditions	18.150	2	9.075	27.923	.000
Message detail * Gender * Conditions	1.717	2	.858	2.641	.080
Error(Message detail)	17.550	54	.325		

Table 14 Tests of Within-Subjects Contrasts of warning message level of detail on influence to leave the building

The interaction plots are illustrated in figure 59 and 60 which shows the mean influence on participants when moving their avatar out of the building in each of the study conditions for each level of detail in the alarm warning message and gender. It can be seen that the mean scores indicate a different pattern of results in each condition, with more influence in the Authority Figure condition in both males and females, in high & no details massage but different outcomes for the experimental conditions for each rate measure.

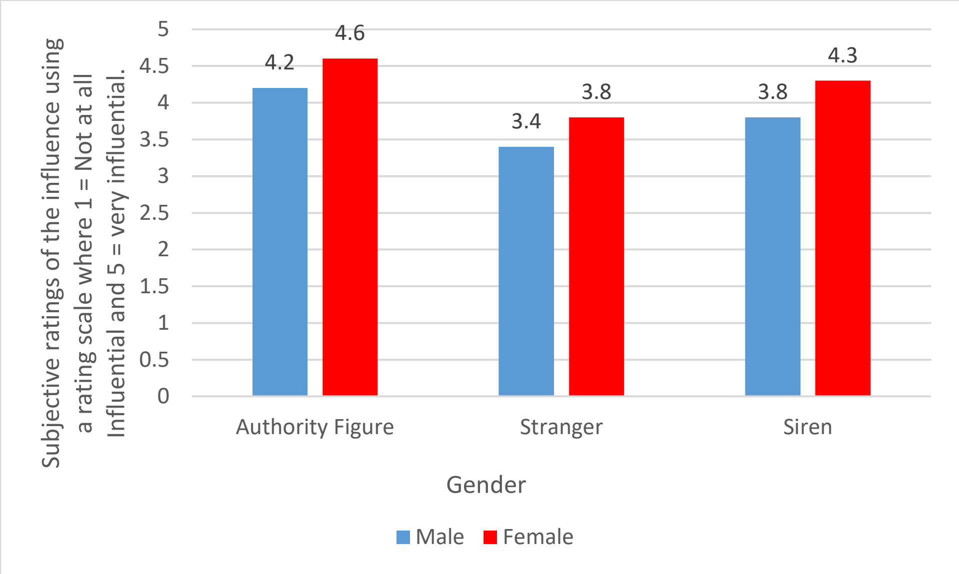

Figure 59 Influence for participants to move their avatar out of the building in each condition in high details massage

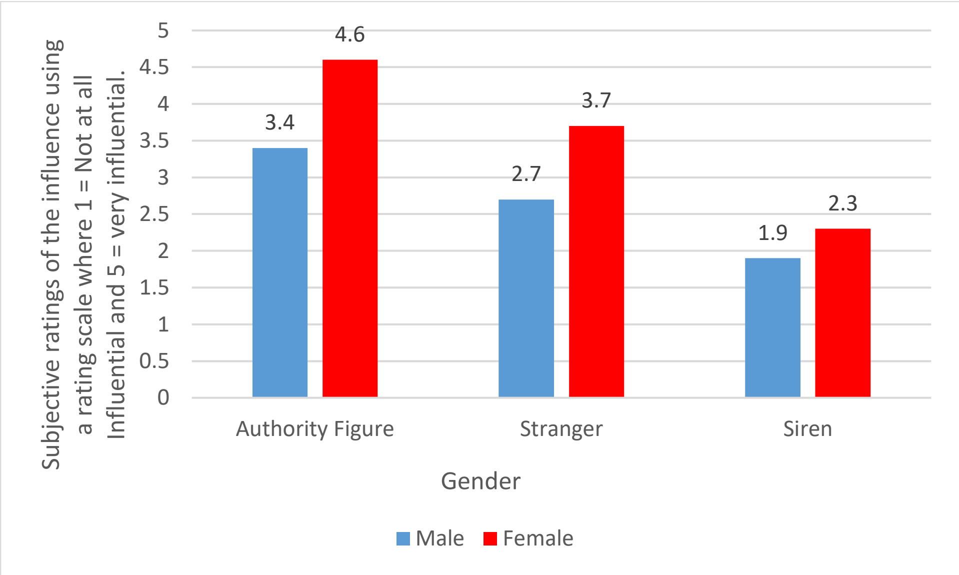

Figure 60 Influence for participants to move their avatar out of the building in each condition in no details massage

Kruskal-Wallis test was conducted to examine the differences in a high detailed message on the perceived influence between the study conditions (information source). There are significant differences (Chi-square = 13.84, p = 0.001, df = 2) were found among the information source of participants (Authority Figure, Stranger, and Siren). Figure 61 shows ratings of the influence of information sources in great details massage.

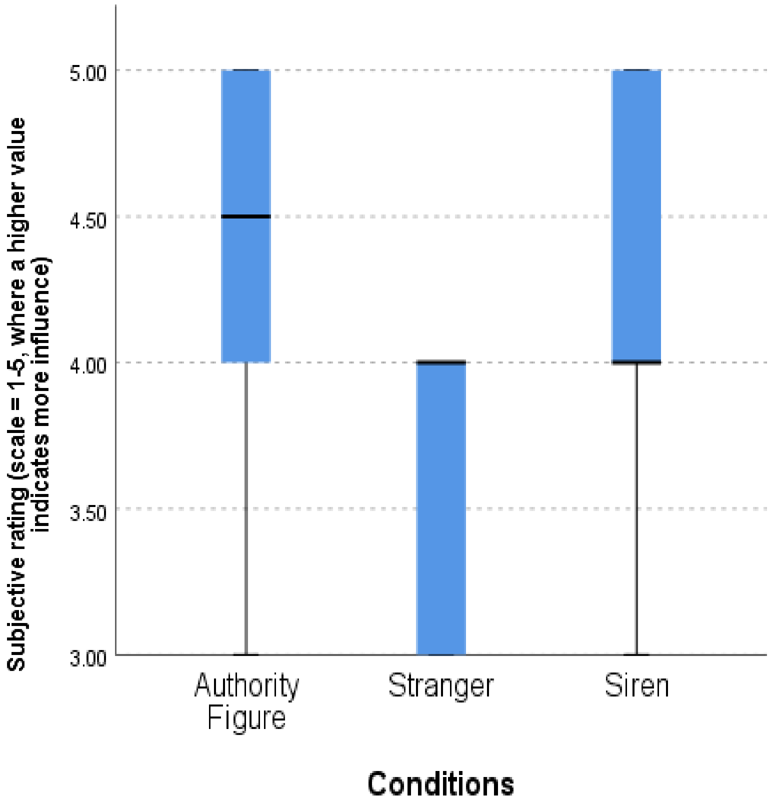

Figure 61 Boxplot of participant ratings of the influence of information sources in great details massage

Kruskal-Wallis Test was conducted to examine the differences on no detailed message on the perceived influence between the study conditions (information source). There are significant differences (Chi-square = 31.142, p = 0.000, df = 2) were found among the information source of participants (Authority Figure, Stranger, and Siren). As illustrated in figure 62.

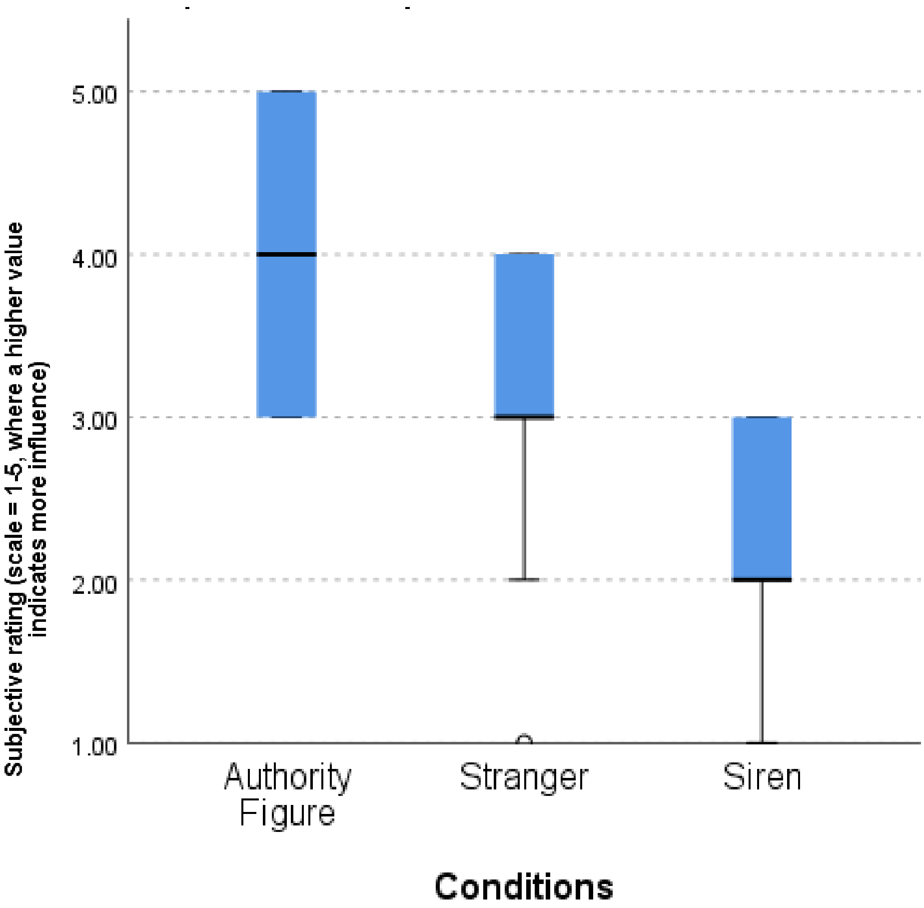

Figure 62 Boxplot of participant ratings of the influence of information sources in no details massage

A Wilcoxon Signed-Ranks test indicated that the authority figure with a high detailed message (mean rank = 10) was rated more favourably than the authority figure with a high detailed message (mean rank = 7.5), Z = -1.886, p = 0.059. Also, it indicated that the stranger with a high detailed message (mean rank = 8) was rated more favourably than the authority figure with no detailed message (mean rank = 20), Z = -1.999, p = 0.048. Further, it indicated that the stranger with a high detailed message (mean rank = 8) was rated more favourably than the authority figure with a high detailed message (mean rank = 0), Z = -3.988, p = 0.000.

Conditions = Authority Figure

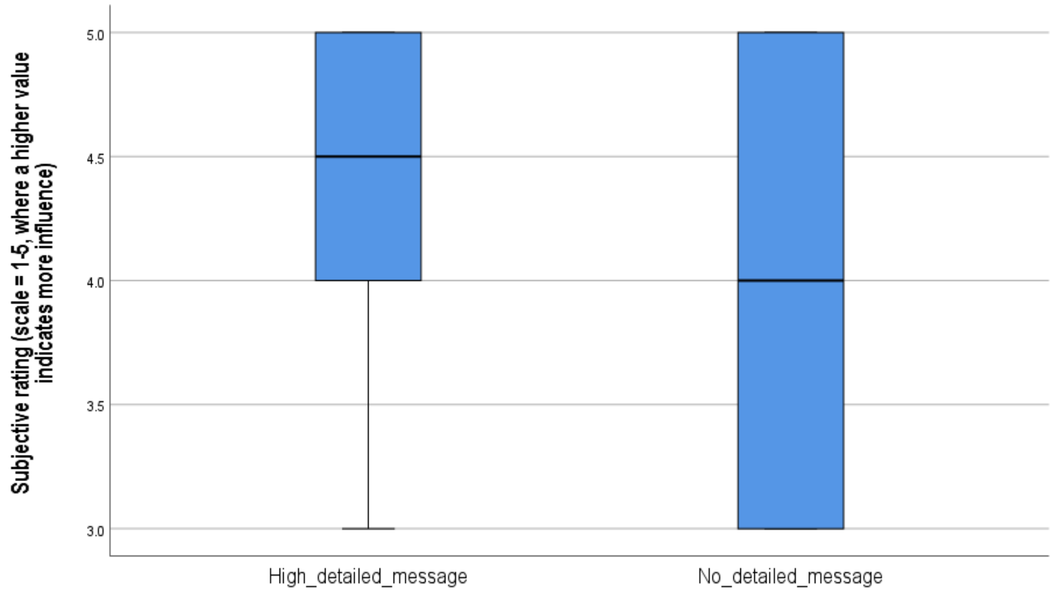

Figure 63 Boxplot of participant ratings of the influence of level of warning

Conditions = Stranger

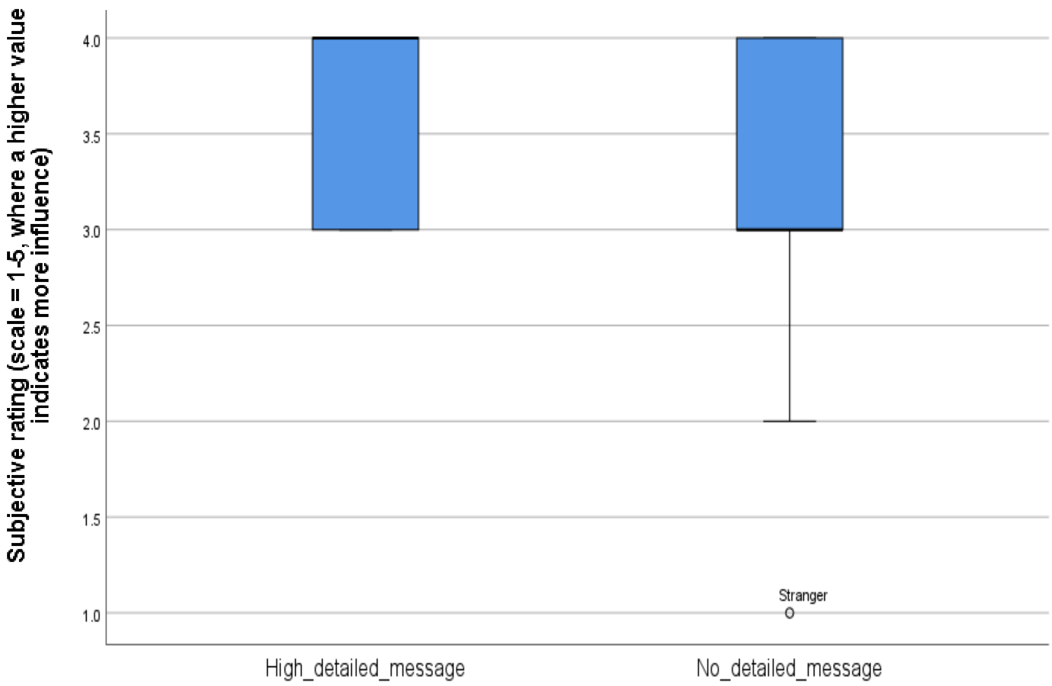

Figure 64 Boxplot of participant ratings of the influence of level of warning

Conditions = Siren

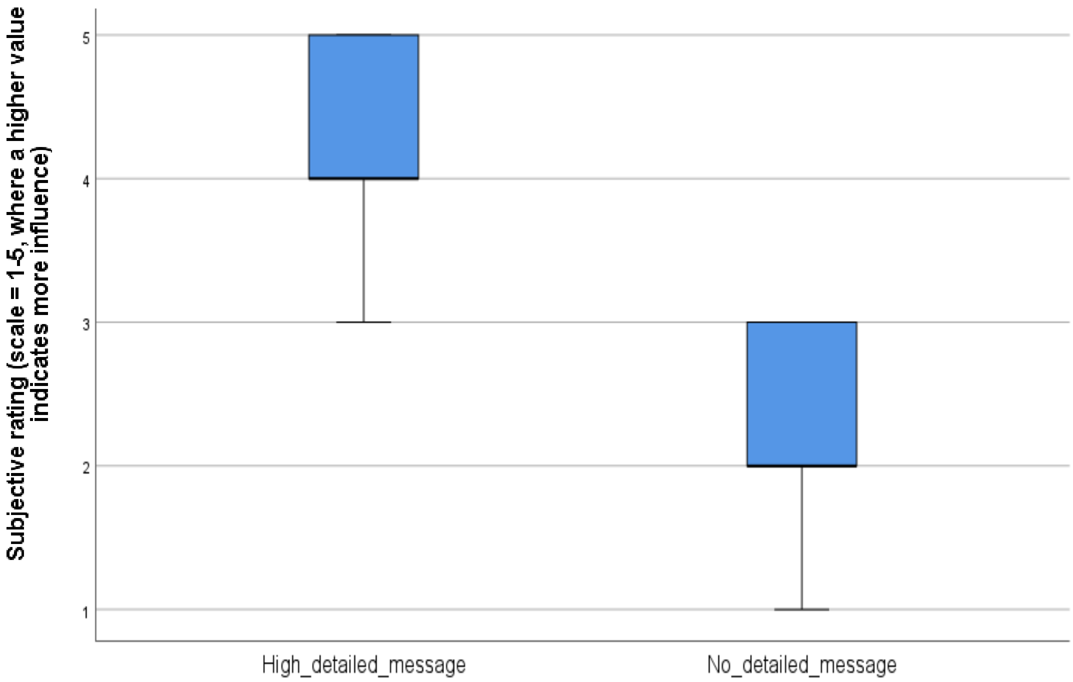

Figure 65 Boxplot of participant ratings of the influence of level of warning

7.5 Discussion

This study followed the previous studies which investigated the impact or effect of social influences during an emergency fire evacuation, indicating a strong link between the behaviour of others on participants' own behaviour. However, this study, while continuing with the use of a virtual environment, sought to investigate the influence of information sources, message content and receiver characteristics on behaviour during emergencies such as fire. It was found that a stranger led to the worst evacuation outcomes (time to evacuate, influence on behaviour), followed by a siren, then an authority figure. The latter led to significantly shorter evacuation times and demonstrated a greater subjective influence on behaviour.

Thus, and building on previous research, it can be seen that there is a link between information sources, receiver characteristics and subsequent level of warning and behaviour during emergency situations such as fire evacuation. It is imperative to note that message effect and ability to influence behaviour are defined by the information, people perceptions, channel, and consequent risk assessment based on the message. Indeed studies by Clerveaux et al. (2008); Lindell & Perry, (2012); and Yang et al. (2013) have shown that when individuals receive information on time, and the subsequent information is detailed, they ultimately factor the information in making a decision on next course of action.

The results from the study were consistent with previous research. For instance, it was established that there was a link between message details and impact on behaviour. In this case, studies by Mileti et al. (1975); Proulx (2001); Dash & Gladwi (2007); and Kuligowski (2013) have shown detailed message impacted quicker and more effective response to emergency fire evacuation compared to ordinary or undetailed messages. Further, studies by Sorensen, (2000); and Lindell & Perry (2012) have shown that messages from the authority seemed to have a greater impact compared to siren messages. Imperatively, studies by Sorensen, (2000); and Lindell & Prater, (2005) have shown that the source of information plays an important role in defining behaviour during emergencies. In this case, by considering messages from an authority, a stranger and a siren. It was established that people tend to react to siren and authority better compared to strangers.

Thus analyzing the study, it is important to note that detailed messages during emergency situations such as fire lead to an effective response. It takes time, or rather such messages take longer time, thus causing delays compared to undetailed information. From the study, it can thus be established that the use of virtual simulated methods in understanding the behaviour of persons faced by emergencies is very reliable and provides important decisions that can be acted upon to ensure an effective response. Indeed studies based on this method provide interesting aspects that can be examined in detail.

These findings showed that people were more likely to evacuate if the information was obtained from reliable sources and was detailed, echoing the findings from Savitt (2015), and are also the same with findings from Kanno (2006), who noticed that information obtained from a private channel is more likely to be trusted than that from a public channel. Participants in all conditions (An authority figure, A stranger, & A siren) were more affected when they heard a very detailed message than a message without detail to evacuate. Female in all conditions (An authority figure, A stranger, & A siren) were, interestingly, observed to more effective and timelier.

7.6 Chapter summary

While studies 1 and 2 looks at the social influences on behaviour during emergencies, this experiment aims to study the effects other factors may have. These factors include the source of information during an emergency, the content of the information, and the recipient's characteristics. In an emergent situation, the warnings as messages have varying degrees of success depending on the message; the channel used the receiver's perception of the message and ability to assess the risk being communicated correctly. Emergent messages, therefore, need to be timely, with the right information, and precise.

Three groups were set up in the experiment while being exposed to a virtual environment. The first group was exposed to a virtual environment where a virtual agent dressed formally shouted a detailed message and another scenario with less detailed information. The second group saw a virtual agent dressed informally and did as the first agent. The last group was exposed to sirens with detailed versus non-detailed information. Several hypotheses were laid out with a total of sixty participants. After each scenario, participants were given questionnaires to fill out regarding the process. Notably, this scenario was in a virtual environment using the VR system and HTC Vive.

It was found that detailed messages were more effective than non-detailed messages, which resulted in delays. Also, across all scenarios, gender influenced response in that female announcers elicited better response times than male counterparts. I was also having an authority figure announce the message is more effective in reducing the evacuation time than otherwise. Information received from a private channel was more positively received than from a public channel. Therefore, the source of information, details of information, and information channels were all identified as significant emergencies such as fire evacuations.

As regards the overall results of this study, this information endorses the original research model; all the structures are significant. The original constructs were identified within each of the three realms: the level of warning, receiver characteristics (Gender), and information Sources /channel access. The findings of this study would further determine the value of the protective action model (PADM) in terms of evacuation interpretation.

Chapter 8

8 Chapter 8. Study 4: Investigation of the effect of information source on (virtual) fire evacuation behaviour in the presence of two social conditions (passive and active-conflict)

8.1 Chapter Overview

This chapter presents research into the use of virtual environments for predicting human behaviour in emergencies. The study presented in this chapter was conducted to investigate the effect of two possible cues to an evacuation (detailed massage with authority and detailed massage with siren) in the presence of social cues (passive or active conflict)

8.2 Introduction

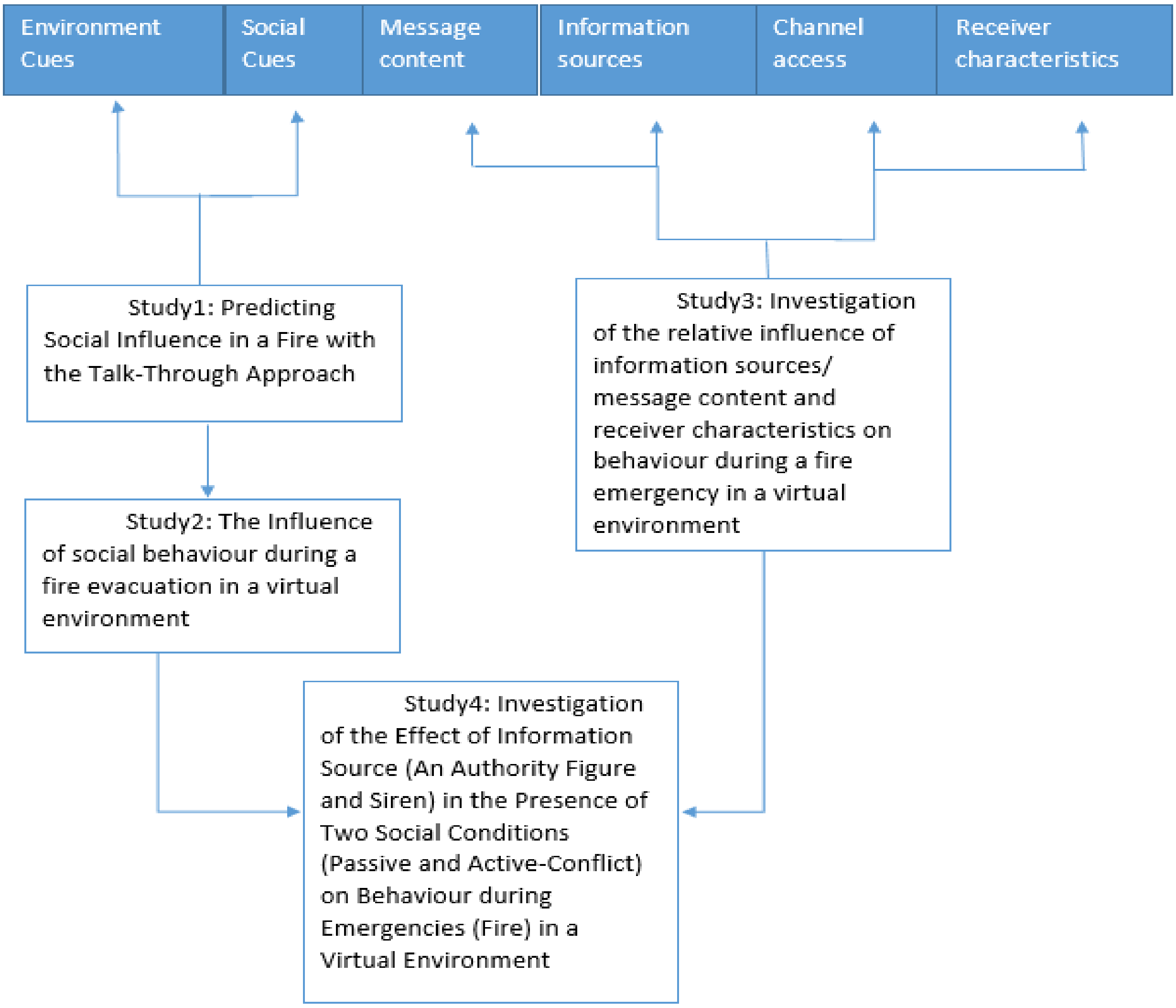

Figure 66 Study 4 mapped to the Protective Action Decision Model (Lindell & Perry, 2012)

Studies 1 and 2 investigated the talk-through method (Lawson et al., 2013) and virtual environments for studying evacuation behaviour in response to social cues. The patterns of results were consistent with previous literature in that passive behaviour of others resulted in longer evacuation times. This finding is also in agreement with that of Kinateder et al. (2014), who confirmed that social influence affects evacuation behaviour, specifically, the passive behaviour of others.

Study 3 investigated the relative influence of information sources/ message content and receiver characteristics on behaviour during an emergency. The main finding was that information from a stranger resulted in significantly longer evacuation times than from a siren or alarm. Also, it showed that information given by a stranger resulted in lower ratings for influence than for authority figures (but not siren). Therefore, a stranger is not the most effective cue to evacuation. Moreover, a higher level of detail was better for influence ratings and for improving evacuation times. For that reason, the level of warning (undetailed massage) was also discounted as an effective cue to evacuation. However, we do not know the effect of an authority figure or siren in the presence of social cues. Therefore, the study presented in this chapter was conducted to investigate the effect of the two most effective cues to an evacuation, detailed message from an authority figure and detailed massage from a siren, but in the presence of social cues (either passive behaviour or active-conflict behaviour including moving away from the evacuation route).

This study addressed the following research question:

RQ: How do social cues affect the influence of information source on human response to fire scenario?

The hypotheses of this work are:

- H1: Evacuation time will be affected by information source (authority and siren).
- H2: Evacuation time will be affected by social cues (passive or active conflict).
- H3: There will be an interaction effect between information source and social cues on evacuation time.

8.3 Method

The study made use of the same virtual environment that had been used in study3 with added (active conflict/passive) as a social condition and discount the stranger and no details massage. Thus in the VR scenario, the fire alarm warning was delivered by one of the following representing the **study condition**:

- A virtual agent informal clothing (to imply an authority figure) who shouted the alarm warning using very detailed message while in the presence of active conflict condition, in which the virtual agents moved towards the opposite direction from the exit of the meeting room in response to the fire alarm, or passive condition, in which the virtual agents remained seated at their desks and displayed no reaction to the fire alarm.
- No visual cue; the fire alarm was given by an audible siren which presented a very detailed message while in the presence of active conflict condition, in which the virtual agents moved towards the opposite direction from the exit of the meeting room in response to the fire alarm, or passive condition, in which the virtual agents remained seated at their desks and displayed no reaction to the fire alarm.

8.3.1 Participants

A total of 64 participants (40 male, 24 female; mean age = 25.64, SD = 9.10) were recruited from students and staff at the University of Nottingham to take part in a simulator experiment using poster requests for participation. As mentioned above, the original intention was to recruit 80 participants, but the experiment had to be cut short due to the Coronavirus pandemic. The statistical analysis was conducted on the data collected from male participants only, and therefore the study analysed 40 participants (mean age = 23.41, SD = 10.21).

8.3.2 Study design

The overall research was a between-group experimental research design. The initial study design intended to assess the effect of three independent variables (information source, social behaviour and gender) on evacuation time, as summarised in table 8. **There were two levels of each IV as follows:**

IV1: information source: authority figure or siren

IV2: social behaviour of virtual agents: active or passive

IV3: gender: male or female

Participants were allocated to one of four study conditions (scenarios) as listed in table 8, and a 2x2x2 between-subjects ANOVA was planned for the analysis of evacuation time. However, the study was only partially completed at the time of the UK national lockdown due to the coronavirus pandemic in March 2020. Table 8 shows that the full quota of participants had completed scenarios A and B, but there was a considerable gender imbalance in the data for scenarios C and D. Due to uncertainty regarding whether or not it would be possible to resume the study, it was decided to remove gender as an independent variable and apply the analysis to the data collected from male participants only.

8.3.3 Materials

8.3.3.1 Pre-test

The experimenter led the participants to a private meeting room in the Human Factors Group room (B3e); then, participants received information about the study, then were asked to read the information sheet & fill the consent form and the questionnaires.

8.3.3.2 VR system

The VR system used the VR system & the HTC Vive. The same VR system, including the HTC Vive, as used in Study 2 (Figure 13) was used again for Study 3.

8.3.3.3 Virtual environments

The VEs was in a building office. The participants were individually presented in an emergency scenario for studying human behaviour. See Figure 67.

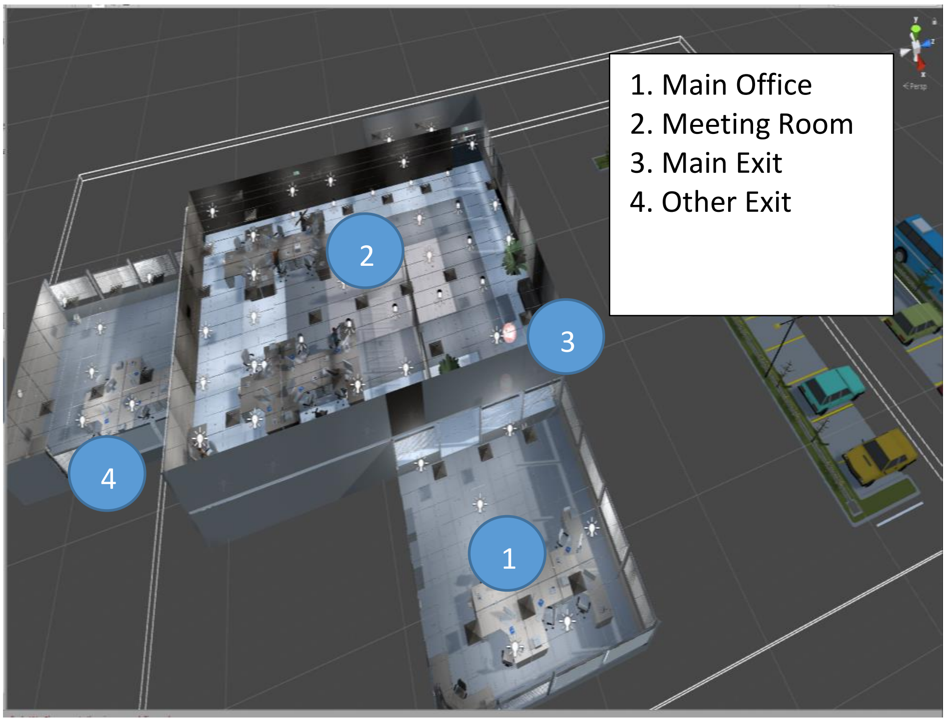

Figure 67 Screenshots of the top scene

8.3.4 Procedure

The participants performed the task in VE. Each participant engaged in one scenario, as shown in table 15. The experimenter allowed the participants to use the simulator before starting and checked they were able to navigate in any direction. They were presented with the fire emergency scenario individually.

The interaction was video recorded using Ultimate Replay to determine evacuation time. After each task was performed, the participant completed the questionnaires shown in appendix E. The pattern of the different VEs is shown in table 8 below:

Fire evacuation scenario	level of warning	Receiver characteristics (Gender)	Sample size n	Social conditions	Information sources
A	Very detailed message	Both(M10/F10)	20	Passive	An authority figure
B	Very detailed message	Both(M10/F10)	20	Active conflict	An authority figure
C	Very detailed message	Both(M10/F4)	14	Passive	A siren
D	Very detailed message	Both(M10/F0)	10	Active conflict	A siren

Table 15 The scenarios for the experiment. Participants were assigned to one of the four scenarios

Scenario A: An authority figure in the presence of passive behaviour of others. In this scenario, the participant started the experiment in an office with other AI agents. After three minutes, the authority figure entered the room and gave the following instructions to the user: “This is your building safety officer; a fire has been reported on the ground floor of the building; you must leave the building now to avoid contact with the fire heat and smoke, go now to the lobby and leave the building”. Then, the authority figure left the building, and the AI agents remained seated and did not leave the building.

Scenario B (An authority figure in the presence of active conflict behaviour of others) – as above, although this time the AI agents headed toward the meeting room (rather than towards the building exit).

Figure 68 Screenshots of the scene for the authority figure giving instructions to the participant (off-camera) showing the other AI agents (Scenarios A & B)

Scenario C: A siren in the presence of passive behaviour of others. Same as Scenario A, although this time after three minutes, the following was announced via a "virtual" siren: "May I have your attention please, May I have your attention please. A fire emergency has been reported in the building evacuate the nearest exit".

Scenario D: A siren in the active conflict condition. The AI agents behaved as per scenario B but with the siren warning as per scenario C.

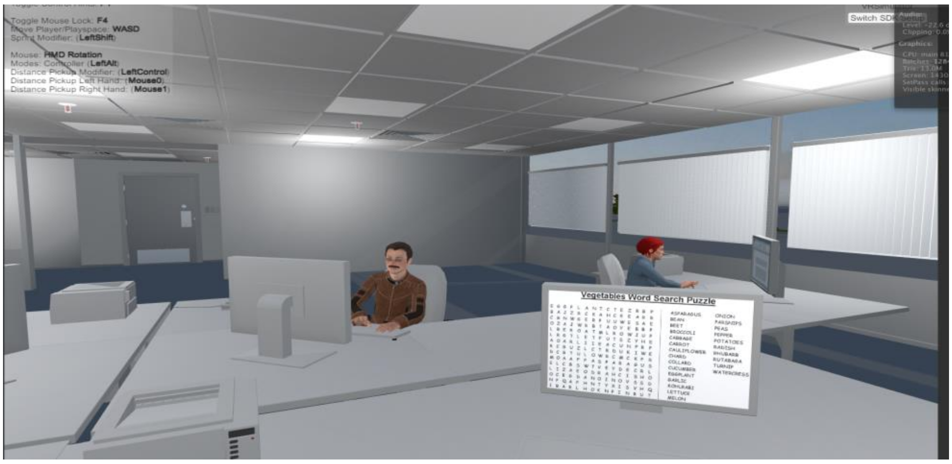

Figure 69Screenshots of the scene for the siren giving instructions to the participant with AI Agents (Scenarios C and D)

8.4 Results

Descriptive statistics of the time taken for participants to evacuate their avatar from the main office and from the building in each study condition are shown in table 16. The mean scores indicate a different pattern of results in each condition, with the fastest evacuation times in an authority figure in an active conflict situation for the experimental conditions for each time measure. Statistical analyses of these results are presented below.

Descriptive Statistics				
Dependent variable: Time to evacuate from the building?				
Information	Social Influence	Mean	Std. Deviation	N
Siren	Active Conflict	45.600	5.929	10
	Passive	58.700	8.042	10
	Total	52.150	9.615	20
Authority Figure	Active Conflict	20.900	3.142	10
	Passive	30.900	4.383	10
	Total	25.900	6.332	20
Total	Active Conflict	33.250	13.486	20
	Passive	44.800	15.592	20
	Total	39.025	15.532	40

Table 16 Meantime for participants to move their avatar from their desk to safety, recorded

A two way ANOVA identified in table17 shows that there was a significant main effect of information on time to leave the building [F (1, 36) = 213.792, p<0.001]. Also, there was a significant main effect of social influence on time to leave the building [F (1, 36) = 41.390, p<0.001].

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	8248.675[a]	3	2749.558	85.309	.000
Intercept	60918.025	1	60918.025	1890.071	.000
Information	6890.625	1	6890.625	213.792	.000
Social Influence	1334.025	1	1334.025	41.390	.000
Information * Social Influence	24.025	1	24.025	.745	.394
Error	1160.300	36	32.231		
Total	70327.000	40			

Table 17 Tests of Between-Subjects Effects time to evacuate from the building

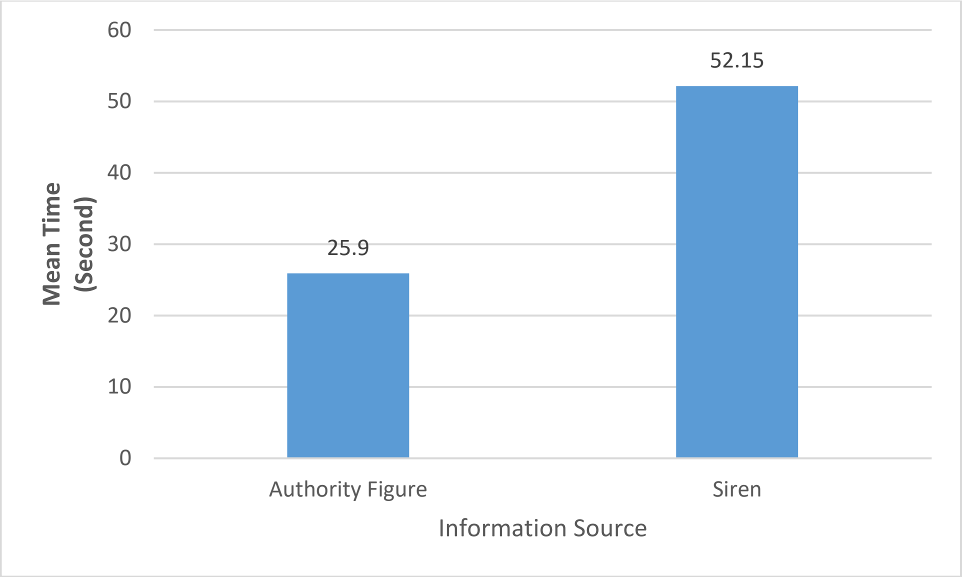

Figure 70 Average time for participants to move their avatar out of the building in each condition

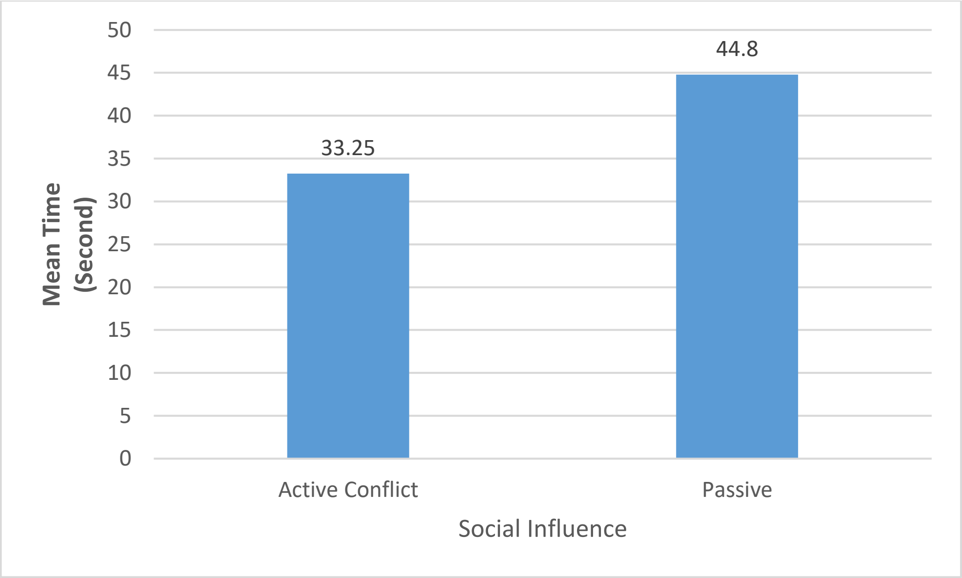

Figure 71 Average time for participants to move their avatar out of the building

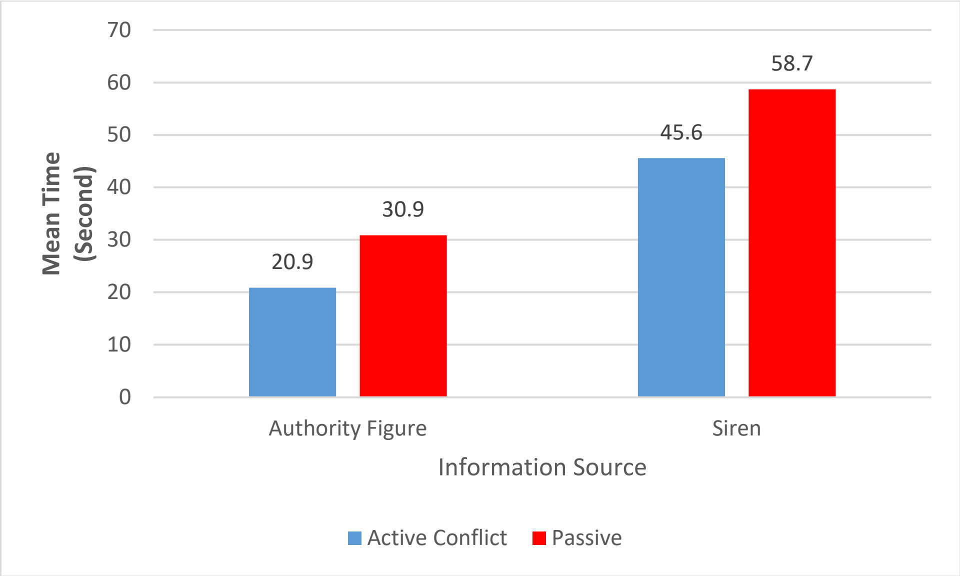

Figure 72 Average time for participants to move their avatar out of the building

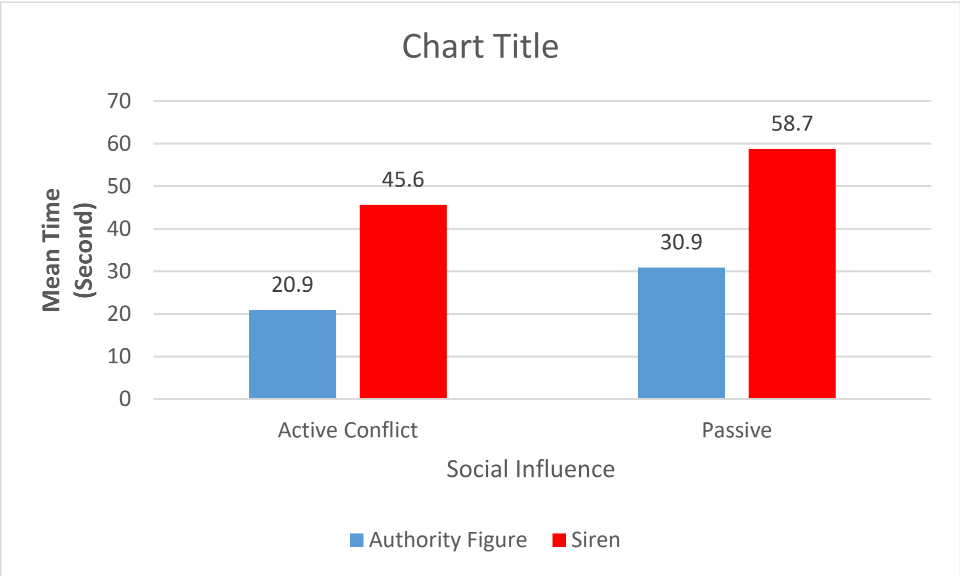

Figure 73 Average time for participants to move their avatar out of the building

At the end of the experiment, participants in the active conflict and passive behaviour conditions were asked to rate how much they considered that their response to the information sources on your decision to evacuate from the building was influenced in the virtual environment. Scores were given using a 5-point ordinal rating scale in which a higher score represents a higher perceived level of influence. Figures 74 and 75 show scores obtained from participants that ratings the influence of information sources on participant's decision to evacuate from the building. A Mann-Whitney U test identified a significant difference in rating scores between the two conditions [U = 399.000, p<0.000], with a higher level of influence in the authority figure (Median = 4; range = 3-5) than the siren (Median = 2; range = 1-3).

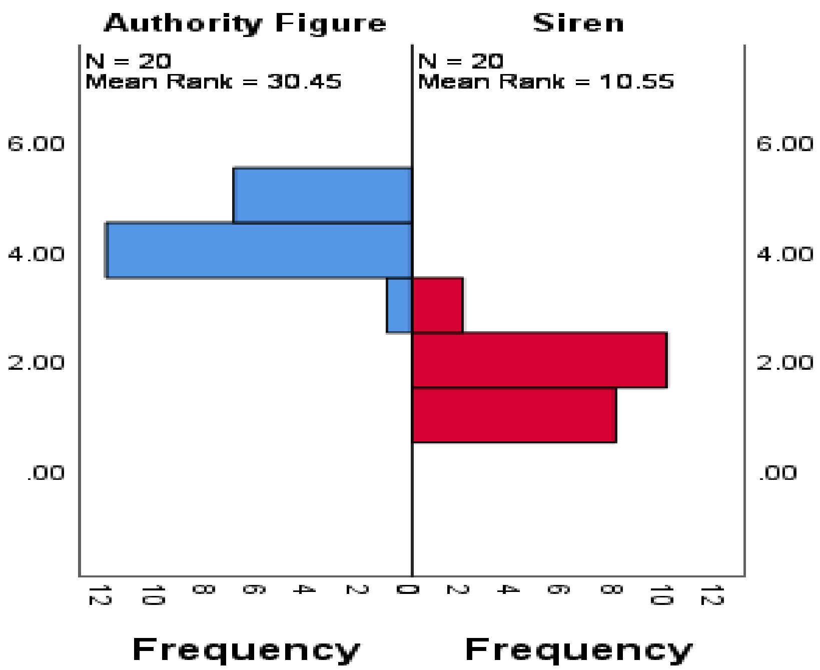

Figure 74 Chart bar of participant ratings of the influence of information sources on participant's decision to evacuate from the building

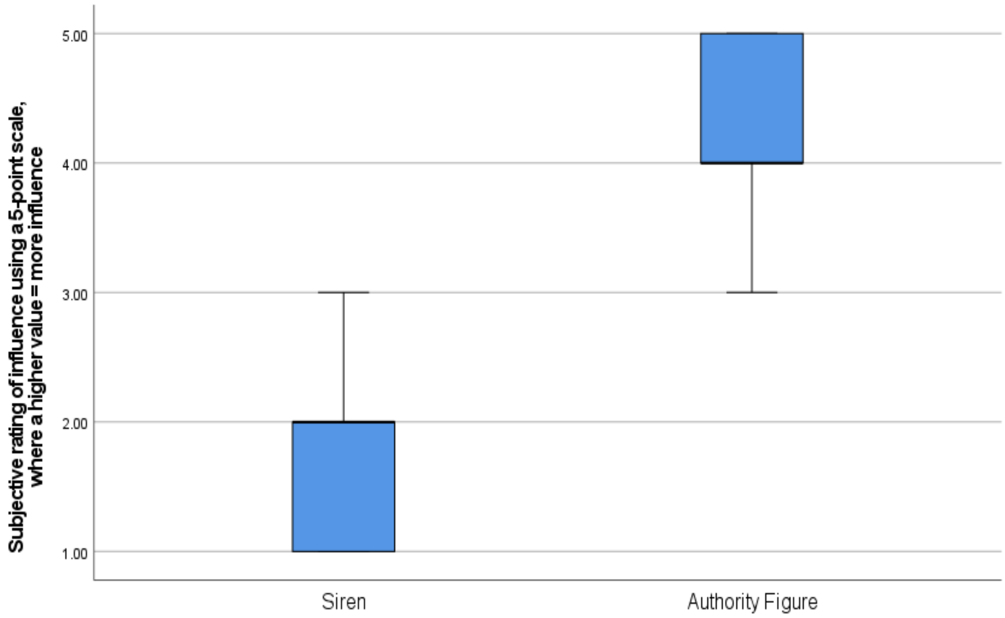

Figure 75 Boxplot of participant ratings of the influence of information sources on your decision to evacuate from the building

A Mann-Whitney U test identified a nonsignificant difference in the influence of other avatars on the decision to evacuate from the building rating scores between the two conditions [U = 259.000, p<0.089], with a higher level of influence in the authority figure (Median = 4; range = 3-5) than the siren (Median = 2; range = 1-3). Figures 76 and 77 show the participants ratings of the influence of other avatars on the decision to evacuate from the building.

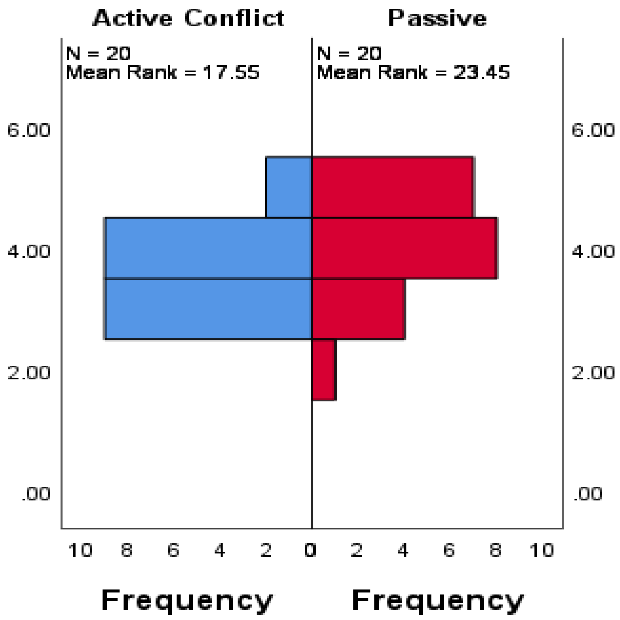

Figure 76 Chart bar of participant ratings of the influence of other avatars on the decision to evacuate from the building

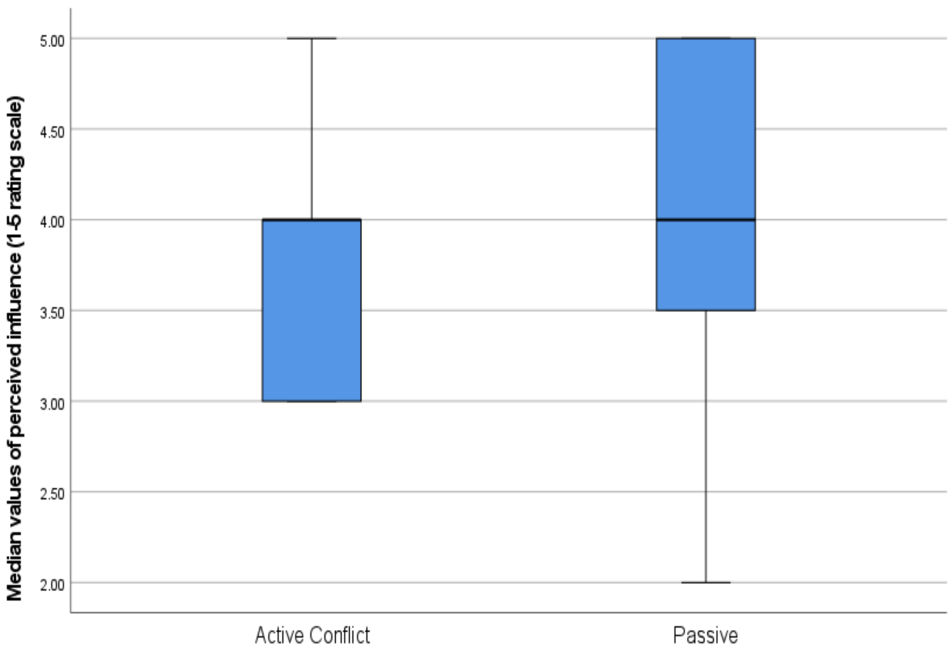

Figure 77 Boxplot of participant ratings of the influence of other avatars on the decision to evacuate from the building

8.5 Discussion

This study explored the influence of information sources (authority figures or siren) on evacuation behaviour under two social conditions: passive behaviour or active conflict. The information sources of authority figures and siren, with a detailed message, were chosen from study 3 as those conditions which would likely give rise to the most effective evacuation response. The results of this study showed that an authority figure with a detailed message led to the fastest evacuation times and had the greatest influence under both social conditions. These results imply that evacuation systems should consider utilising people in a position of authority as part of the fire warning system.

From the study, it was established that the authority combined with detailed information in the presence of social cues that is passive and active conflict conditions had a greater effect in influencing behaviour compared to the siren with detailed information. This study result seems consistent with previous studies; for example, studies by Sorensen, (2000); and Lindell & Perry, (2012) have shown that messages from the authority seemed to have a greater impact than siren messages. Imperatively, studies by Sorensen, (2000); and Lindell & Prater, (2005) have shown that the source of information plays an important role in defining behaviour during emergencies. Further, it is consistent with Latane and Darley (1968), who found that passive behaviour exhibited by individuals who are around smoke leads to a decreased chance of effective evacuation behaviour. This finding is similar to previous research; for example, Kinateder et al. (2014) confirmed that social influence affects evacuation behaviour.

This aspect thus is a crucial factor to consider in designing emergency response effectiveness. Imperatively it can be argued that previous studies have had similar findings, a concept that indicates the importance of adopting virtual reality and simulation in emergency response. From the study, it can be established that adopting technology is key to saving lives. Further, while there are different means and approaches of responding to emergency fire situations, the most important is ensuring or influencing behaviour through detailed messages and subsequent use of siren.

8.6 Chapter summary

This study aimed to explore how cues of an emergency (detailed method delivered by either authority figure or siren) would influence evacuation behaviour in a virtual environment under social influence conditions (passive behaviour or active conflict). The experiment had 64 participants, in a between-subjects design, with a deficit in female participants due to COVID. Results showed that information delivered by an authority figure resulted in significantly faster evacuation times than a similar message conveyed by a siren. The positive effects of an authority figure versus the use of a siren are observed in both passive and active social situations. Overall, receiving information from authority figures matters; detailed messaging is important, and social influence matters.

Chapter 9

9 Chapter 9. General discussion chapter

9.1 Chapter Overview

This section reviews the research conducted in pursuit of this PhD. The discussion focuses on the five important influencing elements of the PADM model, in particular, social influence, environmental cues, information source, warning level of detail, and receiver characteristics (gender) in relation to participants' behaviour in a fire emergency. Each element is further partitioned to review the main considerations or measurements against that factor. Finally, while there are limitations with this work, as with any research, the discussion outlines findings that are likely to have an impact on the outcome of the evacuation process.

9.2 Summary of Findings

This research's main objective was to establish how people make decisions to evacuate, or not evacuate, an office building, or not evacuate, based on using the Protective Action Decision Model as a framework to guide the work. The studies followed previous research to explore and examine the first stage elements (cues to an emergency) described by the Protective Action Decision Model and thus establish how these elements manifest on evacuation behaviour and their interactions. The organisationof the research, studies and results, is demonstrated in Figure 78. An overview of the research mapped to PADM (Lindell & Perry, 2012).

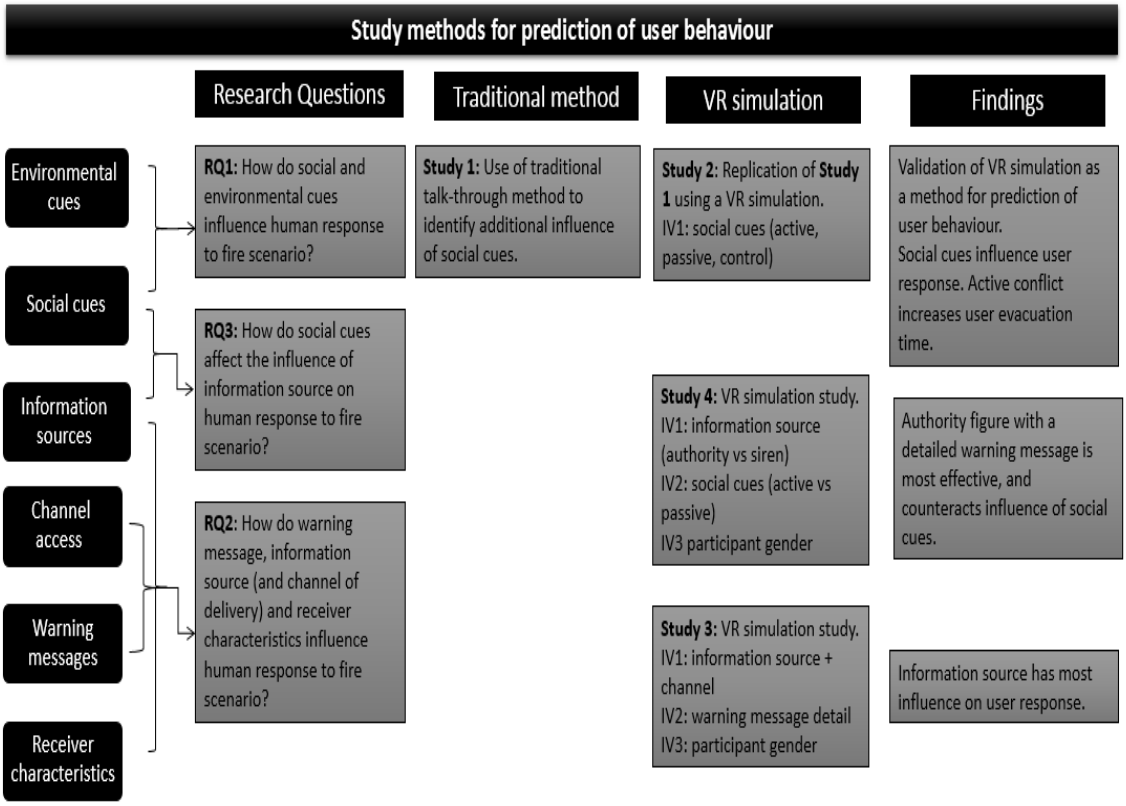

Figure 78 Overview of the studies and results conducted for this thesis, mapped to the first phase of the Protective Action Decision

Study one was conducted to address a gap in the prior literature, specifically to understand whether the talk-through approach (Lawson, 2011) could reveal evacuation behaviour under social influence conditions. Fifteen participants were recruited to three different experimental groups (five per group) in a hypothetical emergency scenario. There were three social conditions: active conflict, in which hypothetical building occupants moved to a meeting room rather than exiting; passive, in which they remained in the office; and control, in which the participants were told they were alone. The active conflict group reported the most extended hypothetical times to leave the building, while the passive group scored highest in leaving the room. In all the results from the three conditions, it was evident that social influence affected evacuation behaviours and that the results matched the patterns of behaviour seen in prior research (Kinateder et al., 2014).

Study 2 aimed to recreate the conditions and results of study 1 but in a virtual reality environment. As for study 1, evacuation times, frequencies of acts, time, and ratings for social behaviour influence were measured under the same three social conditions. Unlike study 1, this study had a larger sample size of 45 participants, 15 per group. Again, the active group took the longest to leave the building, and the passive group took the longest to leave the main office. Thus, in social conditions (active-conflict and passive situations), the behaviour of others once again seemed to influence the response of participants in the VE. There were no significant notable differences observed in the frequency of actions across all situations.

Regarding the sequences of actions, the active conflict condition generated more complex sequences than passive and control situations. This complexity is attributed to the effects of social behaviour. However, the same influence cannot be attributed to the frequency of acts. Overall, the results conclusively demonstrate that passive action leads to a slower evacuation process, while active conflict leads to more confusing patterns of behaviour. However, it was clear that while social behaviour does affect the evacuation process.

Given that study 2 showed virtual environments could reveal evacuation behaviour in response to cues of an emergency, this method was used again for study 3. Study 3 aimed to explore the influence of other factors from PADM (Lindell & Perry, 2012), specifically, the source of information during an emergency, the level of detail in the warning, and the recipient's characteristics. In an emergency situation, the warnings as messages have varying degrees of success in promoting evacuation behaviour depending on: the message, the channel used, the receiver’s perception of the message and ability to assess the risk being communicated correctly. Messages, therefore, need to be timely, with the right information, and precise. It was found that detailed messages were more effective than non-detailed messages, the latter resulting in evacuation delays. Also, across all scenarios, gender influenced response, in that female participants reported a higher level of influence across all conditions. The authority figure announcing the message was more effective in reducing the evacuation time than a stranger or siren. Therefore, the source of information, level of details in the information, message, and receiver gender and information channels were all significant factors in emergencies such as fire evacuations.

Study 4 aimed to take the most favourable cues from study 3 (authority figure, siren, both with detailed message) and explore their influences under social conditions (active conflict; passive). A study was planned for 80 participants were recruited, although COVID-19, unfortunately, lead to a deficit in female representation as the study had to be halted prematurely. The statistical analysis was only conducted on the data collected from male participants only, and therefore the study analysed 40 participants. Again, a virtual reality environment was used with the HTC Vive. Results showed that an authority figure with a detailed message led to a more effective evacuation than a siren across both active conflict and passive social conditions. Overall information from authority figures matters; detailed messaging is important, and social influence matters as demonstrated by the differences seen in the different social conditions in active conflict, passive, and control (i.e. alone working) conditions.

9.3 Discussion of Findings

In study 1, it was established that when it comes to leaving the building, active condition participants reported the longest evacuation times, with participants in the passive condition reporting the longest evacuation when it comes to leaving the main office. This result seems consistent with previous studies, such as Latane and Darley (1968), who concluded that passive behaviour exhibited by individuals around smoke leads to a decreased chance of effective evacuation behaviour. This finding is also in agreement with that of Kinateder et al. (2014), who confirmed that social influence affects evacuation behaviour. From the study, it can also be shown that humans or individuals react differently when it comes to fire evacuations, often relies on their personal experiences in making decisions, given different social conditions. This aspect thus indicates a varying response given different conditions during fire evacuations, again supporting the results from prior literature (Ronchi & Nilsson, 2014), which showed that the shortest distance to arrive at a possible escape point might be an oversimplification of the path of evacuation.

Another important finding from Study 1 was that the talk-through approach revealed the influence of social behaviour on the outcomes of an evacuation. This was a limitation reported by Lawson et al. (2013) early work on the method, yet authors (see (Kinateder & Warren, 2016); (Kinateder et al., 2014); (Nilsson & Johansson, 2009); (Shields & Boyce, 2000); (Latane & Darley,1968)) have clearly shown that social influences can influence the outcomes of an emergency. Thus, the finding that the talk-through approach is appropriate under social conditions affords more significant opportunities for its deployment in predicting behaviour in emergency situations. In study 2, it was interesting to establish that a similar pattern of results was obtained with a virtual environment as for study 1. For instance, the study showed that active condition resulted in the longest evacuation times when it came to leaving the building, with passive condition brought the highest when it came to leaving the main office. Moreover, as expected and hypothesized, the different conditions of social influence resulted in different building evacuation times in a fire emergency. As before, this reflects patterns of behaviour seen in the previous academic literature (Latane and Darley, 1968; Kinateder et al., 2014).

Study 3 continued with the virtual environment work but explored other factors from PADM. The findings showed that people were more likely to evacuate if the information was obtained from reliable sources and was detailed, echoing the findings from Savitt (2015) and Kanno (2006), who noticed that information obtained from a private channel is more likely to be trusted than that from a public channel.

In study 4, it was established that the detailed information delivered by an authority figure had greater influence and effect than detailed information delivered by a siren. This aspect is thus is a crucial factor to consider in designing emergency response effectiveness. While the PADM model (Lindell & Perry, 2012) shows the cues to an emergency, no previous work had looked at the relative importance of these cues, nor how they manifest under conditions of social influence. This work also reveals the importance of adopting virtual environments for the prediction of behaviour in emergency situations. While this is not the first research to adopt this approach (Lawson, 2011), it is the first to explore the PADM model.

9.4 Contribution to knowledge

The investigation has shown of this thesis would further determine the value of the protective action model (PADM) in terms of evacuation interpretation. It is begun to develop a more nuanced understanding of the actual behavioural response to different social influences, information sources, message content and receiver characteristics on behaviour during a fire emergency.

While the previous study from the scientific literature reported evaluations of talk-through approach for predicting behaviour (Lawson et al., 2013), it had not previously been proven that the talk-through could be used under conditions of social influence – this is an important contribution to those involved in fire safety, or fire safety research, as this is a useful tool for predicting human behaviour. Furthermore, Chapter 6 revealed that concerns previouslyraised about the lack of validation in simulation tools were not evident in comparative application of VR simulation to replicate study 1 as similar results were obtained using both methods. Thus, the research reported in this thesis adds to our understanding of when virtual environments can be used to study human behaviour. Furthermore, use of a virtual environment simulation enabled more flexibility with regards to control of the experimental study scenario; the exploration of the influence of other factors from PADM (Lindell & Perry, 2012), specifically, the source of information during an emergency, the level of detail in the warning, and the recipient's characteristics, is a further novel contribution.

9.5 Future work

The following are identified as areas of research that could be addressed in future work:

- This PhD focused on office building fires and did not explore how the results would translate to home, shopping mall, leisure buildings etc. Future suggested studies for the evacuation research would be to apply this research approach to different contexts such as homes, shopping malls, leisure buildings on the evacuation.

- Further study could be conducted to complete stage 2&3 of the PADM, by initiating a series of pre-decisional studies, which consecutively elicit fundamental perceptions of the ecological threat. A final consensus will result in more robust recommendations related to practical measures to investigate the relative influence of other stages on behaviour during emergencies (fire) in a virtual environment. In addition to this, the study should expect to include a higher number of participants.

9.6 Limitations of Research

During the study, a number of limitations were observed. One of the most significant limitations was the relatively small number of participants (n=15) in study1. This was due to time constraints, and while other research may augment this sample, it is hoped that further subsequent research into PADM factors limits the impact of this small sample on the overall success of this research. Another limitation is in our understanding of how these results obtained from virtual environments would translate to real emergencies. Ethically, we cannot create a real emergency to prove the outcomes empirically, but further work is needed to explore these findings as they apply to actual emergencies.

9.7 Conclusion

This research has explored behaviour in response to the early stage of cues of an emergency, as defined by the PADM model (Lindell & Perry, 2012). It achieved this through a number of studies, using mainly virtual environments, although the work also developed Lawson (2011) talk-through approach.

The study findings in the research focused on the subsequent importance of cues as an important aspect of the behavioural response that influences individual behaviour during a fire emergency. Indeed the research has established the effect of perception of cues in an emergency situation. In this regards, the perception of cues informs decision-making process to subsequently improve the ability to predict individuals behaviour, especially during an emergency situation.

The work showed that these methods could be successfully applied to identify behaviour patterns in response to social influence, which matches those reported in the prior scientific literature. We also see that the optimum methods of providing cues to an emergency, the positive effects of an authority figure versus the use of a siren are observed in both passive and active social situations. Overall, receiving information from authority figures matters; detailed messaging is important, and social influence matters.

Considering the application of this research, Saudi Arabia seeks to create a safe and healthy work environment in which facilities are designed, developed and operated in a manner that preserves lives, assets, security and the environment from all surrounding risks and accidents, integrating the goals of Vision 2030. Saudi Arabia indeed faces countless of issues when it comes to response in case of an emergency. This thus calls for the importance of partnerships between universities and subsequent industrial cities. This partnership has numerous benefits for both the industries and the universities. Such partnerships have the ability to transfer learning and to assist development through aspects such as training programs. This has the effect of improving or developing individual capabilities and subsequent acquisition of new skills in various areas fields.

In regards to emergencies, response and evacuation, such partnerships between universities and industrial bodies and cities are essential. This can be advanced by adopting virtual environments for learning on fire forecasting and evacuation as we as leveraging global experiences, practices, and expertise. This is important as it establishes a national model for partnership and result-oriented cooperation to ensure safety in the industrial environment.

This work also has important implications for fire safety. Upon further validation work, in particular, to obtain confidence that the results would apply to different buildings and different social conditions, these findings could ultimately lead to better evacuation outcomes in emergency situations. Based on this, the Saudi government should be able to provide consideration regarding the scope of the legislation. This will ultimately improve opportunities in regards to adopted evacuation culture within workplace stations. The legislation should be tailored based on the understanding of the behavioural response.

10 References

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11 Appendix A: Study1

a. Consent Form

Abdullah Alhuthali | University of Nottingham UK | CHINA | MALAYSIA | Consent form

Consent Form

Evaluation of the talk through approach method for identifying the influence of social behaviour on an emergency situation

My name is Abdullah Alhuthali, a PhD Human Factors student. I am conducting a study into whether the use of the talk through Approach method is able to identify the influence of social behaviour. If you choose to participant in this experiment, you will be presented with a hypothetical scenario related to an emergency situation. You will be asked, what you would do, and the location of your behaviours, and then an approximation of the time to leave. After this you will be asked for subjective ratings of the influence of behaviour of other people. Your responses will be used for sequential analysis and statistical analysis. This information will be kept confidential and may be used in the future publications. Furthermore, you have the right to withdraw at any time.

The experiment will approximately require than half an hour. There is a compensation for your participant in this experiment will be paid £5 for your time. If you feel distressed at any time during the experiment please indicate this to me, and the experimental will be ended.

I have read the information described above. I voluntarily agree to take part.

Name of participant: .... (Sign) .... (Print)
Date: .... Age (Optional): ....

Participant ID :......................(to be completed by experimenter)

b. Questionnaire on control and conflict condition

Abdullah Alhuthali | University of Nottingham UK | CHINA | MALAYSIA | Questionnaire_Control _condition

I

Emergency evacution study: questionnaire

Particpant ID	
Email	
Degree	
Gender	**Male/Female**
Age	

It is Monday morning 10:30 at ITRC building in Human Factor Research Group, imagine that you are with about 5 other people, all working in front of your PCs in B3 (show on building plan below). Imagine that you have started smelling a strange smell, and the room slowly fills with smoke coming from the main door, then suddenly the smoke detector sounds. In this case, what you do think you will do?

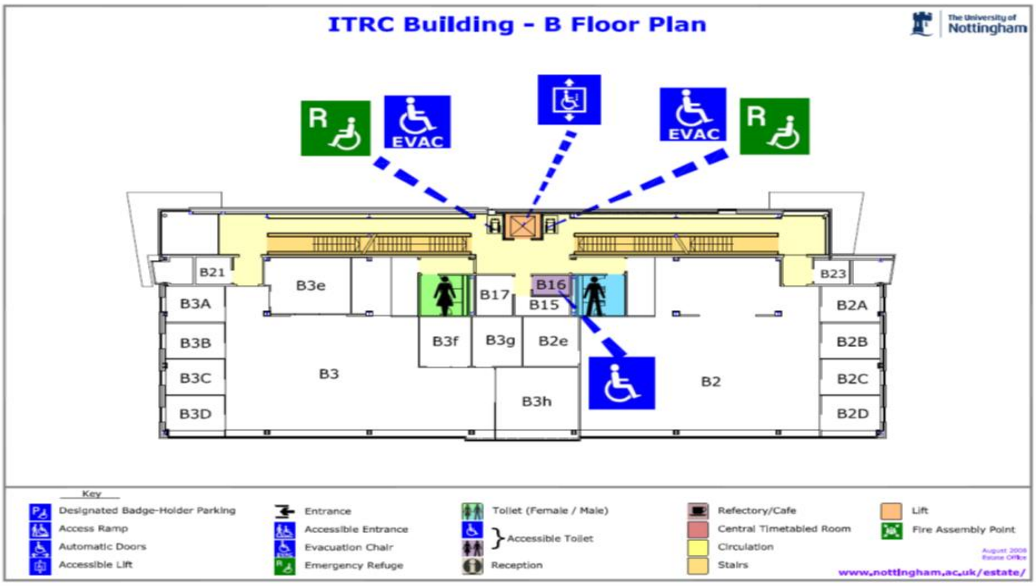


Figure 1: Innovative Technology Research Centre (ITRC): B Floor

Please predict and then list and describe what actions you would take.

What actions (start with first action and state them in order) would you take after smelling strange smell and hearing smoke detector?	Please state the location for each action.
1-	
2-	
3-	
4-	
5-	
6-	
7-	
8-	
9-	
10-	
11-	
12-	
13-	
14-	

1. How long do you think it would take you to leave the Human Factor Research Group?

2. How long do you think it would take you to leave the building?

c. Questionnaire on active conflict condition

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA QuestionnaireActive_Conflict_condition

Emergency evacution study: questionnaire

Particpant ID	
Email	
Degree	
Gender	**Male/Female**
Age	

It is Monday morning 10:30 at ITRC building in Human Factor Research Group, imagine that you are with about 5 other people, all working in front of your PCs in B3 (show on building plan below). Imagine that you have started smelling a strange smell, and the room slowly fills with smoke coming from the main door, then suddenly the smoke detector sounds. At that time, the other co-workers move towrd the meeting room (B3f). In this case, what you do think you will do?

Please predict and then list and describe what actions you would take.

What actions (start with first action and state them in order) would you take after smelling strange smell and hearing smoke detector?	**Please state the location for each action.**
1-	
2-	
3-	
4-	
5-	
6-	
7-	
8-	
9-	
10-	
11-	
12-	
13-	
14-	

1. Please rate how influential of the behaviour of other participants would be on your choice of exit from the building (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

2. How long do you think it would take you to leave the Human Factor Research Group?

3. How long do you think it would take you to leave the building?

d. Questionnaire on passive condition

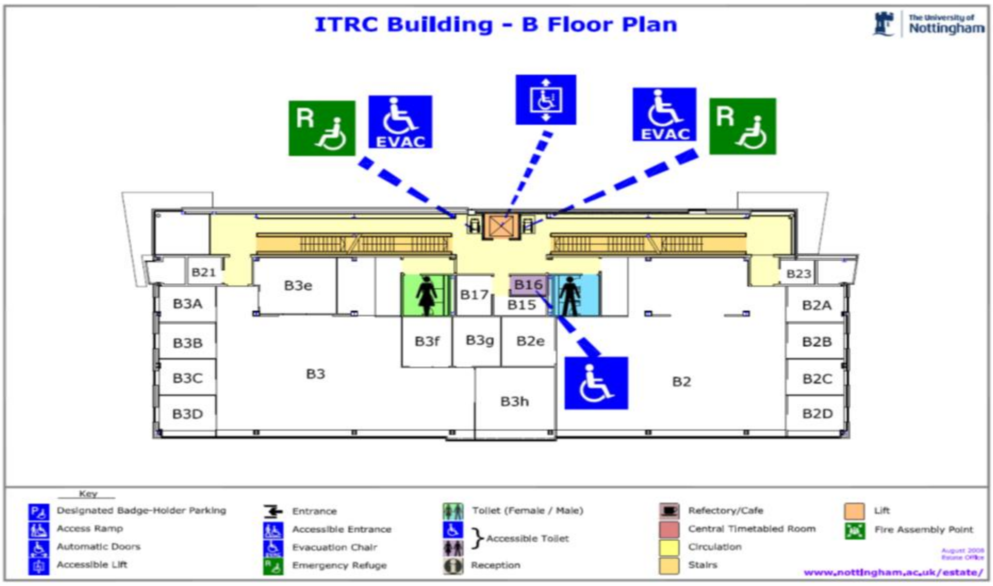
Abdullah Alhuthali | University of Nottingham UK | CHINA | MALAYSIA | Questionnaire_Passive_condition

I

Emergency evacution study: questionnaire

Particpant ID	
Email	
Degree	
Gender	**Male/Female**
Age	

It is Monday morning 10:30 at ITRC building in Human Factor Research Group, imagine that you are with about 5 other people, all working in front of your PCs in B3 (show on building plan below). Imagine that you have started smelling a strange smell, and the room slowly fills with smoke coming from the main door, then suddenly the smoke detector sounds. At that time, the other co-workers continue working and remain in the room. In this case, what you do think you will do?



Please predict and then list and describe what actions you would take.

What actions (start with first action and state them in order) would you take after smelling strange smell and hearing smoke detector?	Please state the location for each action.
1-	
2-	
3-	
4-	
5-	
6-	
7-	
8-	
9-	
10-	
11-	
12-	
13-	
14-	

1. Please rate how influential of the behaviour of other participants would be on your choice of exit from the building (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

2. How long do you think it would take you to leave the Human Factor Research Group?

3. How long do you think it would take you to leave the building?

12 Appendix B: Study2

a. Consent Forms

Abdullah Alhuthali — University of Nottingham UK | CHINA | MALAYSIA — Consent form

The influence of social behaviour in fire evacuation in Virtual Environment

Initials

I confirm that I DO NOT suffer and I never suffered from Simulator sickness, Motion sickness, Migraines, Epilepsy, Dizziness, Blurred vision

I have never involved in fire

I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason. ☐

I understand that my information will be used by the researcher for research purposes. I understand that my data will be anonymised. ☐

I understand that in case of pictures being used in publications, my face will be masked to be unrecognisable. Given that I agree to the publication of pictures taken during the study. (Ticking this box is not mandatory and will not prevent you to take part in the study) ☐

I agree to take part ☐

______________________	____________	________________
Name of Participant	Date	Signature

b. Final consent form

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA Consent form

I declare that I DO NOT currently suffer from cyber sickness symptoms including:

- Dizziness
- Nausea
- Disorientation
- Visual symptoms

I declare that I have been advised not to drive or do any high risk activity for at least the next 30 minutes.

I also declare that I received the £10 voucher for completing the experiment.

________________________ ____________ ________________

Name of Participant Date Signature

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

Abdullah Alhuthali

QuestionnaireActive_Conflict_condition

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire

Participant ID	
Email	
Degree	
Gender	Male/Female
Age	

1. Please rate how influential of the behaviour of other avatars would be on your choice of exit from the building (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire

Participant ID	
Email	
Degree	
Gender	Male/Female
Age	

Abdullah Alhuthali

Questionnaire_Passive_condition

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire

Participant ID	
Email	
Degree	
Gender	Male/Female
Age	

rate how influential of the behaviour of other avatars would be on your choice of exit from the building (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

13 Appendix C: VR source code snapshots

Node.cs : is a Script used to create new nodes with specified properties .

```
public bool walkable; // Indicate if this node walkable or not
public Vector3 worldposstion; // posstion of th node in the game
public int x; // index of the node in nodes array
public int y; // index of the node in nodes array
public int Gcost; // the cost of the path from the start node
public int Hcost; //  estimates the cost of the cheapest path
public Node Parent; // parent of this node " the past node "
```

```
8 references
public int CompareTo(Node nodeToComare){
    int compare = Fcost.CompareTo (nodeToComare.Fcost);
    if (compare == 0)
        compare = Hcost.CompareTo (nodeToComare.Hcost);


    return -compare;

}
```

```
1 reference
void CreateGrid(){

    grid = new Node[grideSizeX, grideSizeY];

    Vector3 BottomLeft = transform.position - Vector3.right * gridWorldSize.x / 2 - Vector3.forward * gridWorldSize.y / 2;

    for (int x = 0; x < grideSizeX; x++) {
        for (int y = 0; y < grideSizeY; y++) {

            Vector3 worldPoint = BottomLeft + Vector3.right * (x * nodeDiameter + nodeRadius) + Vector3.forward * (y * nodeDiameter + nodeRadius);

            bool Can_walk = !(Physics.CheckSphere (worldPoint, nodeRadius,unwalkable));

            grid [x, y] = new Node (Can_walk,worldPoint,x,y);
        }

    }

}
```

Grid.cs : is a Script used to create & build the grid of nodes . The grid will be the map of the scene “the game”.

```
1 reference
public LayerMask unwalkable; // indicate the nodes were its forbiden for the AI
10 references
public Vector2 gridWorldSize; // the size of the grid
4 references
public float nodeRadius; // size of the node
6 references
Node[,] grid; // tree "Array" of nodes
6 references
float nodeDiameter;
6 references | 6 references
int grideSizeX,grideSizeY; // x , y of the grid [,]
```

```
2 references
public Node NodeFromWorldPoint(Vector3 posstion){

    float percentX = (posstion.x + gridWorldSize.x / 2) / gridWorldSize.x;
    float percentY = (posstion.z + gridWorldSize.y / 2) / gridWorldSize.y;
    percentX = Mathf.Clamp01 (percentX);
    percentY = Mathf.Clamp01 (percentY);
    int x = Mathf.RoundToInt ((grideSizeX - 1) * percentX);
    int y = Mathf.RoundToInt ((grideSizeY - 1) * percentY);

    return grid [x, y];


}
```

```
1 reference
public List<Node> GetNeighbours(Node node){
    List<Node> Neighbours = new List<Node> ();

    for (int x = -1; x <= 1; x++) {
        for (int y = -1; y <= 1; y++) {
            if (x == 0 && y == 0) {
                continue;
            }

            int checkX = node.x + x;
            int checkY = node.y + y;

            if ( List<Node> Neighbours  grideSizeX && checkY >= 0 && checkY < grideSizeY) {
                Neighbours.Add (grid [checkX, checkY]);
            }

        }

    }

    return Neighbours;
}
```

MangePaths.cs : is a Script used to Control the path Finding request from The AI and run each request on separated thread to keep performance as high as possible.

```
public void RequstPath(PathRequest requst){
    // called by AI script

    ThreadStart threadStart = delegate {
        pathfinding.FindPath (requst, DoneProcessing);
    };

    threadStart.Invoke ();


}

public void DoneProcessing(PathResult result){
    lock (Results) {
        Results.Enqueue (result);
    }
}
```

PathFinding.cs : is a Script used find the path from AI to the target . This the A* main class were the path will be processed.

```
public void FindPath(PathRequest requst , Action<PathResult> callback) {
    // Find Path To target

    Vector3[] WayToTarget = new Vector3[0]; // save the path to target
    bool pathSuccess = false;

    Node startNode = grid.NodeFromWorldPoint (requst.start); // current AI posstion
    Node TargetNode = grid.NodeFromWorldPoint (requst.end); // current Target Posstion

    if (startNode.walkable || TargetNode.walkable) {


        Tree<Node> Open = new Tree<Node> (grid.MaxSize);
        HashSet<Node> Colsed = new HashSet<Node> ();
        Open.Add (startNode);

        while (Open.Count > 0) {
            Node cuurentNode = Open.RemoveItem ();

            Colsed.Add (cuurentNode);

            if (cuurentNode == TargetNode) {
                pathSuccess = true;

                break;

            }

            foreach (Node neighbour in grid.GetNeighbours(cuurentNode)) {
                if (!neighbour.walkable || Colsed.Contains (neighbour)) {
                    continue;
                }

                int CostToNeigbour = cuurentNode.Gcost + GetDistance (cuurentNode, neighbour);

                if (CostToNeigbour < neighbour.Gcost || !Open.Contains (neighbour)) {
                    neighbour.Gcost = CostToNeigbour;
                    neighbour.Hcost = GetDistance (neighbour, TargetNode);
                    neighbour.Parent = cuurentNode;

                    if (!Open.Contains (neighbour)) {
                        Open.Add (neighbour);

                    }else
                        Open.UpdateItem (neighbour);
                }
```

```
Vector3[] TracePath(Node Start  , Node Traget ){

    List<Node> Path = new List<Node>();
    Node current = Traget;

    while (current != Start) {
        Path.Add (current);
        current = current.Parent;

    }
    Vector3[] wayPoints = SimplifyPath (Path);

    Array.Reverse (wayPoints);

    return wayPoints;
}
```

```
Vector3[] SimplifyPath(List<Node> path){
    List<Vector3> wayPoints = new List<Vector3>();
    Vector2 DirOld = Vector2.zero;

    for (int i = 1; i < path.Count; i++) {
        Vector2 NewDir = new Vector2 (path [i - 1].x - path [i].x, path [i - 1].y - path [i].y);
        if (NewDir != DirOld) {
            wayPoints.Add (path [i].worldposstion);
        }
        DirOld = NewDir;
    }

    return wayPoints.ToArray ();
}
```

Tree.cs : is a Script used by Grid.cs to create tree of nodes, tree is form of Arrays that has special properties , tree are very useful in A* path Finding Algorithm to keep performance while looking for the path.

StartSomke.cs : is a Script used start the smoke particles.

HandleDoors.cs: is a Script used Handle open and closing of doors when Player or AI get near to the door.

AI.cs: Script to control the behaviour of all AI players

```
3 references
public void OnPathFound(Vector3[] newPath,bool Succeccfull){
    // called when fining path process has done

    if (Succeccfull) { // found the  Path to target Succeccfully

        Path = newPath;
         StopCoroutine (FollowPath ()); // stop any path flollowing before start follow new path
        if (transform.name == "Al_2" || (transform.name == "Police")){

            myAnimation.SetBool ("Yell", false);
        }els GameObject AI.Mychair
            Mychair.GetComponent<Animation> ().enabled = true;
        }

        StartCoroutine (FollowPath ()); // follow path
    } else {

    }

}
```

14 Appendix D: Study3

a. Consent Forms

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA Consent form

Investigation of the relative influence of Information sources/Channel access, Message content, and Receiver characteristics on behaviour during emergencies (fire) in Virtual Environments.

Consent Form

Initials box

I confirm that I DO NOT suffer and I never suffered from Simulator sickness, Motion sickness, Migraines, Epilepsy, Dizziness, Blurred vision

I have never involved in fire

I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason.

I understand that my information will be used by the researcher for research purposes. I understand that my data will be anonymised.

I understand that in case of pictures being used in publications, my face will be masked to be unrecognizable. Given that I agree to the publication of pictures taken during the study. (Ticking this box is not mandatory and will not prevent you to take part in the study)

I agree to take part

Name of Participant	Date	Signature

b. Final consent form

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA Consent form

I declare that I DO NOT currently suffer from cyber sickness symptoms including:

- Dizziness
- Nausea
- Disorientation
- Visual symptoms

I declare that I have been advised not to drive or do any high risk activity for at least the next 20 minutes.

I also declare that I received the £5 voucher for completing the experiment.

______________________	____________	________________
Name of Participant	Date	Signature

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA Consent form

No______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

c. Questionnaires

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire

Particpant ID	
Degree	
Gender	
Age	

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- an authority

Particpant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influnce of the authority.

Location A(very detailed message):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number)

Not at all influential				Very influential
1	2	3	4	5

Location B(message without detail):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Abdullah Alhuthali

University of Nottingham
UK | CHINA | MALAYSIA

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- siren

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the siren.

Location A(very detailed message):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Location B(message without detail):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- stranger

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the stranger.

Location A(very detailed message):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Location B(message without detail):

Please rate the influence of the information provided about the emergency situation on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

15 Appendix E: Study4

a. Consent forms

Abdullah Alhuthali Consent form

Investigation of the effect of information sources (authority and siren) in the presence of two social cues (passive and active conflict) on behaviour during emergencies (fire) in Virtual Environments.

Consent Form

Initials box

I confirm that I DO NOT suffer and I never suffered from Simulator sickness, Motion sickness, Migraines, Epilepsy, Dizziness, Blurred vision

I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason.

I understand that my information will be used by the researcher for research purposes. I understand that my data will be anonymised.

I agree to take part

________________________ ____________ ________________

Name of Participant Date Signature

b. Final consent form

Abdullah Alhuthali University of Nottingham UK | CHINA | MALAYSIA Consent form

I declare that I DO NOT currently suffer from cyber sickness symptoms including:

- Dizziness
- Nausea
- Disorientation
- Visual symptoms

I declare that I have been advised not to drive or do any high risk activity for at least the next 20 minutes.

I also declare that I received the £5 voucher for completing the experiment.

Name of Participant	Date	Signature

No_______________ Date____________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

c. Questionnaires for all conditions

Abdullah Alhuthali

University of Nottingham
UK | CHINA | MALAYSIA

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire

Particpant ID	
Gender	
Age	

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- an authority - active conflict

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the siren: active conflict.

Please rate of influential on behaviour of the information provided in case of avatars moving to opposite of emergency exit on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- an authority- passive

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the authority: passive.

Please rate of influential on behaviour of the information provided in case of passive of avatars on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- siren - active conflict

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the siren: active conflict.

Please rate of influential on behaviour of the information provided in case of avatars moving to opposite of emergency exit on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

Abdullah Alhuthali

UNITY VIRTUAL ENVIRONMENT BUILDING

Emergency evacuation study: questionnaire- siren - passive

Participant ID	

For each location, you will be asked to rate the influence of informed about the incident from 1 to 5, where 1 is not at all influential and 5 is very influential.

Please circle the number on the scale below that best represents the influence of the siren: passive.

Please rate of influential on behaviour of the information provided in case of passive of avatars on your decision to evacuate (please circle the appropriate number):

Not at all influential				Very influential
1	2	3	4	5

16 Appendix I: Posters, Presentation

a. Human Factor group showcase

b. Engineering research poster showcase

Human Factors Research Group

Applying Human Factors Approach in Emergency Situations

Student: Abdullah Alhuthali Supervisors: Dr Glyn Lawson, Dr Cobb Sue

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Research Problem:

Conducting research on **human behaviour** in emergency situations is challenging for a number of reasons: **ethical considerations** rightly prevent participants being subjected to actual emergency situations; there are **difficulties accessing survivors** of real events.

Proposed solution:

A **Human Factors approach** can be used to study human behaviour in emergencies as there are many unknown variables affecting the outcome of an emergency, such as the **influence of building type** and **social factors**.

The proposed methodology:

Talk through approach [1]which involves presenting individuals with hypothetical situations and asking them how they would respond with adding an influence of the social factors in to increases the validity of this approach.

Multisensory virtual environment to elicit the validity of human behaviour during a fire emergency.

How do we behave in fires?

This PhD is sponsored by:
1. The Ministry of Education, Saudi Arabia
2. Mechanical Engineering, Faculty of Engineering, Taibah University, Saudi Arabia

References:

[1] G. Lawson, S. Sharples, D. Clarke, and S. Cobb, "Validating a low cost approach for predicting human responses to emergency situations," *Appl. Ergon.*, vol. 44, no. 1, pp. 27–34, 2013.
[2] Image carrying of Charron, David. Angle Champlain Et Villeneuve. 2013. Web. 8 Mar. 2017. Attribute image.

c. Human Factor group showcase (Second Place)